Muriwai Downs - Assessment of Potential Groundwater Supply and Associated Hydrological Effects

Appendix E - Numerical Model Based Analysis of Proposed Groundwater Take

THE BEARS HOME PROJECT MANAGEMENT LTD

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Muriwai Downs - Groundwater Effects Assessment

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Contents

Executive Summary iv
1. Introduction 7
1.1 Objective and Scope of Work 7
1.2 Site Overview 8
2. Relevant Statutory Provisions 10
2.1 Allocation Limit 10
3. Geologic Setting 12
3.1 Geology 12
3.2 Faulting 12
3.3 Hydrogeology 13
4. Site Investigation 15
4.1 Drilling 15
4.2 Test Pumping 15
4.3 ERT Survey 17
4.4 Monitoring 18
5. Model Conceptualisation 21
5.1 Climate 21
5.2 Topography 22
5.3 Soils 23
5.4 Groundwater Recharge 24
5.4.1 SMWBM Overview 25
5.4.2 Recharge Modelling 25
5.5 Geologic Materials 26
5.6 Hydrogeological Interpretation 26
6. Groundwater Modelling Methodology 27
6.1 Model Domain 27
6.1.1 Model Layer Configuration 28
6.1.2 Simulated Groundwater Recharge 30
6.1.3 General Head Boundaries 30
6.1.4 No-Flow Boundaries 30
6.1.5 Stream Boundaries 30
6.1.6 Well Boundaries 30
7. Model Calibration 31
7.1 Observation Points 31
7.2 Steady-State Calibration 31
7.3 Transient Calibration 35
7.3.1 Calibration Results-Groundwater 35
7.3.2 Calibration Results-Surface Water 37
7.3.3 Calibrated Model Parameters 40
7.3.4 Simulated Water Balance 40
8. Predictive Simulations 42

8.1 Scenario Setup 42
8.1.1 Stress Periods and Time Steps 42
8.1.2 Initial Conditions 42
8.1.3 Model Hydraulic Parameters 42
8.1.4 Recharge 42
8.1.5 Groundwater Abstraction Profile 42
8.2 Model Results 43
8.2.1 Aquifer Drawdown 43
8.2.2 Stream Flows 49
8.2.3 Lake Ōkaihau 49
9. Assessment of Effects 51
9.1 Groundwater Effects 51
9.1.1 Effects on Existing Bores 52
9.2 Saline Intrusion 58
9.3 Land Subsidence 58
9.4 Surface Water Effects 60
9.4.1 Stream Baseflow 61
9.4.2 Flooding 61
9.4.3 Wetlands 61
9.4.4 Lakes 61
9.5 Recommendations for Groundwater Monitoring and Reporting 62
10. Conclusions 63
11. References 64
Appendix A. Lithological & As-Built Log 65
Appendix B. SMWBM Overview 67

Executive Summary

Project Overview

Williamson Water & Land Advisory (WWLA) were commissioned by The Bears Home Project Management Limited ("Applicant") in January 2021 to undertake a Groundwater Effects Assessment to support a resource consent application for the partial conversion of the Muriwai Downs property (“Property”) to a Golf Course, Sports Academy and Lodge development. This assessment forms part of a broader water resource analysis that includes baseline water quality monitoring, an Electrical Resistivity Tomography (ERT) Survey, a Site Water Balance and Water Strategy Report, and a Water Balance Assessment of Lake Ōkaihau.

The Groundwater Effects Assessment was undertaken through development of a numerical groundwater model of the Property and adjacent areas. The model was based on historical and ongoing monitoring data (WWLA, 2021 – Appendix A), and findings from previous drilling investigations (WWA, 2018; PDP, 2021a), aquifer hydraulic testing (PDP, 2021b), and the ERT Survey (WWLA, 2021 – Appendix D).

The Site Water Balance and Strategy report (WWLA, 2021 – Appendix B) concluded that both surface water and groundwater, and a storage reservoir would be required to provide a reliable water supply of the anticipated volume. The purpose of this report is to assess the impacts of the proposed groundwater take.

The irrigation supply for the proposed golf course will be obtained from a combination of groundwater and surface water. A production bore has been drilled in the basalt and indicated highly fractured basalt from a depth of approximately 120 mBGL to at least 200 mBGL. Initial airlift yield testing indicated high transmissivity for the basalt, but there was uncertainty as to the lateral extent of the basalt, and it was conservatively indicated as a likely constraint to limit the sustainable groundwater supply volume (PDP, 2021a). The recent ERT survey provides an improved understanding of the lateral extent of the shallow component (top 200 m) of the basalt. A second production bore has been proposed to be drilled at a location approximately 500 m southwest of the existing production bore.

The volume of water that can be sustainably abstracted from this basalt is an integral component of the water supply and storage facilities required for the golf course and associated development. A limited groundwater supply indicates greater reliance on surface water for irrigation, and hence the need for a larger reservoir. Conversely, with higher groundwater supply volumes, storage volume, cost and space considerations associated with the surface water reservoir could be reduced.

Study Objectives

The key objectives of the groundwater modelling exercise were to:

- evaluate the effects of a groundwater take for irrigation of the proposed golf course;
- develop an improved understanding of the local hydrogeological functionality in terms of the groundwater resource; and
- assess the sustainability of groundwater abstraction from the deep aquifer.

The groundwater model is a tool that can be used to evaluate the likely effects of varying rates of groundwater abstraction to support an assessment of effects, where the predicted effects can be evaluated against the relevant statutory provisions. Model results are assessed in terms of likely effects on groundwater and surface water conditions, and the potential effects on neighbouring groundwater users and downstream surface water users. Potential effects are evaluated against the criteria for the taking and use of groundwater as provided in the Auckland Unitary Plan (Operative in Part) (AUP-OP).

This report does not address the development effects on groundwater conditions from wastewater/stormwater discharges, earthworks, and increased impermeable areas. These are addressed in the Water Effects Summary Report (WWLA, 2021).

Model Development

A three-layer model was developed using the USGS MODFLOW code and calibrated to the groundwater level monitoring data collected at four locations, ranging in depth from 4 to 200 m, with the deepest being the pilot bore where the test pumping occurred. Data from the test pumping exercise was also used in the model calibration data set.

Conductivity values calculated from test pumping results were assigned to the materials in the lower aquifer layer representing the basalt-dyke (high conductivity), sandstone (low conductivity), and a presumed deep basalt-flow (intermediate conductivity). A key finding of the calibration process was that to replicate the vertical pressure gradient observed in the monitoring data there must be a down gradient outlet for deep groundwater. This was presumed to be a deep basalt flow based on similar formations in the area.

The calibrated model achieved an RMSE of 1.01 m, which was 4.7% of the range of observations, indicating that the model was suitable for the analysis being undertaken. Notably, the simulated water levels in three of the four monitoring bores were significantly closer to observations, achieving a collective RMSE of 0.2 m.

Two model scenarios were developed to evaluate the likely effects of groundwater abstraction, as follows:

1. ***Naturalised Scenario*** - no groundwater abstraction;
2. ***Abstraction Scenario*** - Groundwater as a supplement for surface water in sustaining necessary water levels in a reservoir. Proposed groundwater abstraction rates are up to 180,000 m^3/yr and 1,728 m^3/day depending on climate conditions.

Summary of Model Results

Model results were assessed in terms of likely effects on groundwater and surface water conditions and evaluated based on criteria in the AUP-OP. The proposed abstraction is classified as a Discretionary Activity (AUP-OP Table E7.4.1 (A26)).

Key findings from the model scenarios described above were as follows:

- The maximum and median drawdown predicted in the deep aquifer at the pumping bore was 16.2 m and 9.7 m, respectively.
- 43 bores were found to be within a 3 km radius of the abstraction site. Model results indicate that maximum drawdown does not exceed 9% of available drawdown for any of the bores.
- Drawdown was significantly less in the upper layers, never exceeding 0.3 m in Layer 1 and 2.6 m in Layer 2 as disconnection between the shallow and deep aquifer minimised the effect on the shallow aquifer.
- There were limited effects on baseflow predicted to occur, with a maximum baseflow reduction of 3.4% at the flow monitoring site adjacent to the pumping bore, and less reduction at the other sites evaluated. The median baseflow reduction was under 0.5% and would in practice be unmeasurable.
- The Ōkiritoto Stream has one consented surface water take downstream from the Property and possibly other smaller permitted takes for stock domestic use and stock water supply. The baseflow reduction would have negligible effect on downstream surface water users.
- Wetland water levels were unaffected by the groundwater abstraction other than a decline of under 0.03 m in a small area directly adjacent to the pumping location, which would in practice be unmeasurable.
- Predicted land subsidence was primarily under 0.1 m, and a maximum of 0.17 m, and limited to the areas near the abstraction site where infrastructure would not be affected.
- Based on an analysis utilising the Gyben-Herzberg relationship, the likely saline interface was found to be several hundred meters below the extent of any economically feasible bore that with or without abstraction.

Summary of Effects

In summary, the proposed groundwater take was found to meet the AUP-OP standards for such activities. The results of this assessment indicated that the proposed groundwater take will have the following effects:

- A less than minor effect on streams;
- a less than minor effect on wetlands;
- a no more than minor effect on groundwater resources;
- a less than minor effect on saline intrusion; and
- a less than minor effect on land subsidence.

1. Introduction

Williamson Water & Land Advisory (WWLA) were commissioned by The Bears Home Project Management Limited ("Applicant") in January 2021 to undertake baseline water quality monitoring and to prepare a water effects assessment to support a resource consent application for the partial conversion of the Property to a Golf Course, Sports Academy and Lodge development. WWLA's scope was expanded in July 2021 to include an Electrical Resistivity Tomography (ERT) Survey, a Groundwater Effects Assessment, a Site Water Balance and Water Strategy Report, and Water Balance Assessment of Lake Ōkaihau.

A 35-year consent period is being sought for all activities related to water takes, use, and discharges for the proposed development. This report details the Groundwater Effects Assessment, which was undertaken through development of a numerical groundwater model of the Property and adjacent areas.

The model was developed for the Ōkiritoto Stream Catchment, wherein the Property is entirely located. Model inputs were based on historical and ongoing monitoring data (WWLA, 2021 – Appendix A), findings from previous drilling investigations (WWA 2018; PDP 2021a), aquifer hydraulic testing (PDP 2021b), and a recent ERT Survey (WWLA, 2021 – Appendix D).

The irrigation supply for the proposed golf course and potable water supply for the associated developments is likely to be obtained from a storage reservoir that will be filled from a combination of groundwater and surface water. A full description of the reservoir functionality is provided in WWLA (2021 – Appendix B) and reservoir design is detailed in an upcoming report to be delivered by Riley Consultants (2021).

A production bore has been drilled in the basalt and indicated highly fractured basalt from a depth of approximately 120 mBGL to at least 200 mBGL. Initial airlift yield testing indicated high transmissivity for the basalt, but there was uncertainty as to the lateral extent of the basalt, and it was conservatively indicated as a likely constraint to limit the sustainable groundwater supply volume (PDP, 2021a). The recent ERT survey provides an improved understanding the lateral extent of the shallow component (top 200 m) of the basalt. An additional production bore has been proposed to ensure that a reliable groundwater supply is available for both irrigation and potable water supply for the associated commercial developments. The second bore is proposed to be drilled approximately 500 m to the southwest of the existing production bore.

The volume of water that can be sustainably abstracted from this basalt has significant implications for the water supply and storage facilities required for the golf course and associated development. Specifically, the size of the reservoir required is inversely related to the volume of groundwater that can be sustainably abstracted from the aquifer (i.e. more available groundwater indicates a smaller reservoir is needed). This study has investigated the potential effects associated with a proposed 180,000 m^3/year groundwater take consent for Muriwai Downs golf development.

1.1 Objective and Scope of Work

The key objectives of the modelling exercise were to:

- evaluate the effects of a large groundwater take for irrigation of the proposed golf course and supplemental water supply for associated commercial developments;
- develop an improved understanding of the local hydrogeological functionality; and
- assess the sustainability of groundwater abstraction from the deep aquifer.

This report does not address the development effects on groundwater conditions from wastewater/stormwater discharges, earthworks, and increased impermeable areas. These are addressed in the Water Effects Summary Report (WWLA, 2021).

The groundwater model is a tool that can be used to evaluate the likely effects of varying rates of groundwater abstraction, and with this information inform estimates of sustainable groundwater yield. Information generated from the model can be used to support an assessment of effects, where the predicted effects can be evaluated against the relevant statutory provisions. Two model scenarios were developed to evaluate the likely effects of groundwater abstraction, as follows:

1. ***Naturalised Scenario*** – no groundwater abstraction;
2. ***Abstraction Scenario*** – Groundwater as a supplement for surface water in sustaining necessary water levels in a reservoir.

Model results are assessed in terms of likely effects on groundwater and surface water conditions, with these effects evaluated against the criteria for the taking and use of groundwater as provided in the AUP-OP.

The report comprises descriptions of:

- high-level relevant statutory provisions (**Section 2**).
- geology and hydrogeology (**Section 3**).
- site investigations and overview of available field data (**Section 4**).
- groundwater model conceptualisation (**Section 5**).
- groundwater model development methodology (**Section 6**).
- numerical model calibration (**Section 7**).
- predictive model simulations and results (**Section 8**).
- the assessment of environmental effects with regard to hydrogeological conditions (**Section 9**).
- conclusions (**Section 10**).

1.2 Site Overview

The Applicant is proposing the establishment of a golf course and other facilities located on the Muriwai Downs Farm property. The existing farm, shown in **Figure 1**, is approximately 507 hectares and located approximately 3 kilometres northeast of Muriwai Beach Township. The Property comprises predominantly pastoral farmland (sheep and beef, and dairy), and contains isolated pockets of high value ecological resources such as wetlands and native forest with stands of Kauri trees.

The study area that is the focus for this groundwater assessment is the Ōkiritoto Stream catchment.

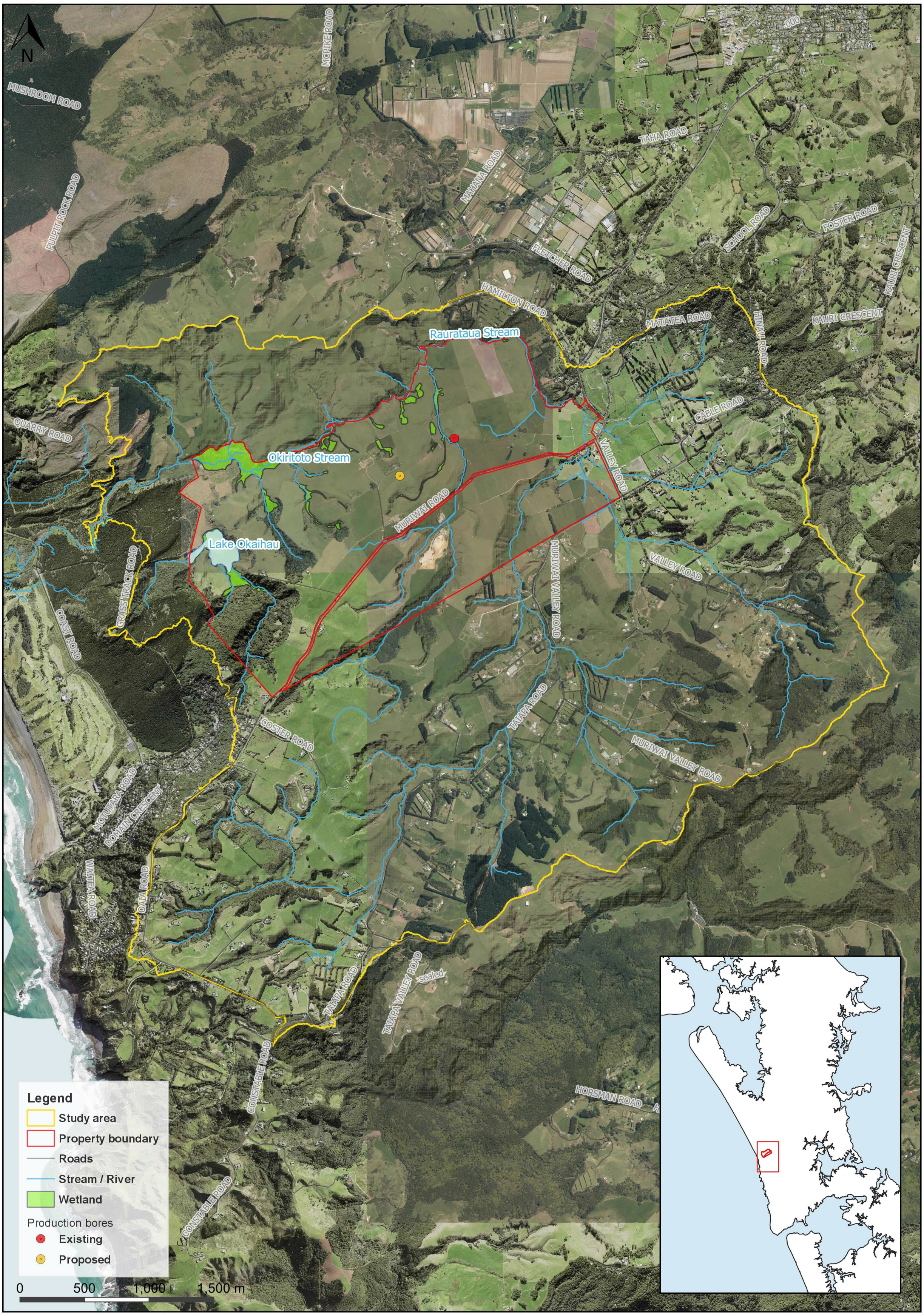

Figure 1. Overview of study area

2. Relevant Statutory Provisions

WWLA has undertaken a review of relevant planning regulations relating to hydrogeology and surface water hydrology.

Planning provisions related to the taking and use of groundwater are provided in the AUP-OP and in particular Table E7.4.1.

Assessment criteria from AUP-OP Table E7.4.1 have been applied to determine the status of the proposed development as related to take and use of groundwater. The specific criteria applicable for determining the activity status are presented in **Table 1**.

Table 1. AUP criteria for determining activity status as related to the proposed development.

Table E7.4.1 Activity Description		**Activity Status Criteria**		**Comment**
Take and use of groundwater	(A14)	Permitted Activity	A groundwater take must not exceed 5 m^{3}3/day over any consecutive 20 day period.	The proposed activity will exceed this criterion.
	(A15)		A groundwater take must not exceed 20 m^3/day over any consecutive 5 day period, and no more than 5,000 m^3/yr.	The proposed activity exceeds the average daily and annual take specified in the criteria.
	(A26)	Discretionary	Take and use of groundwater not meeting the permitted activity or restricted discretionary activity standards or not otherwise listed.	The proposed activity does not meet the permitted activity standards E.7.6.1.3 and E7.6.1.4 therefore the activity status is **Discretionary**.

The proposed groundwater take of up to 180,000 m^3/yr will be sourced from an existing bore (completed November 2021) and possibly an additional bore that may be installed approximately 500 m to the southwest of the existing bore, as indicated in **Figure 1**. The proposed take is classified as a **Discretionary** activity because permitted activity criteria A14 and A15 will not be met, and thereby rule A26 applies. As such, a resource consent is required and may be granted or refused for any relevant resource management reason.

The site includes Significant Ecological Areas overlays, a Natural Stream Management overlay, two Wetland Management Area overlays, and a Quality Sensitive Aquifer Management overlay. In each of these cases, additional criteria for reviewing discretionary activities are applied. Details of the applicable criteria related to these overlays are found in the Chapter D-Overlays section of the AUP-OP. These criteria are considered in the appropriate sections of the Assessment of Effects included in **Section 9** of this document.

2.1 Allocation Limit

Auckland Council Geomaps indicate that the production zone for the existing and proposed bores is within the Waitakere Volcanic Aquifer group aquifer and is thereby classified in Appendix 3 of the AUP-OP as an ‘aquifer not separately listed’. For this class of aquifer, the available allocation is 35% of annual recharge if it is deemed to have connection to a surface water body, and 65% of annual recharge if it is not connected to a surface water body.

Without knowing the precise lateral boundaries of the aquifer, a conservative estimate of the allocation limit based on 35% of annual recharge on the Property amounted to 354,421 m^3/year. The following assumptions were applied for this estimate:

- the recharge area encompasses the entire Muriwai Downs Property (507 ha);

- some connectivity between the aquifer and streams prevail (although this study indicates that connection is limited);
- average annual rainfall of 1,488 mm (Section 5.1); and
- mean annual recharge of 13.4% of rainfall (Section 5.4.2).

This annual allocation amount is nearly twice the maximum annual demand for groundwater abstraction modelled for this study (**Section 8.1.5**).

3. Geologic Setting

3.1 Geology

The geologic setting of the study area defines the structural framework and media within which groundwater flow occurs. Underlying rock type and layering plays a significant role in governing the volume and velocity of groundwater flow, depth of groundwater, and relative magnitude of vertical and horizontal flows.

New Zealand Geological Map (Qmap) was used to provide an overview of the geology within the Property and surrounding surface water catchments. The following descriptions of the primary geologic units that occur within the area of interest have been adapted from Edbrooke (2001):

Karioitahi Group (Q1d) – Early Pleistocene to Holocene aged (2 My to present) coastal sands occurring in the western portion of the study area. Permeability can be variable, for similar reasons to the Awhitu Group.

The Tauranga Group (Q1a) – Late Miocene to Holocene aged (10 My to present) alluvium comprised of sand, silt, mud and clay overlying the Awhitu and/or Nohotupu formations deposited on valley floors predominantly in the eastern portion of the study area. Permeability is typically low to moderate due to high silt and clay content of sediments.

The Awhitu Group (^ad) – Late Pliocene to Early Pleistocene aged (2 to 3 My) interbedded moderate to poorly consolidated sandstone, with paleosols, lignite and carbonaceous mudstone. Permeability is highly variable with lenses of perched groundwater in some discrete locations that may provide baseflow to the Ōkiritoto Stream and its tributaries. This layer is the most predominant surficial unit within the study area.

The Nihotupu Formation (Mtn) – Early Miocene aged (20 My) volcaniclastic sandstone of the Waitakere Group, comprising submarine volcaniclastic grit, sandstone and siltstone, underlying the Awhitu formation. Permeability is typically low.

The Waiatarua Formation (Mtw) – Early Miocene aged (20 My) basalt flows of the Waitakere Group, including pillow lavas with minor basic andesite. A thin outcrop of pillow lava occurs at the pilot bore location and was intersected again at depth. Permeability is typically high due to the fracturing and vesicularity imposed in the rock during its highly violent mode of formation as lava was discharged into water-saturated seafloor sediment forming vertical dykes and long roll like pillow lava structures[1].

Figure 2 shows the surface geology as mapped by GNS Science.

3.2 Faulting

Geologic fault zones often indicate rock material boundaries and/or fracturing. In these areas there may be significant changes in hydrogeological characteristics, which can affect regional flow patterns.

There is one inactive fault mapped in the eastern portion of the study area. However, it is speculated that the Ōkiritoto Stream valley represents a weakness in the sub-surface geology or an eroded fault zone on the basis of the unique geomorphology in the area. In particular, the alignment of the stream and locality of basalt dyke outcrops forming abutments on the valley sides near the stream mouth.

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[1] https://www.nzgeo.com/stories/pillow-talk/

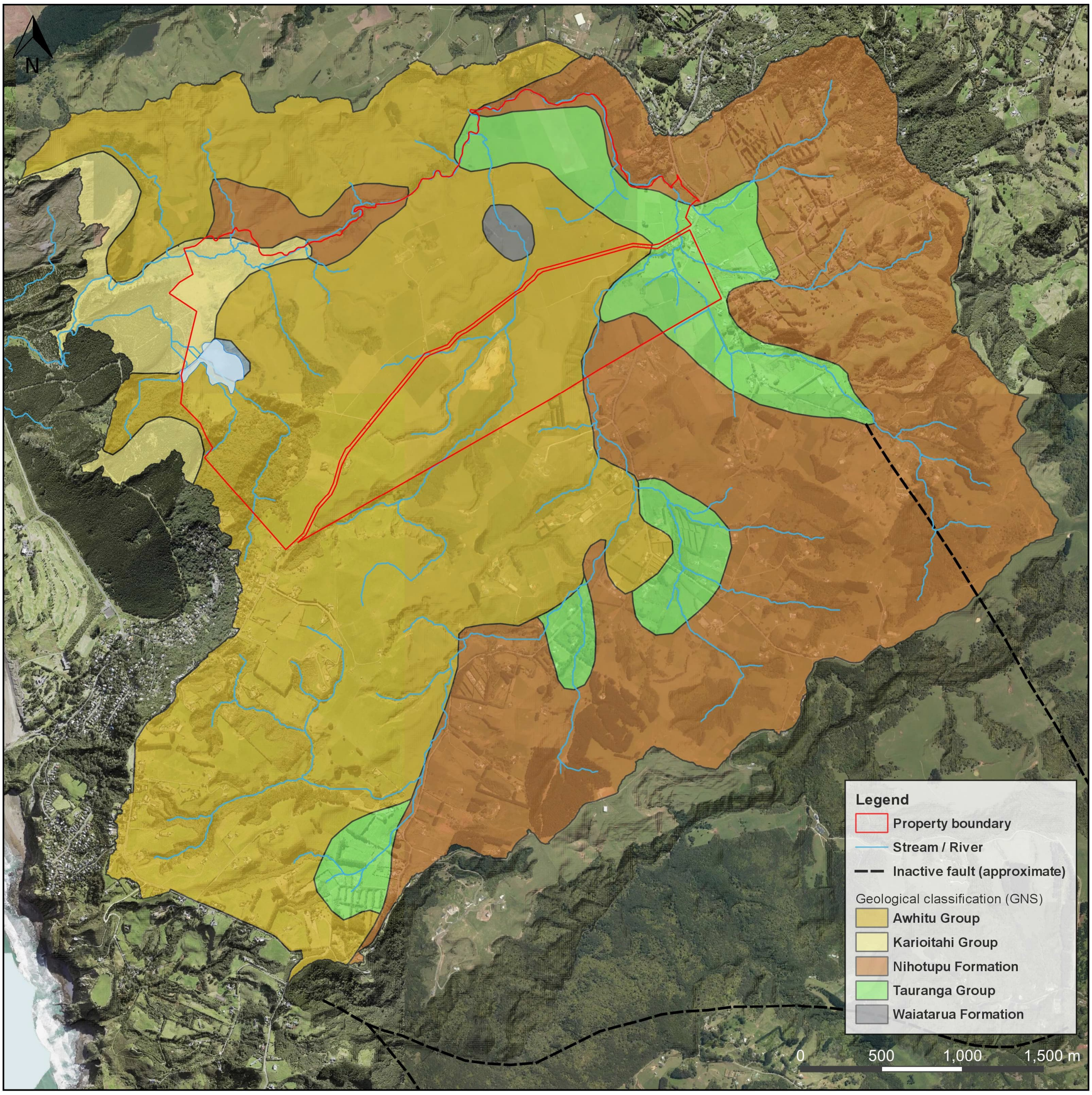

Figure 2. Surface geology as mapped by GNS.

3.3 Hydrogeology

In the deeper subsurface, the Waiatarua Basalt, classified within the Volcanic aquifer group on Auckland Council Geomaps, functions as an underground reservoir of finite size surrounded by the Nihotupu Sandstone Formation. Vertical seepage through the sandstone is the recharge source for the groundwater stored in the basalt.

The volume of water stored within the basalt aquifer is a function of its extent and porosity. The results of initial investigations have determined that there is potential for a productive groundwater yield from the basalt as discussed in **Sections 4.2** and **4.3**. However, the lateral extent of the basalt at depth remains unknown and improving this understanding through numerical modelling analysis is part of the objective of this study.

The Awhitu cemented sands that occur on the Property comprises a portion of the Kaipara Sand aquifer that is listed on the Auckland Council Quality Sensitive Aquifer Management Areas overlay. This material comprises the shallow aquifer within the study area, having potential to provide low to moderate yields of groundwater, though lateral flow along perched lenses that may contribute to baseflow while limiting recharge to the deep aquifer. A test pumping analysis undertaken in 2018 on the nearby Francis irrigation bore indicated that conductivity of the Awhitu Sandstone was in the range of $5.3x10^{-6}$ to $7.5x10^{-6}$ m/s (WWA, 2018). The deeper sandstone formations surrounding the basalt typically comprise poor yielding aquifers in the Muriwai and Waimauku area. Bores drilled into the sandstone formations are often unproductive, and the occasional productive bores that achieve a viable water supply (albeit normally only of the quantum for reasonable domestic and stocking drinking water purposes) are typically hundreds of meters deep.

The proposed activities will impact the Waitarua Basalt Aquifer which is the source of the groundwater take and the Kaipara Sands which is the shallow aquifer which has potential to be affected by proposed wastewater and stormwater discharges to ground. The discharges are not related to the proposed groundwater take and are thereby not addressed in this report; however, the potential effect of these discharges is discussed in the Water Effects Summary report (WWLA, 2021).

Table 2 summarises the aquifers that are reference in this Project in terms of geologic terminology and the nomenclature used on the Auckland Council Geomaps[2] overlay.

Table 2. Summary of aquifers referenced in this study (the name in bold is the geological name, and the term in brackets refers to the grouping used on the Auckland Council GeoMaps Groundwater overlay).

Name	Description	Relevance to this Project
Kaipara Sand (Sand Aquifer)	This is the shallow sand aquifer. Within the Property and wider Ōkiritoto Catchment it predominantly occurs near the surface and comprises the Awhitu cemented sand and Kariotahi sand formations.	Proposed stormwater and wastewater discharges to ground will occur to this aquifer. In the wider Ōkiritoto Catchment, there are a number of shallow bores that draw from this aquifer.
Waitakere Volcanic (Volcanic Aquifer)	This is the basalt aquifer. Within the Property, this predominantly exists at depth, with a small surface expression at the location of the production bore. It is hydraulically disconnected from the sand aquifer above.	The production bore and proposed secondary production bore will abstract water from this aquifer.
Muriwai Waitakere Group (Waitakere Group Aquifer)	This aquifer comprises sandstone/mudstone derived from volcanic material. This aquifer exists within the Property, and wider Ōkiritoto catchment as Nihotupu Sandstone.	No activities are proposed to occur within this group.
Muriwai Waitemata (Waitemata Aquifer)	The Waitemata aquifer classification refers to all aquifers underlying the Waitemata Basin.	Collectively, all aquifers in the Muriwai area are referred to as Muriwai Waitemata, which is a sub-group of the Waitemata Aquifer grouping.

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[2] https://geomapspublic.aucklandcouncil.govt.nz/viewer/index.html

4. Site Investigation

By necessity, hydrogeological investigations are typically based on a combination of known and unknown information. Increasing the amount of known information through field analysis is key to building context through which a site can be evaluated. A broader base of known information benefits the accuracy of overall site characterisation and reduces uncertainty. Several exercises have been undertaken to improve the baseline knowledge to inform the broader analysis represented by the numerical groundwater model for the site.

A small exposure of basalt pillow lava has previously been quarried at the Property. The surface outcrop is mapped with limited lateral extent of approximately 350 m on the QMAP geology map, however the vertical extent and subsurface volume were previously unknown. The following sections detail a series of investigations aimed at furthering our understanding of the basalt aquifer and sustainable groundwater yield potential.

4.1 Drilling

A pilot bore was drilled at the basalt outcrop for investigative purposes. The selected site is adjacent to a very small historic quarry site. The location was identified in a geomagnetic survey as potentially having a productive basalt formation at depth, though survey results had a relatively high degree of uncertainty and conclusions should be considered qualitative in nature (Scantec, 2021). Survey results were unable to determine the size and shape of the formation.

The drilling indicated a thin outcrop of pillow lava at surface extending to a depth of only 15 m, underlain by sandstone and siltstone to 120 mBGL, with a deeper highly fractured pillow lava structure encountered at 120-230 mBGL. The lower extent of the basalt was not determined through the drilling. The lithological log for this bore is provided in **Appendix A** of this report.

As mentioned previously, the fractured basalt/andesitic pillow lava at depth is considered the best prospect for development as a groundwater resource.

4.2 Test Pumping

An airlift test on the pilot bore was conducted by Pattle Delamare and Partners (PDP) for a period of three days, commencing on 3 March 2021. The test consisted of applying compressed air at a pressure of 80 psi initially, reducing as the test progressed to 65 psi, to achieve a constant flow rate of 9 L/s (PDP, 2021b).

The maximum drawdown measured during the test was 4.25 m, however subsequent monitoring indicates that the bore was not in a static state at the time the test started. It is estimated that the true static water level (SWL) was 31.9 mAMSL from the ongoing monitoring, hence the true maximum drawdown from the test is only 3.68 m. After the drawdown phase of the test, water level recovery was monitored for one day during which time a recovery of 53% of the peak drawdown relative to the adjusted SWL was observed.

WWLA has undertaken an analysis of the test pumping data to provide an indication of hydrogeologic properties. The drawdown data shown in **Figure 3** was split into three phases, each with a characteristic slope which was interpreted to indicate that different materials were governing discharge and drawdown dynamics in the bore over the abstraction period. This conclusion supports the notion that the basalt where the bore is located is limited in extent, however further investigation and modelling suggest that there is hydraulic connection to a basalt flow of greater extent.

From geologic knowledge of the area, it is likely that drawdown during the first phase is influenced by the basalt itself, the second phase represents influences from a broader (and potentially deeper) extent of basalt flow, and the third phase is influenced by the cone of depression intersecting the massive sandstone of the Nihotupu Formation surrounding the basalt. The measured drawdown is shown in **Figure 3** with trendlines showing the rate of water level decline in each of the three phases.

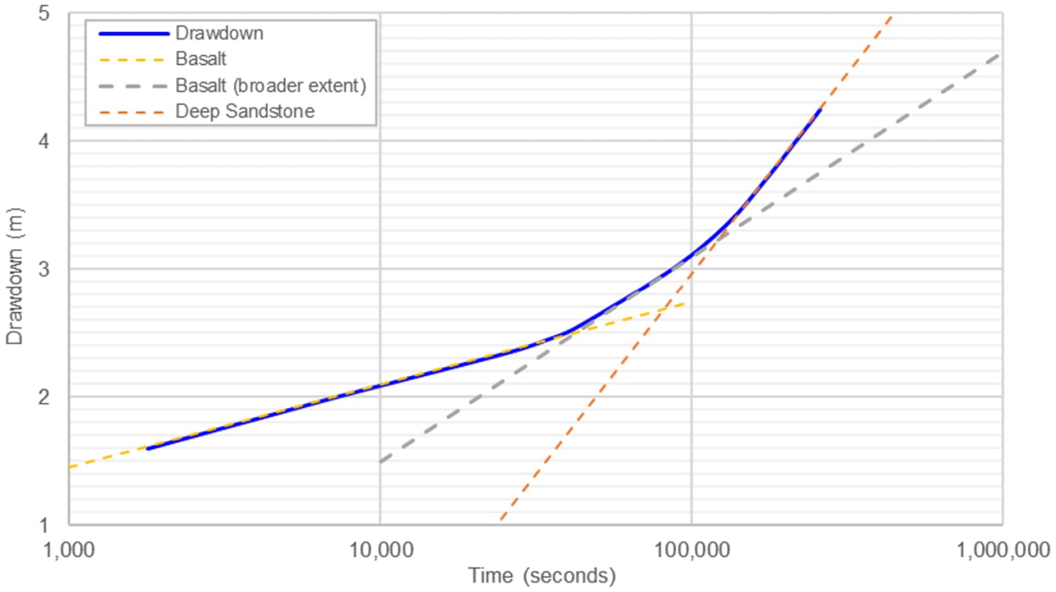

Figure 3. Drawdown phases determined from test pumping results.

The trendline slope of each phase in **Figure 3** was used to calculate the change in water level over a log cycle of time for each phase, providing an indication of the relative permeability of the different materials contributing water to the pumping bore over the course of the test. Results were used to calculate a transmissivity value for each material using the Cooper-Jacob straight line method (Cooper & Jacob; 1946). The transmissivity was subsequently used to calculate hydraulic conductivity for the materials using the 80 m interval of uncased basalt that is intersected by the bore.

The results of this analysis are presented in **Table 3**, and for reference can be compared to the values in **Table 4**, which shows that the basalt results are in the middle of the range for permeable basalt, and slightly lower when influenced by the lower permeability of the sandstone. The Phase 3 hydraulic conductivity, which is likely governed to a moderate degree by the sandstone, is at the higher end of the range for sandstone.

Table 3. Hydraulic parameters derived from Cooper-Jacob analysis applied to test-pumping results.

Phase	Drawdown per log cycle time	Transmissivity	Hydraulic Conductivity	
	(m)	(m²/s)	(m/s)	(m/d)
1. Basalt	0.65	0.0026	3.20×10^{-5}	2.8
2. Basalt (broader extent)	1.60	0.0010	1.29×10^{-5}	1.1
3. Basalt + Deep Sandstone	3.14	0.0005	6.58×10^{-6}	0.6

Table 4. Typical range of hydraulic conductivity for materials (possibly) occurring within the study area (Domenico and Schwartz, 1990).

Material type	Hydraulic conductivity (m/s)	
	Minimum	Maximum
Gravel	3.0E-04	3.0E-02
Coarse Sand	9.0E-07	6.0E-03
Medium Sand	9.0E-07	5.0E-04
Fine Sand	2.0E-07	2.0E-04
Clay	1.0E-11	4.7E-09
Sandstone	3.0E-10	6.0E-06
Siltstone	1.0E-11	1.4E-08
Permeable basalt	4.0E-07	2.0E-02
Fractured Igneous and Metamorphic	8.0E-09	3.0E-04

4.3 ERT Survey

In an effort to better characterise the three-dimensional extent of the basalt and estimate water storage volumes, a series of four electrical resistivity tomography (ERT) surveys were undertaken between 24 June and 1 July 2021 (WWLA, 2021 – Appendix D).

Resistivity data from the four profiles showed a contrast in electrical resistivity between the basalt and surrounding sandstone of the Nihotupu Formation that was used to delineate the basalt extent. A key outcome of the survey was to acquire better visualisation of the shape and extent of the basalt, as shown in **Figure 4**. The three-dimensional surface model developed indicates that the basalt is likely a complex of at least three basalt dykes[3] with associated deeper lava flows. The ERT survey suggests that the surface exposure of basalt was derived from the dyke structure approximately 100 m to the northeast of the pilot bore location.

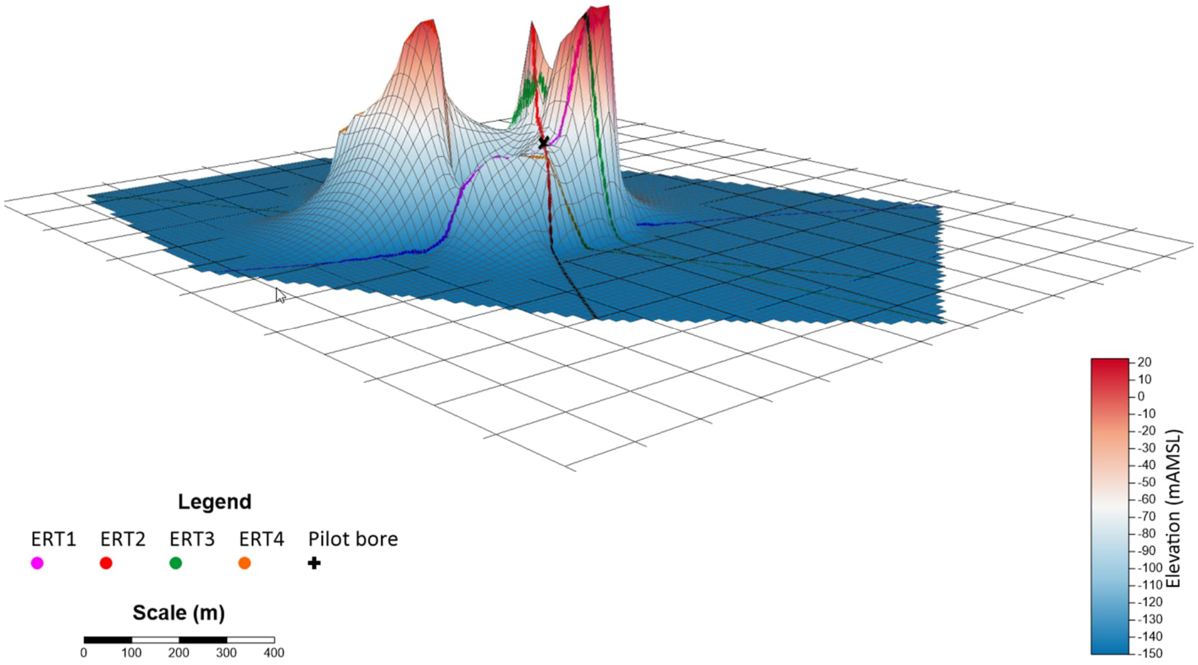

Figure 4. Three-dimensional shape of basalt looking northward (WWLA, 2021 – Appendix D).

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[3] A vertically oriented protrusion of rock penetrating overlying geological layers.

Survey results were also used to derive an estimate of the volume of the basalt dyke to a depth of 200 m (-150 mAMSL).

The estimated water storage capacity was between 500,000 m^3 and 1,000,000 m^3, assuming a porosity of between 5 and 10 % as indicated by the low resistivity found by the ERT survey and the high transmissivity indicated by airlift testing.

4.4 Monitoring

Groundwater

Over the course of the investigations conducted at the Property four groundwater monitoring sites have been established and equipped with data loggers for continuous groundwater level measurement. Three other piezometers were installed to the south of Muriwai Road for the purposes of geotechnical investigations at a proposed reservoir site. These sites have not been equipped with data loggers, though static water level has been measured. Additionally, shallow piezometers have been installed in some of the wetlands (indicated in **Figure 5**) and two in the quarry south of Muriwai Road, however at approximately 1 m in depth these are too shallow to be indicative of regional groundwater levels. Recently, a pair of nested piezometers were installed at 4.5 m and 14.5 m depth on the north shore of Lake Ōkaihau. All monitoring locations are shown in **Figure 5**.

Table 5 provides summary data on the groundwater monitoring locations and **Figure 6** shows the average water level relative to the base elevation of the monitoring sites.

It is apparent in **Figure 6** that that there is a steep vertical gradient with groundwater pressure decreasing with depth. For example, the groundwater level at the pilot bore (cased to 120 mBGL) is nearly 18 m below the water level at the shallow monitoring piezometer (4 mBGL) which is only 17 m away at the surface. This indicates increasing confinement of groundwater with depth, meaning that deep groundwater is hydraulically separated from shallow groundwater.

Table 5. Summary information on monitoring piezometers.

Bore ID	Data Collection	Depth	Surface Elevation (mAMSL)	Base Elevation (mAMSL)	Geologic material	Mean water level
Pilot	Continuous	200	52.2	-147.8	Deep basalt	32.1
MW1	Continuous	4.3	51.0	46.7	Shallow pillow basalt	49.9
MW2	Continuous	10.7	51.0	40.3	Shallow pillow basalt	49.4
MW3	Continuous	60	60.3	0.3	Nihotupu formation (most likely)	44.5
MW4	Manual	13.5	73.3	59.8	Awhitu formation	60.7
MW5	Manual	9	70.3	61.3	Awhitu formation	61.5
MW6	Manual	6	67.9	61.9	Awhitu formation	62.4
MW7	To be determined	5.5	32.6	27.1	Karioitahi sands	To be determined
MW8		14.5	32.6	18.1	Awhitu formation	

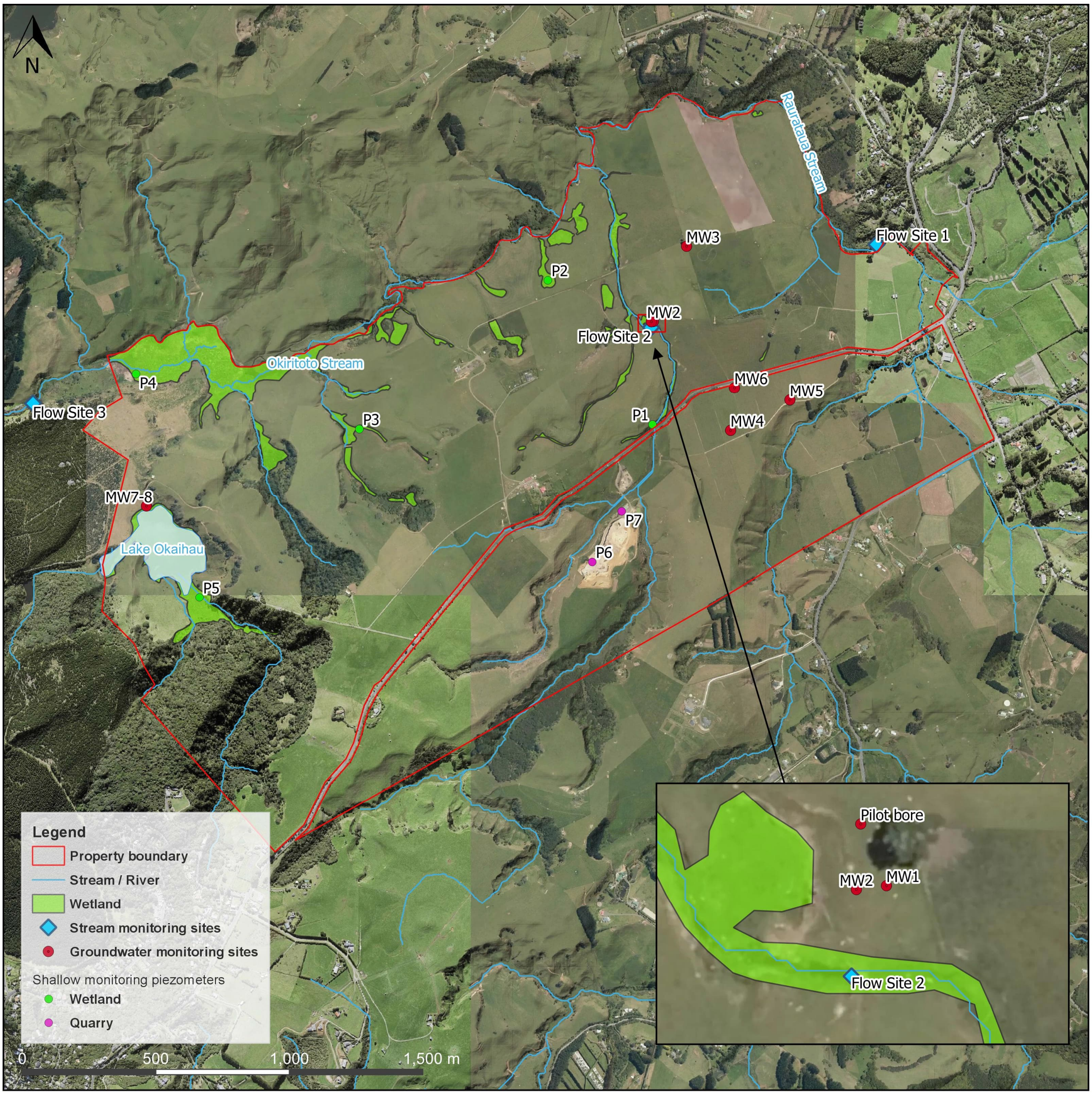

Figure 5. Monitoring locations on Muriwai Downs Property.

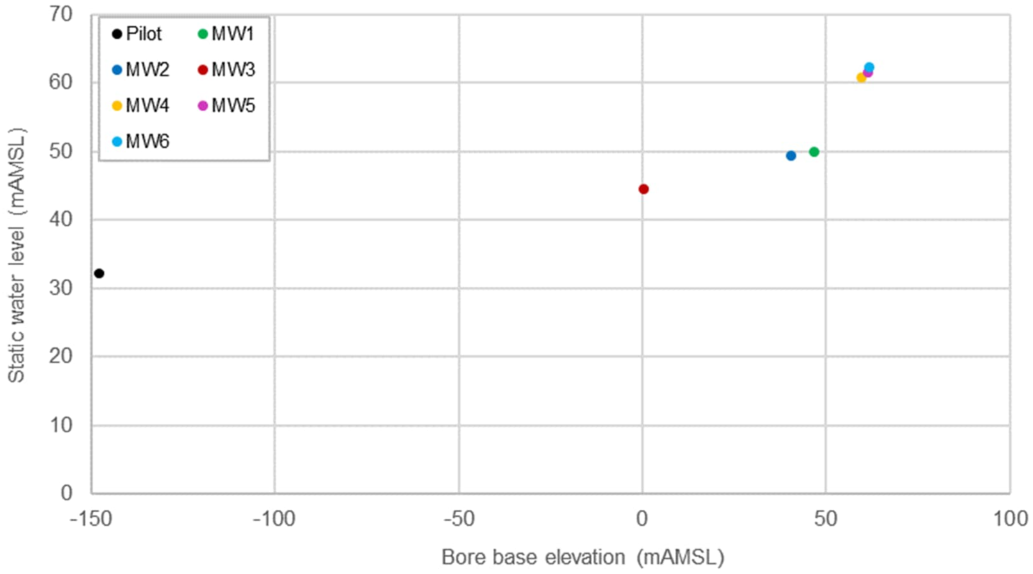

Figure 6. Mean static water level relative to bore base elevation at monitoring locations.

Surface Water

Three stream flow monitoring sites were installed on the Property, representing the two main inflows; the Raurataua Stream (Flow Site 1), Ōkiritoto Stream-upgradient (Flow Site 2), and the Ōkiritoto Stream-Downgradient as it leaves the Property (Flow Site 3). Each site is equipped with an Ultrasonic Level Sensor to collect water level measurements at five-minute intervals. Flow Site 3 was damaged in a flood on 31 August 2021 (after the time period used for this assessment) and is currently out of commission.

A rating curve was developed from stream flow measurements undertaken using a Sontek Flow Tracker. The rating curve was used to transform the level sensor data into a flow time series. Low-flow periods from the data set were used as a benchmark to compare simulated groundwater discharge (i.e. baseflow). Complete details of stream gauge installation and surface water monitoring can be found in WWLA (2021 – Appendix A).

5. Model Conceptualisation

Analysis of hydrogeological conditions of any site typically begins with the development of a conceptual model, which in summary is a collection of data and hypotheses that when considered together, describe the current understanding and functionality of the hydrogeological flow system.

A conceptual hydrogeological model comprises elements that contextualise:

- the structure, type and hydraulic properties of the various earth materials within the groundwater system;
- groundwater input and output mechanisms from the system, such as rainfall recharge and baseflow discharges to streams and oceans; and
- the storage levels and flow rates of groundwater within the system.

The conceptual model is important because it informs the basis for parameterisation and structuring of the numerical model. This section presents the key data and hypothesis that underpin the understanding of the groundwater system.

5.1 Climate

Evaporation and rainfall data were obtained from the National Institute of Water and Atmospheric Research (NIWA) virtual climate station network (VCSN). The VCSN data provides estimates of climate variables on a 5 km regular grid, covering all of New Zealand. Estimates of climate parameters are produced for each VCSN point on a daily time-step based on spatial and temporal interpolation of recorded observation data at the nearest reliable meteorological sites. Daily rainfall and potential evapotranspiration were used to calculate groundwater recharge, as detailed in **Section 5.4**.

Estimates of daily rainfall and potential evapotranspiration (PET) were obtained from VCSN Site 21836, located approximately 2 km south of the Property, but within the groundwater effects study area. A summary of monthly rainfall from 1972 through 2020 for this location is presented in Figure 7.

June and July are the wettest months with lower rainfall in summer with the exception of occasional months where summer storm activity generates unusually high rainfall. Mean annual rainfall was 1,488 mm, ranging from a minimum of 1,110 mm in 2020 to a maximum of 2,049 mm in 1979. As is shown in **Figure 7**, PET frequently exceeds rainfall from November through March causing the soil to become too dry for plant growth and requiring irrigation.

Consideration was given for potential rainfall and recharge conditions that fall outside of the historic range due to climate change. The future climate projections available from NIWA show that the study area is likely to have little change in annual precipitation. The maximum emission scenario shows a change ranging from 0% (unchanged) to a 5% increase in annual rainfall in the study area predicted for 2046-2065[4], a period that extends beyond the length of the proposed consent. For this reason, the range of conditions within the historic data set used in model development were considered sufficient to account for climate change in this region.

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[4] https://ofcnz.niwa.co.nz/#/nationalMaps

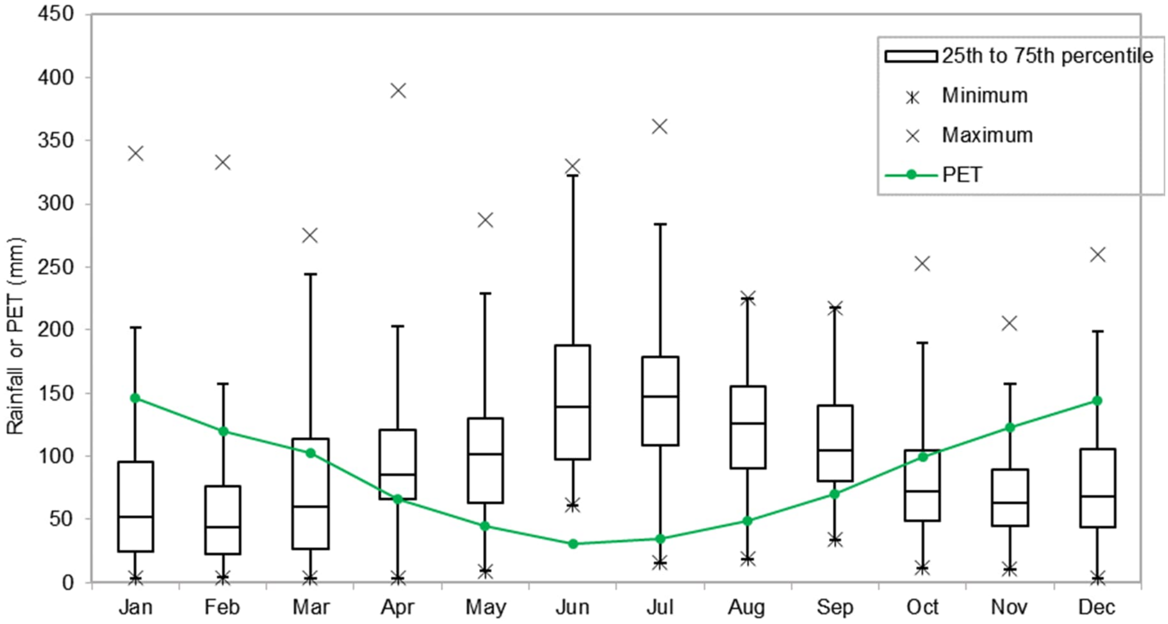

Figure 7. Monthly rainfall and PET (1972-2020) – VCSN# 21836.

5.2 Topography

Auckland Council's 2016 LiDAR data was obtained and utilised to define topography across the study area. The LiDAR vertical datum is NZVD2016, which from the remainder of the report will be referred to as meters above mean seal level (mAMSL). Topography across the study area is generally characterised as gently rolling, with an incised river channel along the northern edge of the Property. In general, the wider Ōkiritoto Stream catchment is characterised as rolling hills with a broad, flat valley floor. Across the catchment, elevations range from approximately 6 m to 192 mAMSL, with the highest elevations occurring in the headwaters to the south-west. The catchment topography is shown in **Figure 8**.

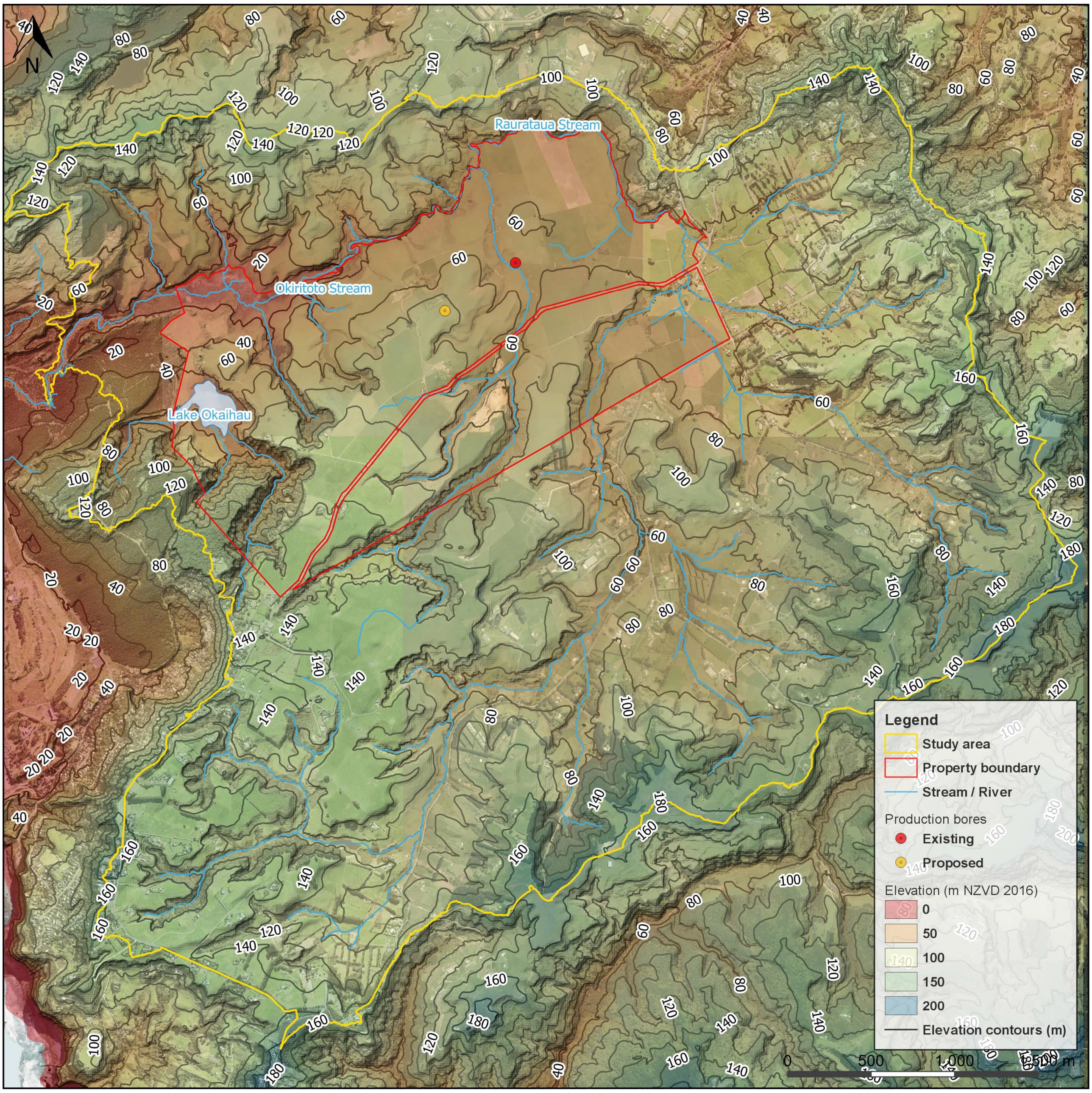

Figure 8. Topography over study area as defined by LiDAR source from Auckland Council.

5.3 Soils

The GNS Fundamental Soils Layer indicates three main soil types across the study area; Waitematā Sandy/Silt Loam, Red Hill Sandy Clay Loam, and Waitākere Clay. Soil texture is predominantly classified as sand clay loam, however in the east, clay and clay loam dominate, hence the soils are heavier moving inland away from the coastal aeolian sand influence.

Soil depths range from 0.89 to 1.5 m, and permeability is classed as medium in the west and medium slow in the east. The heavier soils that occur further inland have characteristically lower permeability, and hence lower infiltration and drainage. Areas with heavier soils typically have more runoff and less groundwater recharge in response to rainfall relative to the more permeable areas.

This information, along with topography, was incorporated into assessments of the study area to delineate sub-catchments which were used to calculate the partitioning of rainfall between evapotranspiration, surface runoff, and groundwater recharge.

Soil classification and sub-catchments (discussed further in **Section 5.4.2**) are shown in **Figure 9**.

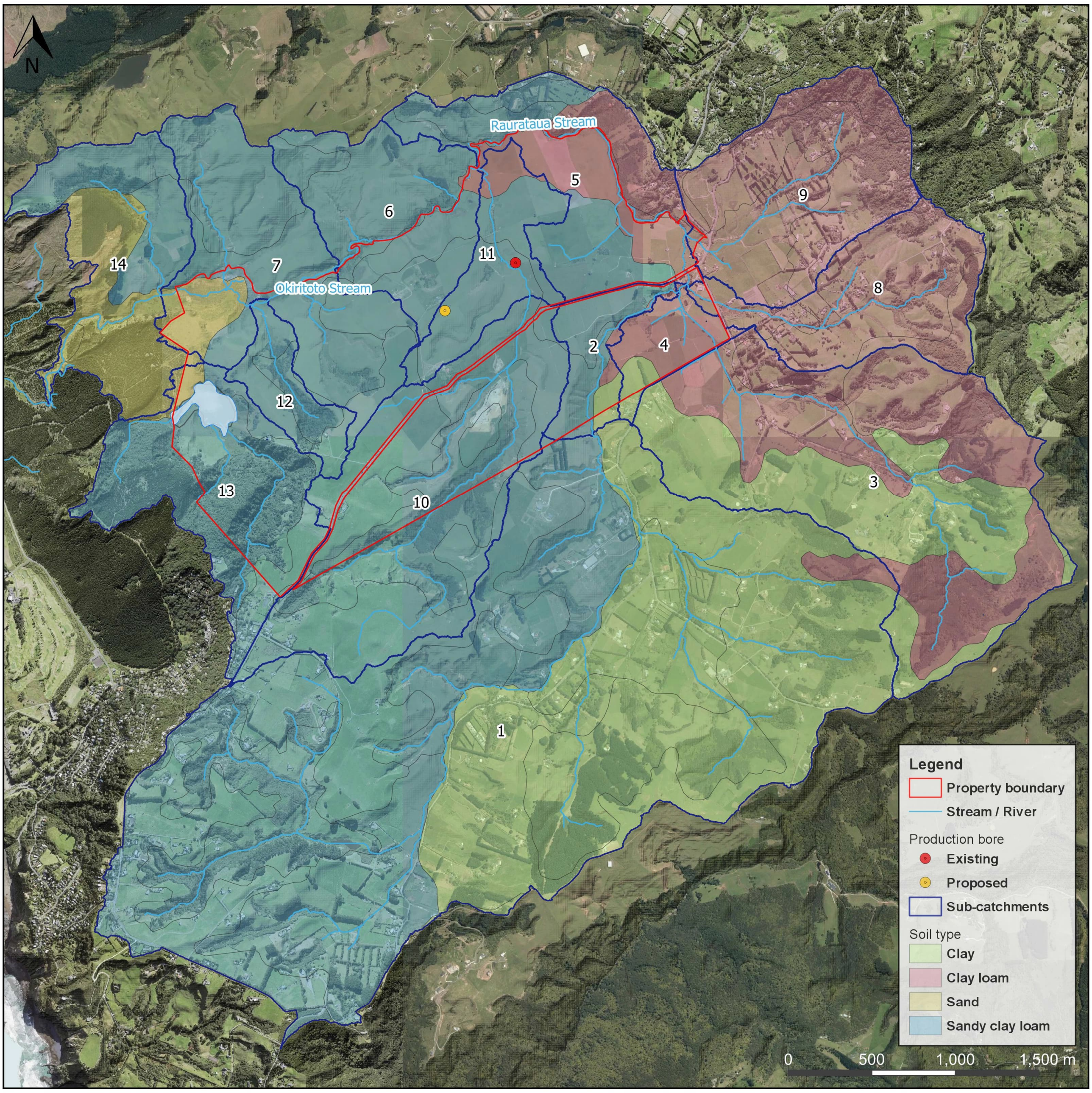

Figure 9. Soil types and analysis sub-catchments in study area.

5.4 Groundwater Recharge

Recharge within the Muriwai Downs catchment occurs through the infiltration of rainfall, subsequent sub-soil drainage and percolation vertically to the groundwater table, as is typical for the rainfall dominated catchments. The Soil Moisture Water Balance Model (SMWBM) was applied to determine the percentage of rainfall that becomes groundwater recharge across the study area.

5.4.1 SMWBM Overview

The SMWBM is a semi-deterministic rainfall-runoff model. Model functionality includes surface ponding function, evaporation functions for differing land cover, vadose zone unsaturated flow and travel time, and an irrigation demand module. The version of the model utilised for this Project is denoted as SMWBM_VZ, to reflect the incorporation vadose zone processes. The SMWBM_VZ was used within the SOURCE framework for this analysis, allowing catchment parameters to be set for each of the model sub-catchments.

The model utilises daily rainfall and evaporation data to calculate the soil moisture conditions under natural rainfall conditions and under different irrigation schemes. The model operates on a daily time step during dry days, however when rain days occur, a finer hourly calculation step is implemented to enable peak flows to be assessed more accurately than a daily time step model.

The SMWBM_VZ incorporates parameters characterising each sub-catchment in relation to the following processes:

- Interception storage;
- Evaporation losses;
- Soil moisture storage;
- Surface runoff;
- Soil infiltration;
- Sub-soil drainage;
- Flow in the unsaturated zone;
- Stream base flows; and
- The recession and/or attenuation of ground and surface water flow components.

Detailed parameter descriptions and a schematic diagram of the function of SMWBM is included as **Appendix B** of this report. Complete details of the development and application of the SMWBM for this study are provided in WWLA (2021 – Appendix C).

5.4.2 Recharge Modelling

Sub-Catchment Delineation

Topographic data, geology, slope, soil type and land use were assessed to develop a series of interconnected sub-catchments that were discretised to reflect the localised characteristics for each catchment. Flow and water quality monitoring sites were also considered in the process of sub-catchment delineation. The sub-catchments used in this assessment were included in **Figure 9**.

SMWBM Application

Previous water quality and water quantity assessment projects undertaken by WWLA and detailed in WWLA (2021 – Appendix C) were used as the basis for initial parameterisation of SMWBM based on physical characteristics determined for each sub-catchment. For example, relating the infiltration rate (Zmax parameter) to the soil texture, and the fraction of ponded water that infiltrates versus runoff (Div parameter) to slope. These existing relationships were further refined and calibrated against site specific local measured flow data. The final calibrated model parameter relationships and flow calibration plots are presented in WWLA (2021 – Appendix C).

Recharge Model Results

The results from the calibrated SMWBM models were used to determine a daily recharge data set for each sub-catchment within the groundwater model. The partitioning between groundwater recharge, surface runoff, and evapotranspiration is shown for each sub-catchment in **Table 6**. Mean annual recharge ranges from approximately 8 to 16 percent of annual rainfall across the model sub-catchments. Maximum recharge corresponded to catchments comprised of relatively deep sandy clay loam soils, generally toward the western portion of the study area; whereas low recharge was simulated where relatively shallow, clay loam soils were predominant, such as in Sub-Catchment 4.

Table 6. Primary SMWBM parameters and rainfall partitioning.

Sub-Catchment	Soil Depth	Maximum Soil Infiltration Rate	Maximum Groundwater Percolation Rate	Soil Depth (mm)	Surface runoff	Groundwater recharge	Evapotranspiration
	(mm)				Percent of rainfall		
1	479.0	9.1	0.8	479.0	31.0%	13.2%	55.8%
2	537.0	10.4	0.8	537.0	29.4%	13.7%	56.9%
3	441.5	6.0	0.8	441.5	35.0%	11.9%	53.1%
4	350.3	6.1	0.5	350.3	39.5%	7.6%	52.9%
5	528.5	9.9	0.8	528.5	29.8%	13.6%	56.7%
6	600.7	14.8	0.8	600.7	27.2%	14.4%	58.4%
7	607.5	15.6	0.9	607.5	25.7%	16.0%	58.2%
8	572.1	6.0	0.8	572.1	33.2%	12.1%	54.7%
9	523.8	6.0	0.8	523.8	33.8%	12.0%	54.2%
10	607.0	8.0	0.9	607.0	28.8%	15.0%	56.1%
11	581.2	8.0	0.6	581.2	32.6%	10.4%	57.0%
12	607.5	15.0	0.9	607.5	25.8%	16.0%	58.2%
13	500.0	8.0	0.8	500.0	26.8%	15.8%	57.5%
14	607.5	15.6	0.9	607.5	25.7%	16.0%	58.2%

5.5 Geologic Materials

The geological material distribution in the groundwater model is the same as that discussed in **Section 3.1**.

5.6 Hydrogeological Interpretation

Observations from site visits and review of the available data indicates several interpretive conclusions regarding hydrogeological conditions over the study area, which are as follows:

- The observation of perennial stream flow particularly below RL 60 mAMSL and diffuse springs suggests that a significant component of the rainfall recharge may discharge to the streams.
- The geological profile of weathered Awhitu sands overlying much lower permeability Nihotupu sediments, suggests that the groundwater flow component in the Awhitu sands will be stronger than the underlying low-permeability layer. Therefore, the majority of groundwater circulation is transmitted laterally through the Awhitu sands (top 90 m) emerging in stream valleys as baseflow.
- The basalt is relatively permeable based on the test pumping and knowledge of similar features in other locations.
- The vertical hydraulic gradient, illustrated in **Figure 6**, suggests the following conclusions regarding regional groundwater flow:
  - The deep aquifer is significantly confined with limited influence from surface conditions.
  - An outlet for deep groundwater flow other than surface streams must exist to account for the lower head in the deep aquifer. This is most likely as discharge to the ocean floor some distance offshore.

6. Groundwater Modelling Methodology

A numerical groundwater model is a three-dimensional representation of a groundwater system and the physical materials within which it occurs. The model consists of a geometric grid covering the study area. The grid is comprised of a network of cells representing three-dimensional space, with each cell is defined in terms of thickness and area. The model can be developed to represent multiple layers of geologic material, as has been done in this study, to account for different materials that occur over a vertical, as well as horizontal profile.

Inflowing and outflowing groundwater is simulated based on hydrogeologic parameters assigned to the cells within the prevailing material properties. Boundary conditions are applied to represent groundwater sources or sinks, for example groundwater recharge, streams, or abstraction bores. The model calculates a water balance for each cell where simulated groundwater pressure is calculated as a function of cell geometry, material properties, applied boundary conditions, and the flow interactions with neighbouring cells.

The aggregate of these calculations for each of the model cells (or a subset, if desired) is the mass water balance, while the groundwater pressure (head) calculated for each cell can be interpolated to represent the position of the water table in an unconfined aquifer or the piezometric surface in a confined aquifer.

A model that is developed to calculate water levels based on a constant condition (i.e. constant recharge) is a steady state model. A model that simulates conditions that change over time is a transient model.

The MODFLOW Unstructured Grid (MODFLOW-USG) developed by the United States Geological Survey (USGS) was utilised within the GMS10.4 modelling platform to construct the groundwater flow model in this Project. The unstructured grid that was developed provides the capacity of fitting irregular boundaries into the model and increasing the resolution in the areas of maximum interest while decreasing resolution in other areas. This spatially varying discretisation approach reduces model computational time, while maintaining enhanced accuracy of calculation at the points of interest, hence optimising computational efficiency.

6.1 Model Domain

The model was constructed based on three layers, with a total of 82,323 active cells (27,441 for each model layer) and covers an area of 3,439 ha. Model grid cell area ranges from 10 m^2 around key features such as the pilot bore and the sandstone-basalt interface, to 39,070 m^2 along the south and east model boundaries where high resolution is unnecessary. Grid resolution in stream corridors is relatively refined at 40 m^2 to provide greater accuracy in the accounting of surface water groundwater interactions. **Figure 10** shows a three-dimensional view of the model grid.

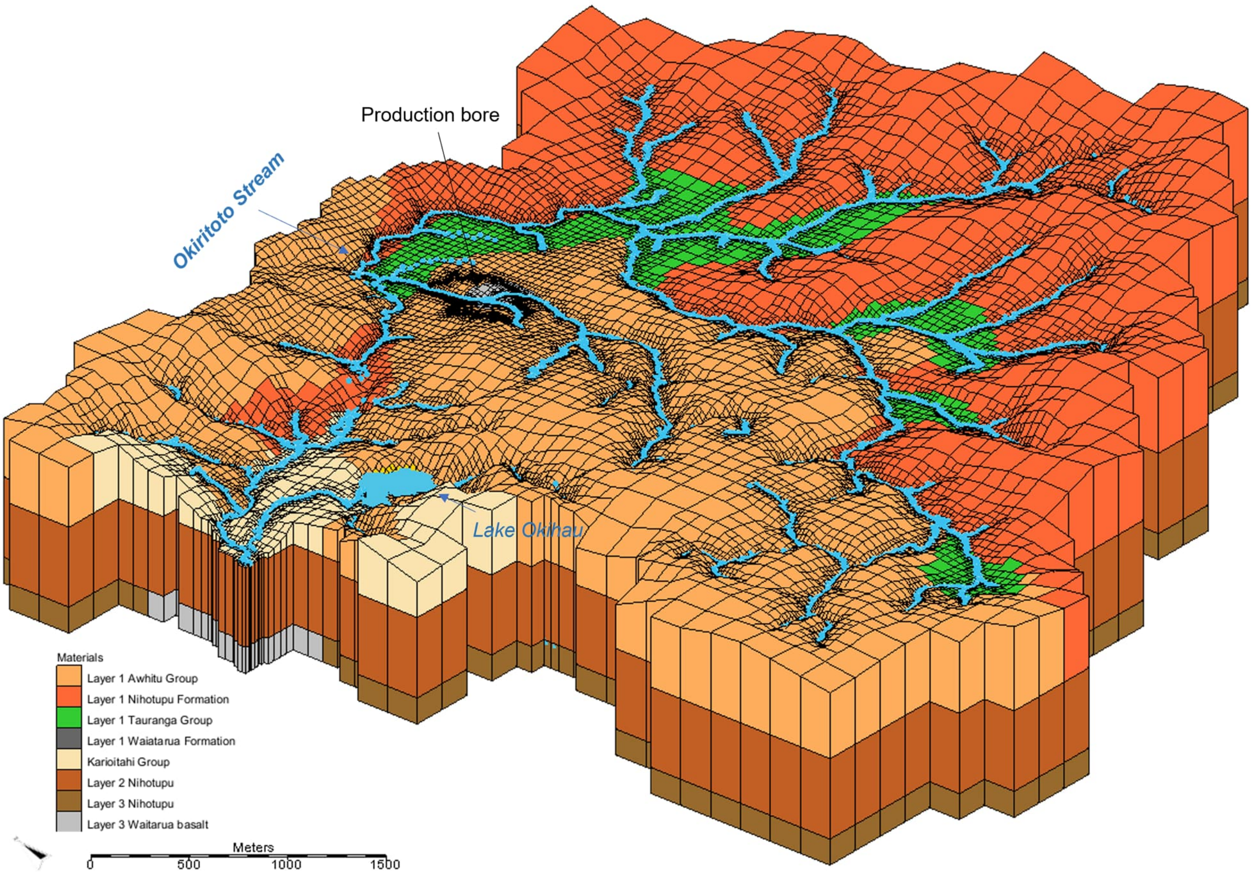

Figure 10. MODFLOW-USG grid (3x vertical magnification).

6.1.1 Model Layer Configuration

The surface elevation used for the model utilised the 1 m LiDAR digital elevation model (DEM) provided by Auckland Council, as was shown in **Figure 8**. The interface between model Layers 1 and Layer 2 was set at 5 mAMSL on the basis that:

- no detailed bore log data on which to base estimates of material thickness exists;
- this level improved the numerical stability of the model; and
- this level allowed anisotropy (ratio of horizontal conductivity to vertical conductivity) that is known to occur in the native materials to be effectively incorporated into the model.

The materials used in Layer 1 were configured to represent the primary geologic material in the study area as described in **Section 3.1**. Awhitu and Nihotupu sandstone was assumed to cover most of the area. The pillow basalt outcropping was input into the model as it was mapped by GNS.

Layer 2 was assumed to be comprised solely of low-permeability Nihotupu sandstone, whilst Layer 3 was comprised of basalt in the area of the pilot bore with the extent defined by the ERT survey (WWLA, 2021 – Appendix D), surrounded by Nihotupu sandstone.

The interface between model Layer 2 and Layer 3 was set to correspond to the bottom of the pilot bore at -150 mAMSL over the majority of the model area, with the exception of the area adjacent to the pilot bore. In this area the interface was adjusted to reflect the top of the basalt dyke formation as defined by the ERT Survey (WWLA, 2021 – Appendix D).

The basalt dyke, as incorporated into the model is illustrated in **Figure 11**.

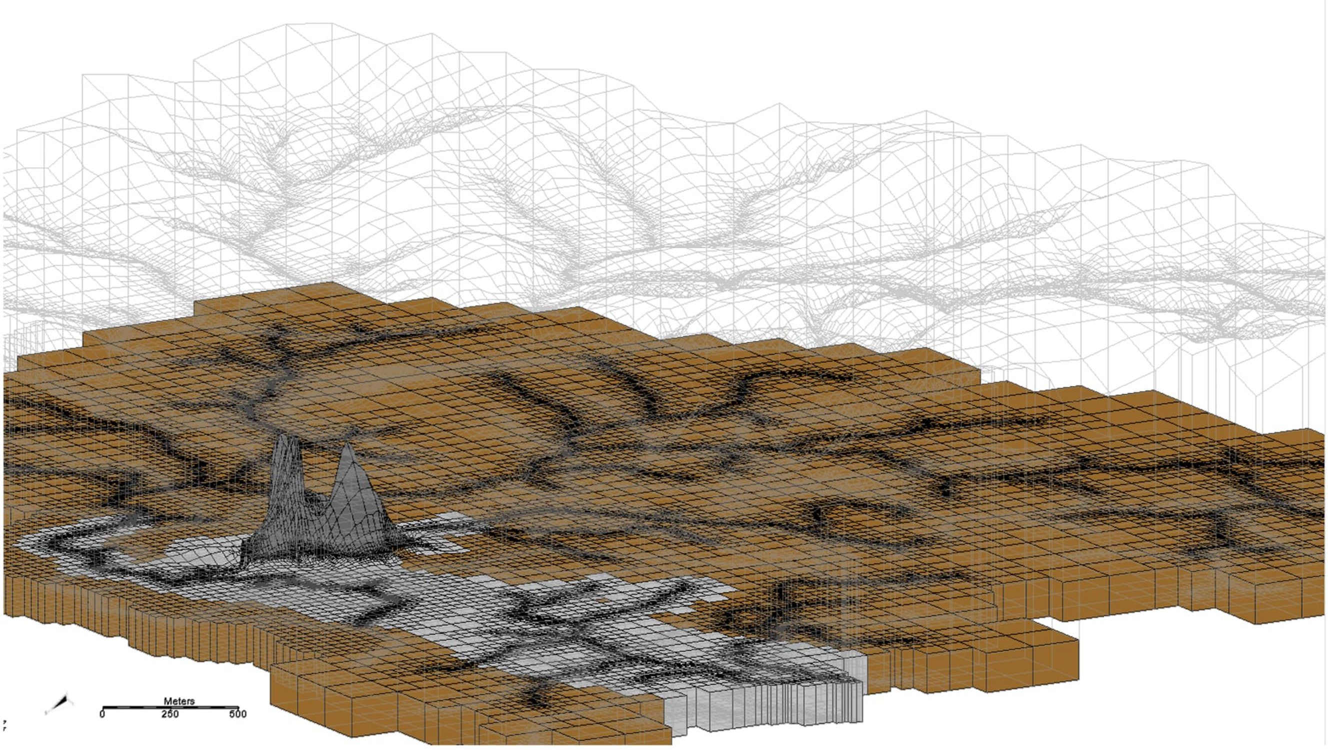

Figure 11. Basalt dyke (grey protrusion) as incorporated into GMS model.

Three permeability profiles (assigned as material types) were used in Layer 3. The majority of the area was considered sandstone while the lateral boundaries of the dyke, as mapped from the ERT survey, were used to define the extent of “known” basalt. It is unknown how far the basalt flow extends in the deep subsurface, however regional geology indicates that the existence of deep basalt formations in this area are likely (Balance, 2009), though specific information on the depth of the basalt is not available due to a lack of drilling data. Furthermore, test pumping results (**Section 4.2**) indicate three hydraulic transitional responses.

In the model calibration process (**Section 7**) testing of model parameters indicated that calibration of the measured strong downward pressure gradient could not be achieved without a deep groundwater outlet to depressurise the deep aquifer, which was achieved via a deep groundwater throughflow (seepage) toward the coast. This was incorporated into Layer 3 by setting a zone of moderately high conductivity that aligns with the Ōkiritoto Valley. This feature is consistent with the conceptual hydrogeological model as alluded to in **Section 3.2** referred to here as a deep basalt flow within a zone of weakness or slightly enhanced permeability.

The base of the model (Layer 3) was set at -200 mAMSL to account for the unknown depth extent of the deep basalt and to ensure that the lower model boundary was sufficiently deep to account for any potential effects of the groundwater abstraction. **Table 7** summarises the model layer elevations.

Table 7. Configuration of model layer materials and elevation.

Model Layer	Top Elevation (mAMSL)	Bottom Elevation (mAMSL)	Material
1	LiDAR Elevation	5	Sandstone, basalt
2	5	-150; basalt dyke surface where applicable	Sandstone (low permeability)
3	-150; basalt dyke surface where applicable	-200	Sandstone, basalt (dyke), basalt (flow)

6.1.2 Simulated Groundwater Recharge

Groundwater recharge was applied in the model by intersecting each cell in Layer 1 with the relevant sub-catchment generated recharge data from the SMWBM, described in **Section 5.4.2**.

6.1.3 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. Flow through a GHB may go into or out of the model. The two parameters that determine the rate and direction of flow (into or out of the aquifer) are the head assigned to the GHB and the conductance through the boundary.

Coastal Boundary

The cells along the western model boundary were assigned a GHB condition in model Layer 3 to allow groundwater seepage from the aquifer to the sea floor. The extent of the GHB was limited to cells adjacent to the Ōkiritoto valley which likely represents the preferential path of regional flow at depth as well as at the surface.

The GHB head was assigned as 0 mAMSL to represent sea level.

Lake Ōkaihau

Lake Ōkaihau was also represented in the model with a GHB. The water balance for Lake Ōkaihau was evaluated in WWLA (2021 – Appendix F), where it was found that the lake is primarily filled by surface inflow and leaks water into the underlying shallow aquifer.

Daily lake levels were estimated based on historic climate and monitoring data. A seepage curve was developed to estimate the rate of seepage from the lake relative to the water level. Daily water levels as determined in the aforementioned study were applied to the GHB and conductivity was adjusted to match the resulting seepage from the lake into the aquifer as part of the model calibration process.

6.1.4 No-Flow Boundaries

No flow boundaries were assigned along the basement and perimeter of the model domain with the exception of the GHB along the portion of the coast described in the previous section. This approach was taken because it is generally assumed that catchment boundaries effectively demarcate groundwater flow divides unless there is specific evidence to the contrary, such as depressurisation adjacent to the boundary, which there is no evidence of at Muriwai Downs.

6.1.5 Stream Boundaries

Streams in the model area were identified from the River Environment Classification (REC) database New Zealand with slight adjustment based on GIS based topographic analysis. Simulated flow in streams and drains corresponds to baseflow alone and does not include the portion of flow that is due to surface runoff.

Streams were incorporated into the model using drain boundaries to simulate the groundwater discharged to the streams within the model area. The drain bed elevations were derived from the DEM using the minimum elevation within each cell as the drain bed elevation.

The conductance value of the drains was set relatively high to reflect limited impedance to water removal (or drain functionality) where surface discharge was expected.

6.1.6 Well Boundaries

The only well simulated in the model was the proposed production bore at Muriwai Downs, which is at the same location as the Pilot Bore shown in the inset of **Figure 5** and will be constructed to the same depths (i.e. cased to 120 mBGL, with a total depth of 200 mBGL).

7. Model Calibration

Model calibration is the process of systematically adjusting the hydraulic parameters applied in the model until the simulated outputs match measured data as closely as possible. It is important to ensure parameters reside within a range that is realistic and appropriate for the material being modelled, otherwise the model cannot be considered highly representative of field conditions. Where there is measured data available for a particular parameter, such as hydraulic conductivity calculated from test pumping results, the parameter is set equal to the measured data and other parameters become the focus of calibration efforts.

Once the best fit between simulated and observed data is achieved, the model is considered calibrated and the parameters can then be applied in scenarios developed to test potential or proposed activities pertaining water use.

7.1 Observation Points

The four monitoring piezometers described in **Section 4.4** were the primary targets for model calibration. This included the recent monitoring period as well as the drawdown and recovery observed during the test pumping exercise. A secondary target was matching the baseflow recorded at the three flow monitoring locations. The three shallow piezometers that only had single water level measurements were only considered as an approximate indicator for calibration purposes but were not a calibration target because of the lack of data.

It is anticipated that upcoming test pumping will initiate the next phase of model calibration, which will incorporate data from the newly installed piezometers in addition to test pumping results and updated monitoring data from the original locations.

7.2 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 determine hydraulic parameters that resulted in as accurate match as possible between simulated and observed groundwater level, and to obtain initial heads for transient model simulation.

The average water levels at each of the four monitoring locations and seepage from Lake Ōkaihau were used as the calibration targets. The four simulated groundwater levels are plotted against mean observed groundwater levels in **Figure 12**.

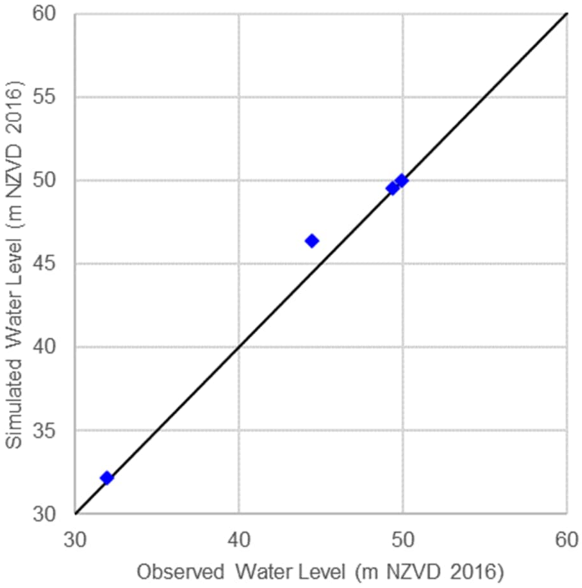

Figure 12. Simulated head versus observed head.

The steady-state simulation has a root mean square error (RMSE) of 0.98 m, which is approximately 5.5% of the range of observations. A simulated RMSE of less than 10% of the measured range is considered a good calibration, hence the model can be considered fit for purpose. It should also be noted that the RMSE for the pilot bore and two adjacent shallow monitoring piezometers is 0.16 m, while the simulated water level at the 60 m deep monitoring piezometer approximately 300 m to the east of the pilot bore was 1.9 m above the measured water level. This likely due to the simplification of stratigraphy, which is a necessary task when developing a numerical model.

The piezometric surface generated by the steady-state model and inferred flow paths for the three model layers are shown in **Figure 13**, **Figure 14**, and **Figure 15**, respectively. In Layer 1 (**Figure 13**) the groundwater flow tends to be in the direction of the closest downgradient stream, supporting the idea that much of shallow the groundwater is discharging as baseflow in the stream network. In Layer 2 (**Figure 14**) groundwater flows toward the coast, with flow paths converging in the Ōkiritoto Valley. In Layer 3 (**Figure 15**) groundwater is flowing broadly toward the coast, with the effects of topography are less apparent at this depth.

In summary the results of the steady-state model calibration indicate that simulated water levels are on average, within 1 m of measured water levels. Simulated water levels in the area around the abstraction bore are significantly more accurate. Shallow groundwater tends to flow laterally towards streams where it discharges to surface water, however groundwater that percolates to greater depths becomes regional groundwater and tends to flow toward the coast with the influence of surface topography decreasing with depth.

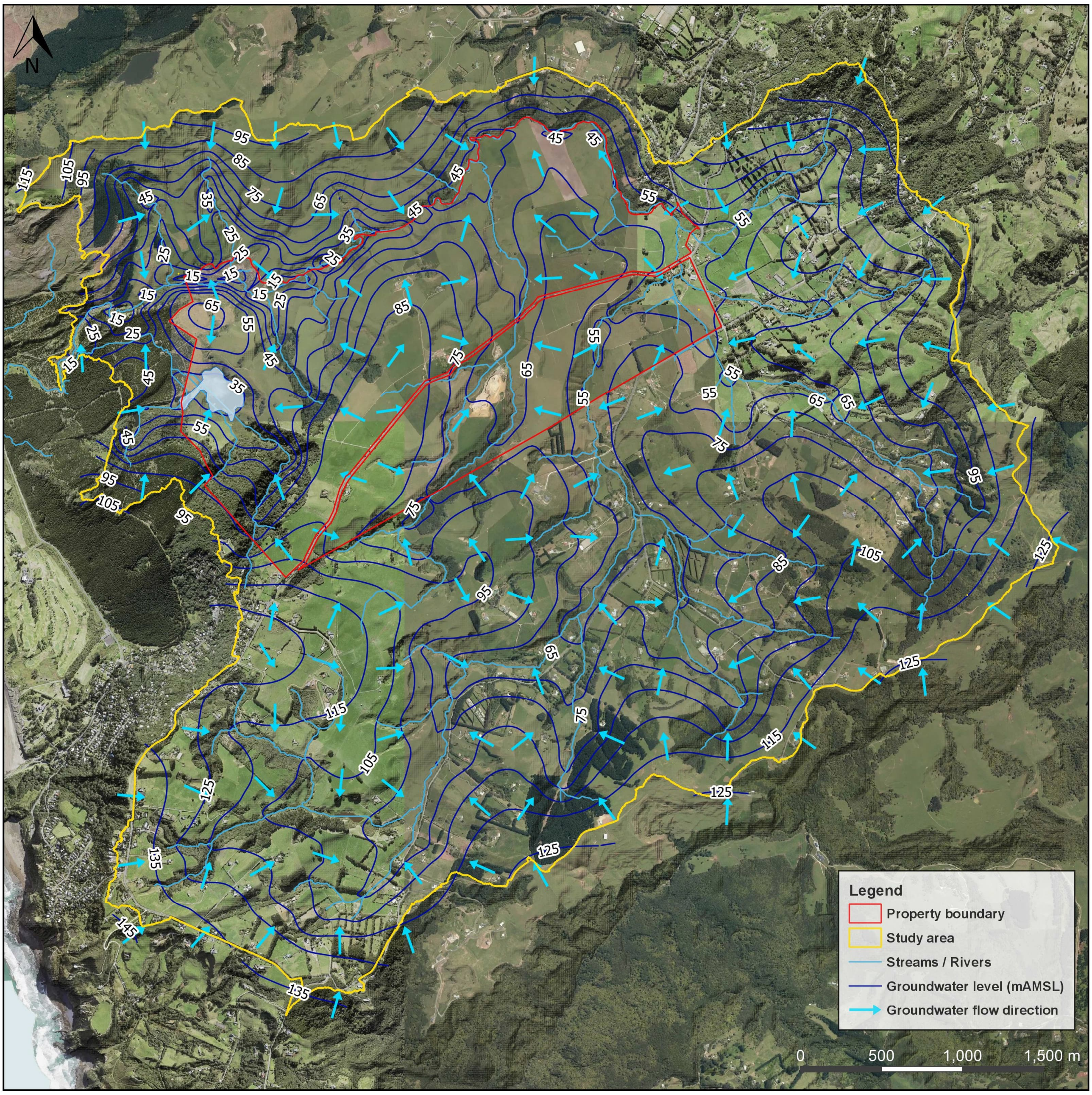

Figure 13. Steady state model piezometric surface for Model Layer 1.

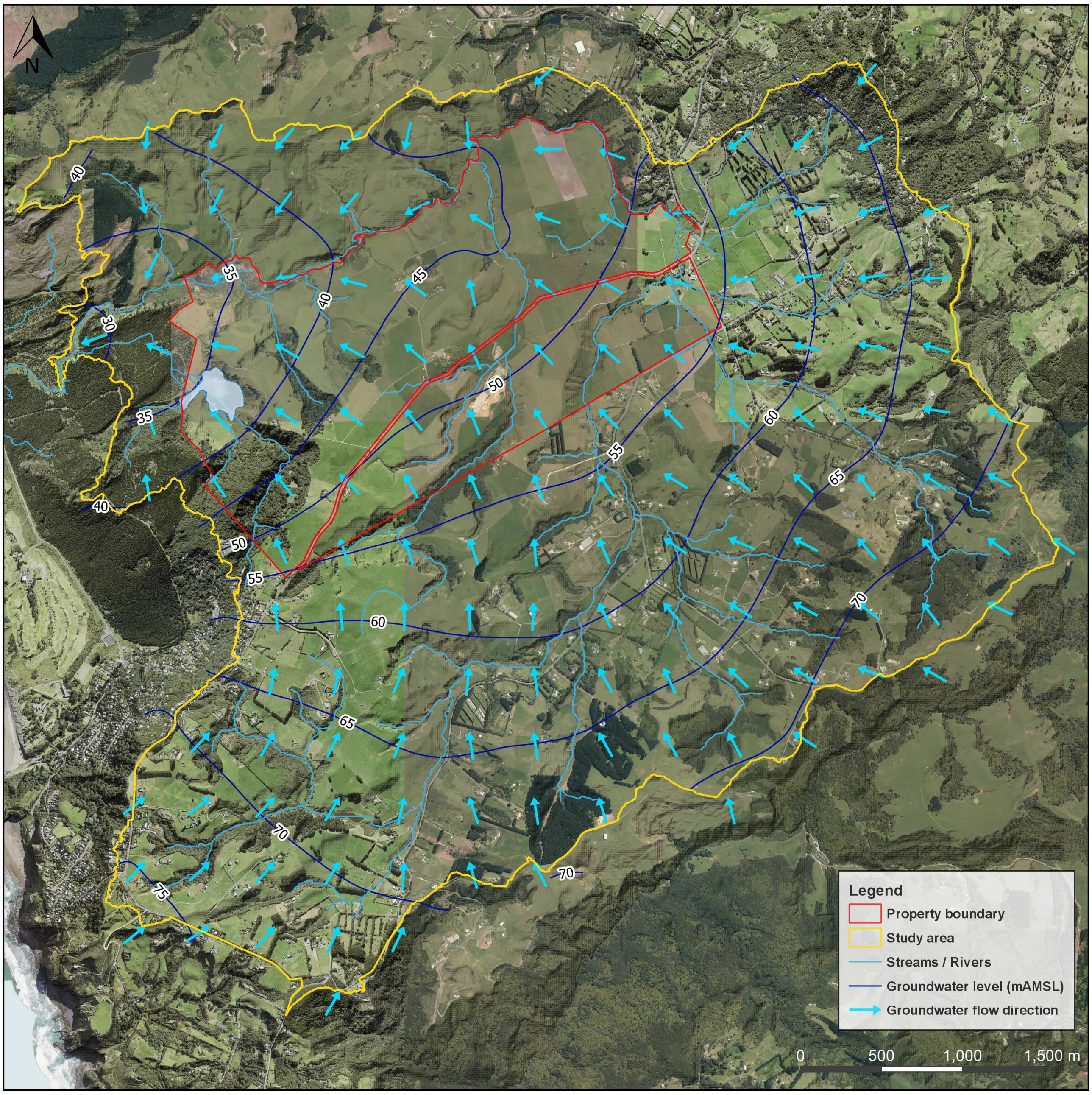

Figure 14. Steady state model piezometric surface for Model Layer 2.

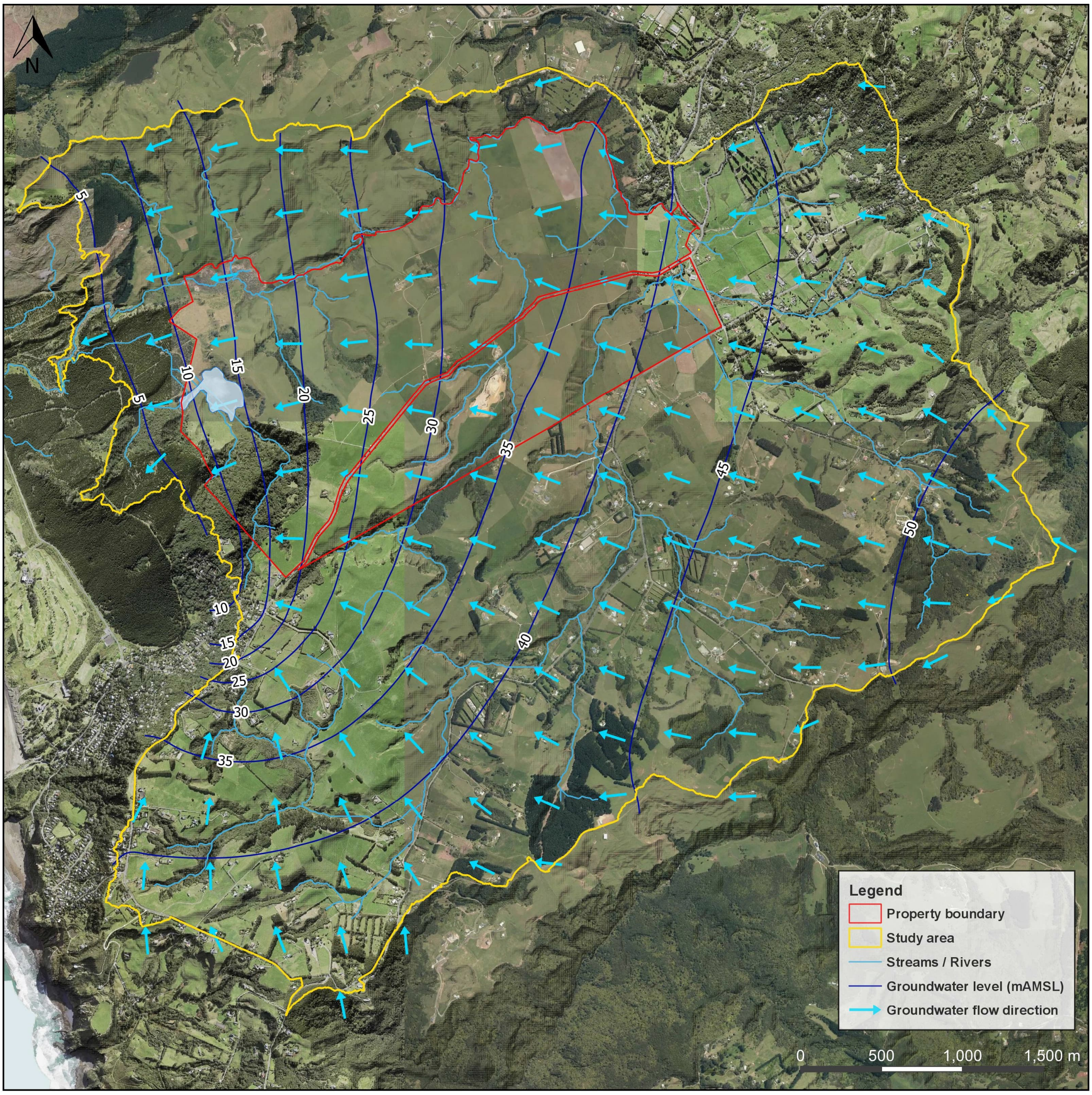

Figure 15. Steady state model piezometric surface for Model Layer 3.

7.3 Transient Calibration

7.3.1 Calibration Results-Groundwater

For calibration purposes the transient model was run for 236 days using a daily time-step. The model run began on 1 January 2021 and was run through 24 August 2021, the last day for which recharge and monitoring data were available at the time of model development. This time period was selected because it included all available monitoring data including the data that was collected at the time of test pumping and included both wet and dry seasons.

As previously alluded to, the steady-state model was used to determine initial conditions for the transient model, and as an initial indication of hydraulic parameter values. Parameters were subsequently adjusted to obtain the best possible agreement between simulated and observed values.

A comparison between simulated and observed groundwater head for the four monitoring piezometers is presented in **Figure 16**. The figure shows that the vertical hydraulic gradient, approximately 18 m at the pilot bore, is well simulated by the model. There is some discrepancy in the simulated water levels for the 60 m monitoring piezometer (M3 in **Figure 5**), which is likely to be an artifact of simplification applied in the numerical model setup relative to the complexity of the physical conditions. Given that the water levels and vertical pressure gradient are well simulated at the abstraction bore, the 2 m discrepancy for M3 is not significant in terms of the reliability of key model outputs. The drawdown that occurred during the test pumping was also well simulated indicating that the calibrated model simulates a realistic response to pumping.

A review of the general trends of simulated water levels show that the model does not capture short term changes in water level, however it does simulate long term response which is further supported by the scenario simulations presented in **Section 8**.

The RMSE for each of the monitoring wells and for the overall model is presented in **Table 8**. The overall RMSE for all of the monitoring wells was 1.01 m, representing 4.7% of the range of observations over the simulation period. The RMSE for the pilot bore and two shallow monitoring piezometers ranged from 0.12 to 0.25 m, considerably better than the overall metric.

The mean residual (observed head – simulated head) for the simulation was 0.45 m, indicating that the average of all simulated heads was higher than the observed values. The error in simulated water level was primarily accounted for by the approximately two-meter offset at the 60 m monitoring piezometer, while residuals at all other monitoring sites were under 0.2 m.

In summary, results for the transient calibration were similar to those for the steady-state calibration. Simulated water levels at the abstraction bore closely matched observations from both deep and shallow monitoring sites and there was approximately a 2 m over simulation (simulated water level was higher) at the M3 monitoring site. The general trends in groundwater flow direction were the same as found in the steady state simulation.

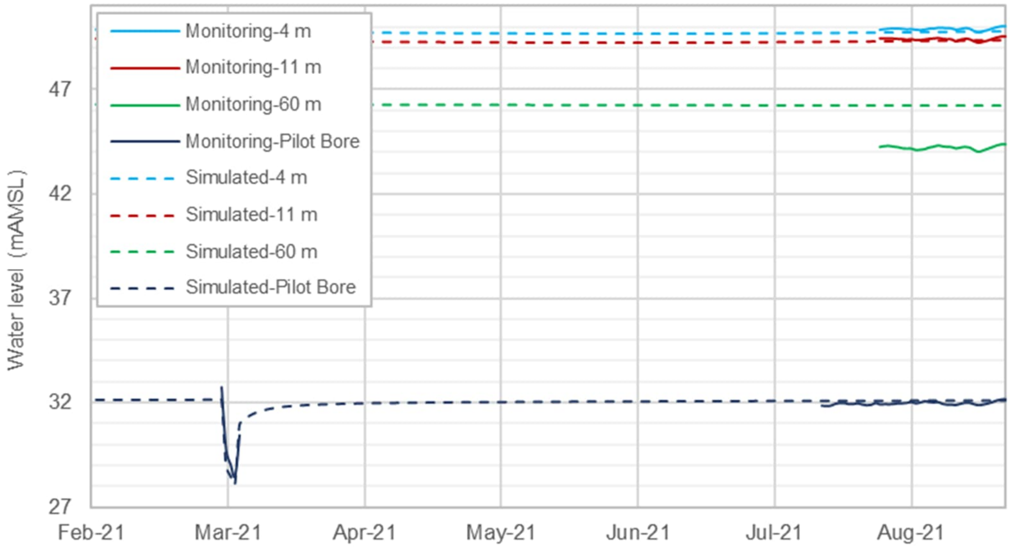

Figure 16. Comparison of observed and simulated groundwater head monitoring piezometers.

Table 8. Summary statistics for transient model

Bore ID	Depth (m)	Monitoring days	RMSE (m)	Mean Residual (m)
Pilot Bore	200	34	0.25	0.08
Monitoring Piezometer – 4m	4.3	29	0.18	-0.16
Monitoring Piezometer – 11m	10.7	29	0.12	-0.09
Monitoring Piezometer – 60m	60	29	2.04	2.04
Overall	-	-	1.01	0.45

7.3.2 Calibration Results-Surface Water

Model results were compared to monitoring data at the three flow monitoring sites. Outputs from a groundwater model are only suitable as an indicator for baseflow (low-flow) conditions, however simulated groundwater discharge to streams serves as a useful reference that there is reasonable agreement between simulated and measured flow under low flow conditions. During high flow times surface runoff contributes the majority of stream flow. To account for this the runoff simulated by SMWBM was added to the simulated baseflow from the groundwater model.

Simulated flow with and without added runoff is shown for the three flow monitoring sites in **Figure 17** through **Figure 19**. It is apparent that baseflows are generally under simulated whereas peak flows are over simulated. This is because a portion of rainfall that infiltrates into the shallow aquifer and discharges to streams (perched groundwater) is not captured by the groundwater model and is instead being included as surface runoff in the SMWBM due to the thickness of the upper model layer.

The groundwater recharge simulated by SMWBM can be considered indicative of intermediate to deep recharge rather than perched groundwater, which never reaches the deep aquifer and instead follows a shorter flow path. These results correlate to the gradual changes in simulated groundwater level shown in the previous section, while the more rapid response to rainfall that is measured in the shallow piezometers is muted in the simulation results.

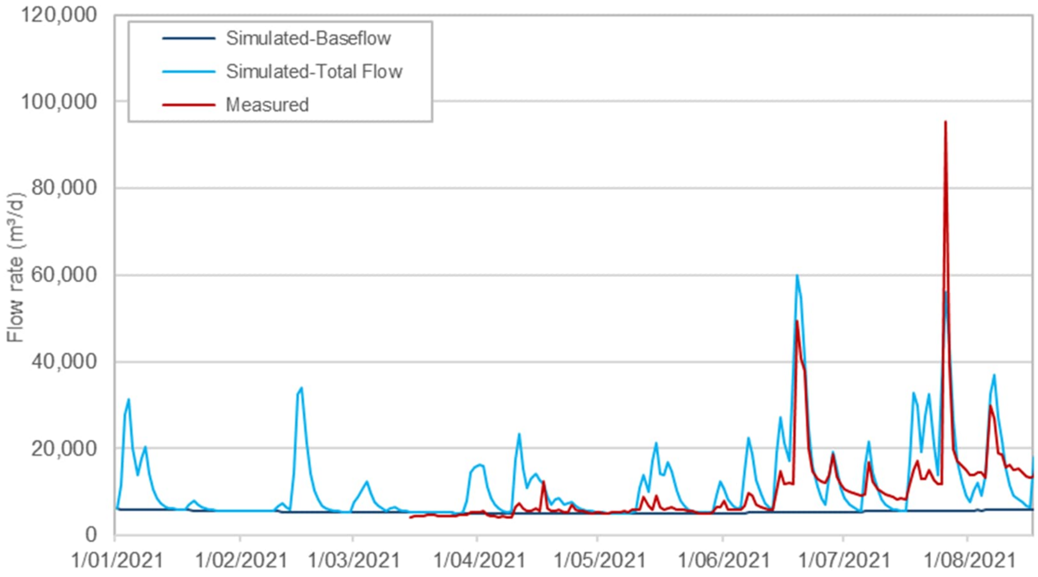

Figure 17. Measured and simulated flow at Flow Monitoring Site 1.

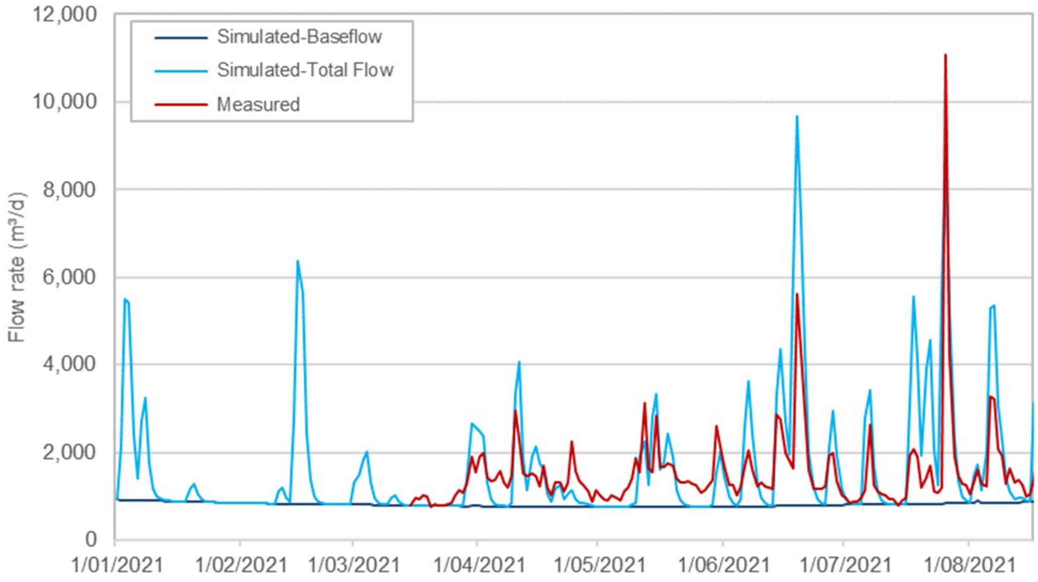

Figure 18. Measured and simulated flow at Flow Monitoring Site 2.

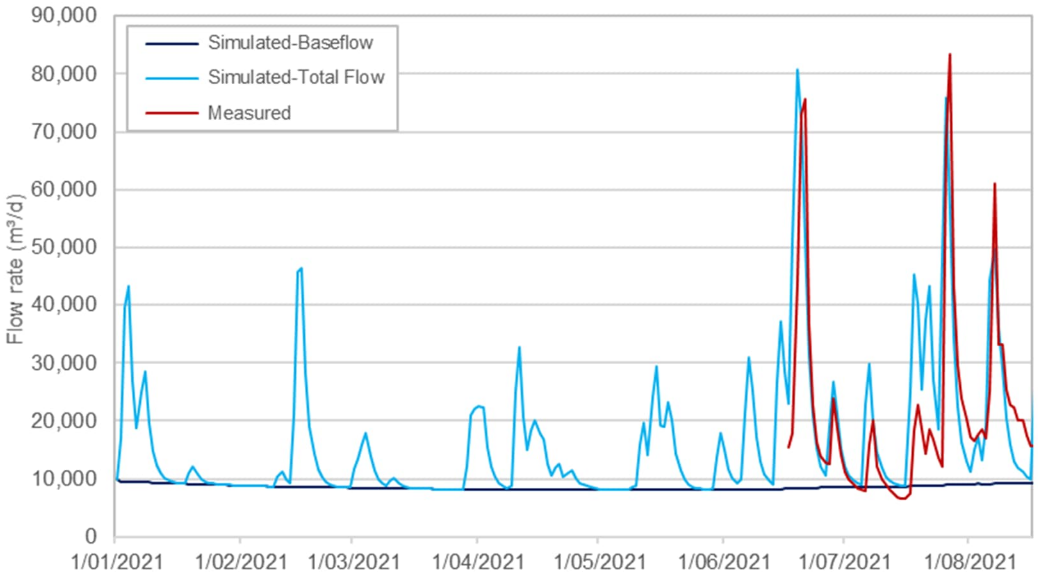

Figure 19. Measured and simulated flow at Flow Monitoring Site 3.

Lake Ōkaihau

The model was also calibrated to match the estimated seepage from Lake Ōkaihau into the underlying aquifer. Head applied to the lake GHB was determined from the staff gauge data and the lake bed conductivity was adjusted such that simulated seepage matched the estimates derived from the water level versus seepage relationship as reported in Lake Ōkaihau Water Balance Assessment (WWLA, 2021 – Appendix F). The estimated seepage from the Lake Ōkaihau Water Balance Assessment is shown in comparison to groundwater model simulation results in **Figure 20**. The RMSE for the simulated seepage from the lake relative to the estimates derived from the lake Level-seepage rate relationship was 14.4 m^3/day, or 3.8% of the range of observations.

In summary, using measured lake levels as a boundary condition, the model simulated seepage from the lake with an accuracy that supported the relationship between lake water level and seepage that was found in the water balance assessment (WWLA, 2021 – Appendix F).

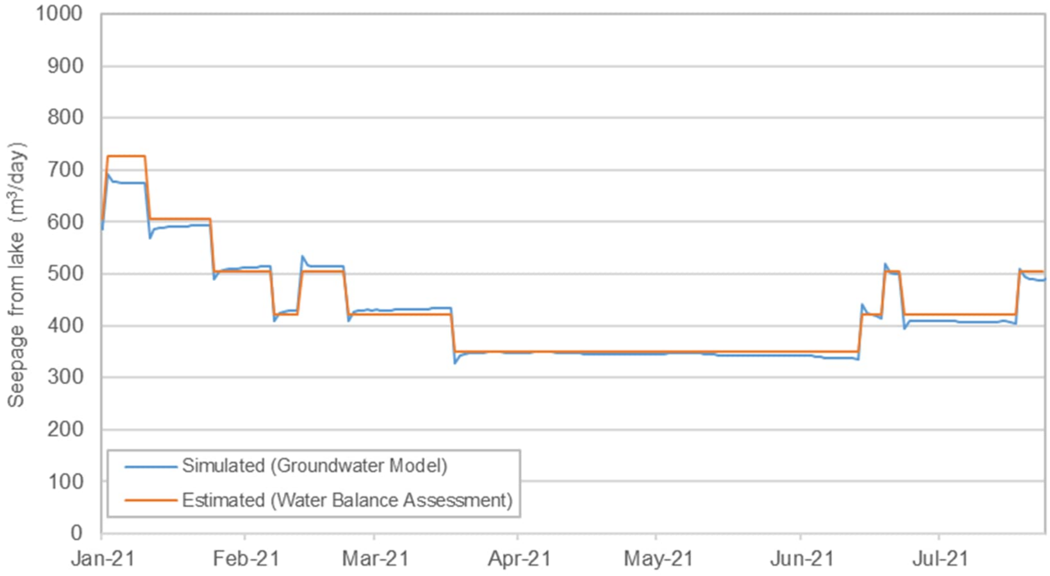

Figure 20. Estimated and simulated seepage from Lake Ōkaihau.

7.3.3 Calibrated Model Parameters

The calibrated model parameters are shown in **Table 9**. During the calibration process the conductivity values for the Layer 3 materials were held constant at values equal to those determined from the analysis of test pumping results reported in **Section 4.2**. Conductivity in the upper two layers, as well as vertical anisotropy, specific yield, and specific storage were adjusted to best match observed data.

The calibrated parameters are consistent with values typically found for the given material types, with the conductivity of the Layer 3 sandstone nearly identical to what was found in the test pumping conducted in this formation at the Francis Bore (WWLA, 2018) approximately 2.6 km to the north.

Table 9. Calibrated model hydraulic parameters.

Material ID		Horizontal Hydraulic Conductivity (m/d)	Horizontal Hydraulic Conductivity (m/s)	Vertical Anisotropy (Kh/Kv)	Specific Storage (Layer 2 & 3)	Specific Yield (Layer 1)
Layer 1	Sandstone	0.017	2.0 x 10-7	20	-	0.03
	Basalt	0.017	2.0 x 10-7	30	-	0.05
Layer 2	Sandstone	0.027	3.1 x 10-7	65	1.0E-04	-
Layer 3	Sandstone	0.57	6.6 x 10-6	5	7.0E-05	-
	Basalt (dyke)	2.76	3.2 x 10-5	9	5.0E-05	-
	Basalt (flow)	1.11	1.3 x 10-5	5	1.0E-05	-

7.3.4 Simulated Water Balance

Table 10 provides the daily average water budget for the transient calibration model during the period January 2021 to August 2021.

Groundwater recharge accounts for 63% of the overall groundwater inflow to the model area. Influx from aquifer storage (decreasing ambient groundwater levels) comprises most of the remaining portion of inputs due to the fact that the model calibration period (where monitoring data was available) spanned a disproportionately dry part of the year. Seepage from Lake Ōkaihau accounted for the remaining 4% of total inflows, though the influence of this influx was limited to the downgradient portion of the model.

Approximately 71% of the total groundwater outflow occurs as discharge into streams or drains. 23% of groundwater outflow occurs as deep groundwater discharge along the coast. Flow into aquifer storage during the winter months accounts for most of the balance of groundwater flow out of the model domain meaning that the groundwater storage is increasing over the winter months with a corresponding rise in the water table elevation.

Table 10. Groundwater flow budget for calibrated transient model (236 day simulation period).

Mass balance	Components	Flow (m^3/d)	Percentage of Flow (%)
Inflow	Storage Inflow-from aquifer storage	4,661.3	32.9%
	Recharge	8,953.5	63.1%
	Seepage from Lake Ōkaihau	569.1	4.0%
	Total inflow	14,183.9	100.0%
Outflow	Storage Outflow-to aquifer storage	915.5	6.5%
	Discharge into Lake Ōkaihau	-107.0	-0.8%
	Deep Coastal Discharge (GHB)	3,302.0	23.3%
	Wells	9.9	0.1%
	Stream Baseflow (Drain)	10,062.3	70.9%
	Total outflow	14,182.6	100%
Discrepancy		-1.3	0.0%

The model was then simulated for 49 years in preparation for the predictive simulations discussed in the following section. The mean annual water balance assuming calibrated model parameters and no groundwater abstraction is presented in **Table 11**. Results from the long-term analysis show that flows in to and out of aquifer storage are in balance from a long-term perspective.

Table 11. Groundwater flow budget for long term transient model (49-year simulation period).

Mass balance	Components	Flow (m^3/yr)	Percentage of Flow (%)
Inflow	Storage Inflow-from aquifer storage	778,568	12.5%
	Recharge	5,107,832	81.8%
	Seepage from Lake Ōkaihau	361,230	5.8%
	Total inflow	**6,247,630**	**100.0%**
Outflow	Storage Outflow-to aquifer storage	790,138	12.6%
	Discharge into Lake Ōkaihau	40,154	0.6%
	Deep Coastal Discharge (GHB)	1,124,723	18.0%
	Stream Baseflow (Drain)	4,293,203	68.7%
	Total outflow	**6,248,218**	**100.0%**
Percentage discrepancy		588	0.0

8. Predictive Simulations

8.1 Scenario Setup

The calibrated groundwater model was used to assess the effects of the proposed groundwater take on groundwater conditions and neighbouring water users, as well as evaluating whether stream depletion, saline intrusion, or land settlement are likely to occur as a result of the proposed abstraction.

The predictive model scenarios are summarised as follows:

- ***Scenario 1: Basecase*** – The calibrated model was run using historic climate conditions and no groundwater abstraction. This scenario was the baseline for comparison against varying levels of abstraction.
- ***Scenario 2: Proposed Groundwater Abstraction*** – Conditions are identical to the Basecase, except that groundwater is abstracted as a supplemental water supply for the golf course and associated development at a maximum daily rate of 1,728 m^3/day and maximum annual volume of 180,000 m^3. The groundwater abstraction profile is discussed in **Section 8.1.5**.

8.1.1 Stress Periods and Time Steps

The numerical simulation was run for a 49-year time period using historic climate records from 1972 through 2020 obtained from the VCSN station 21836. In effect, conditions of the last 49-years have been utilised to simulate conditions that may occur in the next 49-years for the purpose of evaluating potential effects of the scenarios described above. This approach was taken so that environmental response to groundwater abstraction could be evaluated over a range of conditions that included wet and dry periods.

The transient model is divided into a time-series of stress periods. Each stress period has conditions applied at a constant rate. The 49-year simulation used a total of 588 monthly stress periods where the applied recharge and pumping were set to the average daily rate for the given month. For each stress period there were 20 time steps, which are sub-intervals within the stress period where model calculations are performed.

8.1.2 Initial Conditions

The transient model used the steady-state model heads as the starting condition.

8.1.3 Model Hydraulic Parameters

The calibrated model hydraulic parameters shown in **Table 9** were applied for the transient models.

8.1.4 Recharge

Monthly average groundwater recharge was calculated from the daily data set generated by the SMWBM and applied in the long-term model. Monthly average water levels for Lake Ōkaihau were also taken from previous analysis (WWLA, 2021 – Appendix F) and used in the transient model.

8.1.5 Groundwater Abstraction Profile

Whilst the maximum daily and annual volume of groundwater abstraction are 1,728 m^3/day (at a maximum instantaneous rate of 20 L/s) and 180,000 m^3/annum, respectively, the actual groundwater abstraction profile has significantly more variability due to climatic conditions and the irrigation reservoir storage levels.

In this regard, actual groundwater abstraction will vary from close to 0 m^3/annum in wet years to 180,000 m^3 in the worst drought years, with an average of 52,000 m^3/annum. The abstraction of groundwater is generally concentrated in mid to late summer (i.e., February and March), due to the storage available in the reservoir, which will always be full at the start of the irrigation seasons, after being filled by surface water high-flow takes during winter. In terms of this assessment, the maximum abstraction volume is required in 2020 due to the drought of that year, whilst 1982 represents a year with a median pumping requirement that would be typical for the proposed development in a year where groundwater was required to meet irrigation and water supply demand.

The simulated pumping applied in Scenario 2 was based on demand modelling that was undertaken for the Muriwai Downs Property and is reported in WWLA (2021 – Appendix B). Please refer to this report for a detailed description of the reservoir storage model operation, including the high-flow take and irrigation criteria applied. However, in summary:

- Irrigation water is supplied from the reservoir (as mentioned above);
- The daily irrigation demand was calculated by an irrigation model;
- The reservoir has adequate storage to meet all the irrigation needs in most years until mid to late summer when groundwater is needed to supplement the reservoir storage levels;
- During these dry and drought times, the surface water high-flow take will not be available.

This groundwater supplementary abstraction requirement, as calculated by the reservoir storage model, was compiled into a monthly average abstraction time series and input into the groundwater model for the effects assessment.

Table 12 provides a statistical summary of the annual groundwater supplementary abstraction volumes applied in the groundwater model.

Table 12. Summary statistics of annual supplementary groundwater abstraction demand for Scenario 2.

Statistic	Groundwater Abstraction Days per Year	Abstraction Volume (m^3/year)
Minimum	0	0
Median	28	42,552
Mean	34	51,891
90th Percentile	81	133,492
Maximum	110	180,073

8.2 Model Results

The results of the two scenarios are discussed in the following sections. The potential effects under consideration include drawdown at neighbouring bores, stream flow depletion, wetland water levels, and land settlement as a result of dewatering.

The 49-year simulation period includes a range of climate conditions for which the environmental response can be evaluated. To assess the worst-case scenario the driest period in the simulation period should be considered, which in this case was the summer of 2019-2020 where the Auckland area experienced the worst drought on record between November and May[5]. As mentioned previously, climate change is not predicted to cause an appreciable change in rainfall in this area, and therefore not considered to pose a risk for diminishing groundwater resources.

8.2.1 Aquifer Drawdown

The position and magnitude of the cone of depression formed from groundwater abstraction is shown for each model layer respectively in **Figure 21** (Layer 1), **Figure 22** (Layer 2), and **Figure 23** (Layer 3). It is apparent in the figure that abstraction has a far greater effect in the deeper aquifer layer where up to 9.7 m of drawdown is predicted, while the disconnection due to iron pans and impermeable materials in the Nihotupu formation

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[5] https://ourauckland.aucklandcouncil.govt.nz/news/2020/11/auckland-s-residential-water-restrictions-to-be-adjusted-for-summer

(represented by Layer 2) precludes significant drawdown from occurring in the shallow aquifer (Layer 1) where a maximum of 0.1 m of drawdown is predicted.

It should be noted with regard to predicted drawdown along the model boundary to the north of the abstraction site, that the no-flow boundary will preclude seepage from the adjacent catchment resulting in an exaggeration of the drawdown within the model domain in this area.

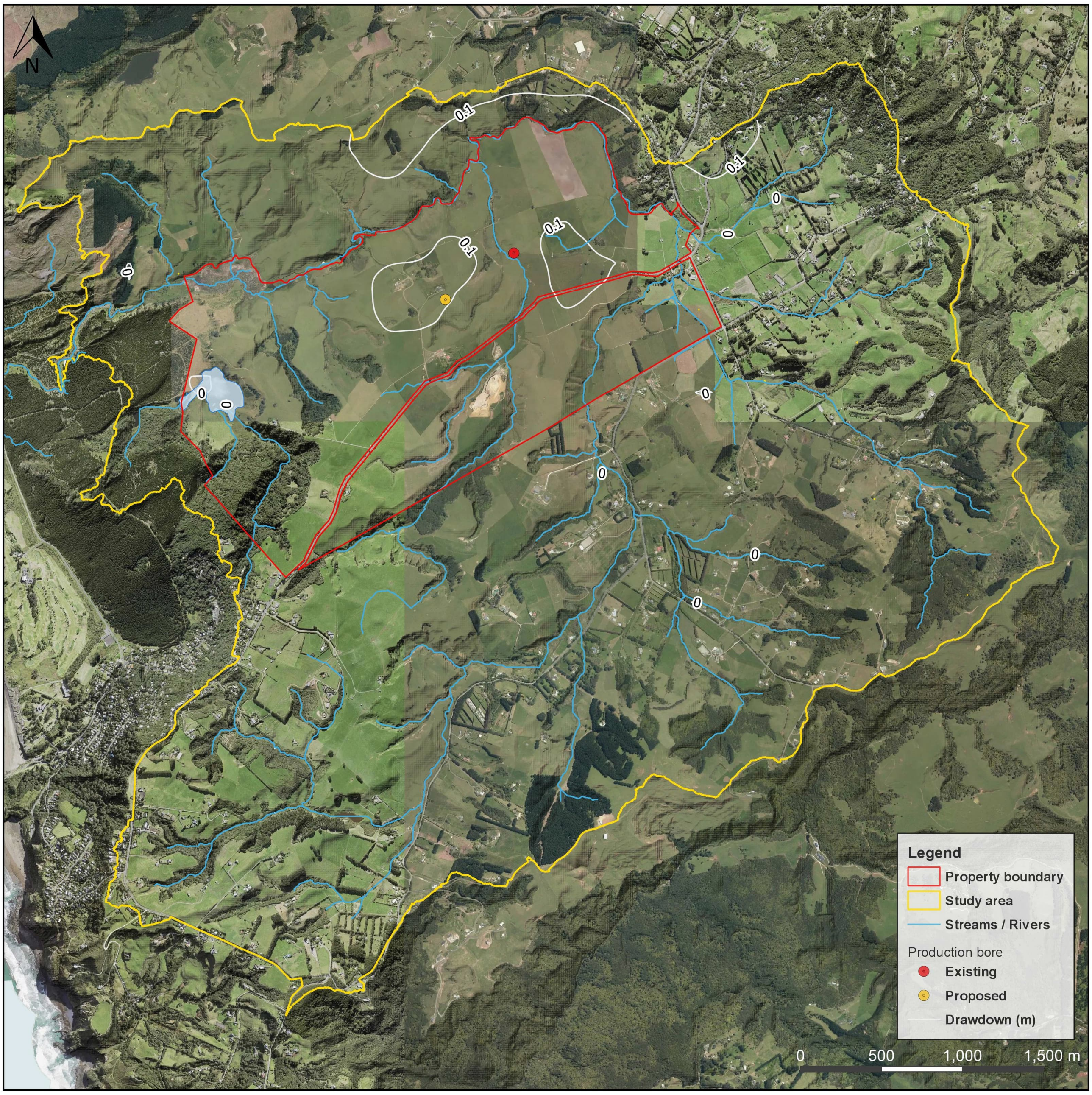

Figure 21. Predicted drawdown in Model Layer 1 for median groundwater abstraction year.

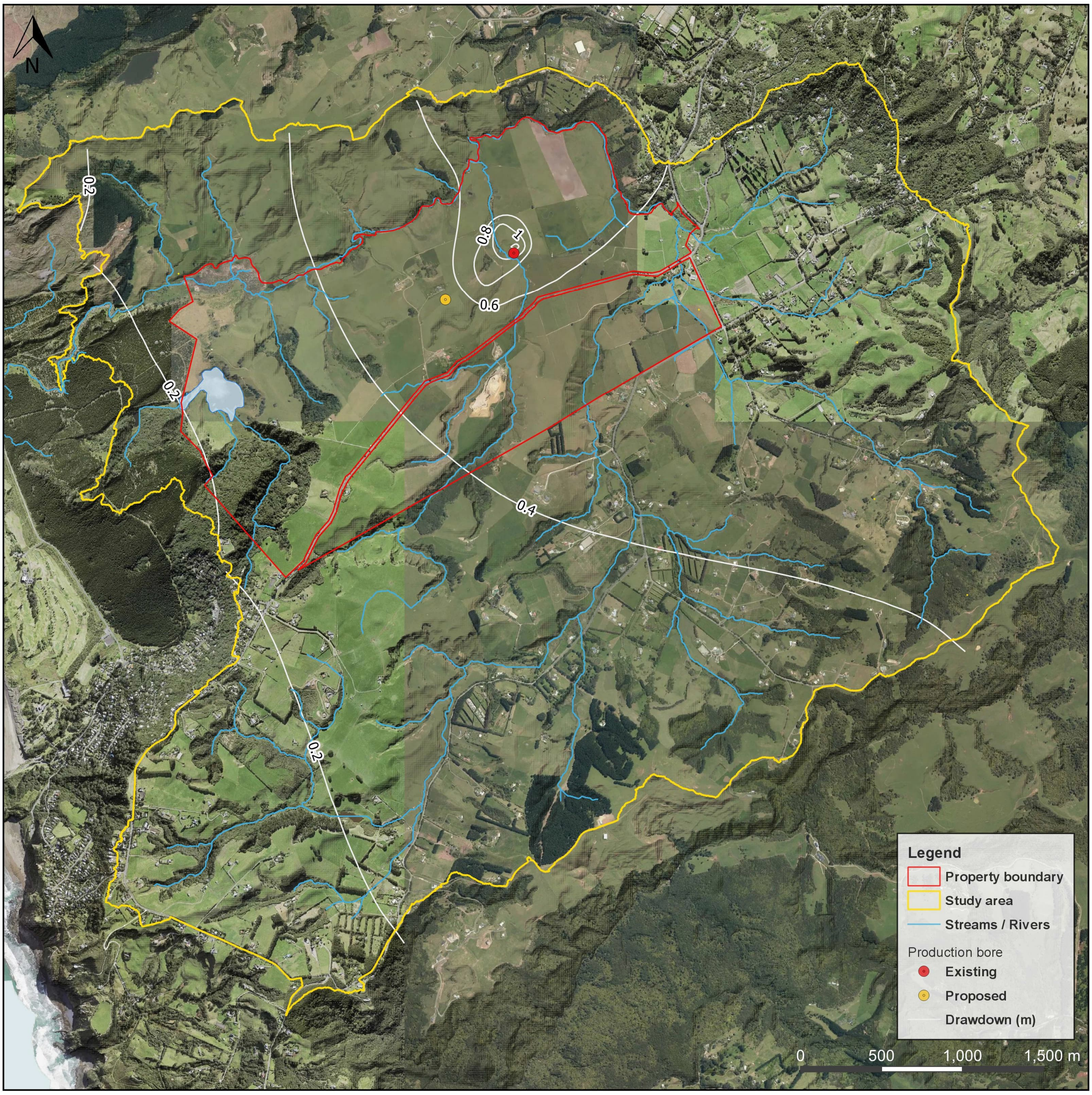

Figure 22. Predicted drawdown in Model Layer 2 for median groundwater abstraction year.

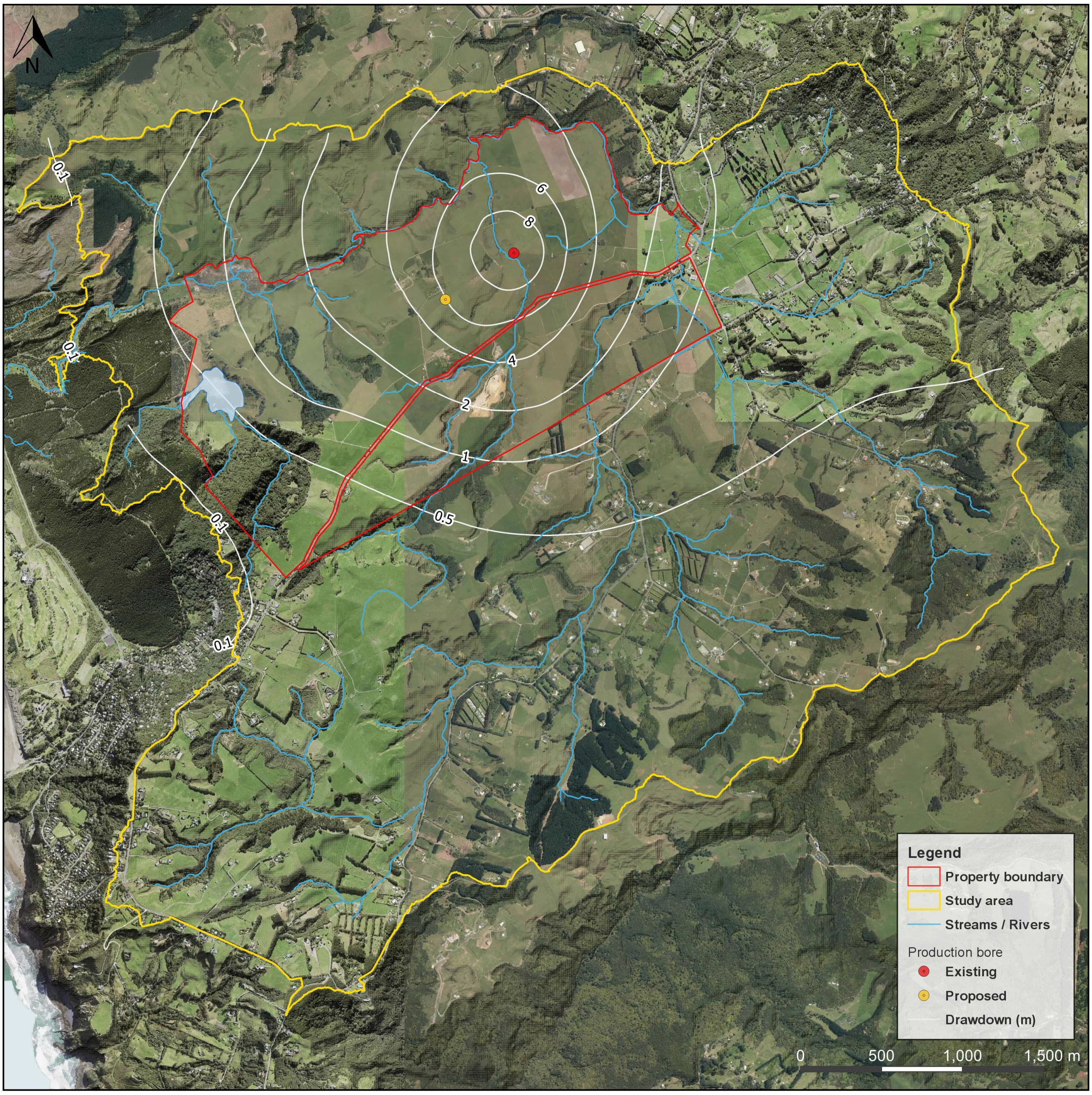

Figure 23. Predicted drawdown in Model Layer 3 for median abstraction year.

The simulated groundwater drawdown at the pumping bore location is shown for each of the model layers in **Figure 24**. The maximum drawdown over the simulation period was 20.4 m immediately adjacent to the production bore which was predicted to occur in Layer 3 at the end of March 2020 following a drought where reservoir storage levels were low and maximum irrigation was required for the entire preceding month. The maximum drawdown in Layer 1 and Layer 2 is 0.3 and 2.6 m, respectively. **Figure 24** also shows that during non-irrigation seasons the water level usually recovers to within 1 m of the Baseline Scenario water levels, though slightly more residual drawdown is predicted in heavy pumping seasons such as 2020. The majority of water level recovery occurs in the first 2 months after pumping ceases, and then continues at a more gradual rate until the next abstraction period.

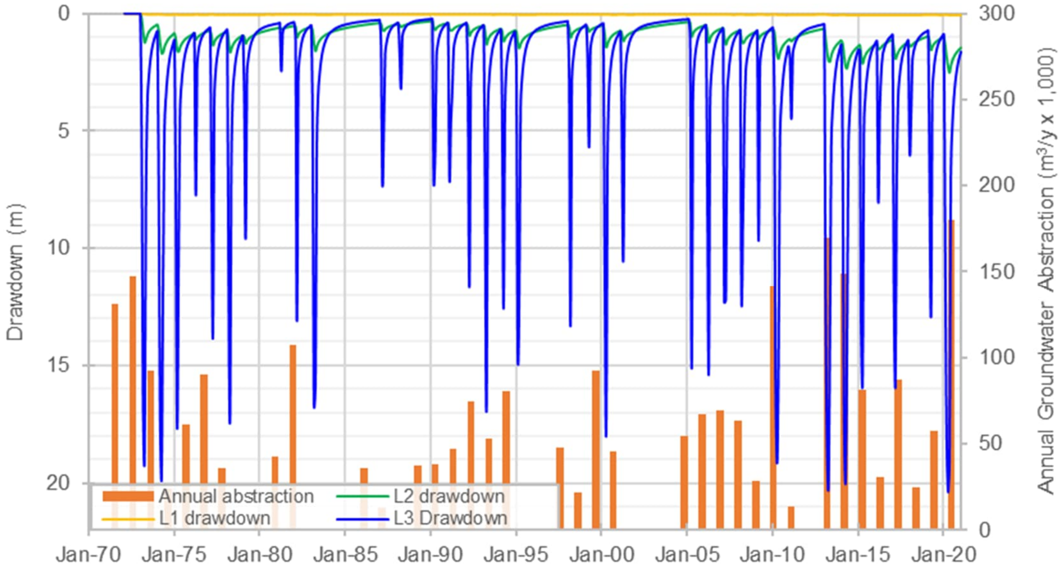

Figure 24. Predicted drawdown relative annual pumping at the pumping bore for each model layer.

Predicted changes in shallow aquifer water levels for the wetland monitoring locations and the newly installed monitoring site on the northern shore of Lake Ōkaihau (refer locations in **Figure 5**) are summarised in **Table 13**. It is noted that wetland water levels are primarily governed by surface water inputs. Furthermore, the water level change that will manifest in a wetland is governed by the porosity of the aquifer material. For example, if an aquifer with a porosity of 10% (typical for wetlands such as those on the Property) experiences a 0.2 m reduction in water level, the corresponding reduction in a standing water body that is connected would be 0.02 m (Williamson, 2018). This methodology was reviewed and accepted by Commissioner Hill and Callander in the hearing decision for the Motutangi-Waiharara Water Users Group Resource Consent Application[6].

The maximum impact on shallow aquifer water level in a wetland area is predicted to occur approximately 500 m to the west of the existing production bore. At this location the maximum shallow aquifer drawdown is predicted to be 0.2 m, with a corresponding maximum temporary change in wetland water level being 0.02 m. The predicted maximum temporary change for all other wetlands was indicated to be less than 0.02 m. This minor level of change is a temporary state estimated nearing the end of the worst drought on record, hence water levels naturally recover the week following the breaking of the drought.

Of the wetland monitoring sites shown in **Table 13**, negligible change in water level is predicted for P1 and P5 while P3 and P6 have approximately 0.04 m of drawdown predicted. At P2, and to a lesser degree, P4, there is slightly greater drawdown in the shallow aquifer predicted over the simulation period. P2 is positioned approximately 400 m directly down gradient from the pumping bore. At this location the predicted decline in the shallow aquifer is predicted to translate to a temporary 0.02 m reduction in water level in standing water in the wetland at the end of the worst drought experienced on record, which would in practice be difficult to measure.

The closest mapped wetland to the existing production bore is approximately 13 m away, adjacent to the Ōkiritoto Stream. This wetland will not be affected by the groundwater take in terms of water level because the wetland is above the stream, which effectively controls the wetland's water level; whereas the proposed groundwater take is sourced from a minimum of 120 mBGL and hydrologically separate from the wetland, as described in **Section 5.6**.

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[6] Council Hearing Decision for REQ.581172 for the Motutangi-Waiharara Water Users Group Resource Consent Application. Hearing commissioners David Hill & Peter Callander. Paragraph 95.

Table 13. Predicted maximum change in shallow groundwater level and corresponding change in wetland water level.

Analysis metric	Wetland monitoring piezometers					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
Maximum change in shallow aquifer water level (m)	0.010	0.179	0.038	0.080	0.006	0.037
Corresponding change in wetland water level (m)	0.001	0.018	0.004	0.008	0.001	0.004

8.2.2 Stream Flows

As explained in **Section 6.1.5**, simulated stream flows from the groundwater model correspond to stream baseflows and do not include surface runoff; however, groundwater abstraction does not impact surface runoff so the predicted effect on baseflow will amount to the total effect. In this regard, the groundwater model is best suited to assess the relative impact of groundwater abstraction on stream baseflows, rather than the absolute change in flow.

Table 14 summarises the simulated effects on baseflow. The maximum reduction in baseflow relative to the Baseline Scenario occurs during later summer and is predicted to be approximately 3.4% (0.4 L/s) at Flow Site 2 (**Figure 5**), directly adjacent to the pumping location. At Flow Site 1 and Flow Site 3 the maximum baseflow reduction is predicted to be 2.1%. The median baseflow reduction at all sites is under 0.5% and would be unmeasurable for practical purposes.

These results are consistent with the findings that the deep groundwater is significantly disconnected from the shallow aquifer where baseflow is generated.

Table 14. Summary of maximum baseflow depletion effects.

Scenario	Flow reduction metric	Reference location		
		Flow Site 1	**Flow Site 2**	**Flow Site 3**
Scenario 1: Supplemental GW abstraction	Max. flow reduction (L/s)	1.7	0.4	2.7
	Max. flow reduction (%)	2.1%	3.4%	2.1%
	Median flow reduction (L/s)	0.2	0.0	0.4
	Median flow reduction (%)	0.3%	0.4%	0.3%

8.2.3 Lake Ōkaihau

Flow into Lake Ōkaihau will not be affected by the proposed groundwater abstraction because it is fed by a stream that is in a separate catchment from the one where the abstraction will take place or where any significant drawdown is predicted to occur. The predicted effect on the net leakage out of Lake Ōkaihau is negligible, predicted to increase by less than 0.5 m^3/day (less than 0.2%) with the groundwater abstraction (**Figure 25**). This slight difference is due to the very slight lowering of the shallow water table (0.01 m) below the lake.

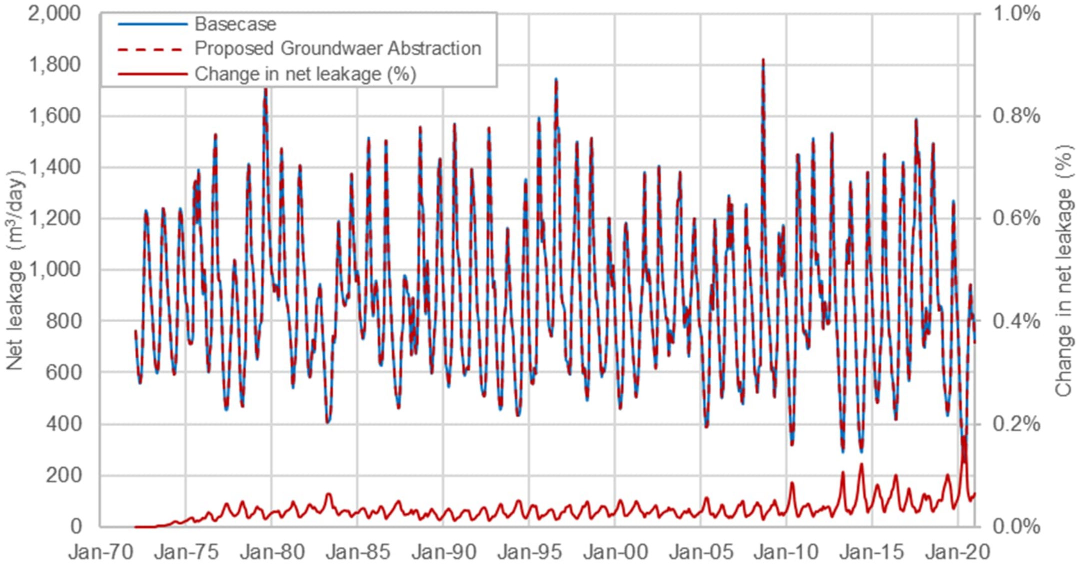

Figure 25. Predicted increase in net leakage from Lake Ōkaihau with groundwater abstraction.

9. Assessment of Effects

The following section comprises an assessment of effects from the proposed groundwater abstraction based on model results and the stated criteria for groundwater impacts as defined in the AUP-OP. Chapter E7 of the AUP-OP addresses 'Taking, using, damming and diversion of water and drilling', and therefore includes the primary criteria upon which the proposed groundwater take will be considered.

The items addressed in the following sub-sections are those within the scope of this report considered relevant to the proposed abstraction.

9.1 Groundwater Effects

Taking and using groundwater is addressed in Chapter E7.8.2 (4) of the AUP-OP. The assessment criteria for restricted discretionary activities are summarised in **Table 15** which have been used as a guidance for the assessment of effects for the proposed groundwater take. However, given the groundwater take will be a discretionary activity, we have assessed all actual and potential effects on the environment. In addition to these criteria, the Kaipara Sand aquifer is indicated as a Quality Sensitive Aquifer Management Area in Chapter D2 of the AUP-OP. This means that the shallow aquifer is considered to be sensitive to contamination, and proposed activities will be considered in this context. The proposed groundwater take in this assessment is sourced from the deep basalt aquifer with limited connectivity to the Kaipara Sand aquifer and does not indicate any discharge to land, therefore contamination of the Kaipara Sand aquifer will not occur as a result of the proposed groundwater abstraction.

Table 15. Criteria for the assessment of groundwater takes as published in AUP-OP Chapter E7.8.2.

Criteria Reference		Matters of Discretion	Comment
E7.8.2 (4)	*Whether the proposal to take and use groundwater from any aquifer demonstrates that:*		
	a)	The take is within the water availabilities and levels for the aquifer in Table 1 Aquifer water availabilities and Table 2 Aquifer groundwater levels, in [AUP-OP Chapter M] Appendix 3 Aquifer water availabilities and levels and: (i) recharge to other aquifers is maintained; (ii) aquifer consolidation and surface subsidence is avoided	1. The groundwater abstraction being sought is less than the allocation limit as calculated based on the criteria in the AUP-OP (**Section 2.1**). 2. The groundwater level for this aquifer is not specified in the AUP-OP. 3. The proposed take will not affect recharge in other aquifers. 4. Aquifer consolidation and land subsidence is addressed in **Section 9.3** of this report.
	(b)	the taking will avoid, remedy or mitigate adverse effects on surface water flows, including: (i) base flow of rivers, streams and springs; (ii) any river or stream flow requirements;	The effect on baseflow of all streams in the study area is minimal, and likely undetectable. This is addressed in detail in **Section 9.4.1**.
	(c)	the taking will avoid, remedy or mitigate adverse effects on terrestrial and freshwater ecosystem habitat;	Effects on ecosystem and habitat are not addressed in this report.
	(d)	the taking will not cause saltwater intrusion or any other contamination;	The saline interface will be maintained well below the depth of any potential bore. This is addressed in **Section 9.2**.
	(e)	the taking will not cause adverse interference effects on neighbouring bores to the extent their owners are prevented from exercising their lawfully established water takes;	Potential effects on neighbouring bores are less than minor, as addressed in **Section 9.1.1**.
	(f)	E7.8.2(5)(c) above will not apply in the following circumstances: (i) where it is practicably possible to locate the pump intake at a greater depth within the affected bore; (ii) where it can be demonstrated that the affected bore accesses, or could access, groundwater at a deeper level within the same aquifer, if drilled or cased to a greater depth;	These criteria must be considered on a case by case basis with regard to any bores that are potentially affected. Where relevant, this is also addressed in **Section 9.1.1**.

Criteria Reference		Matters of Discretion	Comment
	(g)	the proposed bore is capable of extracting the quantity of groundwater applied for;	Initial test pumping results presented in **Section 4.2** indicate that the bore is likely to be suitable to provide the yield being sought in this application.
	(h)	the proposal avoids, remedies or mitigates any ground settlement that may cause distress, including reducing the ability of an existing building or structure to meet the relevant requirements of the Building Act 2004 or the New Zealand Building Code, to existing: (1) buildings; (ii) structures; and (iii) services including roads, pavements, power, gas, electricity	Ground settlement is expected to be minimal and there are no buildings or other infrastructure in the are to be affected. Land settlement is addressed in further detail in **Section 9.3**.

9.1.1 Effects on Existing Bores

A total of 43 bores were found to be within a 3 km radius of the proposed abstraction bore, although we note that many of these bores are old exploratory bores and abandoned (e.g. Penfold wines). 36 of these bores are outside of the model boundary therefore predicted drawdown can only be inferred from model results. The depth is known for 23 of the bores, which range from 40 m to 458 m deep. The estimated effects on neighbouring bores hinges on the available drawdown at the bores, defined as the vertical distance between the bore pump and the SWL.

Eight of the bores had SWL measurements available. For bores where SWL was not available simulated water level for the steady state model developed for the Francis Resource Consent Application (WWA, 2018) was used. Depth of the bore pump, a key consideration in available drawdown, was only known for one bore however casing depth was available for 23 bores. Typically, the pump will be installed approximately at the bottom of the casing. In cases where the bore was significantly deeper than the casing it was assumed that the pump was deeper as well, for example at the Woppet Gardens bore which is indicated to be 441 m deep but the casing is only 98 m deep.

The following assumptions were made to estimate pump depth for the purpose of estimating available drawdown:

- For deep bores - deeper than 100 m - the pump was assumed to be the deeper of the casing depth or half of the bore depth.
- For bores under 100 m the casing depth, if known, was assumed to be the pump depth.
- If the casing depth was unknown and the bore over 100 m deep, the pump was assumed to be 1/2 of the depth of the bore.
- If the casing depth was unknown and the bore was 50 to 100 m deep, the pump was assumed to be 2/3 of the depth of the bore.
- If the casing depth was unknown and the bore under 50 m deep, the pump was assumed to be 10 m above the bottom of the bore.
- The abstraction layer was based on the bore depth and pump elevation. Bores that terminated at depths corresponding to Model Layers 1 or 2 were considered to abstract from that layer. Deep bores that were open in Model Layers 2 and 3 were considered to abstract from both of the deeper model layers.
- Bores of unknown depth were marked accordingly.

The bores are labelled in **Figure 26** with corresponding information provided in **Table 16**, which shows the bore owner, where available, as well as the maximum and median predicted drawdown and additional information pertaining to the characteristics of the bore. Bores that were outside of the model boundary but within the interpolation area are shown with red font in the table.

Bores that were outside of the interpolation area are shown to have an assumed value that is less than the predicted drawdown at the nearest location where there is an available estimate. As stated earlier, the drawdown near the northern model boundary is likely exaggerated due to the effect of the no-flow boundary condition that prevent inflow from adjacent areas. The maximum drawdown is predicted to occur at the JS & RW Francis bore (Figure ID #25) and the Woppet Gardens Ltd bore (Figure ID #32).

The depth of these bores is greater than 250 m in both cases while the casing extends to under 100 mBGL indicating that abstraction can be sourced from the equivalent of Model Layers 2 and 3; hence estimated drawdown for these bores has been based on the average of maximum drawdown in these model layers which is 5.4 m. The depth of these bores means that there is a significant amount of available drawdown, estimated to be 59 m and 154 m in the Francis and Woppet bores, respectively. Maximum expected drawdown as a percentage of the available drawdown is estimated to be 9% for the Francis bore and 3% for the Woppet bore, which is considered no more than minor.

Furthermore, both bores are significantly deeper than the pilot bore and in a different aquifer (Nihotupu sandstone as opposed to basalt), which in practice would likely reduce the amount of drawdown due to the degree of vertical confinement that has been found in the area particularly in the sandstone.

In summary, model results indicate that it is highly unlikely that bores on neighbouring properties will be affected by the proposed groundwater abstraction.

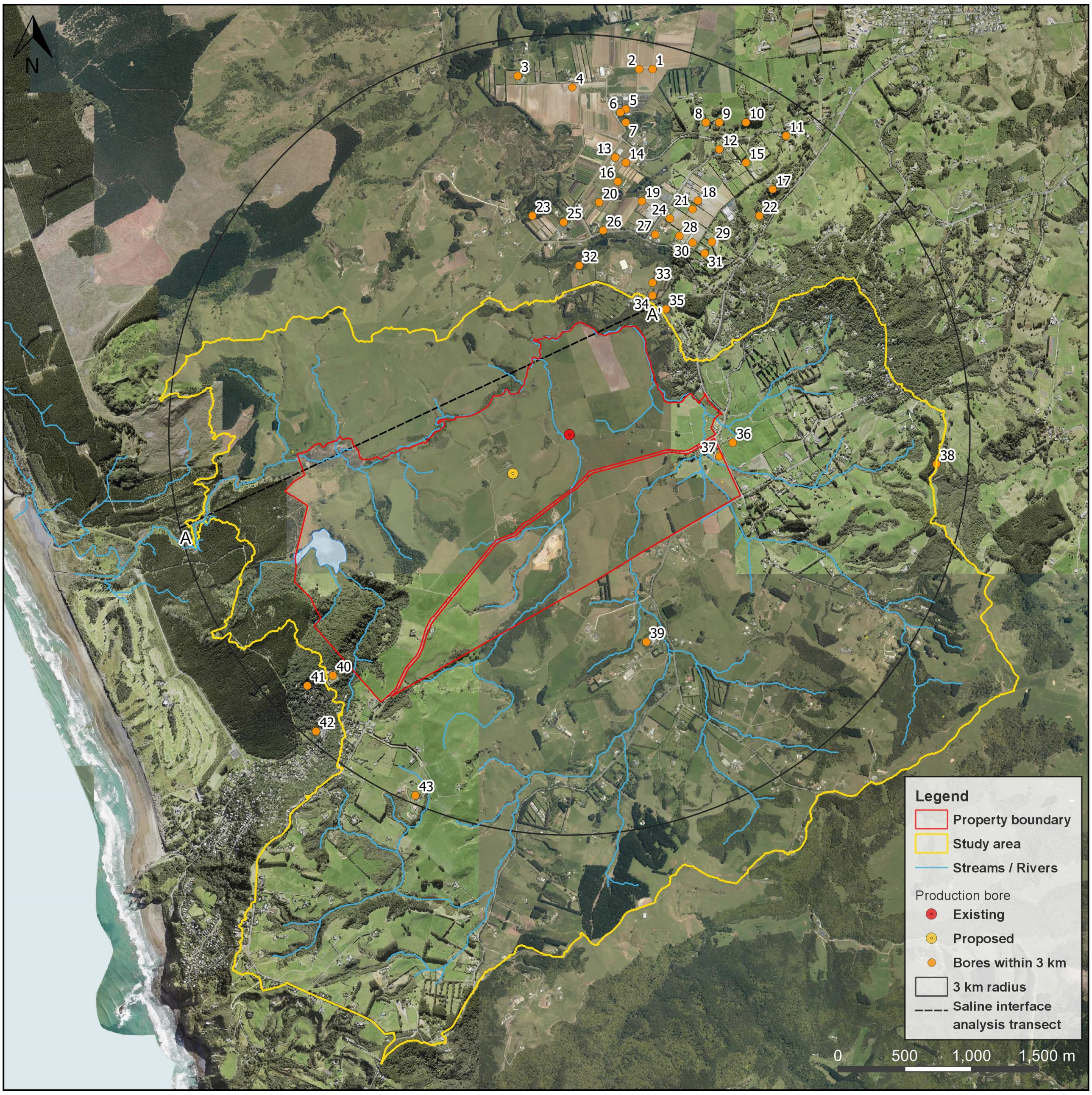

Figure 26. Bores within 3 km of production bore and transect for saline interface analysis.

Table 16. Bores within 3 km of proposed abstraction bore (red font indicates estimated drawdown for bores that are outside the model boundary).

Figure ID	Consent holder or data source	Northing	Easting	Distance to pumping bore (m)	Bore depth (m)	Bore Base Elevation (mAMSL)	Static water level (mAMSL)	Estimated pump elevation (mAMSL)	Status	Abstraction layer	Maximum expected drawdown (m)	Available drawdown (m)	Max drawdown as % of available drawdown
1	PENFOLD WINES	5928900	1730900	2809	197	-116.94	50.6	-18.44		2	<1.24	69.01	1.8%
2	PENFOLDS LOT 5	5928900	1730800	2789	197	-116.58	50.5	-18.08		2	<1.24	68.53	1.8%
3	I H & S E Mitchell	5928850	1729890	2717	80	0.51	45.9	15.51	Expired	2	<1.24	30.38	4.1%
4	FRANCIS	5928739	1730301	2602	90	-7.99	44.5	24.51		2	<1.24	20.00	6.2%
5	PENFOLDS LOT 6	5928600	1730700	2476	Unknown		52.3	-	-		2	<1.24	-
6	Peter Arlen Stott & Joan Vyvienne Stott	5928575	1730660	2444	67	8	48.0	18	Expired	1	<0.24	30.00	0.8%
7	PENFOLD WINES	5928500	1730700	2377	458	-386.15	52.9	-157.15		2 – 3	<5.19	210.09	2.5%
8	WIGHTMAN KF & RM	5928500	1731300	2553	Unknown		52.2	-	-		2	<1.12	-
9	WIGHTMAN KF & RM	5928500	1731400	2595	Unknown		51.6	-	-		2	<1.12	-
10	WIGHTMAN KF & RM	5928500	1731600	2687	Unknown		49.8	-	-		2	<1.12	-
11	WALLIS RA	5928400	1731900	2766	Unknown		48.3	-	-		2	<1.12	-
12	MOULDS A.A.	5928300	1731400	2416	Unknown		52.7	-	-		2	<1.12	-
13	GILBERTSON GB	5928240	1730620	2107	306.6	-226.78	32.3	-73.48		2 – 3	<5.19	105.80	4.9%
14	GILBERTSON GB	5928200	1730700	2083	306.6	-228.01	31.1	-74.71		2 – 3	<5.19	105.80	4.9%
15	SHATTKY DG & WJ	5928200	1731600	2431	Unknown		52.0	-	-		2	<0.24	-
16	FAED J&M (MAHANA GARDENS)	5928060	1730640	1934	182	-104.27	55.6	-13.27		2	<1.24	68.89	1.8%
17	FRANCE DW	5928000	1731800	2388	Unknown		51.6	-		2	1.02	-	-
18	FRANKLIN R	5927913	1731240	1999	150	-72.773	55.5	2.227		2	1.12	53.26	2.1%
19	RODEWYCK E	5927910	1730820	1831	152	-72.875	56.5	3.125		2	1.24	53.38	2.3%
20	FRANCIS BROS./ MR	5927900	1730500	1753	Unknown		56.4	-	-		2	1.24	-
21	LITHERLAND HJ	5927850	1731200	1925	Unknown		55.9	-	-		2	1.12	-

Figure ID	Consent holder or data source	Northing	Easting	Distance to pumping bore (m)	Bore depth (m)	Bore Base Elevation (mAMSL)	Static water level (mAMSL)	Estimated pump elevation (mAMSL)	Status	Abstraction layer	Maximum expected drawdown (m)	Available drawdown (m)	Max drawdown as % of available drawdown
22	SCHOFIELD PA	5927800	1731700	2171	Unknown		52.6	-	-		2	1.03	-
23	WIGHTMAN LS & LA	5927800	1730000	1662	Unknown		55.5	-	-		2	1.21	-
24	GILBERTSON PB&LS	5927780	1731030	1786	164	-86.242	56.8	-4.242		2	1.19	61.09	1.9%
25	James Stanley Francis & Robert Warwick Francis	5927752	1730234	1592	262	-168.395	21.6	-37.395	Expired	2 – 3	5.38	59.00	9.1%
26	Michael David King & Betty Ying	5927690	1730530	1550	155	-61.864	30.1	15.636	Expired	2	1.24	14.50	8.6%
27	MARTIN HJ. -STOTT PA	5927660	1730920	1631	243.8	-163.754	57.5	-41.854		2 – 3	5.14	99.34	5.2%
28	FRANKLIN A	5927650	1731100	1701	220	-143.236	57.1	-33.236		2	1.15	90.32	1.3%
29	PENMAN DJ & OOSTERHEERT MY	5927605	1731345	1796	82	-10.775	56.2	31.625		2	1.10	24.56	4.5%
30	FRANKLIN M	5927600	1731200	1710	152	-78.211	56.9	-2.211		2	1.13	59.11	1.9%
31	William Frank Robert Veitch & Celia Margaret Palmer Veitch	5927520	1731290	1695	450	-378.023	30.2	-153.023	Expired	2 – 3	3.45	183.20	1.9%
32	Woppet Gardens Limited	5927428	1730350	1269	441	-344.59	30.1	-124.09	Expired	2 – 3	5.38	154.20	3.5%
33	YOUNG YC	5927300	1730900	1298	122	-30.671	58.7	30.329		2	1.23	28.37	4.3%
34	AALDERS H	5927200	1730900	1212	122	-29.557	58.9	31.443		2	1.22	27.46	4.5%
35	McKAY G EX. GREENHILL D	5927100	1731000	1185	40	54.958	58.8	55.358		1	0.20	3.48	5.7%
36	NZ Geodatabase 79735	5926101	1731501	1225	Unknown		-	-	-		2	0.96	-
37	NZ Geodatabase 79736	5926001	1731401	1135	Unknown		-	-	-		2	0.96	-
38	LUC60302029	5925941	1733027	2759	Unknown		-	-	-		2	0.82	-
39	LUC80310785	5924607	1730854	1657	Unknown		-	-	-		2	0.73	-
40	LUC80309814	5924357	1728506	2528	Unknown		-	-	-		2	0.35	-
41	NZ Geodatabase 120938	5924281	1728314	2718	Unknown		-	-	-		2	0.32	-

Figure ID	Consent holder or data source	Northing	Easting	Distance to pumping bore (m)	Bore depth (m)	Bore Base Elevation (mAMSL)	Static water level (mAMSL)	Estimated pump elevation (mAMSL)	Status	Abstraction layer	Maximum expected drawdown (m)	Available drawdown (m)	Max drawdown as % of available drawdown
42	Auckland Council 20147	5923938	1728379	2922	Unknown		-	-	-		2	0.32	-
43	NZ Geodatabase 23756	5923461	1729124	2936	Unknown		-	-	-		2	0.37	-

9.2 Saline Intrusion

The proposed groundwater take was assessed for potential saline intrusion and/or saline up-coning effects that could arise as a result of the abstraction. The Ghyben-Herzberg relationship, which theorises the saline interface to be 40 m below sea level for every meter of groundwater head above sea level, was applied for this analysis.

A transect was drawn to assess the level of the saline interface with and without groundwater abstraction along the Ōkiritoto Valley where the greatest drawdown is predicted (**Figure 26**). The transect runs from the outlet of the Ōkiritoto Stream at the western model boundary, approximately 1,200 m inland from the coast, roughly following the Ōkiritoto upstream along the northern portion of the study area to the northeast model boundary.

The results presented in **Figure 27**, shows that the saline interface is estimated at approximately 800 m below sea level at the location of the production bore at the time of maximum drawdown. This depth is well below the depth of any other economically feasible production bore. Furthermore, there is only minor change predicted in the sensitive coastal margin where the saline interface is shallowest. It is noted that this analysis is highly conservative because it is based on the maximum drawdown while saline intrusion in reality is a gradual process. The full potential for saline intrusion will not manifest in the time frame where drawdown occurs and subsequent groundwater level recovery after pumping season will reverse the landward migration of the salt-wedge that initiates during summer.

In summary, the proposed groundwater abstraction will not cause saline intrusion to occur in any way where it will be detectable, and therefore there will be no effect on any groundwater users.

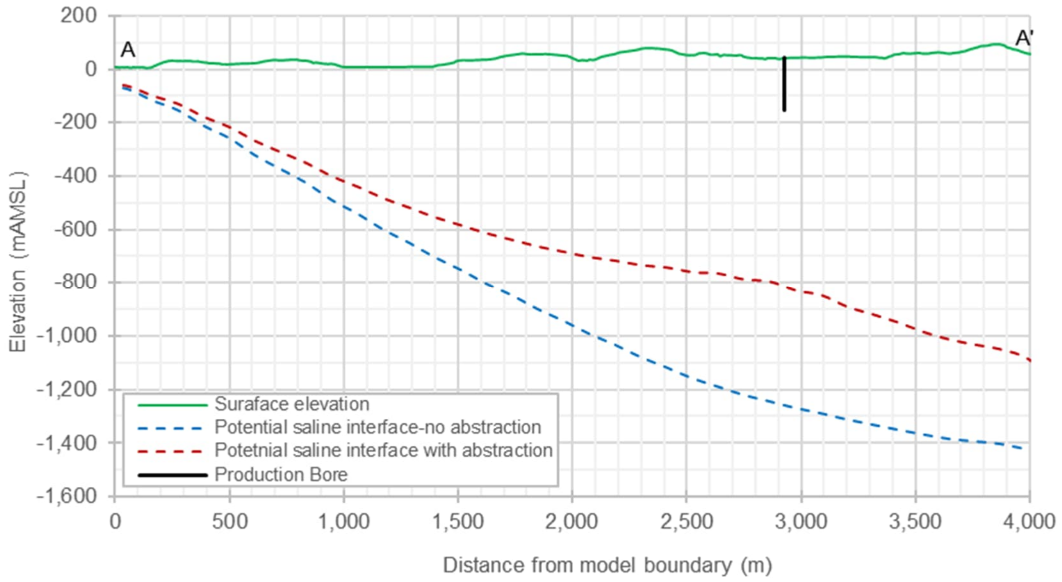

Figure 27. Elevation of saline interface along the Ōkiritoto Valley with and without proposed groundwater abstraction.

9.3 Land Subsidence

Land subsidence due to groundwater diversion and resulting drawdown was calculated using the Bouwer (1977) equation:

$$S_u = (P_{i2} - P_{i1})\frac{Z_1}{E}$$

where S_u = vertical subsidence (m)

$P_{i2} – P_{i1}$ = Increase in intergranular pressure due to drop of the water table
Z_1 = layer thickness
E = modulus of elasticity of the soil

Table 17 show the parameters that were applied for the subsidence calculation. **Figure 28** shows the predicted land subsidence based on the maximum drawdown from the simulation period. The greatest subsidence is 0.17 m and is predicted to occur approximately 350 m east of the abstraction site due to the somewhat more compressible material in that area, as opposed to the incompressible basalt dyke where the bore is located.

The areas that may potentially be affected by land subsidence are primarily pasture and there is no infrastructure in these areas.

Table 17. Parameters used in subsidence analysis calculation.

Model layer	Material	Elasticity (kPa)	Porosity	Specific weight (kg/m^3)
1	Sandstone	100,000	0.10	17.7
	Basalt	250,000	0.06	28.4
2	Sandstone/mudstone	150,000	0.07	19.6
3	Sandstone/mudstone	150,000	0.07	19.6
	Basalt (flow)	200,000	0.05	25.5
	Basalt (dyke)	250,000	0.06	28.4

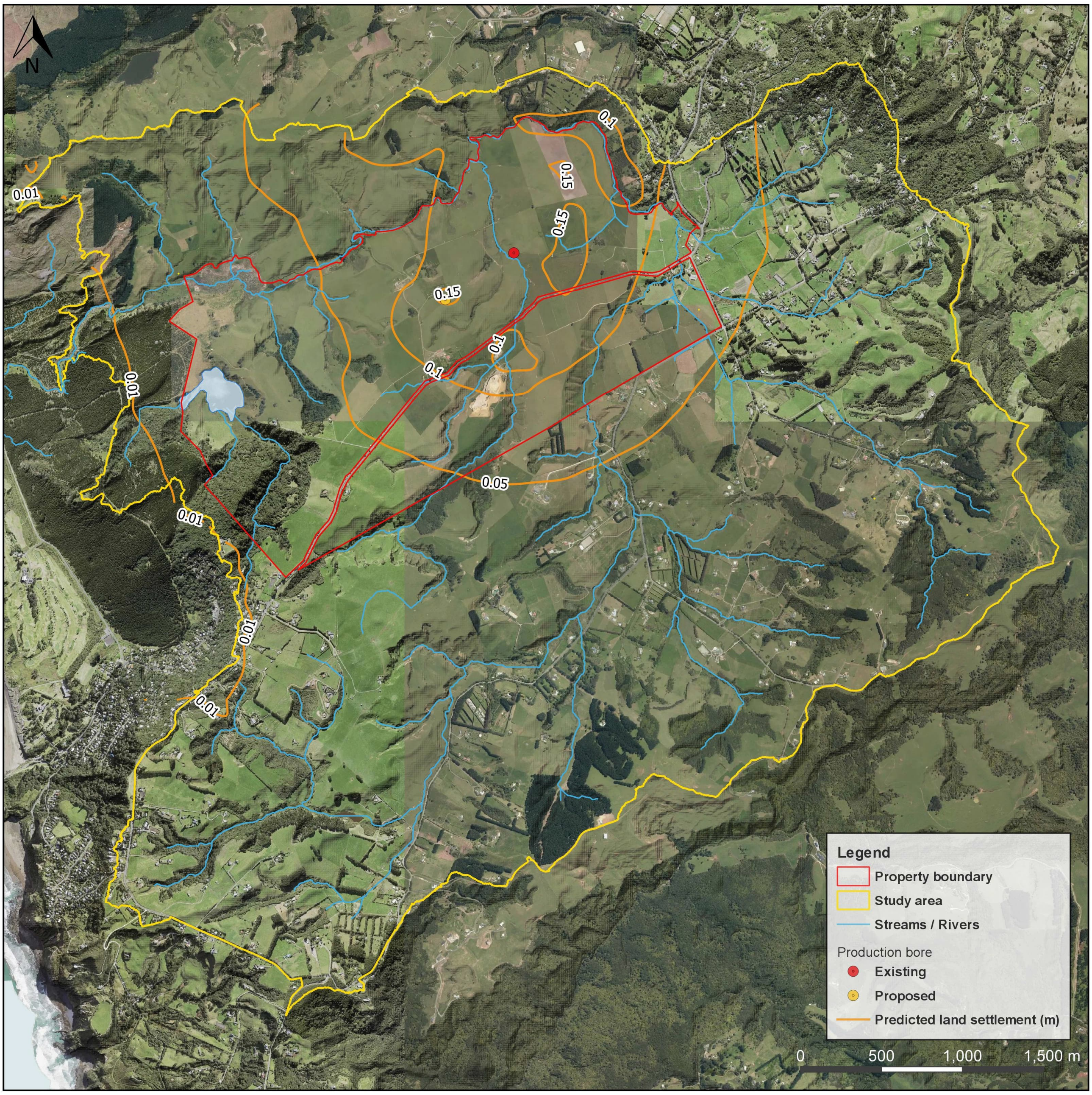

Figure 28. Predicted subsidence from peak drawdown.

9.4 Surface Water Effects

For the purpose of guiding surface water effects associated with the groundwater take, AUP-OP assessment criteria set out in Chapter E7.8.2 (4)(b) are most relevant. They read as follows:

> *Whether the proposal…demonstrates that:*
>
> *the taking will avoid, remedy or mitigate adverse effects on surface water flows, including:*
>
> (i) base flow of rivers, streams and springs;

(ii) any river or stream flow requirements;

The anticipated effects on surface water bodies connected to groundwater are addressed in the following sections based on the relevant provisions in the AUP-OP.

9.4.1 Stream Baseflow

It is appropriate to assess the simulated surface water effects in terms of the predicted change relative to baseline conditions, rather than in terms of absolute flow for which there is relatively high uncertainty due to limited monitoring data.

As discussed in **Section 8.2.2**, the proposed groundwater take is predicted to cause a maximum reduction of 3.4% of baseflow in the stream adjacent to the bore, and a lesser reduction in the larger Ōkiritoto Stream. The median baseflow reduction is predicted to be less than 0.5% at all analysis locations. These findings are consistent with the conclusions derived from monitoring data that baseflows are responsive to conditions in the shallow aquifer that are largely disconnected from the deep aquifer where the abstraction will take place.

The stream flowing into Lake Ōkaihau is within the Natural Stream Management overlay in the AUP-OP, however the predicted impact on baseflow in this stream, which is 1.9 km from the abstraction bore and in a separate catchment, is unmeasurable.

Based on these results the effects on stream flows are predicted to be less than minor.

9.4.2 Flooding

The groundwater abstraction will in no way cause an increase in flooding or flood susceptible areas.

9.4.3 Wetlands

As discussed in **Section 8.2.1**, wetlands will not be impacted by the proposed groundwater take because of the disconnection between shallow and deep groundwater due to the thickness of low-permeability material throughout the study area.

With regard to standing water level in a wetland, as opposed to groundwater, the simulated drawdown in the shallow aquifer does not directly transpose to a water level reduction in a wetland due to the relationship between shallow aquifer porosity (specific yield) and the standing water level. The change in water level is relative to the specific yield of the aquifer material, such that the maximum reduction of 0.2 m in shallow aquifer groundwater level that was predicted to occur within a wetland, during worst case drought conditions, would translate to at most, 0.02 m water level change in a wetland assuming 10% specific yield in the shallow aquifer. All other areas would be even less affected, to a degree that would be unmeasurable in practice.

On the whole, the effect on wetlands from groundwater abstraction will be inconsequential.

9.4.4 Lakes

Lake Ōkaihau is the only lake in the study area. It is shown in the Natural Lake Management Overlay of the AUP-OP and is therefore subject to the criteria listed in Chapter D5 (Natural Lake Management Overlay).

The lake is fed by surface water inputs from a stream that is separated from the production bore by a catchment boundary and therefore will not be affected by proposed take. The effect on the lake water balance will be negligible, with predicted leakage increasing by under 0.2% (under 0.5 m^3/day) over the simulation period.

Overall there will be no adverse effects on Lake Ōkaihau water levels.

9.5 Recommendations for Groundwater Monitoring and Reporting

The AUP-OP Chapter E7.8.2 (6) states that planned monitoring is an important component of the assessment criteria for the proposed abstraction; including the following criteria:

> *Whether the proposal to take and use surface water and groundwater will monitor the effects of the take on the quality and quantity of the freshwater resource to:*
>
> (a) measure and record water use and rate of take;
>
> (b) measure and record water flows and levels;

Currently, there are also two shallow monitoring piezometers (4 and 11 m) directly adjacent to the production bore and another deeper piezometer 300 m to the east of the bore. There are a pair of nested piezometers recently installed at 4.5 m and 14.5 m depth at the northern shore of Lake Ōkaihau. In addition, three shallow piezometers have been installed south of Muriwai Road, ranging from 400 to 600 m from the proposed production site; of these only the deepest, MW4, had water when measured in late August.

Three continuous stream flow gauges have also been installed, though one was lost in a flood on 31 August 2021. Finally, the production bore itself has been outfitted for continuous monitoring.

Monitoring data to date has shown the groundwater water levels to be quite consistent, however exercising the proposed groundwater take will warrant monitoring. Given the number of established sites, no new monitoring locations should be required. **Table 18** provides a suggested monitoring program that will adequately measure any effects from groundwater abstraction using existing bores.

Table 18. Recommended monitoring sites on the Muriwai Downs Property.

Bore ID	Depth	Geologic material / Stream	Recommended monitoring frequency	
			Irrigation season	Non-irrigation season
Pilot bore	200	Deep basalt	Daily	Quarterly
MW1 (Adjacent to Production bore)	4.3	Shallow pillow basalt	Daily	Quarterly
MW2 (Adjacent to Production bore)	10.7	Shallow pillow basalt	Daily	Quarterly
MW3 (300 m NE of Production bore)	60	Nihotupu formation (most likely)	Daily	Quarterly
MW4 (500 m SE of Production bore)	13.5	Awhitu sandstone	Weekly	Quarterly
Lake Ōkaihau North (MW7)	4.5	Kariotahi sands	Weekly	Monthly
Lake Ōkaihau North (MW8)	14.5	Awhitu sandtone	Weekly	Monthly

10. Conclusions

WWLA has developed of a numerical groundwater model of the Muriwai Downs Property and adjacent area. The purpose of this exercise was to evaluate whether the underlying basalt aquifer is likely to be a sustainable source of groundwater to supplement surface water as an irrigation supply for the proposed golf course development. The model was developed based on prior analysis of geologic and hydrogeologic conditions, test pumping, an ERT survey, and ongoing monitoring.

A three-layer model was developed using the USGS MODFLOW code and calibrated to the groundwater level monitoring data collected at four locations, ranging in depth from 4 to 200 m, with the deepest being the pilot bore where the test pumping occurred. Data from the test pumping exercise was also used in the model calibration data set.

Conductivity values calculated from test pumping results were assigned to the materials in the lower aquifer layer representing the basalt-dyke (high conductivity), sandstone (low conductivity), and a presumed deep basalt formation (intermediate conductivity). A key finding of the calibration process was that to replicate the vertical pressure gradient observed in the monitoring data there must be a down gradient outlet for deep groundwater. This was presumed to be a deep basalt flow based on similar formations in the area.

The calibrated model achieved and RMSE of 1.01 m, which was 4.7% of the range of observations, indicating that the model was suitable for the analysis being undertaken. Notably, the simulated water levels in three of the four monitoring bores were significantly closer to observations, achieving a collective RMSE of 0.2 m.

The calibrated model was applied to two scenarios to evaluate the likely effects of groundwater abstraction by way of comparing the most likely water use scenario to a baseline scenario with no abstraction. Each scenario was run using a 49-year record of historic climate data (1972-2020). The scenarios were as follows:

1. No Groundwater abstraction;
2. Groundwater as a supplement for surface water in sustaining necessary water levels in a reservoir.

Model results were assessed in terms of likely effects on groundwater and surface water conditions and evaluated based on criteria in the AUP-OP. The proposed abstraction is classified as a Discretionary Activity (AUP-OP Table E7.4.1 (A26)).

The maximum and median drawdown predicted in the deep aquifer at the pumping bore was 16.2 m and 9.7 m, respectively. Drawdown was significantly less in the upper layers, never exceeding 0.3 m in Layer 1 and 2.6 m in Layer 2. Forty-three bores were found to be within a 3 km radius of the abstraction site, ranging from 40 to 458 m deep. Potential drawdown was evaluated at these locations, and it was found that maximum simulated drawdown never exceeded 9% of available drawdown for any of the bores therefore effects on neighbouring groundwater users are predicted to be less than minor.

The disconnection between the shallow and deep aquifer minimised the effect on the shallow aquifer. As a result, there was limited effects predicted to occur on baseflow, with a maximum baseflow reduction of 3.4% at the flow monitoring site adjacent to the pumping bore, and less reduction at the other sites evaluated. The median baseflow reduction was under 0.5% and would in practice be unmeasurable. Likewise, potential effects on wetland water levels will be limited to a wetland area identified very close to the bore, and only at a predicted reduction of 0.03 m in worst case conditions.

Predicted land subsidence was primarily under 0.1 m, and a maximum of 0.17 m, and limited to the areas near the abstraction site where infrastructure would not be affected. Potential saline intrusion was also evaluated, and it was found that with or without abstraction the saline interface is likely to be several hundred meters below the extent of any economically feasible bore.

In summary, based on the numerical model evaluation the proposed groundwater abstraction at Muriwai Downs has been considered in the context of the criteria in the AUP-OP and found to meet the standards for such activities.

11. References

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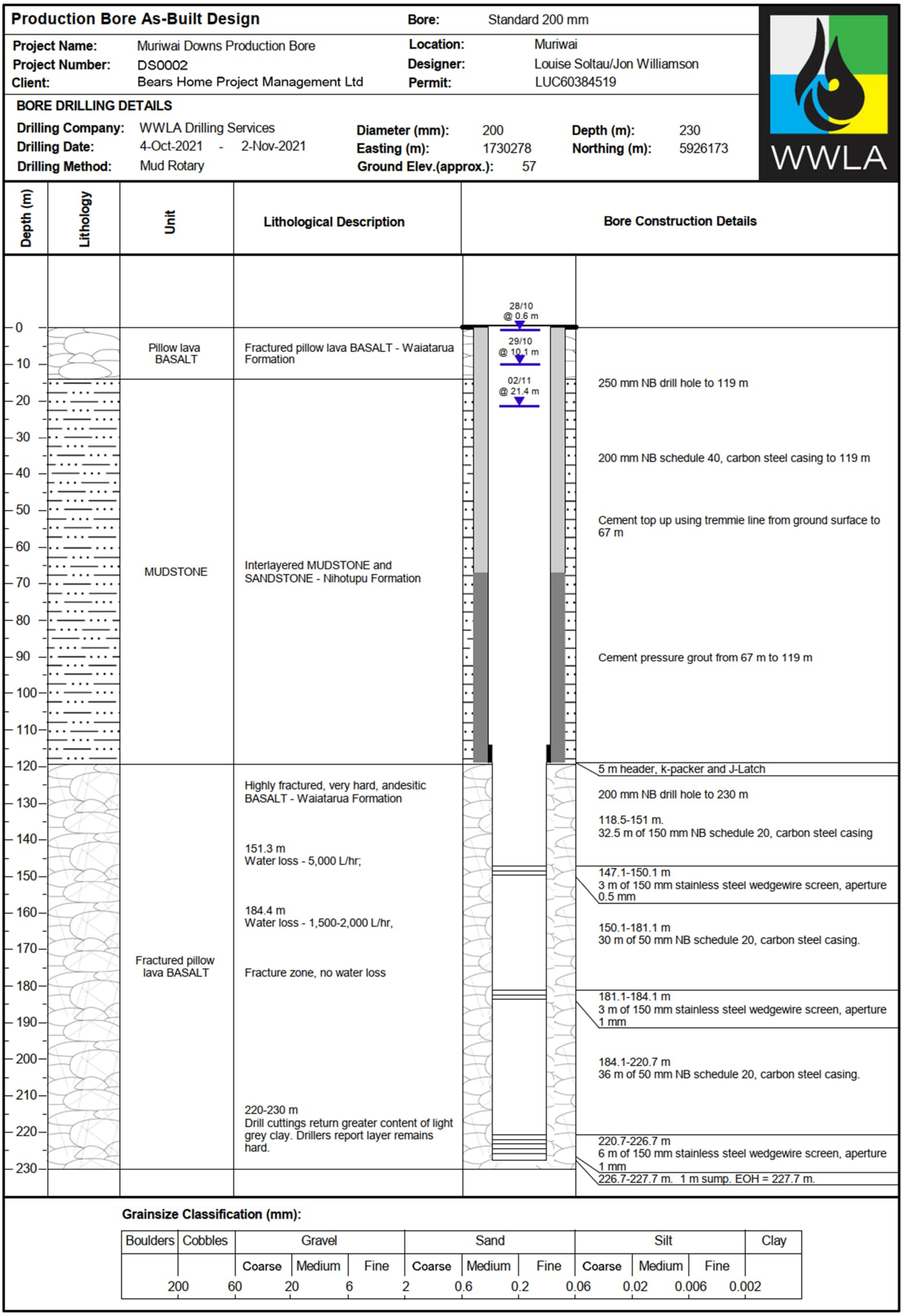
Appendix A. Lithological & As-Built Log



Production Bore As-Built Design
Bore: Standard 200 mm

Project Name: Muriwai Downs Production Bore
Project Number: DS0002
Client: Bears Home Project Management Ltd
Location: Muriwai
Designer: Louise Soltau/Jon Williamson
Permit: LUC60384519

BORE DRILLING DETAILS
Drilling Company: WWLA Drilling Services
Drilling Date: 4-Oct-2021 - 2-Nov-2021
Drilling Method: Mud Rotary
Diameter (mm): 200
Easting (m): 1730278
Ground Elev.(approx.): 57
Depth (m): 230
Northing (m): 5926173

Pillow lava BASALT

Fractured pillow lava BASALT - Waiatarua Formation

MUDSTONE

Interlayered MUDSTONE and SANDSTONE - Nihotupu Formation

Fractured pillow lava BASALT

Highly fractured, very hard, andesitic BASALT - Waiatarua Formation

151.3 m
Water loss - 5,000 L/hr;

184.4 m
Water loss - 1,500-2,000 L/hr,

Fracture zone, no water loss

220-230 m
Drill cuttings return greater content of light grey clay. Drillers report layer remains hard.

250 mm NB drill hole to 119 m

200 mm NB schedule 40, carbon steel casing to 119 m

Cement top up using tremmie line from ground surface to 67 m

Cement pressure grout from 67 m to 119 m

5 m header, k-packer and J-Latch

200 mm NB drill hole to 230 m

118.5-151 m.
32.5 m of 150 mm NB schedule 20, carbon steel casing

147.1-150.1 m
3 m of 150 mm stainless steel wedgewire screen, aperture 0.5 mm

150.1-181.1 m
30 m of 50 mm NB schedule 20, carbon steel casing.

181.1-184.1 m
3 m of 150 mm stainless steel wedgewire screen, aperture 1 mm

184.1-220.7 m
36 m of 50 mm NB schedule 20, carbon steel casing.

220.7-226.7 m
6 m of 150 mm stainless steel wedgewire screen, aperture 1 mm

226.7-227.7 m. 1 m sump. EOH = 227.7 m.

Grainsize Classification (mm):

Boulders	Cobbles	Gravel			Sand			Silt			Clay
		Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine	

200 60 20 6 2 0.6 0.2 0.06 0.02 0.006 0.002

Figure 29. Bore log for Muriwai Downs pilot bore.

Appendix B. SMWBM Overview

Table 19. SMWBM_VZ parameters.

Parameter	Name	Description
ST (mm)	Maximum soil water content	ST defines the size of the soil moisture store in terms of a depth of water
SL (mm)	Soil moisture content where drainage ceases.	Soil moisture storage capacity below which sub-soil drainage ceases due to soil moisture retention.
FT (mm/day)	Sub-soil drainage rate from soil moisture storage at full capacity	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.
ZMAX (mm/hr)	Maximum infiltration rate	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. 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	
POW (>0)	Power of the soil moisture-percolation equation	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.
PI (mm)	Interception storage capacity	PI defines the storage capacity of rainfall that that is intercepted by the overhead canopy or vegetation and does not reach the soil zone.
AI (-)	Impervious portion of catchment	AI represents the proportion of the catchment that is impervious and directly linked to drainage pathways.
R (0,1)	Evaporation – soil moisture relationship	Together with the soil moisture storage parameters ST and SL, R governs the evaporative process within the model. Two different relationships are available. The rate of evapotranspiration is estimated using either a linear (0) or power-curve (1) 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	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.
TL (days)	Routing coefficient for surface runoff	TL defines the lag of surface water runoff.
GL (days)	Groundwater recession parameter	GL governs the lag in groundwater discharge or baseflow from a catchment.
QOBS (m^3/s)	Initial observed streamflow	QOBS defines the initial volume of water in the stream at the model start period and is used to precondition the soil moisture status.
K_v (m/s)	Vertical hydraulic conductivity at full saturation	K_v defines the vertical hydraulic conductivity of the parent geology type when at full saturation. The Kv value sets the upper limit on the rate of flow in the vadose zone.
VGn (-)	van Genuchten constant soil type	VGn is a text book value used to define the relationship between soil moisture status and hydraulic conductivity of soil. It is used to determine the actual vertical hydraulic conductivity, which reduces as the soil dries.
n_s (-)	Soil zone porosity	n_s defines the porosity of the soil zone.

Parameter	Name	Description
n_{vz} (-)	Vadose zone porosity	n_{vz} defines the porosity of the vadose zone and is therefore determined from an understanding of the parent geology material.
D (m)	Thickness of vadose zone (depth to water table)	D defines the thickness or the depth of the vadose zone.
GW_OnOff (True/False)	Groundwater on or off Selection	This feature of the SMWBM allows you to turn off the groundwater component of a sub-catchment so it does not report back to the river. This feature is useful when integrating with groundwater models.
AA, BB	Coefficients for rainfall disaggregation.	Used to determine the rainfall event duration and pattern. Default values usually suffice.

A conceptual diagram of the key components of SMWBM_VZ model structure and functionality is shown in **Figure 30**.

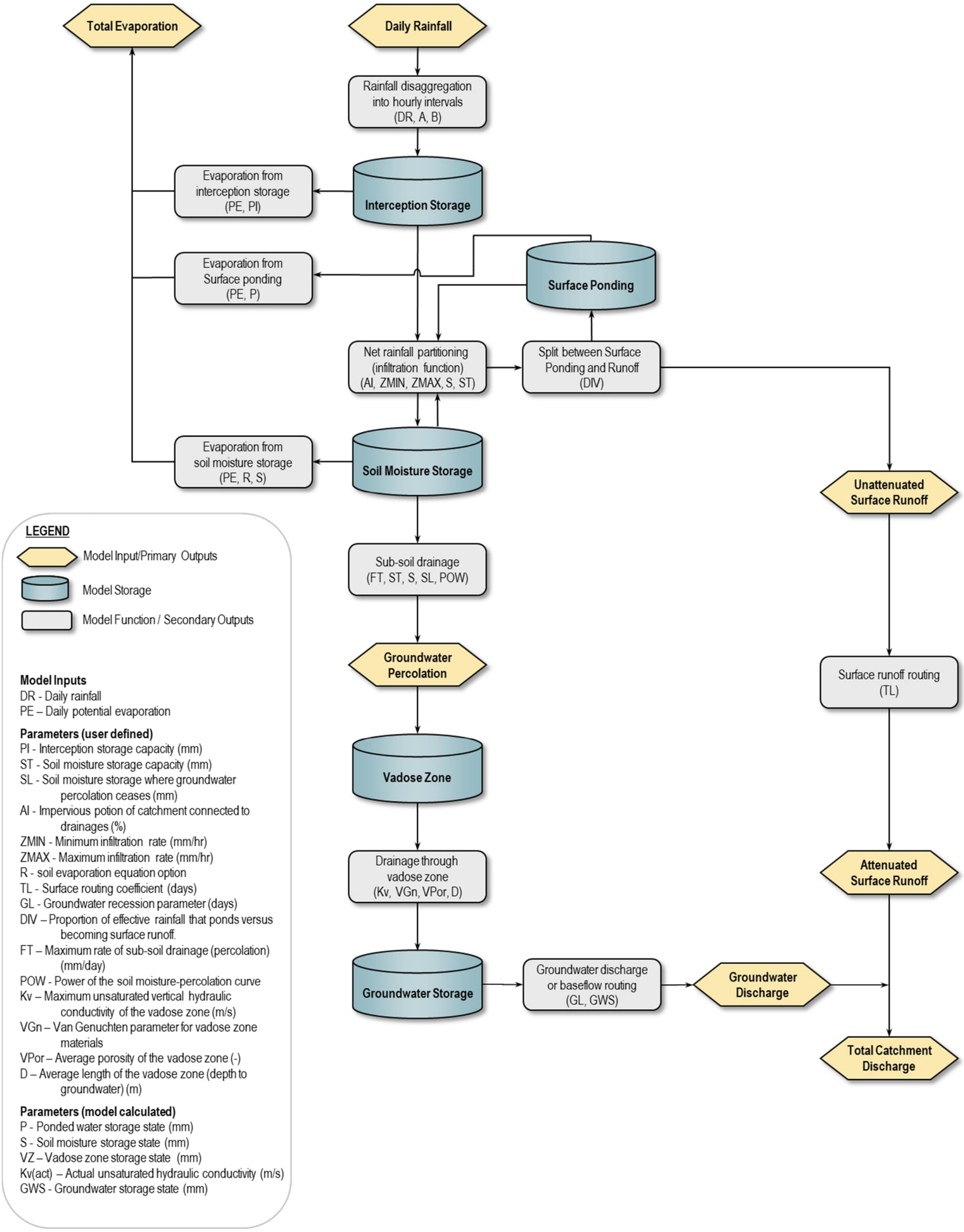


Figure 30. Flow diagram of the SMWBM_VZ structure and parameters.