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Lake Ōkaihau

Appendix F - Lake Water Balance Assessment

THE BEARS HOME PROJECT MANAGEMENT LIMITED

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Muriwai Downs Golf Project

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Contents

Executive Summary

A water balance study was undertaken to provide insight into the likely hydrological functionality of Lake Ōkaihau. The conceptual understanding, which was reinforced by a water balance model developed for the lake, is summarised as follows:

- The lake bed consists of lower permeability material than the surrounding shallow sand aquifer, which is thicker in the deepest part of the lake and pinches (i.e., thins) towards the margins of the lake;
- This results in low groundwater seepage loss from the lake during periods of low lake water levels (summer), and higher rates of seepage during periods of elevated water levels (winter);
- The largest inflow to the lake is from the stream catchment from the south; and
- The largest net loss from the lake is through groundwater seepage towards the Ōkiritoto Stream via historic sand dunes to the northwest.

The proposed golf course development is planned for the northern side of the lake only. Therefore, there are no proposed earthworks or changes in land use within the southern catchment of the lake, and no disruption to inflows to the lake are anticipated.

The conceptual understanding is that groundwater seepage is occurring from the lake towards Ōkiritoto Stream west of the downstream extend of the Property. The risk of nutrients leaching from the golf course development (e.g., from fertiliser), to the lake is considered very low, because groundwater only flows into the lake on the upgradient side (which is a native bush and forested catchment) and flows away from the lake on the downgradient side.

As noted above, part of the golf course is planned along the northern margins of the lake. A small margin of land surface in this location currently, and in the proposed development, gently slopes down towards the lake, and therefore the lake may be subject to small contributions of surface runoff from this land during high intensity events. In this area, it will be important to ensure:

- appropriate erosion and sediment control measures are in place when undertaking the gentle grading and earthworks proposed; and
- best practice fertiliser application and management, to ensure no adverse or elevated nutrient runoff to the lake.

Provided appropriate erosion and sediment control measures are followed during construction, and best practice fertiliser application and management practices are adhered to, any potential effects on the lake are considered to be no more than minor.

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 Muriwai Downs property (Property) to a Golf Course, Clubhouse, Sports Academy and Lodge development (Project).

WWLA's scope was later expanded to include Electrical Resistivity Tomography (ERT) Survey, a Groundwater Effects Assessment of the proposed groundwater irrigation take, a Site Water Balance and Water Strategy Report, and a Water Balance Assessment of Lake Ōkaihau.

This report details the Lake Ōkaihau Water Balance Assessment. A lake water balance assessment considers the temporal variation in lake inputs (surface water inflow, rainfall), balanced against lake losses/outflow (evaporation and seepage), to provide an understanding of the proportional contribution of each component. The objective of the scope of works was to provide the following:

- Insight into the hydrological functioning of the lake through simulation of the lake water balance (analysis of lake inputs such as rainfall and surface water, and outputs such as evaporation and groundwater seepage); and
- Draw conclusions on potential effects on the lake water balance, and water quality impacts from the proposed golf development on the lake (if any).

1.1 Report Structure

The report comprises:

- An overview of the lake (**Section 2**);
- Descriptions of available data used throughout the assessment (**Section 3**);
- Lake water balance assessment (**Section 4**); and
- Discussion on findings of the water balance assessment (**Section 5**).

2. Overview

Lake Ōkaihau is a dune lake located in the western extent of the Property on the southern side of the Ōkiritoto Stream (**Figure 1**). The lake covers an area of approximately 6 hectares (ha) and is up to 9-10 metres deep near the centre of the lake (Cunningham et al., 1953). The lakes surface water catchment extends approximately 94 ha upstream of the lake, and predominately consists of forested land, with overland flow channels in fairly steep-sided gullies.

Historically there has been little research or long-term monitoring undertaken on the lake. Cunningham et al. (1953) undertook a bathymetry, ecology, and water quality survey of the lake in 1950, and classified Lake Ōkaihau as a basin dune lake in consolidated sands.

The Auckland Regional Water Board (ARWB, 1980) undertook a water balance study of the lake in the late 70's. Based on overland water flow from the adjacent land, and rainfall and evaporation data, they determined an average daily water balance for the summer of 1977/78 as follows:

1. Inflow to the lake: 4.0 L/s
2. Evaporation from the lake: 4.46 L/s; and
3. Change in daily lake storage from outflow: 8.59 L/s.

Their study showed the lake lost water through outflow, and it was believed this flow contributes to the Ōkiritoto Stream via springs above the Forestry Bridge.

Auckland Council began collecting routine monthly lake water quality samples and lake water level measurements in March 2021.

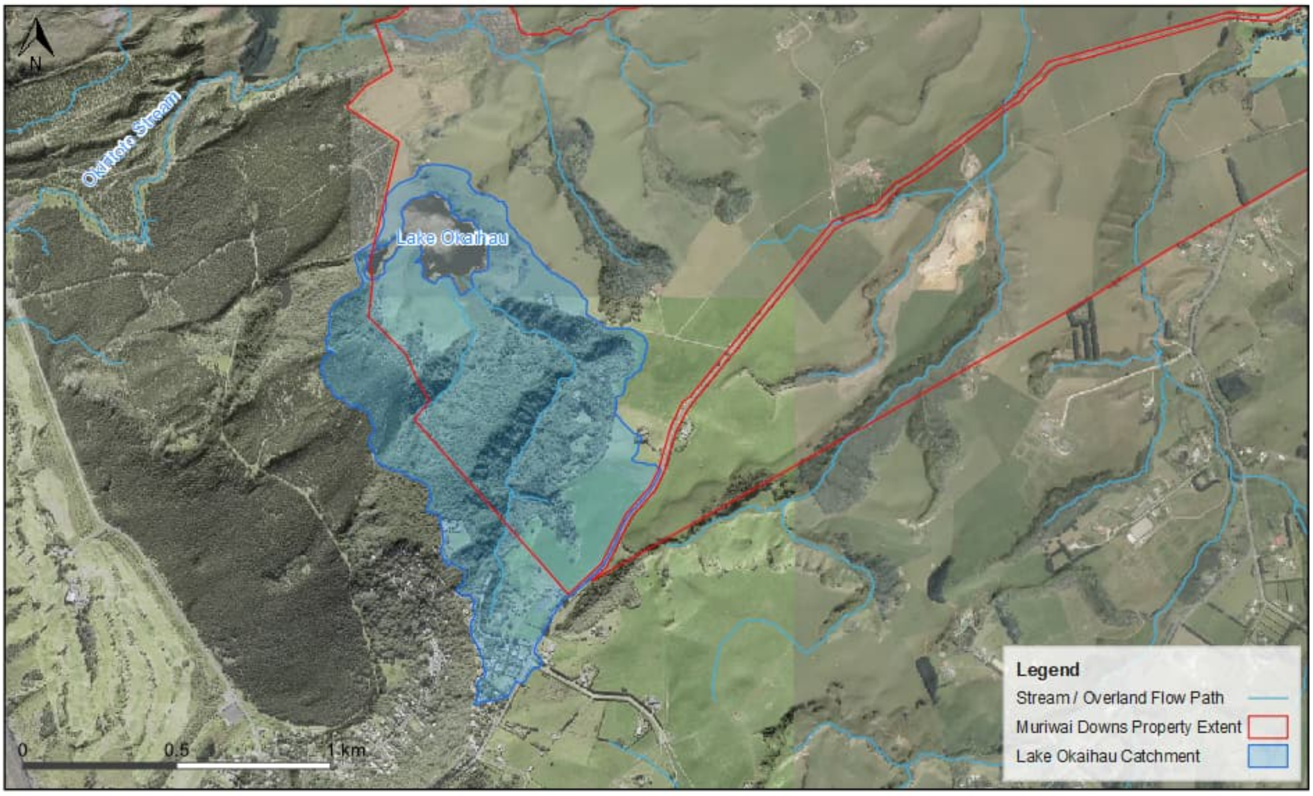

Figure 1. Overview map.

Figure 2. Oblique photograph of Lake Ōkaihau – facing south-west.

3. Available Data

The following section details the available data that was utilised for the lake water balance assessment.

3.1 Climate Data

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.

VCSN data was used in favour of local rain gauge data as it provides a long duration record with no periods of missing or bad quality data. Auckland Council list two rain gauges in close proximity to the Muriwai Downs Property, one at Muriwai Golf Course and one a Kumeu, that have operated since 2013, and 1993, respectively.

Estimates of daily rainfall and evaporation were obtained from the VCSN Site 21836, located approximately 2 km south of The Property. A summary of annual rainfall and evaporation for this location is presented in **Figure 3**.

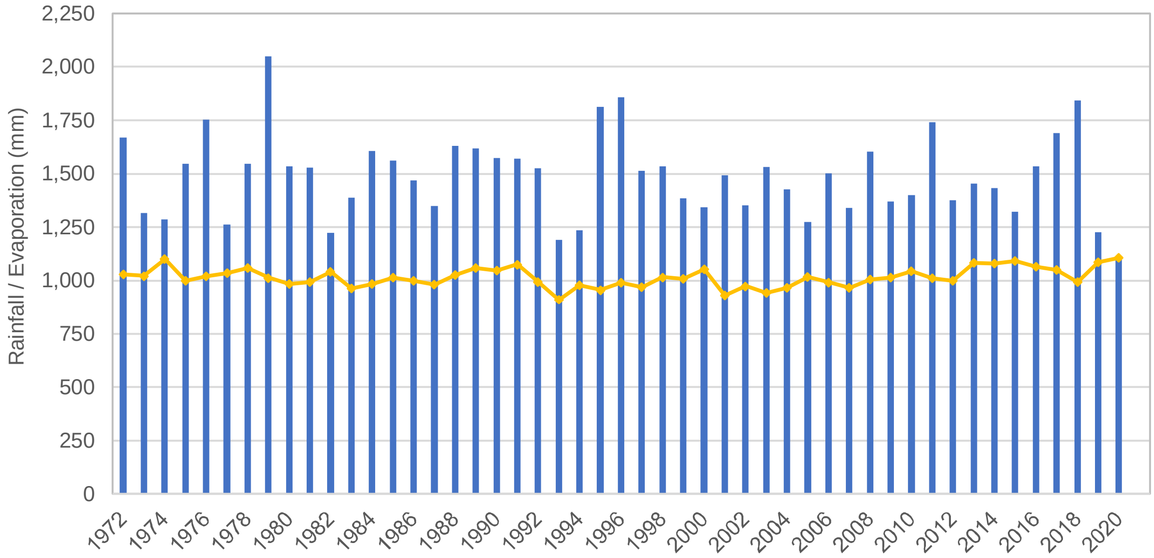

Figure 3. Climate data summary.

Data was obtained for 2021 to late July but is excluded from **Figure 3** as it does not cover a complete year.

3.2 Lake Bathymetry

As alluded to in **Section 2**, Cunningham et al. (1953) undertook a bathymetric survey of the lake in the early 1950's. This survey is presented in **Figure 4**. The survey was collected from a small row boat, using a weighted cord line with sinker to manually measure the depth across survey lines over the lake.

Depths were measured relative to the water level on the day of the survey, and therefore the exact vertical datum is not known. The bathymetric survey was georeferenced, digitised to provide digital lake depth contours, and converted to a raster grid Digital Elevation Model (DEM).

The lake bathymetry DEM was then merged with Auckland Council's 2016 LiDAR DEM. For the purposes of merging the two DEM's it was assumed lake levels were consistent with an average summer water level during the time of the survey, as exact levels were unknown.

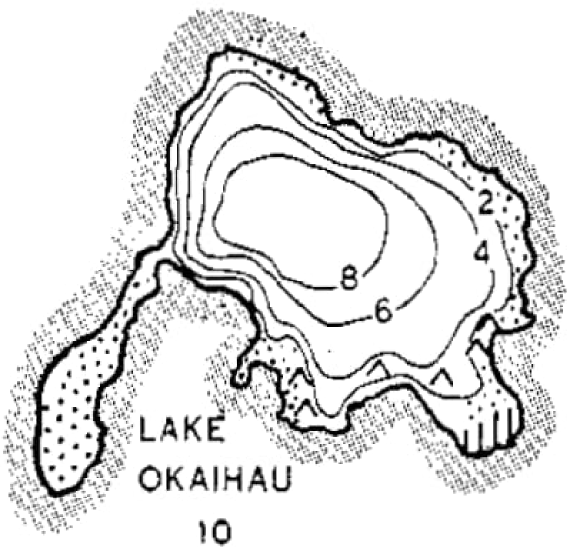

Figure 4. Lake Ōkaihau bathymetric survey (from Cunningham, ***et. al.*,** 1953).

3.3 Historic Water Level Data

Historic lake water level data were sources from Auckland Council's Research and Evaluation Unit (RIMU) Team and estimated from historic Google Earth imagery. These two datasets are further described in turn below.

3.3.1 Auckland Council Monitoring Data

Auckland Council installed a staff gauge on the end of the wooden jetty on the north-western shoreline of Lake Ōkaihau (**Figure 5**). The staff gauge is used to monitor and record relative water level change during their routine monthly water quality monitoring visit. The monitoring programmed commenced in March 2021. At the time of preparing this report, only four measurements were available (**Table 1**).

Auckland Council confirmed the staff gauge has not been surveyed, therefore the vertical datum of staff gauge zero is unknown. In order to relate staff gauge water levels to the combined lake bathymetry and LiDAR DEM, WWLA estimated the staff gauge vertical datum by spot sampling the elevation at the landward end of the jetty from the LiDAR DEM. Based on this approach, staff gauge zero was calculated as 30.32 m NZVD2016.

Moving forward in this report, all lake water levels are reported as relative to the lake staff gauge unless otherwise specifically stated.

Figure 5. Lake Ōkaihau staff gauge.

Table 1. Auckland Council Lake water level measurements.

Date	Water Level (m RL)
24/03/2021	0.8
27/04/2021	0.78
24/05/2021	0.785
17/06/2021	0.927

3.3.2 Historic Google Earth Imagery

As only four water level readings were available from Auckland Council's routine monitoring, additional historic water levels were estimated based on historic Google Earth satellite imagery. Sixteen historic images were available between 2010 and the present, where the lake shoreline was visible and easily distinguishable. The horizonal location of the lake's edge was marked, sampled from the combined bathymetry and LIDAR DEM, and the elevation converted relative to the local staff gauge.

The locations of the 16 shoreline positions are displayed in **Figure 6**, and estimated lake water level elevations presented in **Table 2**. Water level locations were all identified along the north-western shoreline of the lake, as this section of shoreline has the lowest gradient (slope), and thus exhibited the greatest change in horizontal shoreline position for a given change in water level.

It is noted that due to the resolution of Google Earth imagery, it was difficult to determine the exact location of the shoreline in a number of images. However, despite this and in the absence of a longer-term historical water level record, this approach was considered appropriate and to provide a useful additional record for verification of the water balance record.

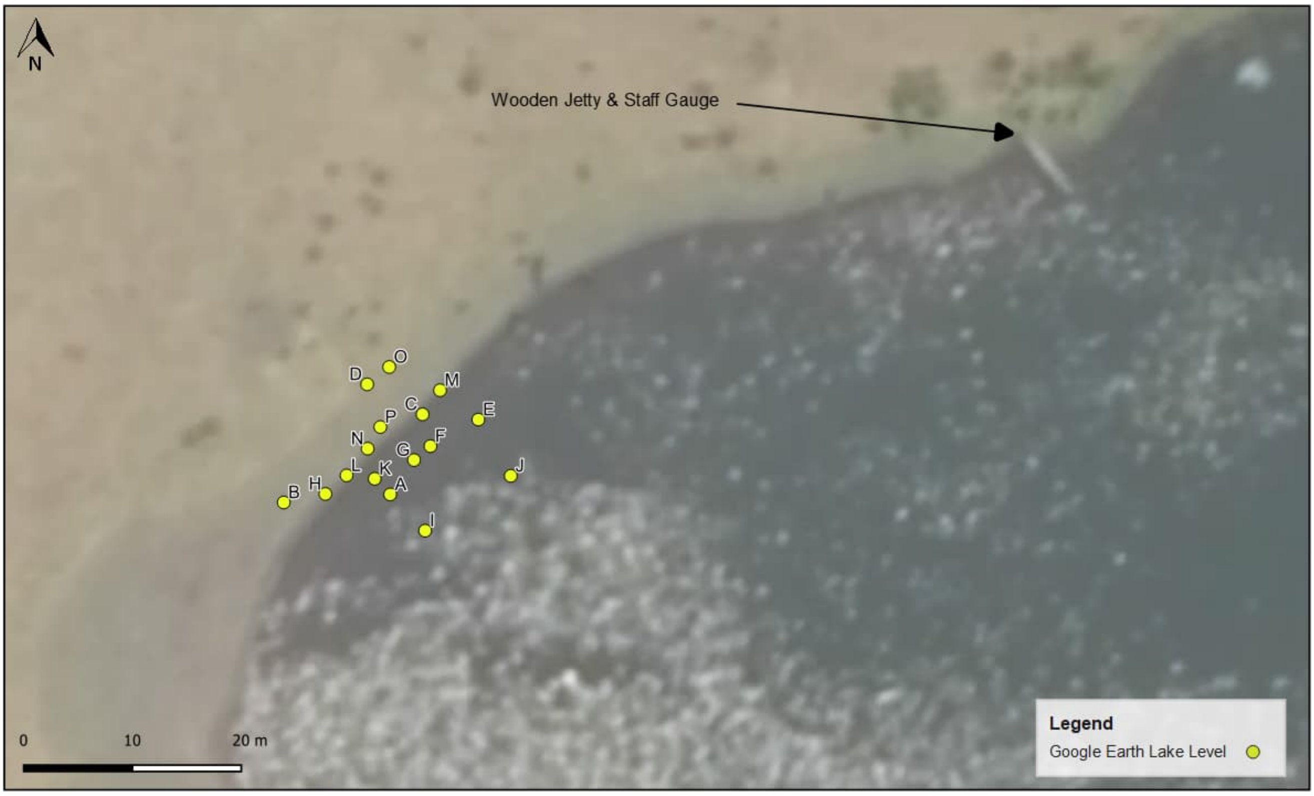

Figure 6. Historical lake shoreline positions from Google Earth imagery.

Table 2. Lake water levels estimated from Google Earth.

ID	Date	Water Level (m RL)
A	07/04/2010	1.42
B	03/03/2012	1.80
C	21/12/2012	1.45
D	30/08/2013	2.08
E	01/03/2015	1.42
F	29/05/2015	1.42
G	09/07/2015	1.42
H	05/11/2015	1.61
I	30/12/2015	1.42
J	05/02/2017	1.42
K	24/04/2017	1.41
L	10/06/2017	1.58
M	02/05/2018	1.52
N	10/02/2019	1.58
O	20/09/2019	2.13
P	15/08/2020	1.68

In summary, only four measured water level data points are available for Lake Ōkaihau. Historical lake shoreline positions were identified from historical Google Earth imagery, and intersected with the combined LiDAR and bathymetry DEM to provide an additional sixteen estimates of historical lake water level. Together, these twenty historic lake water level measurements will be used to calibrate and verify the Lake Ōkaihau Water Balance Model developed by WWLA (discussed in **Section 4**).

4. Lake Water Balance Assessment

4.1 Overview

WWLA's Reservoir Storage Model (RSM) was used to undertake the lake water balance assessment. While the model is referred to as a reservoir storage model, conceptually, lakes are essentially a large reservoir. The RSM operates on a daily timestep, performing water balance calculations, accounting for inputs (rainfall and catchment inflows), and losses (evaporation, seepage (losses to groundwater), and abstractions) to determine the daily changes in storage volume and by inference water level.

The RSM provides a tool that enables rapid simulation and can, therefore provide valuable insight into the hydrological functioning of a lake or storage reservoir through the simulation of exploratory scenarios involving trial and adjustment of key model inputs (e.g., the proportion of groundwater inflow or seepage loss).

The RSM configured for this Project is referred to as the Lake Ōkaihau Water Balance Model, hereon.

4.2 Model Inputs

The following sub-sections describe the configuration of each model input parameter.

4.2.1 Stage, Area, and Volume Curves

The lake stage (water level from the deepest point) vs. surface area and stage vs storage curves were calculated from the combination of lake bathymetry and LiDAR DEM. The resulting curves are presented in **Figure 7**.

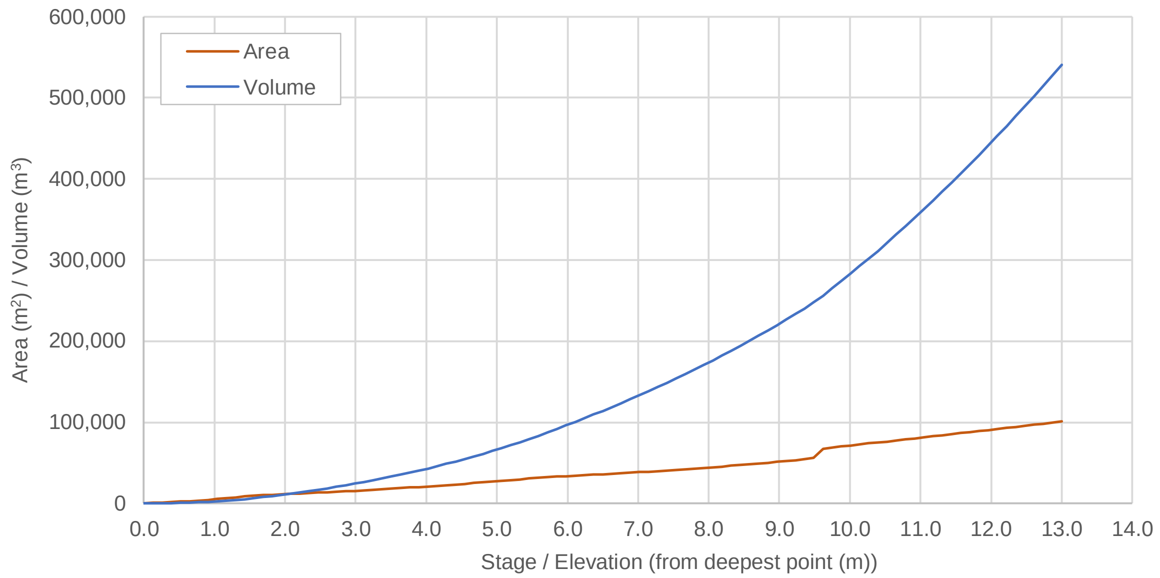

Figure 7. Lake stage, surface area and volume curve.

4.2.2 Rainfall and Evaporation

The Lake Ōkaihau Water Balance Model was configured with daily rainfall and evaporation data from NIWA's VCSN, as described in **Section 3.1**.

4.2.3 Catchment Inflows

Catchment inflows to the lake were simulated using WWLA's Soil Moisture Water Balance Model (SMWBM). Full details on the model development are provided in WWLA (2021 – Appendix C). The simulated catchment inflow to the lake is displayed in **Figure 8**.

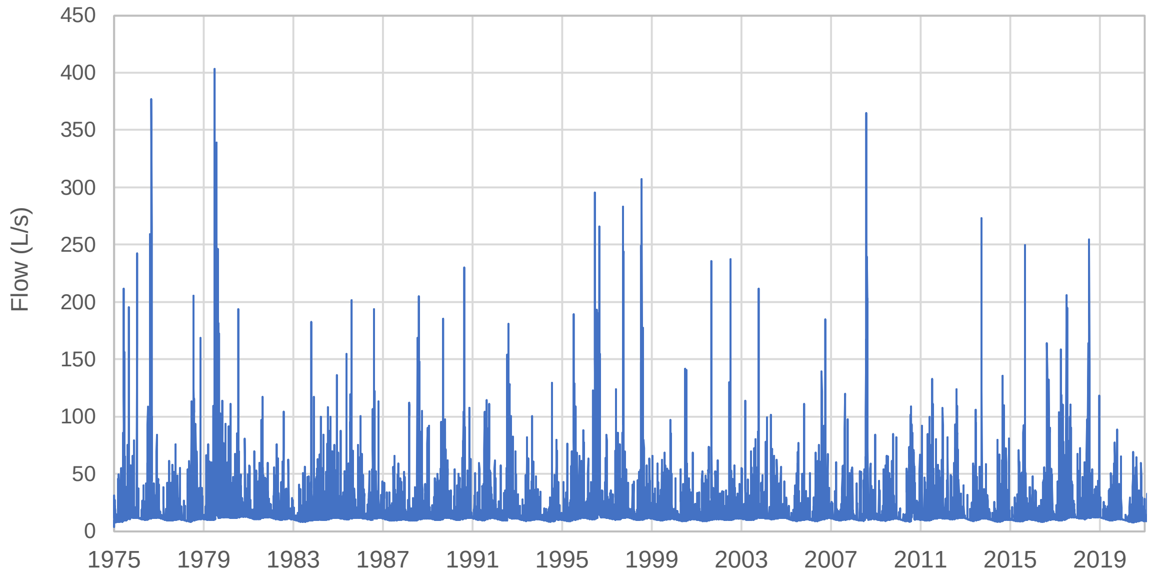

Figure 8. Simulated historic catchment inflows to Lake Ōkaihau.

4.2.4 Groundwater Seepage from Lake

Groundwater seepage from the lake is a function of lake surface area, head (the average height of the water column above the bed), and vertical hydraulic conductivity. Seepage from the lake can be described in a simplistic manner using Darcy's Law for groundwater flow, which is given as:

$$Q = kv\ x\ h\ x\ A$$

Where:

- Q = discharge (m^3/s);
- kv = hydraulic conductivity (m/s);
- h = head (m); and
- A = area (m^2).

The depositional environment of the lake likely comprised coalescing fine sediment forming and self-accentuating the lakebed substrate with time. Conceptually, this implies that:

- the lakebed substrate thickness at the edges is likely thinner than the centre; and

- the vertical hydraulic conductivity of the lakebed sediments is not uniform across the lake, with lowest hydraulic conductivity in the deepest part of the lake where the sediment is thickest and likely more consolidated.

The vertical hydraulic conductivity was adjusted as a calibration parameter as further described in **Section 4.3**.

4.3 Exploratory Scenarios

Three exploratory scenarios were simulated in order to test a range of hypotheses on the hydrological functioning of the lake. The exploratory scenarios are summarised as follows:

- **Scenario 1** – Catchment inflows with no seepage loss;
- **Scenario 2** – Catchment inflows with seepage loss according to simplistic Darcy Law calculation; and
- **Scenario 3** – Catchment inflows with complex seepage loss.

4.3.1 Scenario 1 – Surface Water and Groundwater Inflows with No Seepage

The first exploratory scenario investigated the potential functioning of the lake based on the assumption of evaporation losses only (i.e., no seepage loss), with both rainfall and catchment inflow gains. This resulted in water levels flatlining at the maximum lake level of the model (4.7 m RL). In reality, the lake would have continued to fill even further until it completely overflowed.

This scenario analysis demonstrated that, from a water balance perspective, there must be an additional loss of water from the lake. As there is no defined lake outlet, this must be through seepage via the bed sediments and downgradient historic sand dune embankment. This is consistent with the conclusions of the Auckland Regional Water Board (1980) study, which concluded there must be a seepage loss from the lake the historic sand dunes to the Ōkiritoto stream.

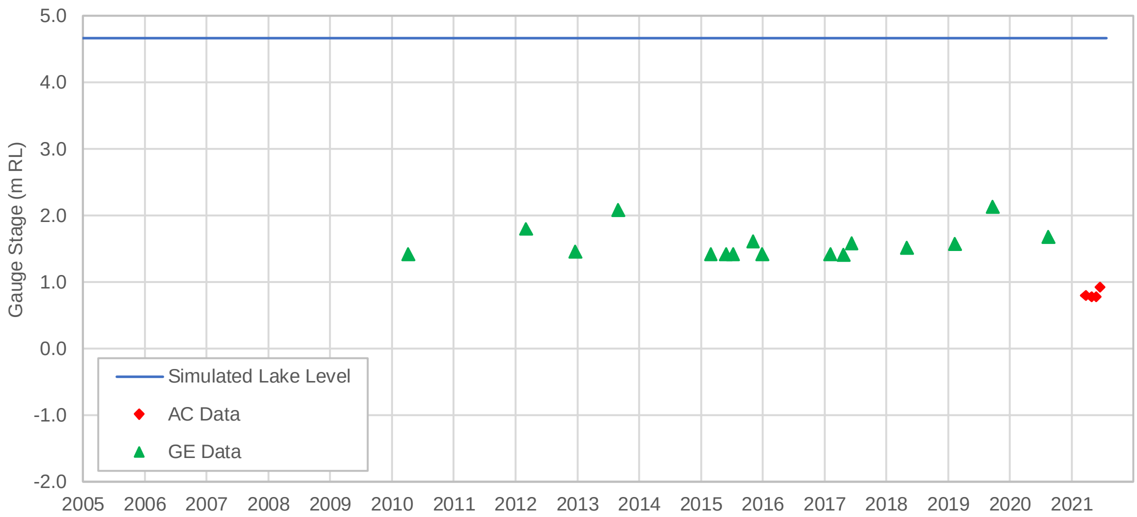

Figure 9. Simulated lake water levels assuming no seepage losses.

4.3.2 Scenario 2 – Inclusion of Groundwater Seepage Losses (Darcy's Law)

In order to test the theory that there is an additional loss from the lake via seepage outflow, a scenario was simulated where a seepage loss was applied based on Darcy's Law (**Section 4.2.4**). The hydraulic conductivity parameter was adjusted within reasonable bounds until the best agreement with historic water levels was obtained. The resulting water levels are presented in **Figure 10**.

A comparison of simulated water levels to estimates of historic water levels demonstrated that the application of a seepage curve following this approach resulted in too higher seepage during periods of low lake levels, and not enough seepage during periods of high lake levels.

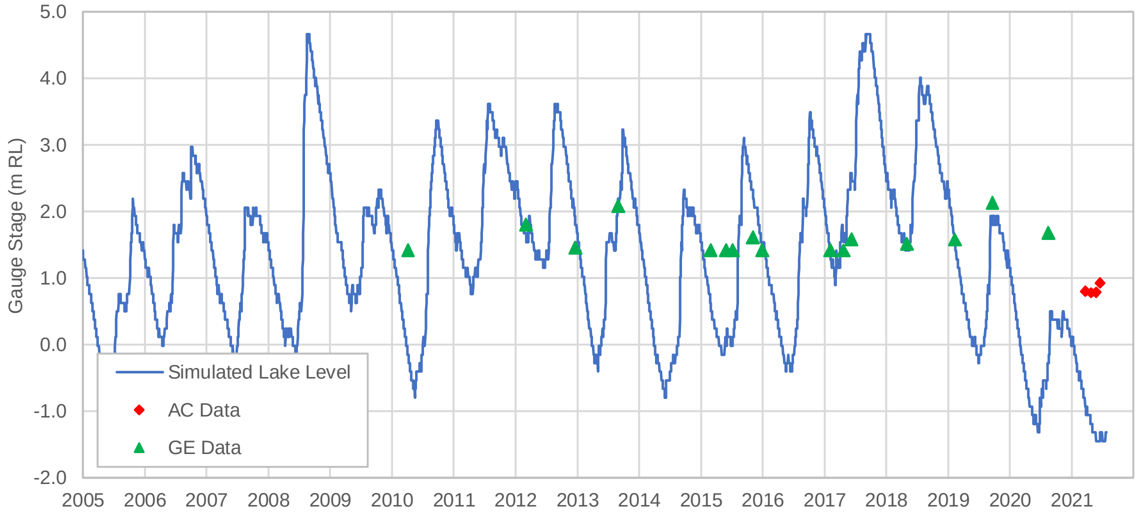

Figure 10. Simulated lake water levels with inclusion of groundwater seepage losses.

4.3.3 Scenario 3 – Inclusion of Groundwater Seepage Losses (Complex Seepage Curve)

While Scenario 2 did not produce acceptable agreement to the historic estimates of lake water level, it proved very useful in informing the conceptual functioning of the lake for Scenario 3. The hypothesised hydrological functioning is described by way of a conceptual cross-section profile. The location of the cross-section profile is presented in **Figure 11**, and the conceptual schematic in **Figure 12**.

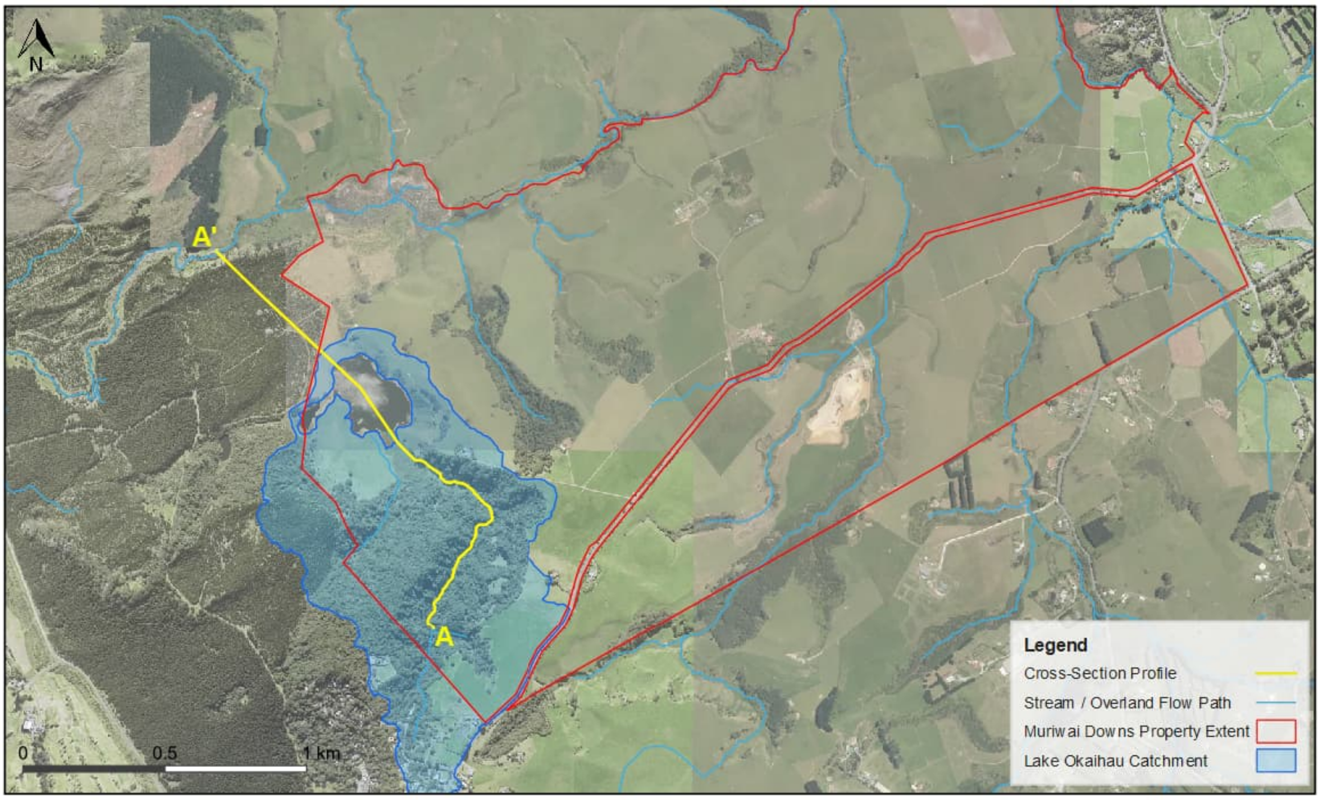

Figure 11. Cross-section profile location.

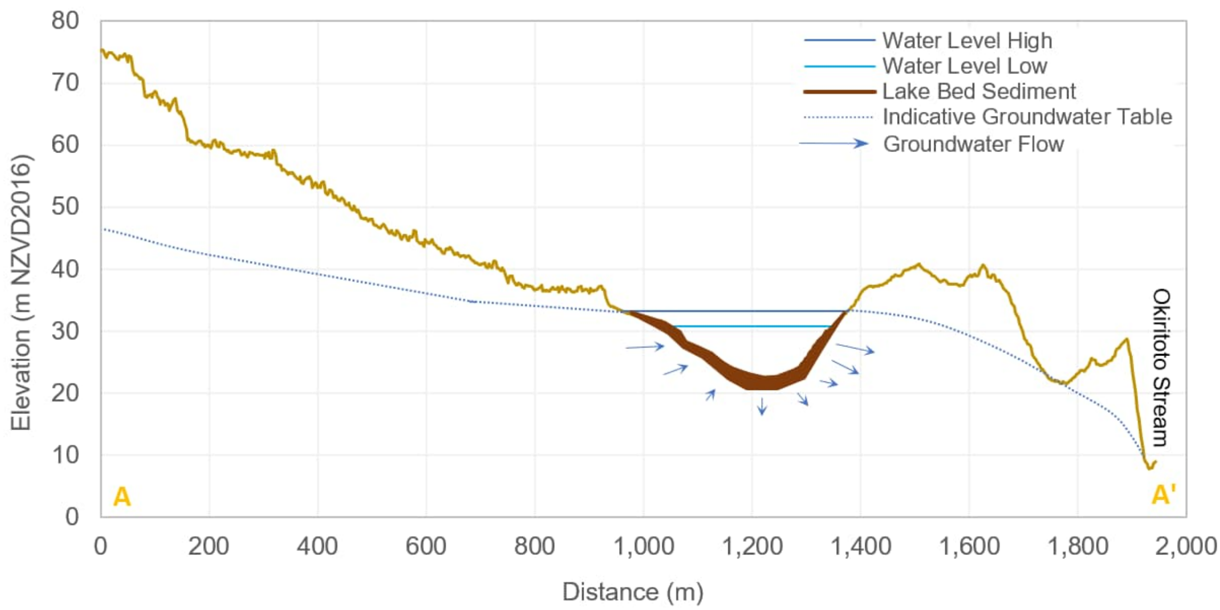

Figure 12. Cross-section conceptual schematic.

As discussed in **Section 4.2.4**, the conceptual understanding of the hydrological functioning of the lake is that the lake bed consists of a deposit of low permeability sediment that varies in thickness radially within the lake, becoming thinner at the extremities (or under the highest lake levels), which results in low seepage losses when lake levels are low. When lake levels increase above the median lake level, the lake bed profile in the zone above median lake water levels becomes progressively sandy and increasingly permeable, resulting in greater losses from the lake during periods of elevated water levels

To test this conceptual understanding (discussed above and further in **Section 4.2.4**), an “adjusted” seepage curve was developed where seepage was low during periods of low water levels and high during periods of elevated water levels (**Figure 16**). The resulting simulated water levels are presented in **Figure 14**. The simulated water levels demonstrate good agreement to historic estimates of lake water level. This good agreement provides weight and a high degree of validation to our conceptual understanding of the hydrological functioning of Lake Ōkaihau (**Figure 12**).

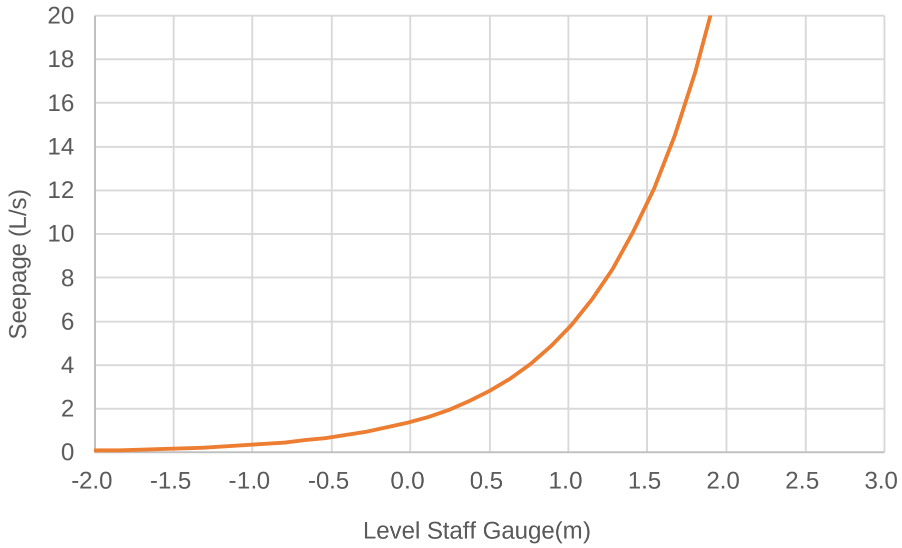

Figure 13. Adjusted seepage curve.

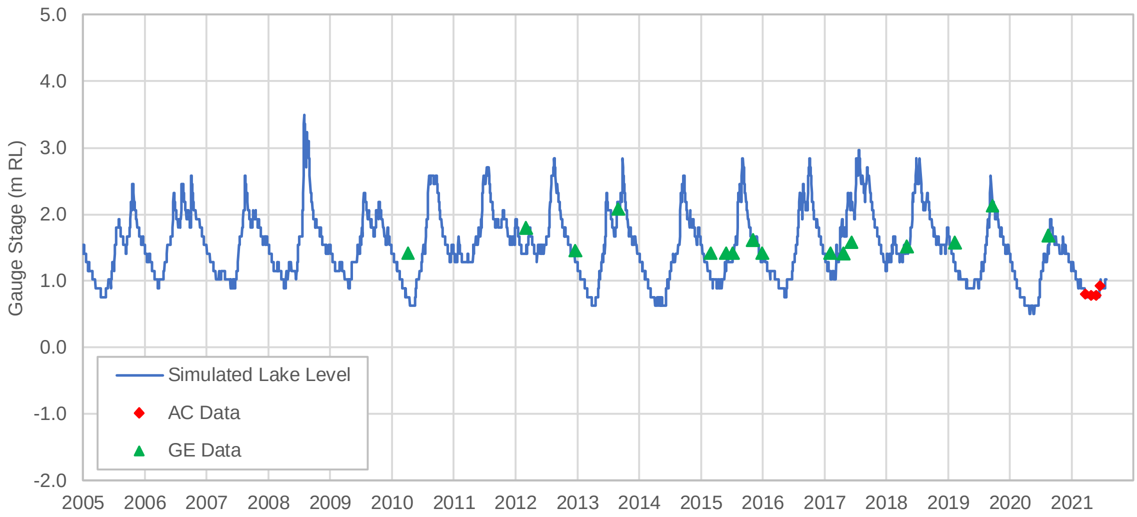

Figure 14. Simulated lake water levels with inclusion of groundwater seepage losses (complex seepage curve).

4.4 Lake Water Balance

In order to provide insight into the overall water balance of the lake, the annual average volume and flow rate of the various gains and losses were calculated from Scenario 3 (**Section 4.3.3**). The components of the water balance are presented in **Table 3**. This analysis shows that the largest gain (inflow) of water into the lake is via catchment inflows, primarily from the south, with significantly smaller contributions around the lake. The largest loss (outflow) from the lake is via seepage through the historic sand dunes, likely predominantly in a northward's direction towards the Ōkiritoto stream. These components of the water balance are illustrated on **Figure 16**.

Table 3. Lake water balance components.

Input / Loss	Water Balance Component	Annual Average (m^3/yr)	Average (L/s)	Percentage
Inputs	Rainfall	91,140	2.8	14%
	Catchment Inflows	556,726	17.7	86%
	TOTAL Inputs	647,866	20.5	
Losses	Evaporation	60,068	1.9	9%
	Loss Through Seepage	588,344	18.7	91%
	TOTAL Outputs	648,412	20.5	
Percent Discrepancy		0.08%	0.08%	

These findings are generally consistent with those concluded in the Auckland Regional Water Board (1980) study, which estimated an average seepage loss of 8.59 L/s during the summer of 1977/78, compared with 13 L/s calculated over the same period (summer 1977/78) from this study.

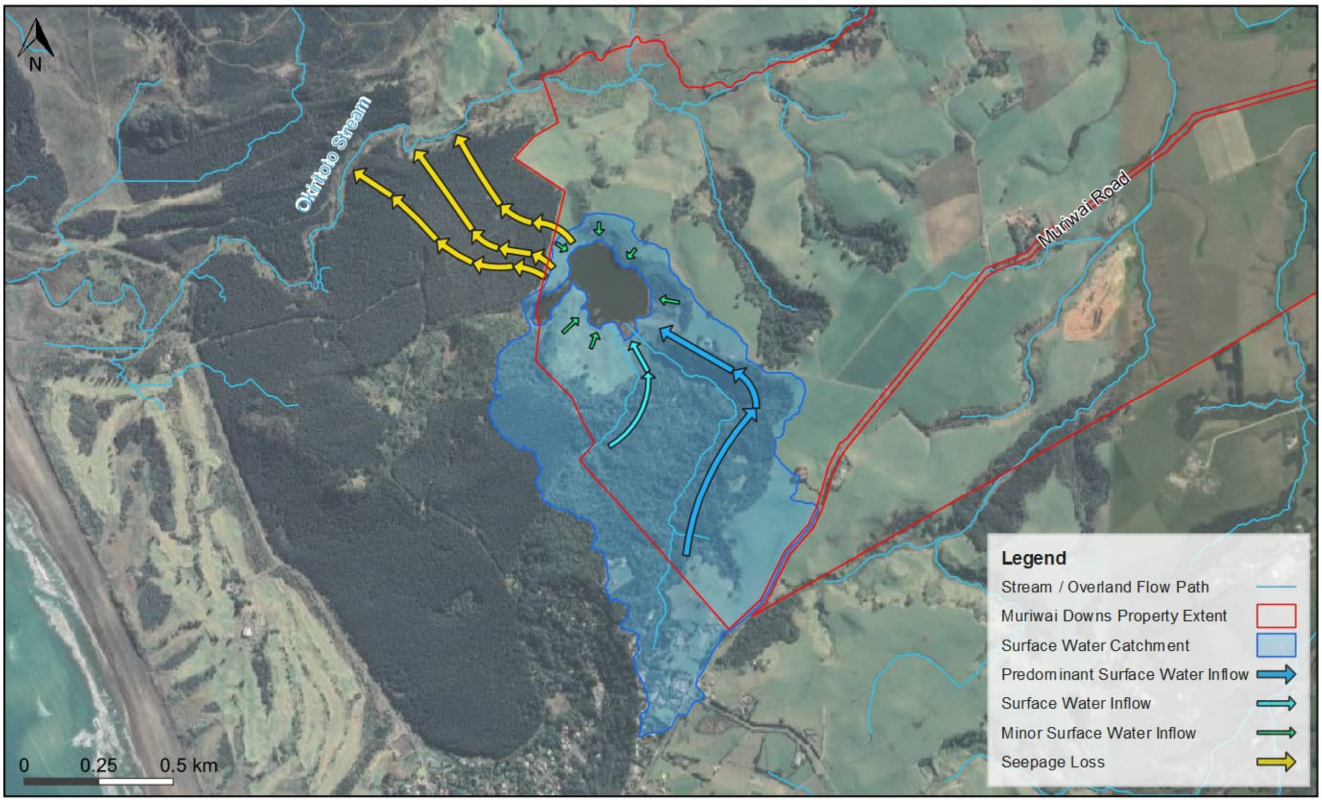

Figure 15. Predominant water balance components and directions.

Seepage loss and groundwater flow from the lake into the Ōkiritoto Stream to the north-west of the lake is also consistent with the general steady state groundwater flow paths simulated by the groundwater model (WWLA, 2021 – Appendix D, Section 7.2).

5. Site Investigations

Two shallow monitoring piezometers were constructed ten metres north of the northern edge of the lake on 29 September 2021 (**Figure 16**). The first piezometer was installed to a depth of 5.5 metres, and the second to a depth of 14.5 metres. The purpose of the piezometers was firstly to provide an understanding of below ground material and the identification of any vertical pressure gradients in groundwater levels, which could inform either groundwater seepage loss or inflow to the lake.

Figure 16. Lake Ōkaihau piezometer locations.

The bore log from the deeper piezometer is presented in **Figure 17**. The analysis of the deeper piezometer revealed the below ground material comprises predominately stratified fine sand and clayey sand to a depth of approximately 11.5 metres. Below this, the material comprises layers of clay to 14.5 m. The piezometers are located outside the lake margin, hence the lithology encountered is consistent with the conceptual model in that no well-defined lakebed substrate (lower permeability organic silt layer at current lake level) was encountered.

At the time of preparing this report, water levels had been dipped from the monitoring piezometers on one occasion (11 October 2021). The depth to water in the shallow piezometer was 3.75 metres below the top of the casing, and 4.26 metres below for the deeper piezometer. This demonstrates a strong downward gradient, suggesting perched water with steady leakage potential, in agreement with our conceptual understanding of the lake.

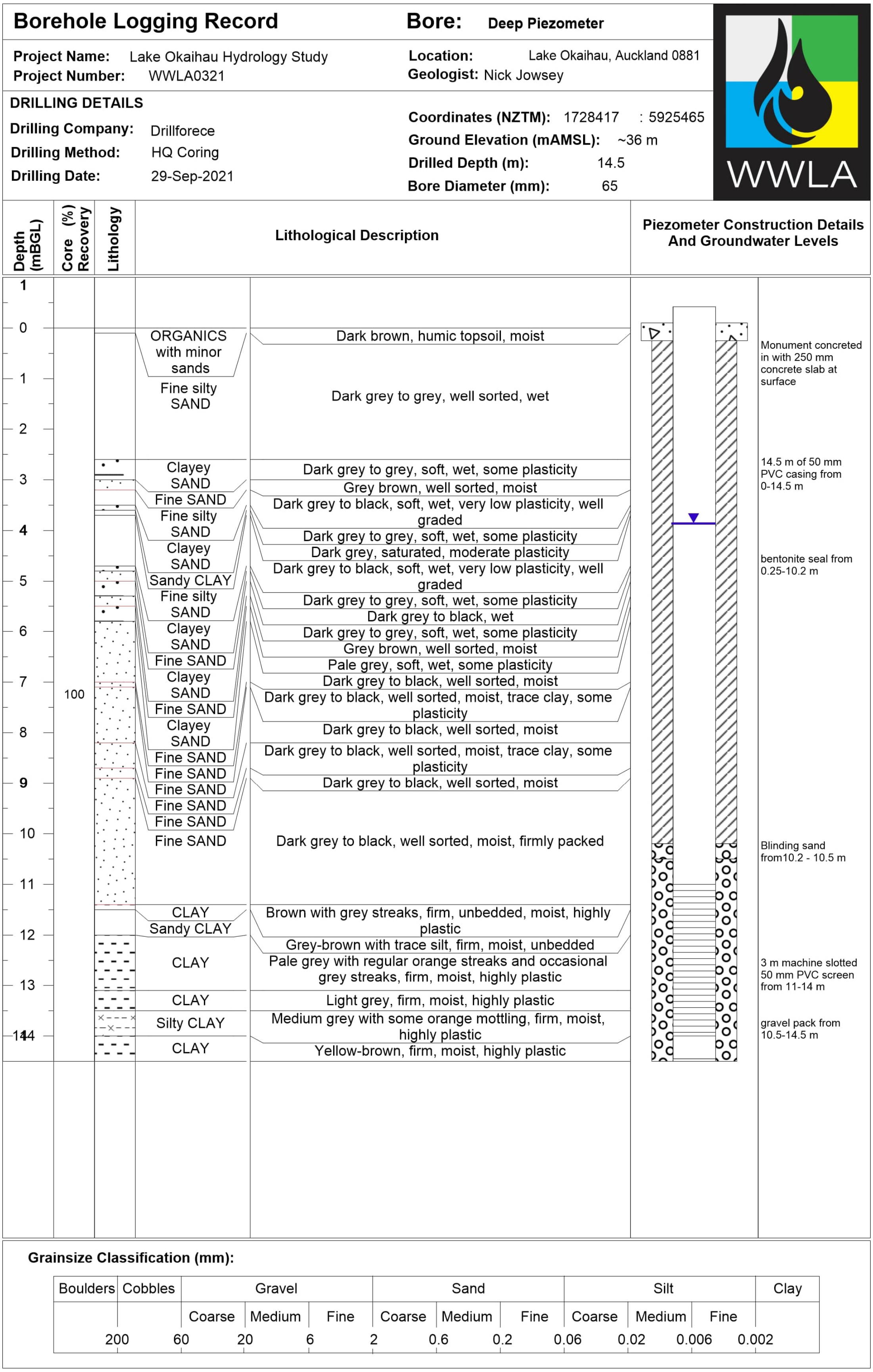

Figure 17. Piezometer core log.

6. Summary of Water Balance Study

The water balance model of Lake Ōkaihau balances inflows (catchment surface water runoff and rainfall) with losses (seepage losses and evaporation). The model was calibrated to recent measurements of lake water level collected by Auckland Council, and historic estimates from Google Earth satellite imagery.

The water balance study provided insight into the likely hydrological functioning of Lake Ōkaihau. Understanding the hydrological functioning of the lake is important as it provides knowledge of the proportional contribution of inputs such as rainfall and surface water inflow, and outflows such as evaporation and groundwater seepage. Understanding the relative importance of each of these processes enables potential impacts of the proposed development to be assessed.

The conceptual understanding, which was reinforced by the water balance model, is summarised as follows:

- The lake bed consists of low permeability material, that is thicker on the bottom, and pinches (i.e. thins) towards the margins of the lake;
- This results in low groundwater seepage loss from the lake during periods of low lake water levels (summer), and higher rates of seepage during periods of elevated water levels (winter);
- The largest inflow to the lake is from the stream catchment from the south; and
- The largest net loss from the lake is through groundwater seepage via the historic sand dunes to the north, towards the Ōkiritoto Stream.

The implications of this conceptual model with regards to the golf course development are that so long as the:

- upgradient catchment area remains unchanged; and
- the downgradient sand ridge is not deeply excavated or have deep (> 2 m) linear infrastructure installed (such as pipe trenches) that could potentially enhance seepage losses from the lake, the lake water balance will remain unchanged.

7. Assessment of Effects

The proposed golf course development in close proximity to Lake Ōkaihau is presented in **Figure 18**. It should be noted, additional infrastructure, such as the water storage reservoir, are located further afield outside of the frame of view in **Figure 18**. The proposed golf course development is planned for the northern side of the lake only.

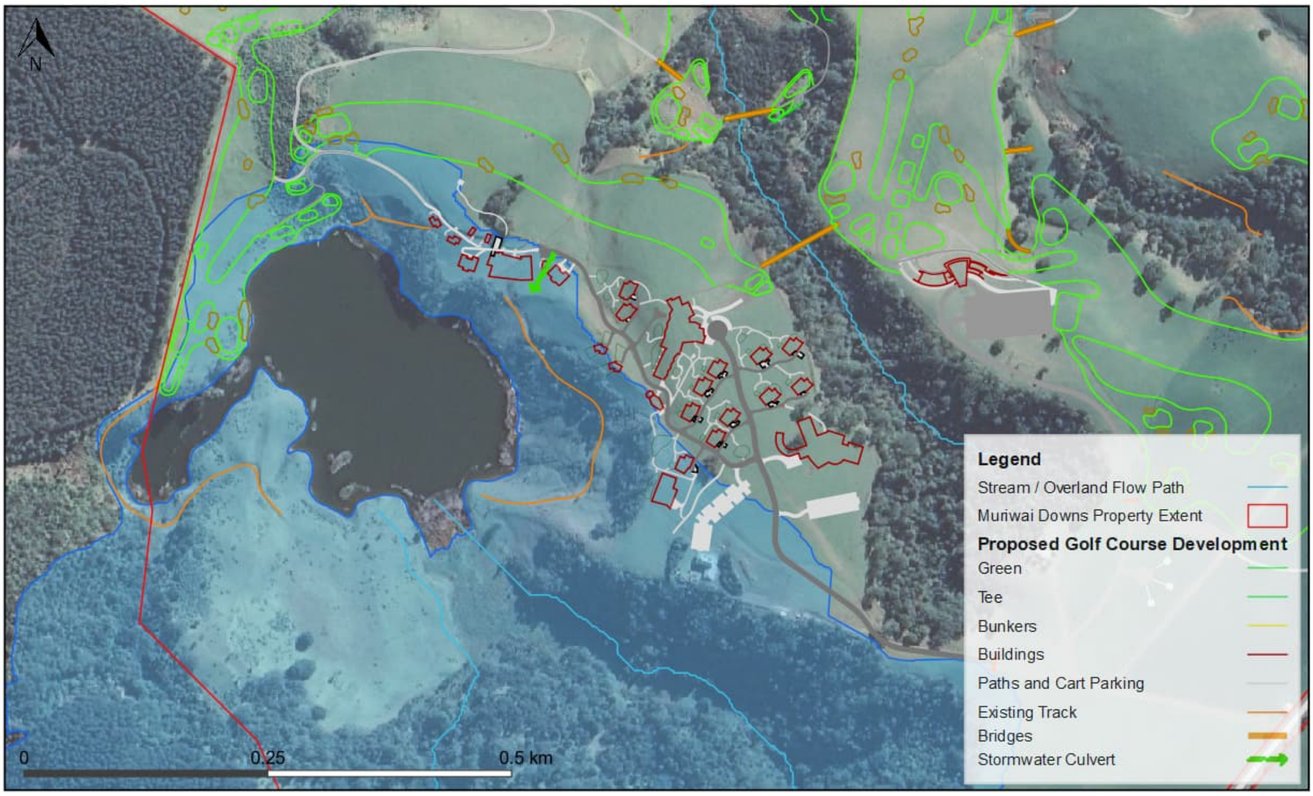

Figure 18. Proposed golf course area in proximity to Lake Ōkaihau.

7.1 Potential Effects on Lake Water Levels

The proposed golf course development could potentially affect water levels in Lake Ōkaihau through either earthworks resulting in changes to surface water inflows to the lake, or through earthworks resulting in changes to seepage losses from the lake. The potential for both of these impacts is discussed in turn below.

7.1.1 Potential Changes in Surface Water Inflows

The largest surface water inflow to the lake occurs from the south, with only minor components entering along the western, northern, and eastern margins (**Figure 15**). No earthworks or development are planned within the surface water catchment to the south of the lake, and therefore there will be no change in inflows on this side of the lake.

Figure 19 (prepared by WWLA[1]) presents the natural contours (current landform), and post-development site contours surrounding Lake Ōkaihau. Minor earthworks and recontouring associated with the development of golf course hole 2 are proposed along the northern margins of the lake. The proposed minor recontouring will

[1] Using post-development contours provided by McKenzie and Co.

maintain a gentle slope towards the lake similar to the present, and thus minor surface water runoff into the lake will still occur along the northern margins of the lake.

Only minor recontouring is proposed around the margins of the lake, and no changes (either development or land contouring) are proposed within the surface water catchment to the south of the lake, where the majority of surface water inflows are generated (**Figure 15** – predominant surface water inflow). On the basis that any changes in surface water inflows to the lake are unlikely, any actual or potential effects on surface water flows from the proposed development are also unlikely.

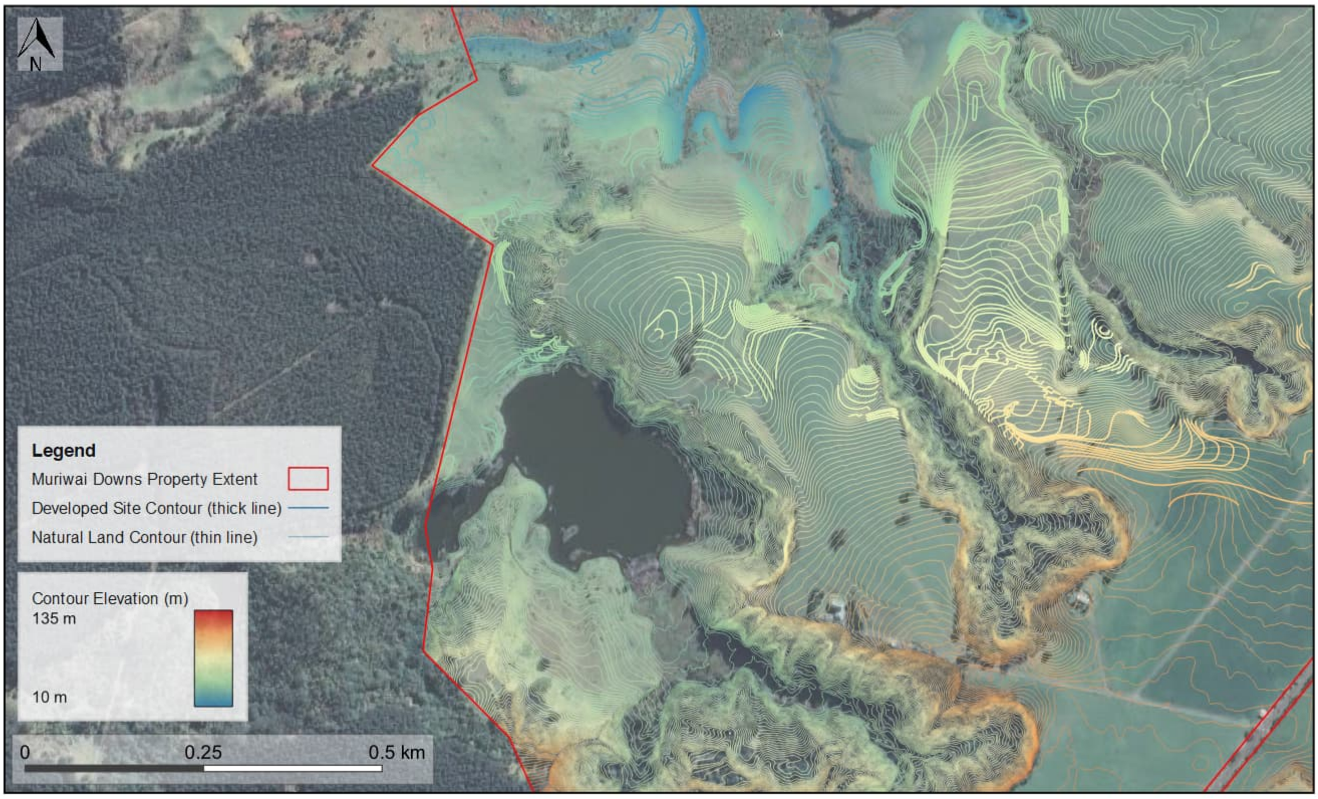

Figure 19. Proposed site grading in the vicinity of Lake **Ō**kaihau.

7.1.2 Potential Changes in Seepage Loss

A resource consent pre-application site visit was held between the applicant's core project team and Auckland Council on 22 June 2021. During this site visit, Auckland Council staff raised concerns that earthworks surrounding Lake Ōkaihau could potentially result in an increase in seepage loss from Lake Ōkaihau, ultimately resulting in a permanent reduction in lake water levels and thus lake extent.

The lake water balance assessment presented in this report in conjunction with groundwater piezometric surfaces (groundwater flow patterns) from the groundwater modelling study (WWLA, 2021 – **Appendix E**) reinforces the understanding that the lake loses groundwater via seepage in the general north-west direction.

Minor recontouring but no major excavation is planned along the northern margin of the lake, and additional flattening (infilling of a small depression in the current land surface) of the natural land surface approximately 200 metres further north (**Figure 19**). As the proposed works in the flow path of groundwater losses are surficial grading only and confined to recontouring the existing land-surface, they will not cause or exacerbate seepage loss from Lake Ōkaihau.

7.1.3 Actual Effects on lake water levels

As detailed in **Section 7.1.1**, and **Section 7.1.2**, the changes in surface water inflows, and groundwater seepage losses from Lake Ōkaihau will be no more than minor. Therefore, there will not be any change to natural lake water levels from the proposed development.

7.2 Effects on Lake Water Quality

As discussed above, the conceptual understanding is that the lake is predominately fed from surface water and rainfall, and balanced by groundwater seepage loss from the lake, north-westward towards the Ōkiritoto stream. This is also consistent with the findings of our recently completed groundwater modelling study (WWLA, 2021 – Appendix E). Therefore, the risk of nutrients leaching from the golf course development (e.g., from fertiliser), into the lake is considered low, with groundwater predominately flowing away from the lake on the northern western side of the lake.

A narrow margin of land along the north-western margins of the lake gently slopes down towards the lake, and therefore the lake will be subject to small contributions of surface runoff from this land during high intensity rainfall events, under both the current state and under the proposed golf course development. Therefore, sediment and nutrients (i.e., fertiliser) could runoff from this area, into the lake. Depending on the quantity of sediment or nutrients, this could result in a change in lake nutrient profile. It is noted that this area (parts of Hole 2 and Hole 3) represents less than 2% of the total surface water catchment to the lake.

Sediment-laden runoff entering the stream is considered a potential temporary effect during earthworks and construction. It will be important to ensure appropriate erosion and sediment control measures are in place when undertaking the gentle grading and earthworks proposed for this area. The Construction Environment Management Plan (AEE Report – Appendix 18) notes specific erosion sediment control methodologies will be prepared by the contractor specific to each works type and location and will be approved by the site engineer and regulatory monitoring representative. Once earthworks are complete, the modified land surface will be revegetated (grass). Accordingly, erosion and sediment-laden runoff are not considered a potential or actual effect post completion of construction of Holes 2 and 3.

The golfing area will be fertiliser as required to promote turf density and playing quality (AEE Report – Appendix 3). Surface water runoff could contain high concentrations of nitrogen and phosphorus if heavy rainfall occurred shortly after fertiliser was applied, or if excess fertiliser was applied. High concentrations of nitrogen and phosphorus could impact on the water quality of the lake. Provided best practice fertiliser application and management processes are followed (e.g. not applying fertiliser if heavy rain is forecast), the potential for fertiliser leaching or runoff to the lake is considered to be low. In addition, if fertiliser enriched runoff did occur during heavy rainfall, the proposed golfing area of Hole 2 and 3 represents less than 2% of the total surface water catchment, and thus runoff from the golfing area would be minor in comparison to total surface water runoff to the lake.

The remainder of the golfing area (outside of the surface water catchment) is located down gradient of the lake in terms of groundwater flow paths, and therefore the potential for nutrients leaching from the golfing area into the lake via groundwater is considered to be very low.

It is also noted that, at present, sheep occasionally graze the northern margins of the lake. Following construction of the proposed development, grazing will be excluded from this area. Therefore, the proposed development may result in a reduction in nutrients entering the lake (i.e., from urine patches and droppings). If so, the development could have a positive effect on the water quality of the lake.

Stormwater from the roads, and carpark on the ridge along the eastern margin of the lake will be discharged via a culvert into the lake at the location indicated on **Figure 18**. Full drawings of the stormwater network in this area are presented in McKenzie and Co 1976_Combined_Civil_Drawings – Drawing No. 1976-L1-400A (AEE Report – Appendix 5). The stormwater is proposed to be treated through a combination of raingardens and vegetated swale channels, and thus water quality effects associated with stormwater discharge to the lake are considered to be very low. Stormwater from the Lodge roof will be captured within the green roof of the Lodge, and stormwater from the roofs of the cottage units will be discharged via soakage to ground, and therefore this stormwater will not enter the lake. As such, there will be no effects on the lake as a result of stormwater from the Lodge and the Cottage units.

Furthermore, a significant portion of the lake's catchment (15.2 ha, 16%) will experience ecological restoration in the form of new forest and wetland planting. This will likely have a beneficial effect on lake water quality, with the expectation that water quality in the lake will steadily improve with time post the golf course development.

Changes in lake nutrient profile resulting from fertiliser (e.g. nitrogen and phosphorus) runoff and leaching are considered no more than minor.

7.2.1 Evaluation

Auckland Council currently undertake routine monthly water quality samples from the lake. It is recommended routine water quality sampling is maintained, particularly over the first two to five years of golf course operation, to confirm the assessment that the lake will not be subject to any water quality changes that differ to what has historically occurred.

7.3 Conclusion

In summary, the actual effects on Lake Ōkaihau associated with the proposed golf resort development are assessed as being no more than minor. There will be no change to the natural variation in lake water levels as the lakes surface water catchment remains unchanged, and the proposed earthworks to the north of the lake are surficial only, they will not cause or exacerbate seepage loss from the lake. Similarly, water quality effects associated with stormwater discharges and nutrient runoff or leaching from the lake are considered to be very low.

8. References

Auckland Regional Water Board. 1980. Okiritoto Catchment Water Resources Survey Water Allocation Plan.

Cunningham, B. T., Moar, N. T., Torrie, A. W., & Parr, P. J. 1953. A survey of the western coastal dune lakes of the North Island, New Zealand. Australian Journal of Marine and Freshwater Research 4(2) 343-386.

WWLA. 2021. Muriwai Golf Project - Water Effects Summary Report. Report prepared for the Bears Home Project Management Limited.