Lake Wahakari

MANAGEMENT PLAN

Northland
REGIONAL COUNCIL

CONTENTS

LAKE WAHAKARI MANAGEMENT PLAN

1. PURPOSE

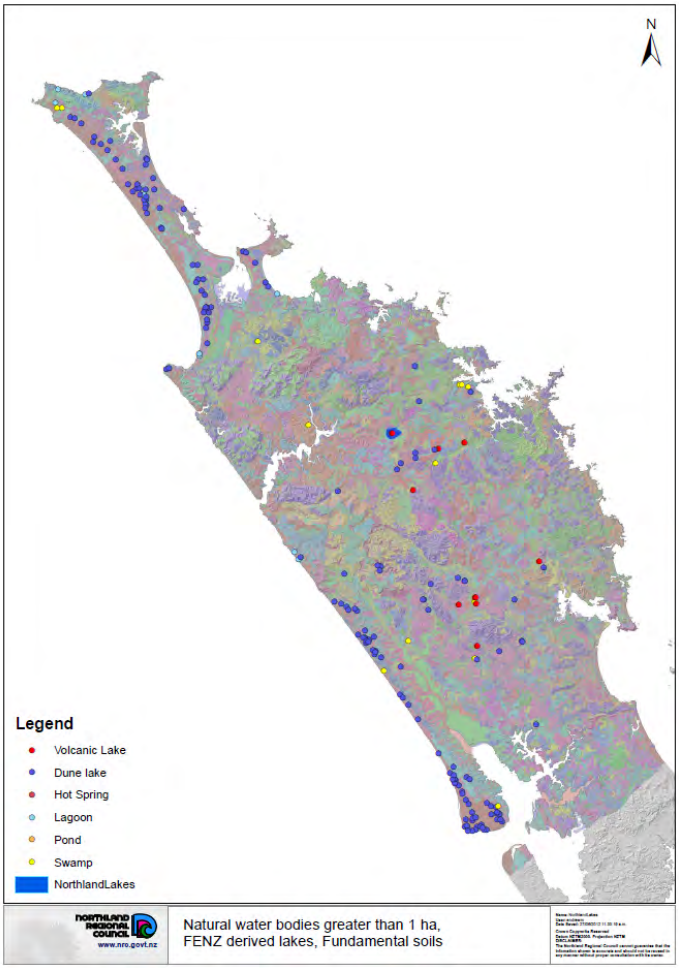
The purpose of the Outstanding Northland Dune Lakes Management Plans is to implement the recommendations of the Northland Lakes Strategy Part II (NIWA 2014) by producing Lakes Management Plans, starting with the 12 'Outstanding' value lakes, and by facilitating actions with mana whenua iwi, landowners and other stakeholders in the lake catchments to deliver priority work which will protect water quality and mitigate current pressures.

2. INTRODUCTION

The following text is taken directly from the Northland Lakes Strategy. Northland dune lakes and their associated wetlands are of national and international significance. These lakes, most of which have been formed between stabilised sand dunes along the west coast, represent a large proportion of warm, lowland lakes in New Zealand which still have relatively good water quality and high ecological values.

The outstanding dune lakes are grouped on the Aupouri, including Sweetwater, Karikari and Pōuto Peninsulas and the Kai Iwi group North of Dargaville.

The lakes vary in size, with the majority being between 5 and 35 hectares in area and generally less than 15 metres deep. Lake Taharoa of the Kai Iwi Group is one of the largest and deepest dune lakes in the country, covering an area of 211.07 hectares and being 38.81 metres deep. Lake Taharoa also has the deepest recorded submerged vegetation of any lake in the North Island, to 24 metres.



The dune lakes generally have little or no continuous surface inflows or outflows, being primarily fed by rainfall directly onto their surfaces and surrounding wetlands. As a result, their levels fluctuate considerably with climatic patterns. As most of the lakes are relatively small and shallow, they have limited capacity to assimilate any contaminants. They are prone to nutrient enrichment from stock and fertiliser, particularly where lakeside vegetation has been grazed or removed, and where there is direct stock access to the lake. Further effects on the lakes result from forestry fertilisation, sediment mobilisation during harvest and water budget dynamics.

These lake and wetland ecosystems are important habitats for a wide variety of plant and animal species, some of which are regionally or nationally significant because of their rarity. These include birds such as the pateke/brown teal, banded rail, New Zealand dabchick, marsh crake, fern bird and Australasian bittern, the aquatic plants *Hydatella inconspicua* and *Myriophyllum robustum* and native freshwater fish including the giant kokopu, banded kokopu, short jawed kokopu, inanga, dwarf inanga and dune lakes galaxias.

The most outstanding characteristic of these lakes is the limited impact of invasive species on their biota, which is unparalleled elsewhere on mainland New Zealand. Despite these values, the status of these lakes is not secure and the overall trend has been gradual deterioration.

Northland Regional Council monitors water quality quarterly in 26 dune lakes and undertakes ecological monitoring, along with NIWA, for ~90 dune lakes on an annual rolling basis. Annual weed surveillance is undertaken at high value lakes with public access. Threats and pressures include biosecurity (aquatic weeds, pest fish and the risk of invasion and spread), eutrophication from surrounding land use for farming and forestry, occurrence of algal blooms and water level fluctuations, especially dropping lake levels. Natural events such as summer droughts and high rainfall events place further pressure on these lakes.

Recreational and commercial activities on or around some of the lakes can affect water quality, lake ecology and increases the risk of introduction of pest weeds and fish.

The Northland Lakes Strategy (NIWA 2012) presents a classification and ranking system for Northland lakes including assessment of ecological values and lake pressures and threats. The 12 highest ranked lakes from north to south are:

Outstanding (12)

- Lakes - Wahakari, Morehurehu, Waihopo, Ngatu, Waiporohita, Waikare, Kai iwi, Taharoa, Humuhumu, Kanono, Rotokawau and Mokeno

Northland Lakes Strategy (NIWA 2012, 2014) recommends that individual lake management plans should be developed for each high value lake. This would include:

- Descriptions of each lake and lake catchment
- Outline of lake values and significance (including ecological and social)
- List of agencies and individuals involved in management
- Communications plan
- Monitoring plan
- Identification of gaps in knowledge/research plan
- Current threats and pressures
- Management actions to mitigate or ameliorate threats and pressures
- Work implementation plan

Key principals of lake management are:

- Balance between protection and utilization
- Managing the environmental quality of the catchment, in particular water quality
- Integrated management of habitat and species (including pests)
- Monitoring as a key environmental management tool

The plan takes the approach of presenting robust information on all aspects of the lakes. This includes social and cultural, physical, chemical and biological summaries of information not generally available to the public in a condensed format. This data is the best available at the time of writing and does not represent peer-reviewed science in the sense that errors may be inherent in the raw data and presence and absence of species changes over time. Yet it offers trends for further discussion among partners involved in protection and restoration activities. The plan goes on to scope required work for the mitigation of threats and offers a communication strategy to implement this work.

2.1. Geographic Lake Groupings

The outstanding dune lakes within these plans all sit within two broad ecological districts; Aupouri and Kaipara. Within these two districts there are further geographical associations of lakes, especially relevant to biosecurity species spread.

Within the Aupouri group, there are three lakes situated near Parengarenga and Houhora Harbours on the narrow Aupouri Peninsula (Lakes Wahakari, Morehurehu and Waihopo).

At the base of the Aupouri peninsula, another cluster of lakes form the west coast Sweetwater group and Lake Ngatu is the only outstanding lake in this area. To the east, on the Karikari Peninsula, Lake Waiporohita is found.

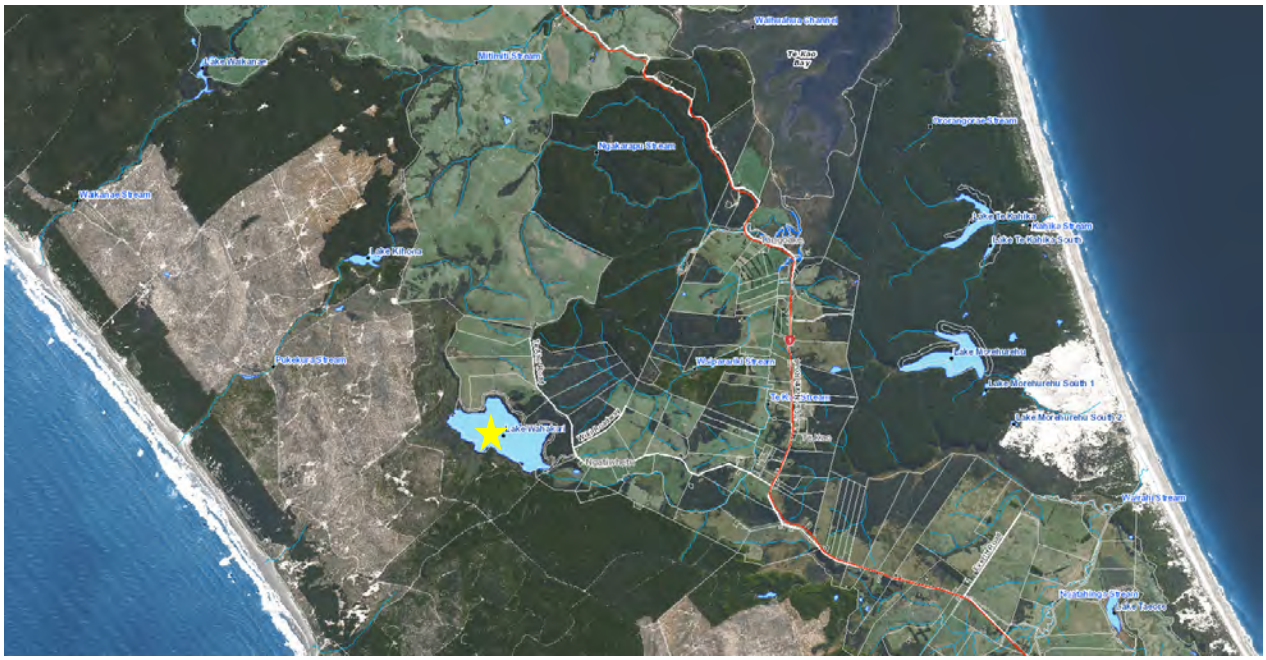
Further south within Northland, on the west coast north of Dargaville, are the three Kai Iwi Lakes (Lake Kai Iwi itself, and Lakes Taharoa and Waikare, sometimes referred to as Waikere).

Finally, four outstanding lakes on the Pōuto Peninsula, on the north head of the Kaipara Harbour, round out the final twelves lakes of covered in the Outstanding dune lake plans. These include the west Pōuto Lake Mokeno and the east Pōuto lakes Humuhumu, Kanono and Rotokawau (Pōuto).

Most lake names come from te reo Māori and, therefore, some names refer to several lakes around Northland. Rotokawau is a name given to several lakes, with one in Pōuto, two in Karikari and one in Sweetwater. Additionally, the word "kawau" means the waterbird shag or cormorant and two additional lakes are also called Shag Lake. To avoid confusion, lakes sharing a name are further referred to with their sub-regional area following in parentheses.

LINZ topographic maps do not legally name every freshwater body. Therefore, for the purposes of the lake plans, additional common lake names are used which are the same as those used in the NIWA ecological surveys. These may not be the same as traditional names used by iwi, which are yet to be known by the NRC. NRC will endeavour to consult with mana whenua iwi on their preferred traditional names for each lake.

3. LAKE LOCATION MAP



4. LAKE OVERVIEW

Lake Wahakari (NRC Lake Number 35) is a deep, 90.19 ha (12.7 m max and 6.04 m mean depth) dune lake with a single south-central basin, with the western end of the lake being shallower. It is located west of Te Kao and Route 1, off Ngatiwhetu Road on the Northern Aupōuri Peninsula in Far North Northland. The lake is classified as a Class 1 Perched dune lake (Timms, 1982), meaning it sits above the water table.

The lake is situated in a catchment dominated by exotic pine forest, high producing grassland, manuka/kanuka scrub and freshwater sedgeland/rushland. The surface area of the lake is 90.19 ha and the NRC-defined catchment area, including the lake, is 809.7 hectares. Wahakari has major wetland associations including a multi-armed branching system to the north, the margins of which are unfenced and affected by stock access, as well as a fringing wetland mostly to the south-west.

Wahakari is the only lake of the twelve outstanding dune lakes to have little water quality data available, with only four seasonal samples available covering a 12-month period.

The lake does not stratify thermally nor become oxygen-depleted at depth, although the data only represents a single summer, so may not be truly representative. The pH trend is slightly alkaline for three samples and slightly acidic for the winter sample.

Wahakari is an oligotrophic lake, meaning it has good water quality. The Trophic Level Index is most influenced by nitrogen, followed by water clarity (Secchi), with the influence of phosphorus and chlorophyll-a being lower. There is no data available on lake level. A staff gauge is due to be installed. The lake has an estimated water residence time of just under 13 months.

The most relevant factor from a human perspective is that this lake is the water source for the Te Kao community, so maintenance of good water quality is essential. Much of the catchment remains unfenced along the wetland edge and along the lakefront, allowing stock access.

The lake hosts 25 native aquatic plants, the second highest diversity of any lake on Aupōuri Peninsula apart from Morehurehu, and three exotic non-invasive plants; the bladderwort *Utricularia gibba*, bulbous rush and the water starwort, *Ludwigia palustris*. There are three rare submerged native plants present; Isolepis fluitans, *Myriophyllum votschii*, and *Utricularia australis*.

The Invasive Impact Index has seen a sharp rise with a corresponding fall in Native Condition Index and Submerged Plant Index due to the invasion and spread of *Utricularia gibba*. The lake has seen a gradual displacement of charophyte meadows with the native *Potamogeton ochreatus*, which then later declined. P. ochreatus favours a high level of fertility, so it likely reacted to the influence of nitrogen. Maximum depth of plants also declined. Water quality decline will be a factor.

Gambusia are present as a pest fish species, the only lake where it is found on the Peninsula north of Lakes Katavich and Waiparera. Land-locked smelt are an interesting native fish species present.

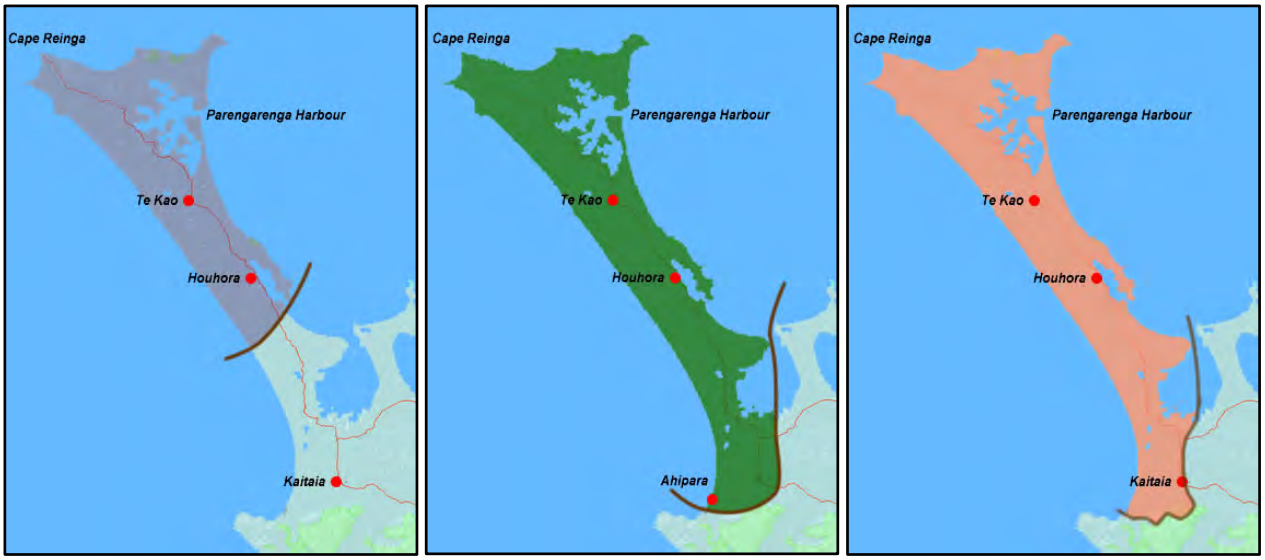
The lake has a moderate level of bird diversity. Canada geese (*Branta canadensis*) are found at the lake and pose a threat to water quality due to over-nutrification when number grow.

5. SOCIAL AND CULTURAL DIMENSION

5.1. Mana whenua

Three mana whenua groups have rohe whenua Area of Interest in the area of Lake Wahakari; Ngāti Kurī (grey), Ngāi Takoto (green) and Te Aupōuri (pink). The lake is a specific Area of Interest for Te Aupōuri. The lake bed is owned by the agriculture and forestry company of Te Aupōuri.

Rohe whenua is displayed in the diagram below and was sourced from Te Puni Kōkiri's Te Kahui Mangai web pages (www.tpk.govt.nz).



5.2. Land Tenure

5.2.1 Catchment landowners and Lake bed owners

Seven landowners own 13 parcels of land within the lake catchment. The lake bed is owned by the agriculture and forestry company of Te Aupōuri.

5.3. Community involvement

Conservation efforts are being planned for the lake are through the Ministry for the Environment's Te Mana o Te Wai fund. This programme is setting up youth training and education in riparian management, including fencing and planting.

5.4. Public use

5.4.1. Access

Accessed from Te Ahu Road via a rough gravel track and locked gate.

5.4.2. Boating

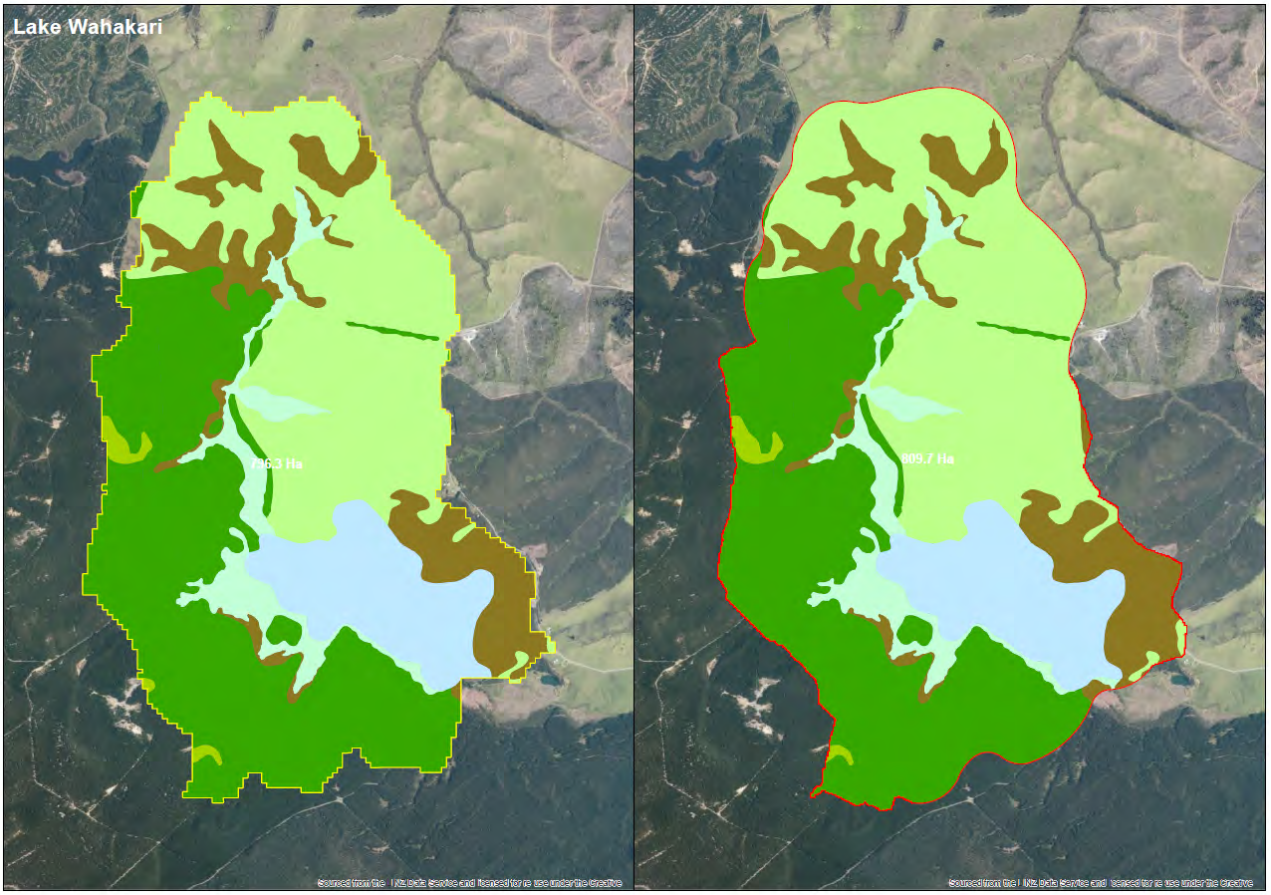
5.4.2.1. Boat access

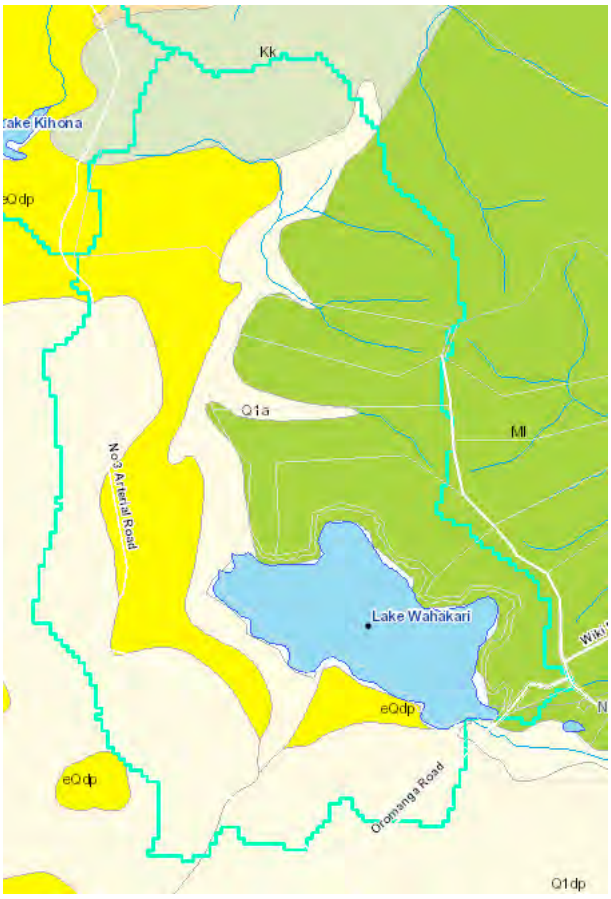
Access by boat is difficult from the north, but the southern end of the lake has new access for boats and waka ama.

6. PHYSICAL CHARACTERISTICS

6.1. Catchment Area with Map

The following image shows the extent of the lake catchment. The FENZ boundary is on the left and a rationalised boundary created by NRC staff is on the right. The NRC-defined catchment area, including the lake itself, is 809.7 hectares.



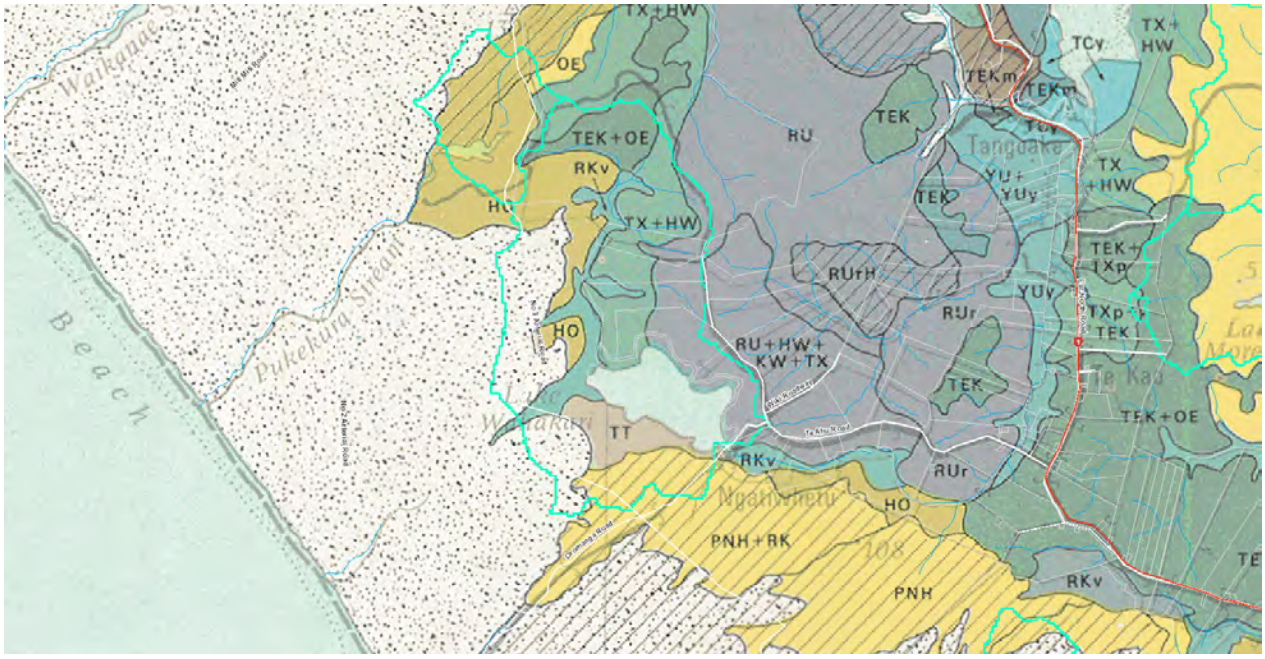


6.2. Catchment Geology and soil types

The following map ((C) GNS Science 2016) of the Aupōuri Peninsula and table below it shows the geological history of the lake catchment. The base geology is predominantly basalt pillow lava of the Tangihua Complex on the north and weakly cemented and uncemented Early Quaternary dune to the south with the catchment continuing into poorly consolidated sands of Late Quaternary dune to the west.

Lake Name/Plot Symbol	eQd	KtA	KkA
Wahakari	x	x	x
Name	Early Quaternary dunes	Tangihua Complex	Mangakahia Complex
Description	Weakly cemented and uncemented dune sand and associated facies. Clay-rich sandy soil. These dunes arose during higher sea level 12,000 years ago and earler.	Basalt pillow lava and sheet flows with subvolcanic intrusive basalt, dolerite and gabbro; local serpentinised peridotite and minor intercalated mudstone and limestone.	Structurally complex units of tectonically intercalated micaceous sandstone and mudstone, siliceous mudstone and minor micritic limestone.
Geologic history	Early Quaternary	Cretaceous to Early Oligocene	Late Cretaceous to Early Eocene
Simple name	Zealandia Megasequence Terrestrial and Shallow Marine Sedimentary Rocks (Neogene)	Zealandia Megasequence Allochthonous Rocks	Zealandia Megasequence Allochthonous Rocks
Absolute minimum age (millions of years before present)	0.78	28.1	47.8
Absolute maximum age (millions of years before present)	2.6	145	100.5
Supergroup equivalent stratigraphic name	Pakihi Supergroup	Momotu Supergroup, Haerenga Supergroup, Ruaumoko Volcanic Region	Haerenga Supergroup
Terrane equivalent name		Northland Allochthon	Northland Allochthon
Lithology	sand	basalt, dolerite, gabbro, peridotite, mudstone, limestone	sandstone, mudstone, limestone

The catchment features a truly complex soil mosaic, unrivalled by any other dune lake in Northland, consisting of Tangitiki sandy loam (TT) podzols to the south, Ruakaka peaty silt loam organic soils (RKv) to the west and east and a mix of Te Hapūa fine sandy loam podzols (TX) and Hurewai fine sandy loam (HW) podsols to the west, with a mix of Rangiuru clay (RU), Huruwai fine sandy loam (HW) loam, Kapowairua clay and silty clay (KW) and Te Hapūa fine sandy loam podzols (TX) to the north.



Soil Symbol	Genetic soil group	Geological origin	Suite	Subgroup	Series	Soil name	Description
TEK	Podzols	Soils of Lower Quaternary terraces and dunes	Pinaki		Te Kopuru	Te Kopuru sand (podzols)	**Te Kopuru series** – the most mature of the soils on dune sands and old sand terraces, a podzol with a dense, cemented silica sand pan. An iron pan may or may not be obvious below the silica pan.
RK	Organic soils		Ruakaka		Ruakaka	Ruakaka peaty sand loam	**Ruakaka peaty sand loam** (**RK**) is found throughout Northland (except around the Kaipara where there is PZ) in what were swampy basins adjoining dunes, for example, in inter-dune swamps and the fringes of peaty sand plains. A representative profile of this low to very low fertility soil would have 150 mm of black fine sandy peaty loam, on 450 mm of black to reddish brown fine sandy peaty loam, on black loamy peat, which will contain wood fragments. There may well be ash layers where the swamp has been burnt and then peat has developed on top.
HW	Podzolised yellow-brown earth soils		Omania	Weakly to moderately podzolised	Hurewai	Hurewai fine sandy loam	Kapowairua clay and silty clay (KW & KWH), a strongly leached to moderately podzolised member of the suite which has developed on interbedded sandstone and mudstone around Parengarenga Harbour, usually in a mosaic with **Hurewai fine sandy loam** (**HW** & HWH), a more mature, weakly to moderately podzolised soil. These soils have been overlain or influenced by dune sand and by podzolisation of that sand, adding Te Hapua fine sandy loam (TX a podzol in the Pinaki Suite) to the mosaic. These are low fertility soils, prone to gully erosion and to mass movement.
KW	Yellow-brown earth soils		Omania	Strongly leached to weakly podzolised	Kapowairua	Kapowairua clay and silty clay	**Kapowairua clay and silty clay** (**KW** & KWH), a strongly leached to moderately podzolised member of the suite which has developed on interbedded sandstone and mudstone around Parengarenga Harbour, usually in a mosaic with Hurewai fine sandy loam (HW & HWH), a more mature, weakly to moderately podzolised soil. These soils have been overlain or influenced by dune sand and by podzolisation of that sand, adding Te Hapua fine sandy loam (TX a podzol in the Pinaki Suite) to the mosaic. These are low fertility soils, prone to gully erosion and to mass movement.
HO	Yellow-brown sands	Sands of Upper Quaternary dune series	Pinaki	Moderately to strongly leached	Houhora	Hourhora sand	**Houhora series** – on older west coast dunes, more mature than Pinaki series, having more soil development, more organic matter and stronger structure. Can have iron cementing but generally iron content is a much lower than Red Hill series. [Either developed on sand from a separate source – (Central North Island rhyolitic/feldspathic sand rather than Taranaki iron sands) or the iron had settled out before this sand reached the Aupouri Peninsula.] A typical profile of Houhora sand (HO & HOH) may include: 80 to 150 mm of very dark greyish brown to olive brown loamy sand, on 80 to 150 mm of yellowish brown to pale brown sand, on brownish yellow to strong brown loamy sand.
OE	Yellow-brown sands	Soils of Lower Quaternary terraces and dunes	Pinaki	Strongly leached to podzolised	Ohia	Ohia sand	**Ohia series** – These are soils formed on old lake beds and other fresh water-sorted sands along the eastern side of the Aupouri and Karikari Peninsulas. They tend to have a finer texture than the marine or estuarine sorted sands found on broad ridge tops and terraces. They are heavily podzolised and, in many places, severely eroded, leaving only remnants of the former profile.

Soil Symbol	Genetic soil group	Geological origin	Suite	Subgroup	Series	Soil name	Description
PNH	Yellow-brown sands	Soils of Holocene sands and sand flats	Pinaki	Weakly to moderately leached	Pinaki	Pinaki sand	**Pinaki series - Pinaki sand** (**PN** & **PNH**), the youngest soil in the suite, is found on rolling, stabile former dunes inland of the loose sand along the west coast. Its natural vegetation is sand grasses and scrub. A typical profile would have: 0 to 150 mm of black to very dark grey brown fine to medium sand, on 150 mm dark grey brown to very dark brown fine sand, on light olive brown to light yellowish brown medium sand.
TT	Podzolised yellow-brown earths	Soils of Lower Quaternary terraces and dunes	Pinaki	Weakly to moderately podzolised	Tangitiki	Tangitiki sandy loam	Tangitiki series – usually rolling to steep with some very steep escarpments. Is usually a mosaic of more or less podzolised soils determined by slope and the presence or absence of kauri. Soils brownish with a relatively shallow topsoil. A typical profile of **Tangitiki sandy loam (TT & TTH)** may include: 90 to 150 mm of very dark grey to greyish brown loamy sand, on 100 to 200 mm of pale brown to yellowish brown sandy loam to loamy sand, on 300 to 350 mm of yellowish brown to light yellowish brown sandy loam, over a 250 to 350 mm cemented brownish yellow with grey veins and mottled sandy loam. This overlies brownish yellow, strongly consolidated weathered sands.
TX	Podzols	Soils of Holocene sands and sand flats	Pinaki		Te Hapua	Te Hapua fine sandy loam (a podzol)	Kapowairua clay and silty clay (KW & KWH), a strongly leached to moderately podzolised member of the suite which has developed on interbedded sandstone and mudstone around Parengarenga Harbour, usually in a mosaic with Hurewai fine sandy loam (HW & HWH), a more mature, weakly to moderately podzolised soil. These soils have been overlain or influenced by dune sand and by podzolisation of that sand, adding **Te Hapua fine sandy loam** (**TX a podzol in the Pinaki Suite**) to the mosaic. These are low fertility soils, prone to gully erosion and to mass movement.
RKv	Organic soils		Ruakaka		Ruakaka	Ruakaka peaty silt loam	**Ruakaka fine sandy peat** (**RKu**), **Ruakaka loamy peat** (**RKd**), **Ruakaka peaty silt loam** (**RKv**) and **Ruakaka peaty fine sandy loam** (**RKl**) all variants of these Ruakaka soils, reflecting more or less sand, and sand blown and/or washed from difference sources, some already podzolised. The comments for RK above and the general comments on organic soils above apply equally to these soils.
RU	Brown granular loams and clays		Te Kie	Strongly to very strongly leached	Rangiuru	Rangiuru clay	Rangiuru red and brown clay (RUr & RUrH) and **Rangiuru clay** (**RU** & RUH) are strongly to very strongly leached Brown Granular Clays, the first developed on older (?), perhaps more basaltic parts of the Tangihua volcanics of the northern part of the Aupouri Peninsula and near Te Kao. There are extensive areas of Rangiuru clay within the Mangonui Harbour catchment, helping to explain the discolouration that occurs after heavy rain. These soils are very deeply leached and weathered, even more so than the Waimatenui soils. A general profile description will include 100 mm of grey-brown granular clay, on light-brown strongly granular clay, in places a greenish sticky granular clay. There are elevated concentrations of aluminium in the low pH subsoils, severely restricting root penetration, making trees and grass more susceptible to droughts. These soils are seriously phosphate deficient and, with the root-penetration restrictions described above, are generally unsuited to production forestry.

6.3. Catchment Hydrogeology

Although the Aupōuri sands hold an extensive groundwater aquifer, Class 1 Perched dune lakes such as Wahakari sit above the water table.

6.4. Catchment drainage and sedimentation rates

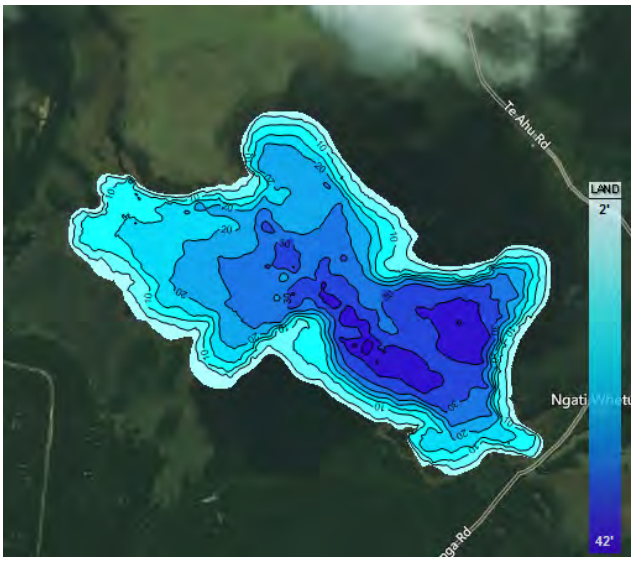
The NRC-defined catchment area, including the lake itself, is 809.7 hectares and produces a mean annual flow, based on hydrological models, of 3,162,150.7 m³/year. The lake has an estimated lake residence time of 1.062 years, meaning any water entering the lake will remain for just under 13 months. The average particle size of surface rock in the catchment is 2.32 on a scale of 5, a value of 1 being sand (all data from FENZ database).

6.5. Geomorphology - Lake type and origin, area, depth, volume

In common with other dune lakes on the Aupōuri Peninsula (Katavich, Yelavich, Waiparera, Waihopo, Salt, Te Arai, Taeore, Morehurehu South 1, Te Kahika South, and Waipara), Wahakari is a Class 1 Perched dune lake. The lake has a maximum depth of 12.7 m with a mean overall depth of 6.04 m. The surface area of the lake is 90.19 hectares with a volume of 5,556,780.50 m³. The NRC-defined catchment area, including the lake itself, is 809.7 hectares.

6.6. Bathymetry map

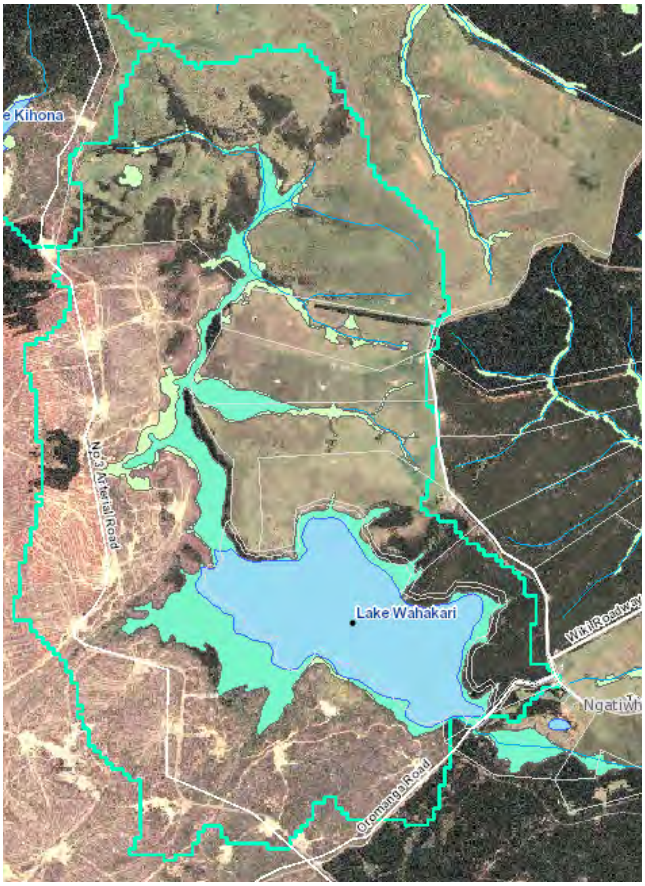
The adjacent bathymetric depth map comes from a survey done by NIWA for the NRC. Wahakari's deepest point is the south-central, 12.7 m basin with the western end of the lake being shallower.
Please note that the scale of this map is in feet, not meters.



6.7. Natural inlets and outlets

A natural inlet enters the lake from the north-west from a three km long arm of wetland most likely a fen of intermediate fertility.

A natural outlet, Te Kao Stream, flows from the lake to the south-east, through a raupo swamp and out to Parengarenga Harbour.



6.8. Wetland associations

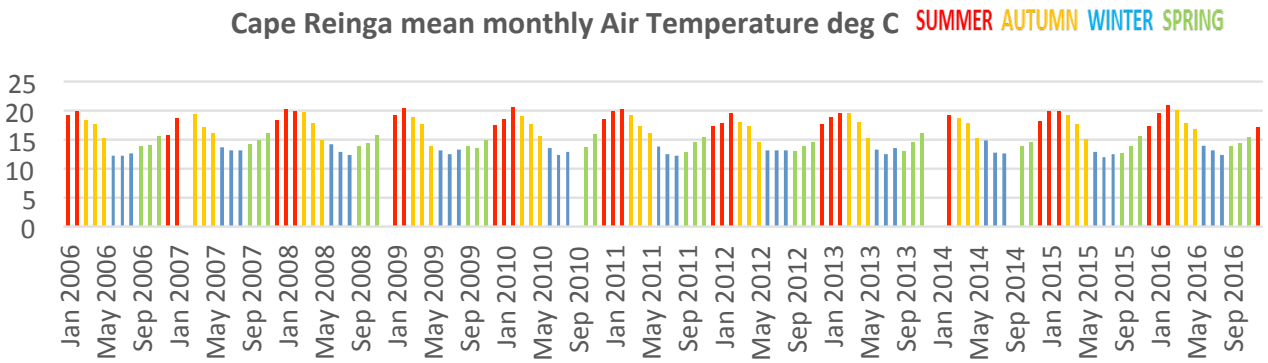
Wahakari has major wetland associations including a multi-armed branching system to the north which is partially unfenced, allowing stock access, as well as a fringing wetland, most prominent in the south-west. This wetland system is a "Top 150" wetland ranked as the 59th most important wetland in the region.

6.9. Connectivity

The lake is not connected to other waterbodies.

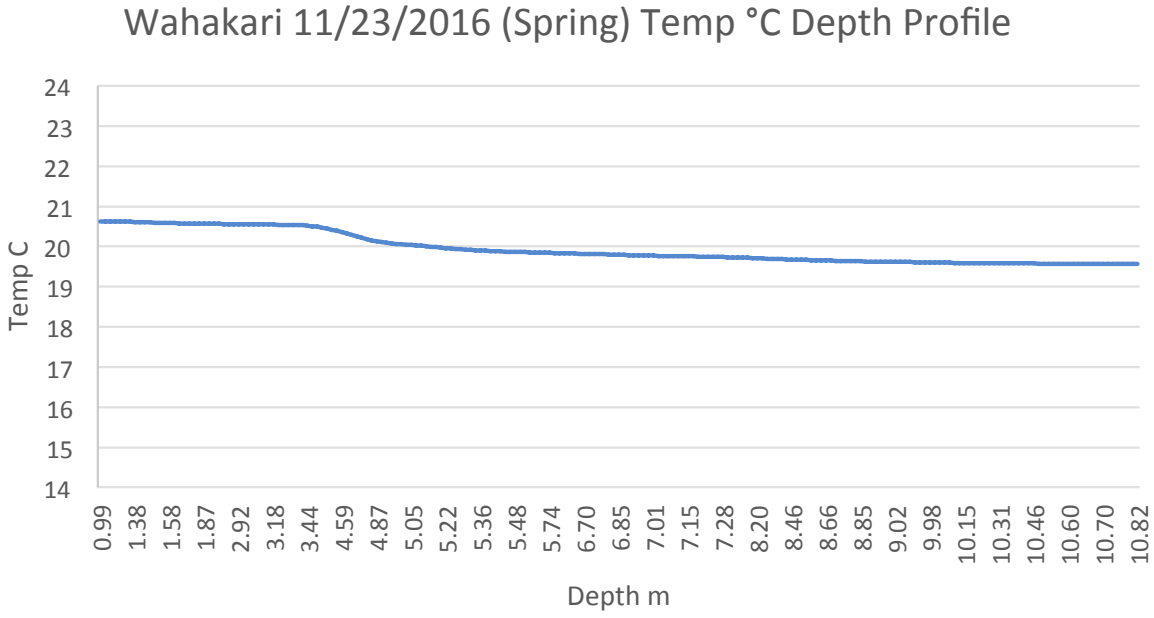
6.10. Air Temperature

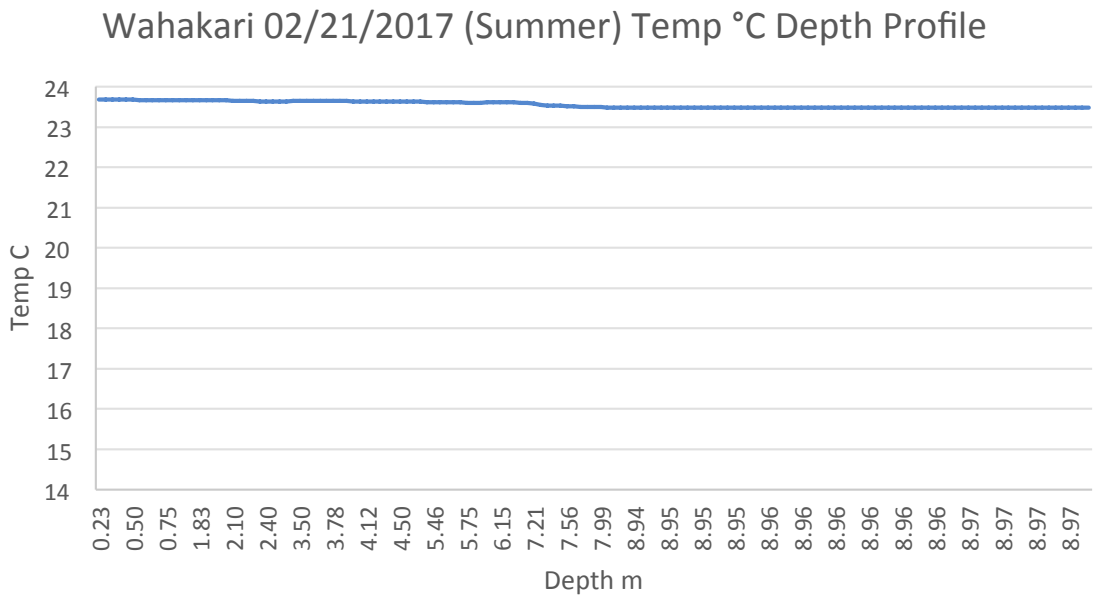
Cape Reinga air temperature recordings are used as a proxy.



6.11. Thermal stratification

Wahakari does not thermally stratify during any season, based on very limited information. This means that nutrients are more readily available throughout the water column for phytoplankton growth due to wind mixing. Summer maximum water temperature is 23.68 degrees C and the winter low is 14.475 degrees C.




Wahakari 02/21/2017 (Summer) Temp °C Depth Profile
Temp C
24
23
22
21
20
19
18
17
16
15
14
0.23
0.50
0.75
1.83
2.10
2.40
3.50
3.78
4.12
4.50
5.46
5.75
6.15
7.21
7.56
7.99
8.94
8.95
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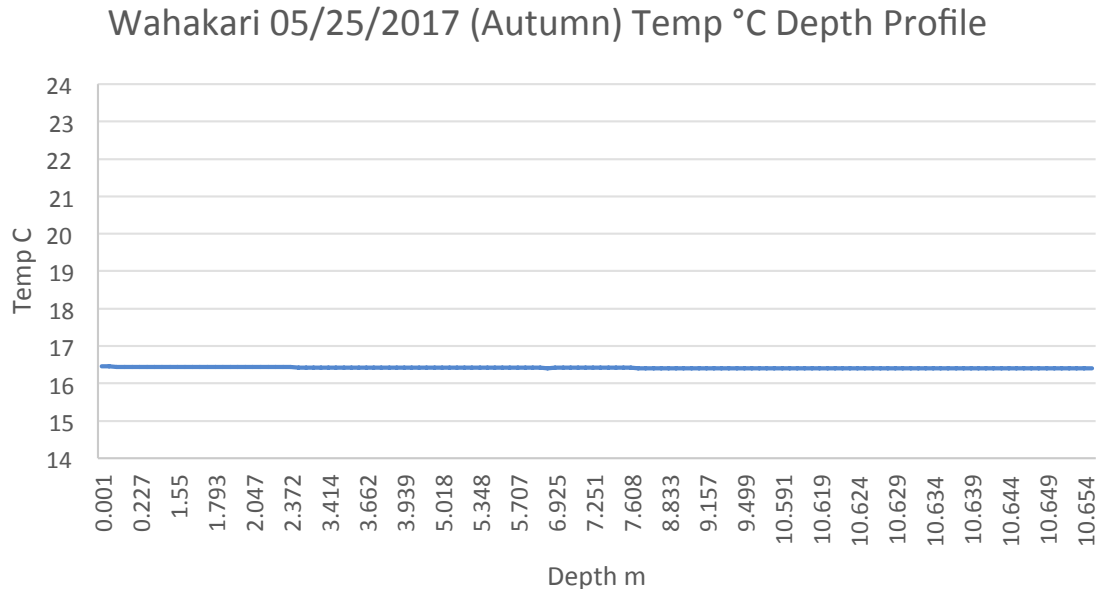
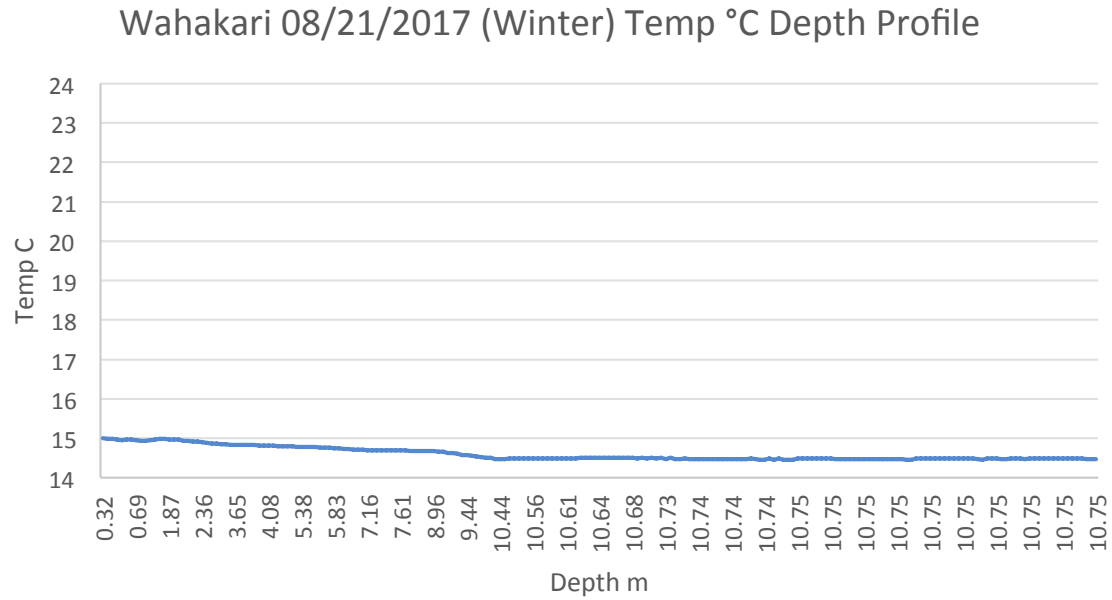
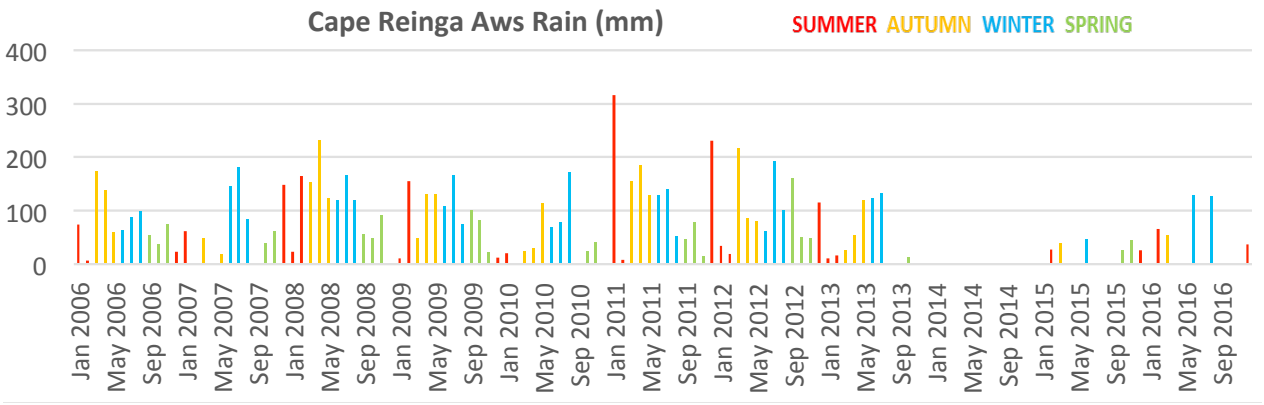
Depth m

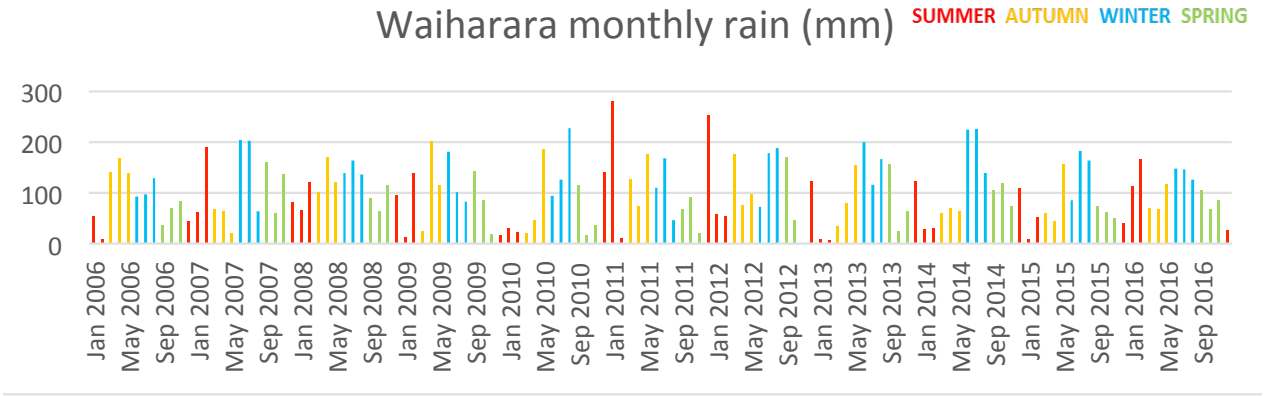

Wahakari 05/25/2017 (Autumn) Temp °C Depth Profile
Temp C
24
23
22
21
20
19
18
17
16
15
14
0.001
0.227
1.55
1.793
2.047
2.372
3.414
3.662
3.939
5.018
5.348
5.707
6.925
7.251
7.608
8.833
9.157
9.499
10.591
10.619
10.624
10.629
10.634
10.639
10.644
10.649
10.654
Depth m

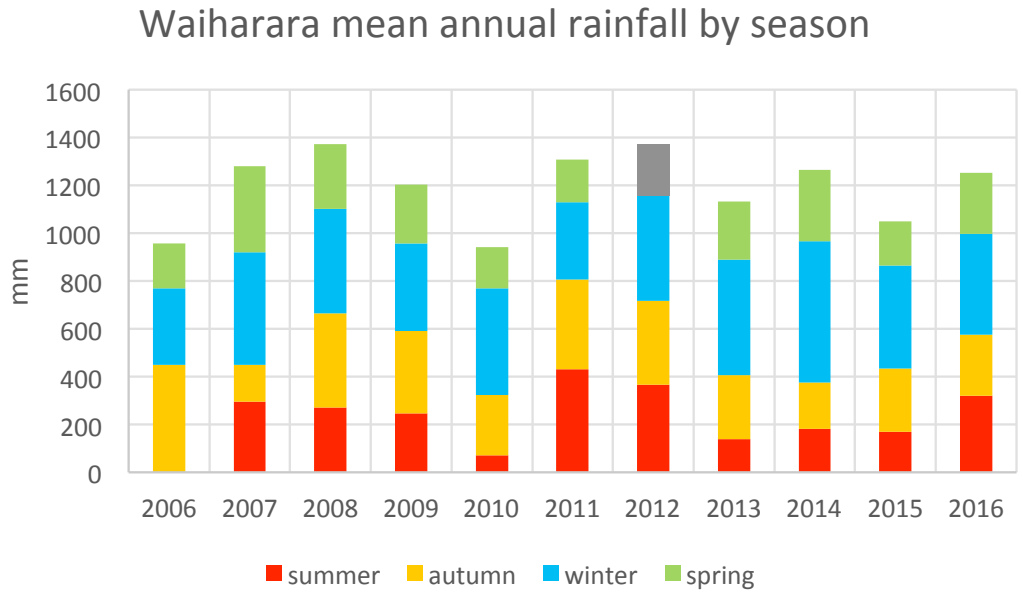

Wahakari 08/21/2017 (Winter) Temp °C Depth Profile
Temp C
24
23
22
21
20
19
18
17
16
15
14
0.32
0.69
1.87
2.36
3.65
4.08
5.38
5.83
7.16
7.61
8.96
9.44
10.44
10.56
10.61
10.64
10.68
10.73
10.74
10.74
10.74
10.75
10.75
10.75
10.75
10.75
10.75
10.75
10.75
10.75
Depth m

6.12. Rainfall and drought

Both Cape Reinga and Waiharara (far south of the lake) rainfall data is shown below. Cape Reinga data has many missing months so zero values are actually a lack of data for those months. Waiharara can be used as a reference for these gaps. The third graph shows cumulative rainfall by year by season for Waiharara. The grey 2012 spring area indicates that one month out of three for that season has no data, so is an underestimate. Similarly, summer 2006 data is missing. Summer data begins in the December before the year on the X axis.







6.13. Lake level

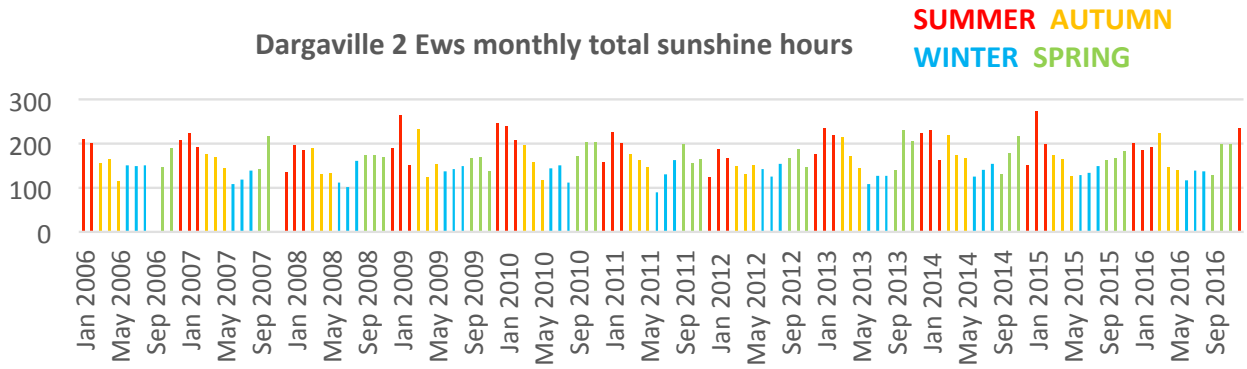
There is no data available on lake level. A staff gauge is due to be installed.

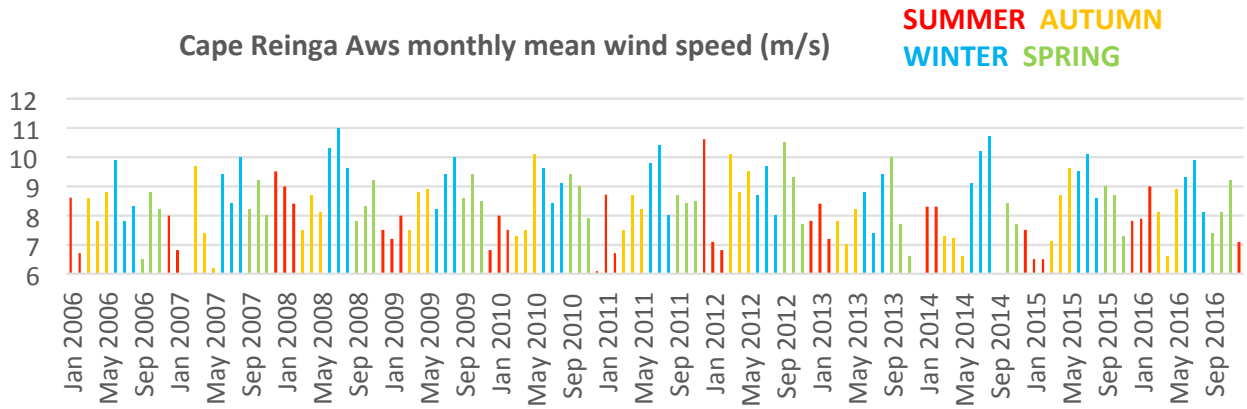
6.14. Sunshine

Dargaville sunshine hours recordings are used as a proxy. This weather station is the closest available data, but is possibly too far from this lake to be representative.

6.15. Wind speed

Cape Reinga wind speed recordings are used as a proxy.





6.16. Light incidence (Secchi, Total Suspended Solids, Chlorophyll-a)

As only three data points exist for water quality, no timeline for changes in light incidence variables is available. Please refer to the section on Trophic Level Index for information on these variables.

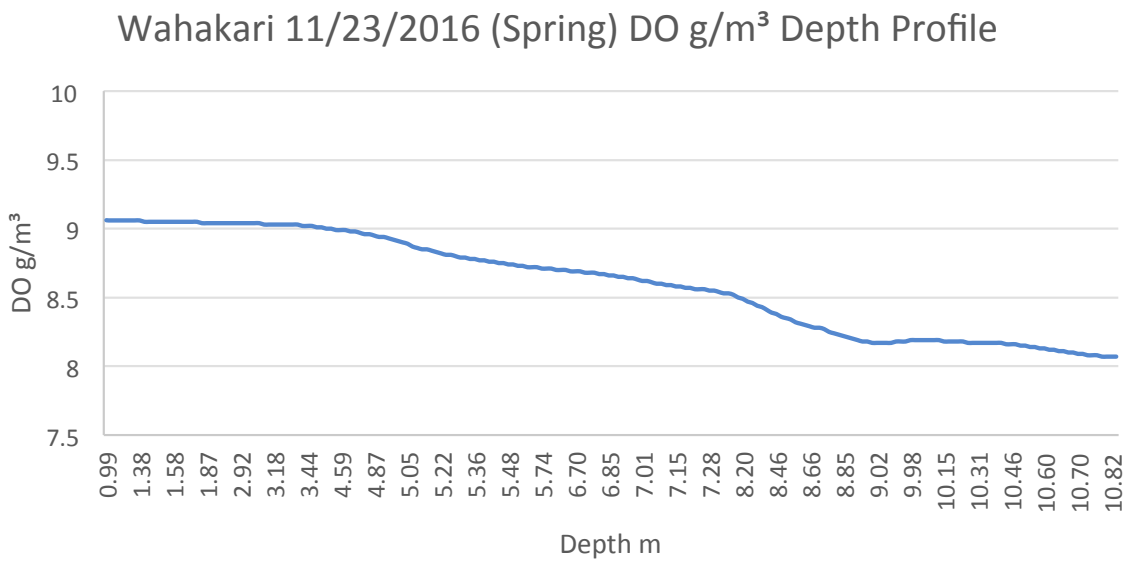
7. CHEMICAL CHARACTERISTICS

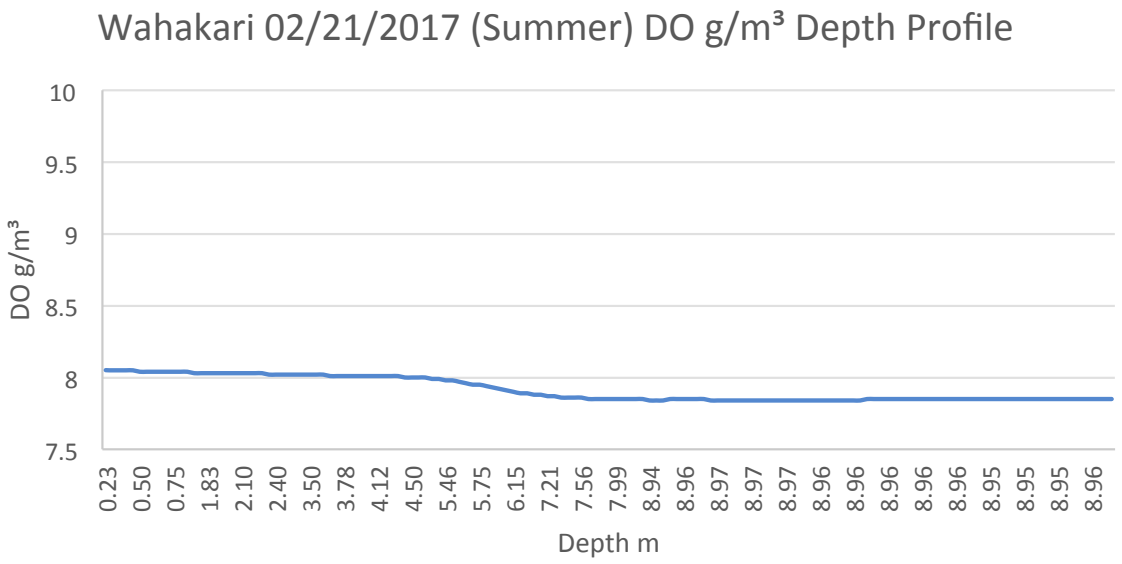
7.1.1. Dissolved Oxygen g/m³

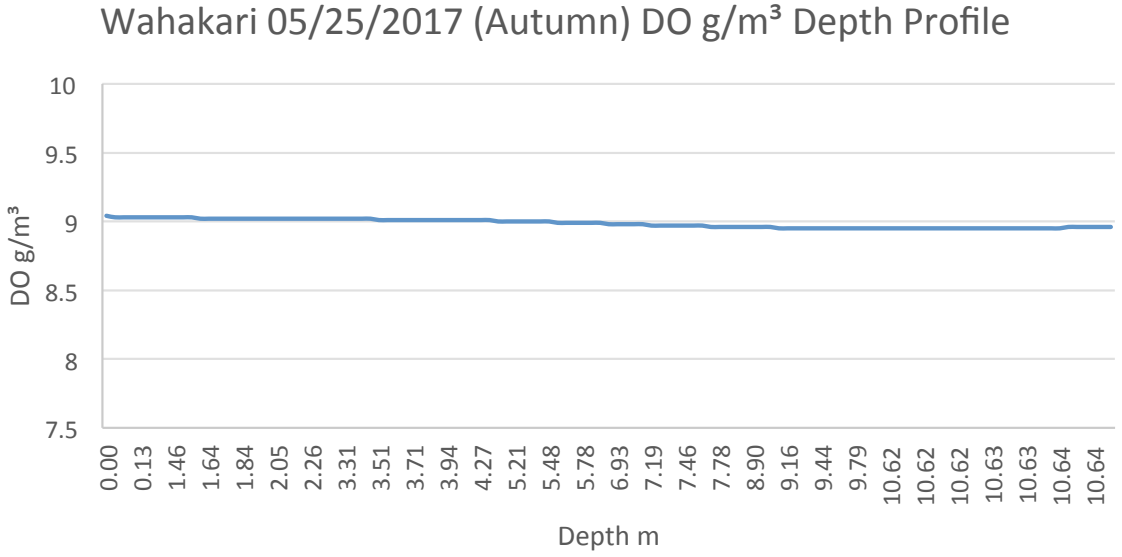
Just as the lake has not been seen to thermally stratify (although this is based on a single summer sample and therefore may not be not conclusive), there is no strong deoxygenation phase, even in summer (again from limited data). Oxygen levels are quite healthy. However, this data is limited to only four single seasonal samples.

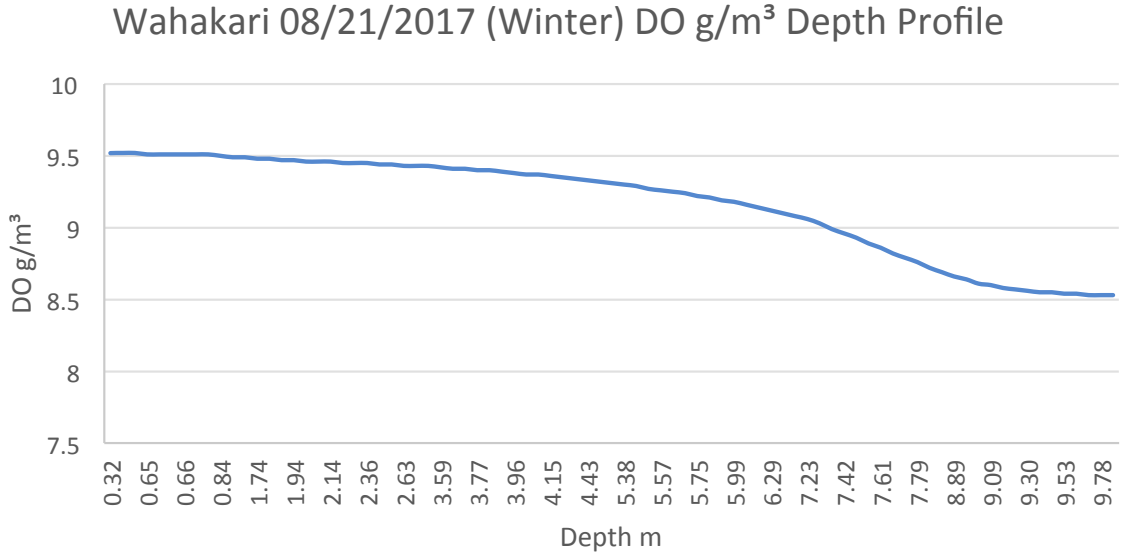
The table below shows the dissolved oxygen (at 15 degrees C) limits for New Zealand freshwater fish from https://www.niwa.co.nz/freshwater-and-estuaries/research-projects/dissolved-oxygen-criteria-for-fish. These guidelines help interpret the depth profiles as to the depth of the water column usable by fish species during the different seasons displayed in the graphs.

Dissolved Oxygen		Early life stages	Adults
30-day mean (mg L^{-1})	Guideline	9.0	8.0
	Imperative	6.5	6.0
7-day mean (mg L^{-1})	Guideline	7.5	6.5
	Imperative	5.5	5.0
7-day mean minimum (mg L^{-1})	Guideline	6.0	5.0
	Imperative	5.0	4.0
1-day minimum (mg L^{-1})	Guideline	6.0	4.0
	Imperative	4.0	3.0



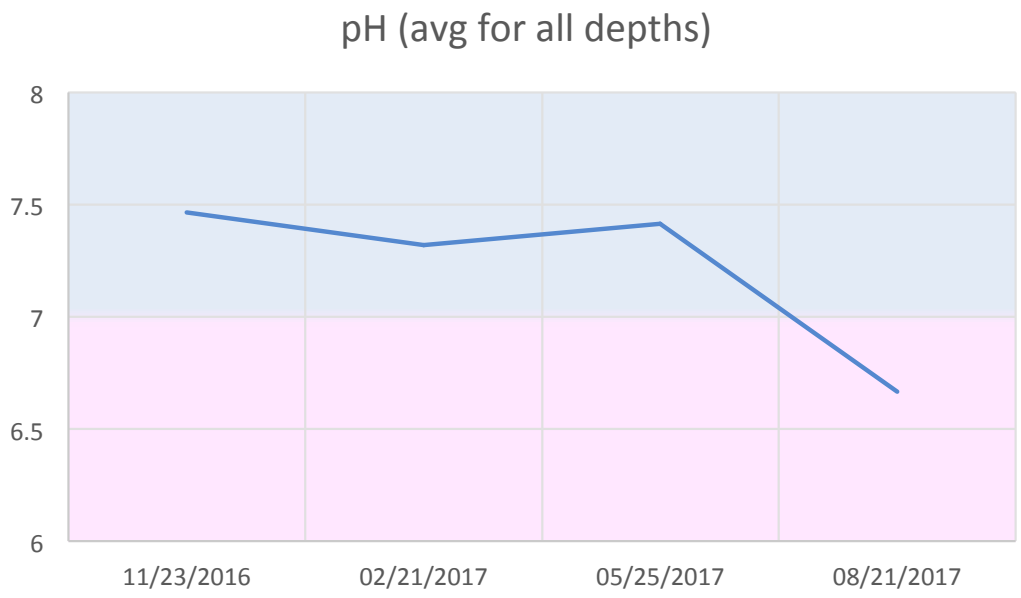

Wahakari 02/21/2017 (Summer) DO g/m³ Depth Profile
DO g/m³
10
9.5
9
8.5
8
7.5
0.23 0.50 0.75 1.83 2.10 2.40 3.50 3.78 4.12 4.50 5.46 5.75 6.15 7.21 7.56 7.99 8.94 8.96 8.97 8.97 8.97 8.96 8.96 8.96 8.96 8.96 8.95 8.95 8.95 8.96
Depth m


Wahakari 05/25/2017 (Autumn) DO g/m³ Depth Profile
DO g/m³
10
9.5
9
8.5
8
7.5
0.00 0.13 1.46 1.64 1.84 2.05 2.26 3.31 3.51 3.71 3.94 4.27 5.21 5.48 5.78 6.93 7.19 7.46 7.78 8.90 9.16 9.44 9.79 10.62 10.62 10.62 10.63 10.63 10.64 10.64
Depth m


Wahakari 08/21/2017 (Winter) DO g/m³ Depth Profile
DO g/m³
10
9.5
9
8.5
8
7.5
0.32 0.65 0.66 0.84 1.74 1.94 2.14 2.36 2.63 3.59 3.77 3.96 4.15 4.43 5.38 5.57 5.75 5.99 6.29 7.23 7.42 7.61 7.79 8.89 9.09 9.30 9.53 9.78
Depth m

7.1.2. pH

Only four samples are available. These values are an average of all pH values in the depth profile for the sample day. The winter decline is likely due to reduced photosynthesis consumption of carbon.



7.1.2.1. Trophic Level Index (Total Phosphorus, Total Nitrogen, Secchi (visual clarity) and Chlorophyll-a (algal bloom)

The trophic level index (TLI) is used in New Zealand as a measure of the nutrient status of lakes. The index combines four variables; phosphorus, nitrogen, visual clarity (Secchi disk depth) and chlorophyll-a, each weighted equally.

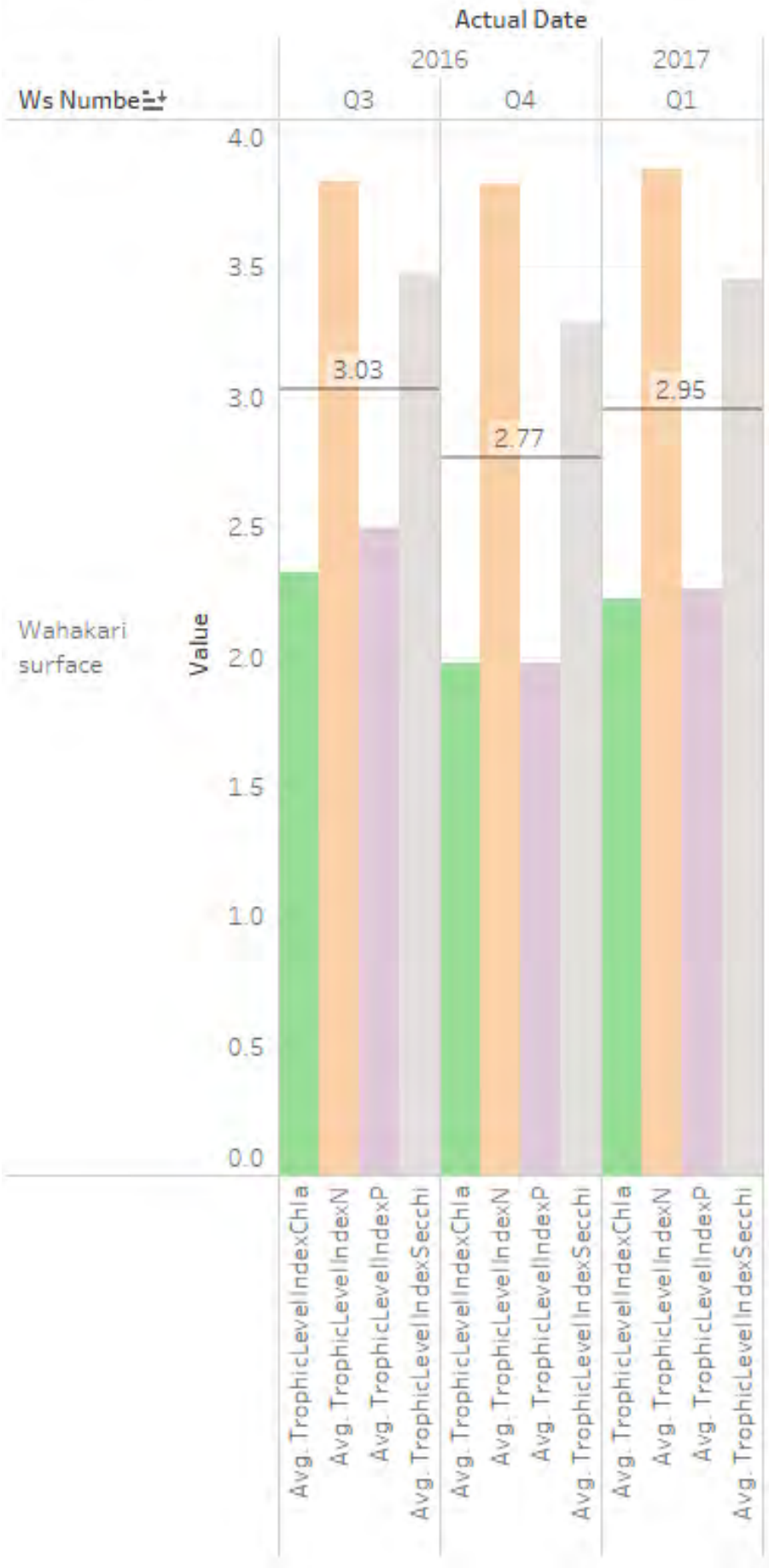
A low TLI score indicates a healthy lake with clear water and little algal bloom occurrence. A high TLI shows an overly nutrient-rich lake prone to algal blooms and poor light incidence, this shading affecting the health of submerged native plant communities. Water quality sampling by NRC began in August (quarter 3) 2016, hence there are only three data points in the time series, unlike most monitored lakes which have timelines as far back as 2005.

Therefore, the following chart is used to present trophic level index (TLI) and the variable which comprise this index, being chlorophyll-a, total nitrogen, total phosphorus and Secchi depth.

In the case of the TLI scores presented, nitrogen (the tan bar) followed by Secchi depth are the major contributors to overall TLI.

From the three quarterly TLI scores, Lake Wahakari is an oligotrophic lake, meaning it has good water quality. The average of the three quarterly TLIs is 2.91.

Sampling quarters 3, 4 and 1 correspond to the months of August, November and February, with quarter 2 (not included) being May.



Water Quality	Trophic Level	TLI Score
Very Good	Microtrophic	<2
Good	Oligotrophic	2-3
Average	Mesotrophic	3-4
Poor	Eutrophic	4-5
Very Poor	Supertrophic	>5
No Data	No data available	

8. BIOLOGICAL CHARACTERISTICS

8.1. Lake Biodiversity and Biosecurity species

8.1.1. Plants

Wahakari hosts 25 native aquatic plants, the second highest diversity of any lake on Aupōuri Peninsula apart from Morehurehu, and three exotic non-invasive plants; the bladderwort *Utricularia gibba*, bulbous rush and the water starwort, *Ludwigia palustris*. There are three rare native plants present; *Isolepis lenticularis (formerly I. fluitans), Myriophyllum votschii,* and *Utricularia australis. Isolepis lenticularis* is very rare in Northland waterbodies but appears to have a viable population in Wahakari. *Utricularia australis* has not been recorded in the lake since 2008.

The table is organised as a depth gradient, from emergent plants to those which are submerged, for each of the invasives and natives.

The table presents plant communities in nearby dune lakes as a comparison and indication of biosecurity species of concern which should be contained wherever possible. Data is derived from annual NIWA ecological surveys.

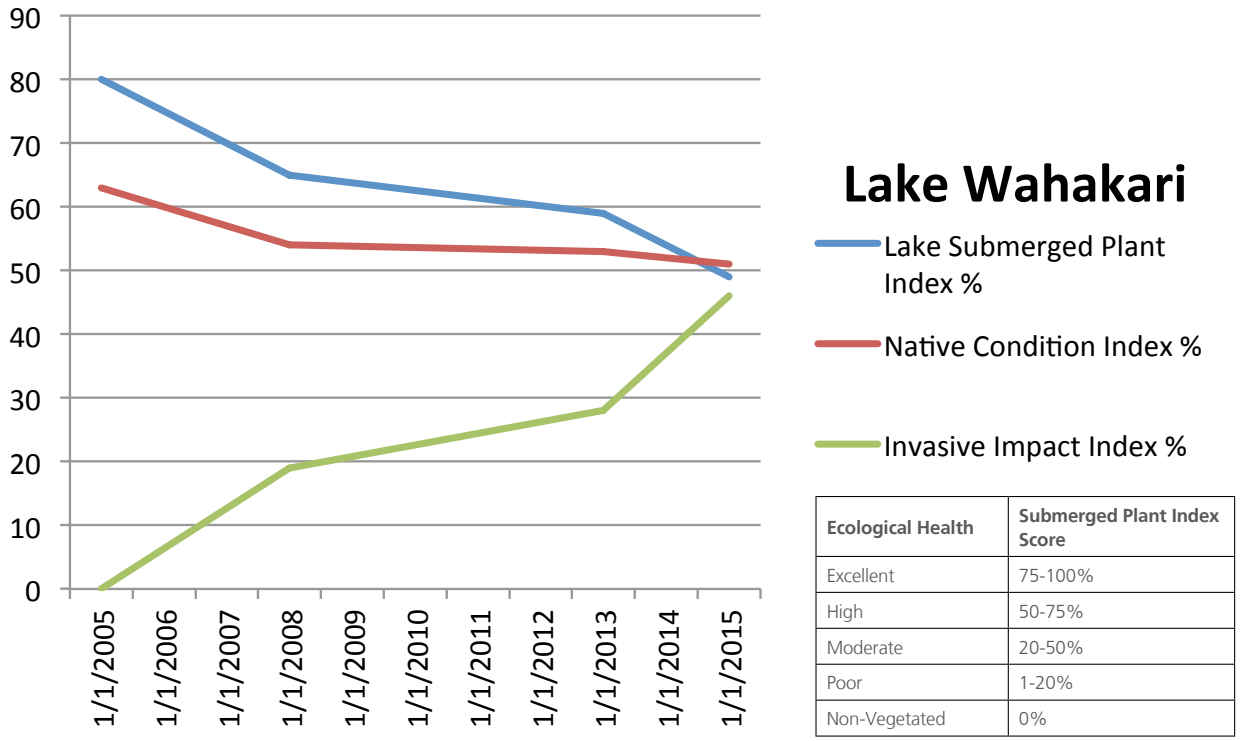
Depth and Plant Type Zone	Biogeography	Common Name	Species	Waitahora lagoon	Waitahora Lakes	Te Werahi Lagoon	Ngakeketa North/Te Paki	Ngakeketa South	Te Paki Dune Lake	Austria	Pretty	Waipara/Dead	Kihona	Wahakari	Te Kahika	Te Kahika South	Morehurehu	Morehurehu South 1	Morehurehu South 2	Taeore (dried out)	Te Arai Lake	Te Arai Ephemeral Wetland	Bulrush	Salt	Waihopo	Yelavich	Katavich	Waiparera	Frequency
Erect emergent	Invasive exotic	royal fern	Osmunda regalis																									x	1
Erect emergent	Non-invasive exotic	bulbous rush	Juncus bulbosus											x															1
Sprawling emergent	Invasive exotic	alligator weed	Alternanthera philoxeroides										x															x	2
Sprawling emergent	Invasive exotic	gypsywort	Lycopus europaeus			x																							1
Sprawling emergent	Invasive exotic	mercer grass, paspalum	Paspalum distichum																			x							1
Sprawling emergent	Non-invasive exotic	water purslane	Ludwigia palustris		x		x							x						x		x	x	x	x				8
Low growing turf	Non-invasive exotic	water starwort	Callitriche stagnalis																			x							1
Floating leaved	Non-invasive exotic	swamp lily	Ottelia ovalifolia		x				x																				2
Free floating	Non-invasive exotic	ferny azolla	Azolla pinnata		x																				x				2
Free floating	Non-invasive exotic	bladderwort, yellow bladderwort	Utricularia gibba						x	X			x	x	x		x	X	x		x				x	X			11
Submerged tall pondweed	Invasive exotic	hornwort, coontail	Ceratophyllum demersum			x		x					x																3
Submerged tall pondweed	Invasive exotic	lakeweed, egeria	Egeria densa			x	x																					x	3
Submerged tall pondweed	Invasive exotic	lagarosiphon, lakeweed, oxygen weed	Lagarosiphon major																									x	1
Submerged tall pondweed	Non-invasive exotic	curly leaved pondweed, curled pondweed	Potamogeton crispus			x	x																						2
Erect emergent	Native	oioi, jointed wire rush	Apodasmia similis	x						x				x			x		x									x	6
Erect emergent	Native	kiokio, horokio, palm leaf fern	Blechnum novazelandiae														x												1
Erect emergent	Native	maori sedge	Carax maorica			x							x																2
Erect emergent	Native	pukio	Carex secta										x																1
Erect emergent	Native	swamp sedge, pukio, toitoi, toetoe	Carex virgata										x																1
Erect emergent	Native	swamp coprosma, hukihuki	Coprosma tenuicaulia														x												1
Erect emergent	Native	cabbage tree, ti, ti kouka, palm lily	Cordyline australis				x																						1
Erect emergent	Native	giant umbrella sedge, Upokotangata	Cyperus ustulatus	x									x																2
Erect emergent	Native	sharp spike sedge	Eleocharis acuta						x		x		x	x			x								x				6
Erect emergent	Native	bamboo spike sedge, tall spike sedge	Eleocharis sphacelata		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x	x	22
Erect emergent	Native	wire rush, lesser wire rush	Empodisma minus													x	x												2
Erect emergent	Native	wire rush, lesser wire rush	Empodisma robusta (haplotype of E. minus)												x				x										2
Erect emergent	Native	sea rush	Juncus kraussii var. australiensis	x																									1
Erect emergent	Native	leafless rush	Juncus pallidus								x																		1
Erect emergent	Native	manuka, tea tree, kahikatoa	Leptospermum scoparium														x												1
Erect emergent	Native	sedge	Machaerina arthrophylla (syn. Baumea arthrophylla)											x		x	x	x			x							x	6
Erect emergent	Native	jointed baumea, jointed twig rush	Machaerina articulata (syn. Baumea articulata)		x	x		x	x	x	x	x	x	x			x							x	x		x	x	14
Erect emergent	Native	sedge, tussock swamp twig rush	Machaerina juncea (syn. Baumea juncea)	x					x					x		x	x	x							x				7
Erect emergent	Native	baumea	Machaerina rubiginosa (syn. Baumea rubiginosa)											x		x									x				3
Erect emergent	Native	pakihi rush	Machaerina teretifolia (syn. Baumea teretifolia)												x		x		x										3
Erect emergent	Native	flax, harakeke, korari	Phormium tenax			x	x									x	x												4
Erect emergent	Native	softstem bulrush, grey club-rush, great bulrush	Schoenoplectus tabernaemontani											x			x			x							x		4
Erect emergent	Native	burr-reed, maru	Sparganium subglobosum						x																x				2
Erect emergent	Native	raupo	Typha orientalis			x	x	x	x				x	x			x	x		x	x	x		x	x		x	x	15
Erect emergent	Rare native	none known	Cyclosorus interuptus																						x			x	2
Erect emergent	Rare native	swamp blueberry, swamp ink berry, swamp Dianella	Dianella haematica														x												1
Erect emergent	Rare native	pygmy sundew	Drosera pygmaea														x		x										2
Erect emergent	Rare native	Marsh fern, swamp fern	Thelypteris confluens																						x				1
Erect emergent	Rare native	Royal Fern, Hard todea, King fern	Todea barbara												x	x	x												3
Sprawling emergent	Native	centella	Centella uniflora																			x							1
Sprawling emergent	Native	tangle fern, swamp umbrella fern	Gleichenia dicarpa												x		x												2
Sprawling emergent	Native	swamp millet	Isachne globosa				x							x	x										x				4
Sprawling emergent	Native	swamp willow weed	Persicaria decipiens		x				x															x					3
Sprawling emergent	Rare native	New Zealand sneezewort	Centipeda aotearoana																			x							1
Sprawling emergent	Rare native	sneezeweed, centipeda	Centipeda minima												x														1
Sprawling emergent	Rare native	native hibiscus, swamp hibiscus, prickly hibiscus	Hibiscus diversifolius	x	x																								2

Sprawling emergent	Rare native	native musk, maori musk, native monkey flower	Mimulus repens	x																							1
Low growing turf	Native	starwort	Callitriche petriei						x																		1
Low growing turf	Native	waterwort	Elatine gratioloides																x								1
Low growing turf	Native	none known	Glossostigma diandrum																x								1
Low growing turf	Native	none known	Glossostigma elatinoides				x			x			x								x						4
Low growing turf	Native	none known (sedge)	Isolepis prolifera						x							x							x				3
Low growing turf	Native	Zelandiae chain sword	Lilaeopsis novae-zelandiae	x					x	x			x			x										x	6
Low growing turf	Native	mudwort	Limosella lineata						x																		1
Low growing turf	Native	waoriki	Ranunculus amphitrichus				x																x				2
Low growing turf	Native	Sea primrose, shore pimpernel, water pimpernel, maakoako	Samolus repens	x																							1
Low growing turf	Native	moss	Sphagnum sp.											x													1
Low growing turf	Native	arrow grass	Triglochin striata	x									x			x		x						x			5
Floating leaved	Native	red pondweed	Potamogeton cheesemanii		x				x			x	x			x	x	x		x	x	x		x	x		12
Free floating	Rare native	none known (sedge)	Isolepis fluitans										x	x													2
Submerged milfoil	Native	common water milfoil	Myriophyllum propinquum		x		x		x	x	x		x			x					x	x		x			10
Submerged milfoil	Native	water milfoil	Myriophyllum triphyllum										x														1
Submerged milfoil	Rare native	Stout water milfoil	Myriophyllum robustum																						x		1
Submerged milfoil	Rare native	small water milfoil	Myriophyllum votschii				x		x				x														3
Submerged tall pondweed	Native	blunt pondweed	Potamogeton ochreatus		x	x	x	x			x		x			x							x	x	x		x	11
Submerged tall pondweed	Native	horses mane weed, lakeweed	Ruppia polycarpa	x																							1
Submerged tall pondweed	Rare native	bladderwort, yellow bladderwort	Utricularia australis	x	x				x	x			x	x	x	x	x								x			11
Submerged charophyte	Native	stonewort	Chara australis		x	x	x		x	x		x	x	x			x		x		x	x	x		x	x	x	16
Submerged charophyte	Native	stonewort	Chara fibrosa		x		x		x				x			x									x			6
Submerged charophyte	Native	stonewort	Chara globularis																							x	1
Submerged charophyte	Native	stonewort	Lamprothamnium sp.	x																							1
Submerged charophyte	Native	stonewort	Nitella hyalina																							x	1
Submerged charophyte	Native	stonewort	Nitella leonhardii			x							x			x	x	x									5
Submerged charophyte	Native	stonewort	Nitella pseudoflabellata								X		x			x								x			4
Submerged charophyte	Native	stonewort	Nitella sp. aff. cristata			x			x				x			x		x					x	x	x		x	9
			Total Plant Diversity	**12**	**13**	**13**	**15**	**5**	**20**	**9**	**7**	**4**	**13**	**28**	**11**	**8**	**31**	**7**	**12**	**3**	**8**	**10**	**6**	**8**	**23**	**6**	**4**	**16**	
			Exotic Plant diversity	**0**	**3**	**4**	**3**	**1**	**2**	**1**	**0**	**0**	**3**	**3**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**3**	**1**	**1**	**3**	**1**	**0**	**4**	
			Native Plant Diversity	**12**	**10**	**9**	**12**	**4**	**18**	**8**	**7**	**4**	**10**	**25**	**10**	**8**	**30**	**6**	**11**	**2**	**7**	**7**	**5**	**7**	**20**	**5**	**4**	**12**	

8.1.1.1.1. Lake Submerged Plant Index (LakeSPI), Native Condition Index and Invasive Impact Index

Three indices are valuable for considering the health of a lake's plant community; Lake Submerged Plant Index, Native condition Index and Invasive Plant Index.

Invasive Impact Index has seen a sharp rise with a corresponding fall in Native Condition Index and Submerged Plant Index. The lake has seen a gradual displacement of charophyte meadows with the native *Potamogeton ochreatus*, which later declined. Maximum depth of plants also declined. Water quality decline is the most likely driver for reduction in submerged plant bottom limits.



Ecological Health	Submerged Plant Index Score
Excellent	75-100%
High	50-75%
Moderate	20-50%
Poor	1-20%
Non-Vegetated	0%

8.1.2. Fish and Amphibians

The table below displays the fish of the upper Aupōuri Peninsula. Pest fish are shown in green and native species in pink. Lake Wahakari appears in yellow. The lake has a moderate level of native fish diversity, but is the only upper Aupōuri lake where *Gambusia* are present north of Lake Waiparera. *Gambusia* were probably introduced to the lake accidently on boats or other equipment.

The exotic golden bell frog, *Litoria aurea*, has also been found at the lake. The only other surveyed lake with this species recorded is Phoebe's Lake in the Pouto Peninsula, but it is likely more widespread.

Common bully and an eel species are present, as is the only occurrence of smelt on the peninsula.

common name	species	Conservation status	Degree of loss	Waitahora lagoon	Waitahora Lakes	Te Werahi Lagoon	Ngakeketa North/Te Paki	Ngakeketa South	Te Paki Dune Lake	Pretty	Kihona	Wahakari	Te Kahika	Morehurehu	Morehurehu South 1	Morehurehu South 2	Waihopo	Yelavich	Katavich	Waiparera	frequency
golden bell frog	Litoria Aurea											x									1
hylidae tree frog	Litoria								x												1
goldfish	Carassius auratus																			x	1
Gambusia	Gambusia affinis											x							x	x	3
rudd	Scardinius erythrophthalmus																			?	1
shortfinned eel	Anguilla australis								x		x		x	x					x	x	6
longfinned eel	Anguilla dieffenbachii	at risk	declining																	x	1
eel	Anguilla sp											x									1
inanga	Galaxias maculatus	at risk	declining											x		x				x	3
common bully	Gobiomorphus cotidianus					x	x	x		x	x	x		x	x			x	x	x	11
grey mullet	Mugil cephalus			x		x		x			x										4
black mudfish	Neochanna diversus	at risk	relict														x				1
smelt	Retropinna retropinna											x									1
	diversity pest fish			0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	3	
	diversity native			1	0	2	1	2	1	1	3	3	1	3	1	1	1	1	2	4	

8.1.3. Waterbirds

The table on the following page displays the waterbirds of the Aupōuri Peninsula (north of Sweetwater). Game birds are shown in green and non-game bird native species in pink. Canada goose is an exception, having been taken off the game bird list but able to be hunted year-round. Lake Wahakari appears in yellow. The lake has a moderate level of bird diversity and would likely not be a popular waterfowl hunting site. They also occur as far north as Te Werahi Lagoon on the Aupōuri Peninsula's north-west tip, as well as east of Lake Wahakari at Lake Morehurehu.

common name	species	Conservation status (DOC: *Conservation status of NZ birds* , 2016)	Criteria / Degree of loss	Waitahora lagoon	Waitahora Lakes	Te Werahi Lagoon	Ngaketeta North/Te Paki	Ngaketeta South	Te Paki Dune Lake	Austria	Pretty	Waipara/Dead	Kihona	Wahakari	Te Kahika	Te Kahika South	Morehurehu	Morehurehu South 1	Morehurehu South 2	Taeore (dried out)	Te Arai Lake	Te Arai Ephemeral Wetland	Bulrush	Salt	Waihopo	Yelavich	Katavich	Waiparera	frequency
Australasian (NZ) shoveler	Anas rhynchotis (resident native (not introduced) on game bird list)	(resident native)											x																1
black swan	Cygnus atratus (resident native (not introduced) on game bird list)	Not threatened				x	x	x					x															x	5
pukeko	Porphyrio m. melanotus (resident native (not introduced) on game bird list)	not threatened					x						x																2
paradise shelduck	Tardorna variegata (resident native (not introduced) on game bird list)	Not threatened					x	x														x		x		x	x	6
Canada goose	Branta canadensis (Introduced & naturalised, not protected, able to be hunted at any time)	Introduced & naturalised				x								x			x					x							4
brown teal	Anas chlorotis	at risk	recovering	x																									1
New Zealand scaup	Aythya novazeelandiae	not threatened								x				x											x			x	4
Australasian bittern	Botaurus poiciloptilus	threatened	nationally critical		x			x				x					x				x				x			x	7
North Island fernbird	Bowdleria punctata vealeae	at risk	declining	x	x				x	x		x	x	x	x		x	x	x		x				x				13
Caspian tern	Hydroprogne caspia	threatened	nationally vulnerable												x														1
little black shag	Phalacrocorax sulcirostris	at risk	naturally uncommon												x														1
pied shag	Phalacrocorax v. varius	at risk	recovering				x						x																2
New Zealand dabchick	Poliocephalus rufopectus	at risk	recovering							x				x	x						x		x		x				6
marsh crake	Porzana pusilla affinis	at risk	declining	x																									1
spotless crake	Porzana t. tabuensis	at risk	declining							x					x										x		x		4
Australasian little grebe	Tachybaptus n. novaehollandiae		coloniser							x																			1
chestnut-breasted shelduck	Tadoma tadornoides		vagrant																						x				1
	diversity resident native (not introduced) on game bird list			0	0	1	3	2	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	1	0	0	1	2	
	diversity introduced & naturalised			0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	
	diversity native			3	2	0	1	1	1	5	0	2	2	3	5	0	2	1	1	0	3	0	1	0	6	0	1	2	

8.1.4. Invertebrates

Invertebrates are of interest in lake systems as indicators of lake health. They are generally very sensitive to poor water quality. In the case of Wahakari, freshwater mussels/torowai, which require at least good water quality, are abundant yet diversity of invertebrates is low. Freshwater crayfish/koura/ kewai are also present, but are not recorded in the surveys. Data is combined from NIWA and Northtec surveys.

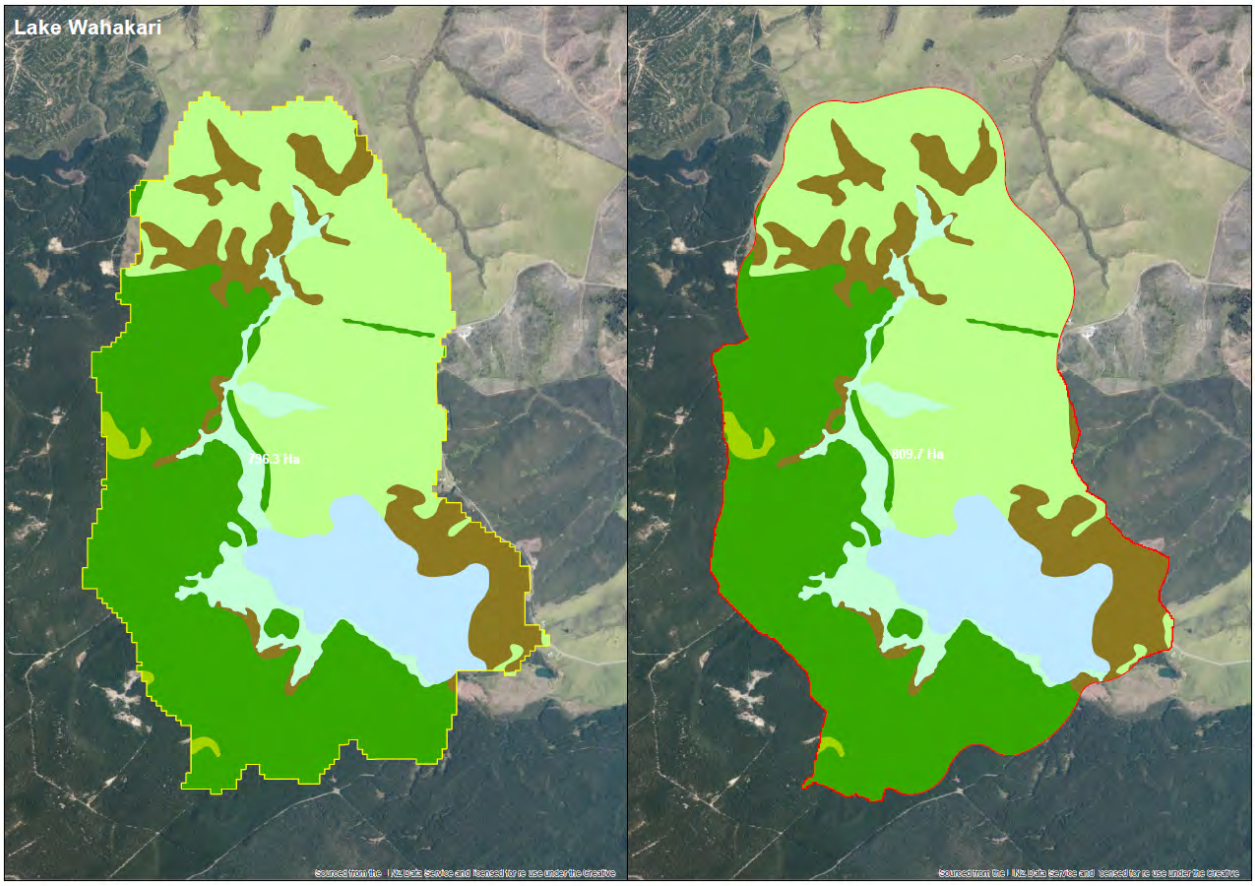
Order or phylum and common name	Family or species	Pollution minimum tolerance - Clean Water (>5.99) Mild Pollution (5.00-5.90) Moderate Pollution (4.00-4.99) Severe Pollution (<4.00)	Waitahora lagoon	Waitahora Lakes	Te Werahi Lagoon	Ngaketeta North/Te Paki	Ngaketeta South	Te Paki Dune Lake	Austria	Pretty	Waipara/Dead	Kihona	Wahakari	Te Kahika	Te Kahika South	Morehurehu	Morehurehu South 1	Morehurehu South 2	Taeore (dried out)	Te Arai Lake	Te Arai Ephemeral Wetland	Bulrush	Salt	Waihopo	Yelavich	Katavich	Waiparera	frequency
Mollusc, snail	*Physa (Physella) acuta*	0.1											x								x		x		x			x	5
Mollusc, snail	Pseudosuccinea												x																1
Coleoptera, dytiscid diving beetle	*Onychohydrus hookeri*								x			x																	2
Coleoptera, whirigig beetle	*Gyrinus*								x			x		x															3
Crustacea, Isopoda	Sphaeromatoidea	4.5						x																					1
Crustacea, Ostracoda, koura	*Paranephrops planifrons*	8.4																											0
Diptera, midge, non-biting, Chironomid	*Chironomas sp*	3.4				x						x		x		x						x			x			x	7
Diptera, midge, non-biting, Chironomid	Orthocladiinae	3.2						x																	x				2
Diptera, midge, non-biting, Chironomid	Tanypodinae	6.5												x															1
Diptera, non-biting midge, Chironomid	*Parachironomus*													x															1
Hemiptera, bug, backswimmer	*Anisops*	2.2				x		x				x		x								x			x			x	7
Hemiptera, bug, backswimmer	*Sigara arguta*	2.4												x			x				x	x			x			x	6
Hemiptera, bug, waterboatman	*Diaprepocoris sp*	4.7						x				x										x							3
Hemiptera, bug, waterboatman	Corixidae sp															x									x				2
Hirudinea, leech	Alboglossiphonia																											x	1
Hirudinea, leech	*Richardsonianus mauianus*							x																					1
Hydrozoa, hydra	*Hydra* sp																								x				1
Lepidoptera, aquatic moth	*Hygraula nitens*	1.3				x																							1
Mollusca, freshwater mussel	*Hyridella menziesi*	6.7				shells								x															2
Mollusca, pea mussel	*Musculium novazelandiae*					x		x				x	x									x			?				6
Mollusca, pea mussel	*Sphaerium novaezelandiae*											x																	1
Mollusca, snail	*Gyraulus corinna*	1.7						x																					1
Mollusca, snail, native	*Potamopyrgus antipodarum*	2.1				x	x						x	x								x						x	6
Neuroptera, spongillafly larvae	*Sisyra*					x							x																2
Odonata, damselfly	*Xanthocnemis sp*	1.2				x	x	x				x	x		x		x					x			x			x	10
Odonata, dragonfly	*Hemicordulia australiae*	0.4										x	x		x		x								x				5
Odonata, dragonfly	sp							x							x			x							x				4
Porifera, freshwater sponge	sp					x	x					x		x			x								x			x	7
Trichoptera, caddisfly	Leptoceridae																											x	1
Trichoptera, caddisfly	*Oecetis unicolor*	6.8																					x						1
Trichoptera, caddisfly	*Paroxyethira hendersoni*	3.7										x	x												?				3
Trichoptera, caddisfly	sp														x														1
Trichoptera, caddisfly	*Triplectides sp*	5.7																					x						1
	diversity invasive		0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	6
	diversity native		0	0	0	9	5	9	0	0	11	6	3	10	0	5	2	0	0	1	0	9	0	12	0	0	8	

9. LAND USE

9.1. Catchment land cover table and map

The lake is situated in a catchment dominated by exotic pine forest, high producing grassland, manuka/kanuka scrub and freshwater sedgeland/rushland.

Lake	Cover Type	Total FENZ (ha)	Total Hand-drawn (ha)
Lake Wahakari	Exotic Forest	299.85	289.97
Lake Wahakari	Herbaceous Freshwater Vegetation	51.23	51.78
Lake Wahakari	High Producing Exotic Grassland	258.12	271.87
Lake Wahakari	Lake or Pond	84.25	84.35
Lake Wahakari	Low Producing Grassland	5.92	5.43
Lake Wahakari	Manuka and/or Kanuka	96.91	106.26
Lake Wahakari Total		796.28	809.66



9.2. Fire-fighting mitigations

A road drain at the south entrance to the lake could be bringing in nutrients and sediment and requires investigation plus remedial works, if necessary.

9.3. Pastoral farming

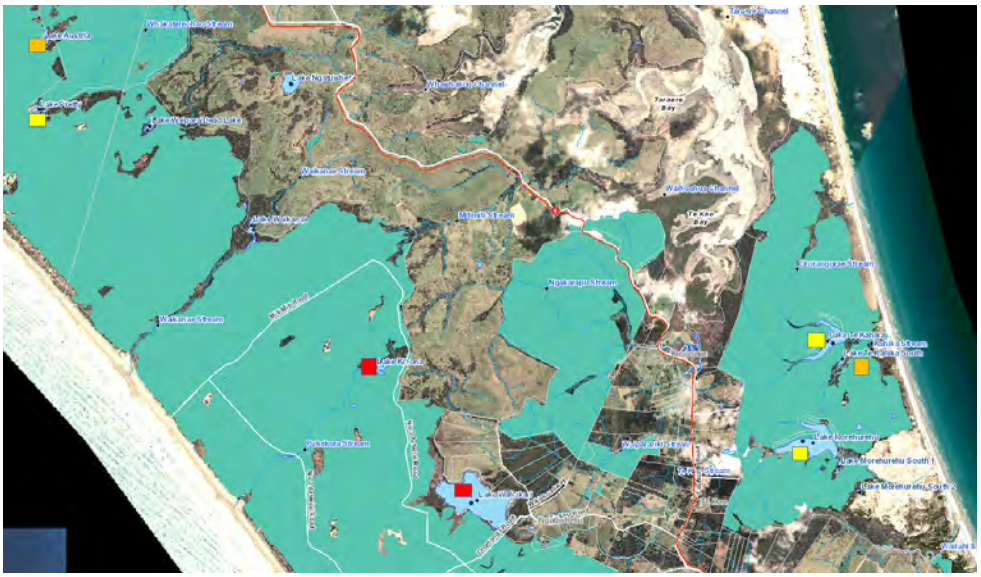
Pastoral farming dominates the north side of the lake and its catchment. There are no fences along the lake front and the southern end of associated wetlands allowing stock access. The slopes coming down to the lake are low fertility and are highly pugged by stock. Fencing along the western wetland arms needs repair but an aged shelterbelt of falling pine would threaten any new fence, so is recommended for removal. The bush area which includes a stream to the North-east of the lakefront requires fencing.

9.4. Forestry

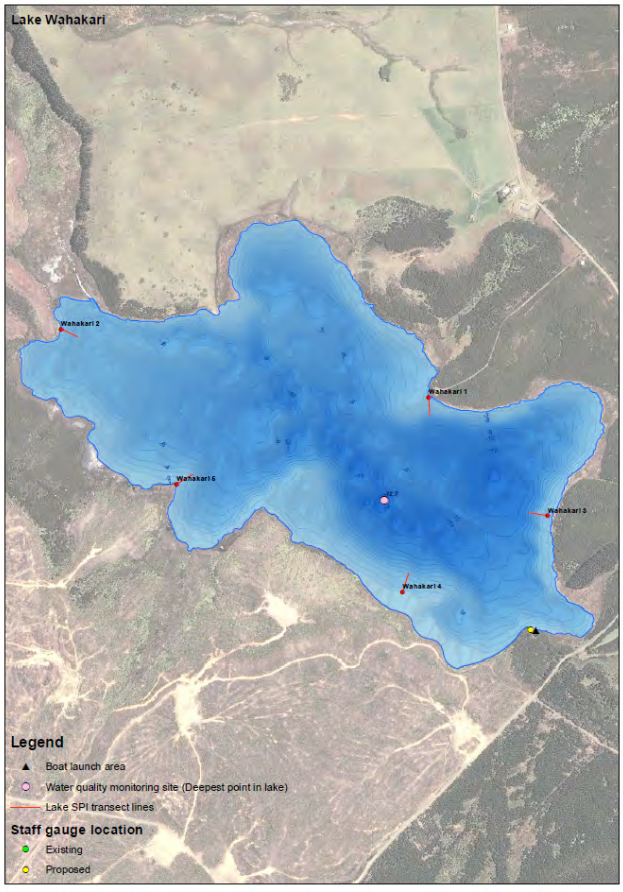
It is likely that forestry harvest impacted water quality in the past and is likely to do so again on the next cycle unless measures are put in place to manage it.

9.5. Fire-fighting mitigations

The lake is a high risk (red square on the map) for use as a water source for fire- fighting by helicopter bucket due to the potential transfer of *Gambusia* to other water bodies.



Fire-fighting mitigations



10. MONITORING PLAN

The map below shows the five transect lines surveyed during ecological surveys. The dark triangle on the south-west side of the lake is the access point for the NRC vessel for water quality sampling. The pink point in the middle of the lake is the water quality sampling point, corresponding to the deepest part of the basin.

10.1. NIWA ecological monitoring

The lake is scheduled to be fully ecologically monitored every five years with weed surveillance annually. There have been seven full surveys since 1985. The value class of the lake has remained at Outstanding throughout. The next full survey is likely to be done in 2020.

KEY
O = Outstanding
H = High
M = Medium
L= Low
Ecological Survey
Reconnaissance or Visit
Weed Surveillance
Grass Carp Assessment
Endothall Assessment
SPI = Submerged Plant Index
Surveillance

Lake	Eco Survey (yr)	Weed survey (yr)	1984	1985	1986	1987	1988	1989	1990	1991	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Austria															M										M						
Bulrush															L																
Half Mile Lagoon															L																
Katavich															L																
Kihona															L											SPI					
Morehurehu	1													H		O			O				H	H		H					
Morehurehu South 1																				L-M											
Morehurehu South 2	1													H		H							M	M		M					
Ngakeketa															L											SPI					
Ngakeketa North/Te Paki	5													H					M-H												
Ngatuwhete															L																
Pretty															M										M-H					SPI	
Salt (Taumatawhaua)															L																
Taeore																				L-M											
Te Arai Ephemeral Wetland															M																
Te Arai Lake																L															
Te Kahika	5													O		O			H				M-H	M-H							
Te Kahika East																															
Te Kahika South	5																			H											
Te Paki dune	5														H		O						H		H						
Te Paki Stream 1 (nearest carpark)																															
Te Paki Stream 2 (nearest sea)																															
Te Werahi Lagoon														H									M								
Wahakari	5	1												O				O					O		O						
Waihopo	5													O		O			O				H								
Waipara/Dead															H										H						
Waiparera	5														M-H					M-H												
Waitahora lagoon	10																O		O					O							
Waitahora Lakes	10																M		M						M						
Yelavich	5																	H		H							M-H					

10.2. NRC Ecological monitoring

10.2.1.Water quality and quantity monitoring

Water quality sampling occurs quarterly in February, May, August and November but only began in August 2016. Earlier monitoring data from Far North District Council is being sought.

Number of samples per year appear below.

Row Labels	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Grand Total
Wahakari lower																	1			1								2	1	5
Wahakari surface	1							1					1	1	1													2	1	8

11. WORK IMPLEMENTATION PLAN

Conservation efforts being planned for the lake are through the Ministry for the Environment's Te Mana o te Wai Fund. This programme is setting up youth training and education in riparian management, including fencing and planting.

Bushland Trust (a Kaitaia-based conservation trust) also monitor the terrestrial ecology.

Ongoing work includes:

- The NRC/NIWA ecological surveys will continue every five years with weed surveillance annually. The next full survey will be in 2020. Quarterly NRC water quality monitoring will continue.
- Installation of a staff gauge and a continuous electronic water-level recorder is planned by NRC.
- The NRC Freshwater Improvement Fund project is due to model nutrient losses to the lake from pastoral farming. Mitigation will be through the Te Mana o Te Wai project.

Further mitigation work to consider includes:

- Investigate and mitigate the causes of the significant decline in vegetation bottom limits, including full catchment assessment and recommendations for works to improve water quality.
- Waka ama represents a biosecurity vector risk to the lake unless the Check Clean Dry protocol is advocated throughout this sector. Recent access to the southern end of the lake, coupled with increased community usage, poses a risk of introduction of water-weeds.
- A road drain at the south entrance to the lake requires investigation and remedial works to prevent entry of sediment and nutrients to the lake.
- Fencing and planting the northern lake front slopes which is currently open to stock access. The slopes are low fertility and are highly pugged by stock.
- Fencing along the western wetland arms needs repair but an aged shelterbelt of falling pine would threaten any new fence, so the trees are recommended for removal.
- The bush area which includes a stream to the north-east of the lakefront requires fencing.
- Work with forestry managers to minimise risks of damage to lake during next harvest cycle including recommendations for next cycle. These could include retirement of key areas from forestry or increasing setbacks of trees from lake margin.
- The lake is a high risk for use as a water source for fire-fighting by helicopter bucket due to the potential transfer of *Gambusia* to other water bodies.
- A full fish survey is recommended.

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13. APPENDIX 1. GLOSSARY

Largely adapted from https://www.lawa.org.nz/Learn

Aquatic - Refers to anything that is related to water. For example, aquatic organisms are plants or animals that live in or near water.

Algal or phytoplankton bloom - A rapid increase in the population of algae in an aquatic system. Blooms can reduce the amount of light and oxygen available to other aquatic life.

Bathymetry – The measurement of depth of water.

Biodiversity - The variety of lifeforms at a given time in a given place.

Biosecurity - The precautions taken to protect against the spread harmful organisms and diseases.

Catchment (area) - The total area of land draining into a lake, expressed in hectares (ha).

Chlorophyll a – Chlorophyll a is a green pigment in all plants, including algal phytoplankton, that is used for photosynthesis and is a good indicator of the total quantity of algae present. It can be measured in micrograms per litre (ug/l) or reflective florescence units (RFU). Large amounts of algae in a lake can decrease the clarity of the water, make the water green, form surface scum, reduce dissolved oxygen and alter the pH of the water.

Clarity (of water) - Refers to light transmission through water and has two important aspects: visual clarity and light penetration. Visual clarity indicates how much sediment or runoff is in the water. Light penetration is also important as it controls light availability for growth of aquatic plants.

Classification of dune lakes (Timms, 1982)

Dune lake class (Timms, 1982)	Description
1. Perched lakes in deflation hollows	Perched in leached dunes, in deflation hollows in elevated leached dunes where organic material has sealed the basin floor and provided humic (tea-stained) water.
2. Swamp-associated perched lakes	Similar to Class 1 but close to the sea, associated with extensive swamps.
3. Window lakes	Water table window lakes in a drowned valley or interdune basin, fed by springs with clear water character.
4. Dune contact lakes	Waterbodies where at least one shore is in contact with a coastal dune, often but not exclusively humic.
5. Marine contact lakes	Freshwater lakes with marine contact, where there may be intermittent connection with the sea.
6. Ponds in frontal sand dunes	Ponds where wind erodes sand to form deflation hollows.

Deoxygenation – Also called hypoxia. Air is 20.9% oxygen, whereas water contains around 1% oxygen and this fluctuates depending on the presence of photosynthetic organisms (higher submerged plants and microalgae) and the distance to the surface, as air diffuses oxygen into surface waters. Hypoxia can occur throughout the water column as well as near sediments on the bottom. It usually extends throughout 20-50% of the water column, but depending on the water depth, it can occur in 10-80% of the water column. For example, in a 10-meter water column, it can reach up to 2 meters below the surface. In a 20-meter water column, it can extend up to 8 meters below the surface. Oxygen depletion can result from a number of natural factors, but is most often a concern as a consequence of pollution and eutrophication in which plant nutrients enter a lake, and phytoplankton blooms are encouraged. While phytoplankton, through photosynthesis, will raise Dissolved Oxygen (DO) saturation during daylight hours, the dense population of a bloom reduces DO saturation during the night by respiration. When phytoplankton cells die, they sink towards the bottom and are decomposed by bacteria, a process that further reduces DO in the water column. If oxygen depletion progresses to hypoxia, fish kills can occur and invertebrates like freshwater mussels on the bottom may be killed as well.

Dissolved oxygen (DO) - The oxygen content of water. Dissolved oxygen is important for fish and other aquatic life to breathe. For example, water quality guidelines recommend that water should be more than 80 percent saturated with DO for aquatic plants and animals to be able to live in it.

Eutrophic – A trophic level referring to a lake having an abundant accumulation of nutrients that support a dense growth of algae and other organisms, the decay of which may deplete the shallow waters of oxygen in summer resulting in potential death of animal life. In the Trophic Level Index (TLI), a trophic level of 4-5, meaning the water quality is poor.

Exotic species (also called introduced, alien, non-indigenous or non-native) - A species living outside its native distributional range, which has arrived by human activity, either deliberate or accidental. Exotic

species can have various effects on the local ecosystem. Exotic species that become established and spread beyond the place of introduction are called invasive species.

Hapū - Te reo Māori for a sub-tribe or a clan. Each iwi can have a number of hapū. For example, the Ngāti Whātua iwi has hapū including Te Uri-o-Hau, Te Roroa, Te Taou, and Ngāti Whātua ki ōrākei.

Humic - Of, relating to, or derived from humus, which is a dark brown or black mass of partially decomposed organic matter in the soil. Humic acids are present in peats. Humic acids are produced by the bacterial decomposition of dead plant residues and by the prolonged action of atmospheric oxygen or water on organic matter. Run-off from land of this soil type can stain lake-water a dark brown (known as humic or tanin staining), limiting light for plant growth. Forestry harvest has been shown to disturb this soil type, leading to lake water quality decline.

Invasive exotic plant – An exotic species that becomes established and spreads beyond the place of introduction, posing a risk to native ecology.

Invasive Impact Index - The percentage of invasive weeds within a lake. A high Invasive Impact is undesirable.

Invertebrate - An animal that has no backbone or spinal column, such as insects, worms, snails and freshwater mussels.

Lake Submerged Plant Index (SPI) - A method of characterizing the ecological health of lakes based on the amount of native and invasive plants growing in them. Higher Lake SPI scores are associated with the better ecological health.

Limiting nutrient assay – An analytic procedure to determine what nutrient is limiting algal growth in a lake. If the limiting nutrient becomes available, increased growth of algal phytoplankton will occur.

Macrophyte - Large water plants and algae that live in freshwater and are visible to the naked eye, as opposed to the microscopic periphyton and phytoplankton. Macrophytes can be either submerged, floating or emergent. Most macrophytes in Northland are rooted to the bottom.

Mana whenua – Te reo Māori for territorial rights, power from the land, authority over land or territory, jurisdiction over land or territory - power associated with possession and occupation of tribal land. The tribe's history and legends are based in the lands they have occupied over generations and the land provides the sustenance for the people and to provide hospitality for guests.

Mesotrophic - A trophic level of 3-4 meaning the water quality is average. The lake has moderate levels of nutrients and algae.

Native Condition Index - The percentage of native vegetation within a lake. A high native condition is desirable. It is one of the measures used to determine the Lake Submerged Plant Index.

Native species (also indigenous species) - A species found naturally in an ecosystem, including naturally-arriving migrant species which may be found in other countries as well. Endemic natives are found only in one place or country.

Non-invasive exotic plant - Exotic species of plants that become established and do not readily spread beyond the place of introduction, posing little threat to native species.

Oligotrophic - A trophic level of 2-3 meaning the water quality is good. The lake has low levels of nutrients and algae, high oxygen levels due to a lack or decaying organic material. The lake is clear and blue, with very low levels of nutrients and algae.

pH - The degree of acidity or alkalinity as measured on a scale of 0 to 14 where 7 is neutral, less than 7 is more acidic, and greater than 7 is more alkaline. Most natural waters fall within the range between pH 6.5 to 8.0 and in the absence of contaminants most waters maintain a pH value that varies only a few tenths of a pH unit.

Phytoplankton - Microscopic algae and cyanobacteria that drift or float in the water column and are able to produce oxygen through

photosynthesis. When overgrowth or algal bloom occurs, it is an indication that excess nutrients are a problem. Algal blooms can shade light from reaching submerged plants and if a bloom collapses, deoxygenation of the water may occur.

Quaternary dunes – We are currently still living in the Quaternary period of geological time. The Quaternary period is subdivided into the Pleistocene epoch (2.6 million years ago to 11,700 years ago), the Holocene epoch (11,700 years ago to 1950) and the Anthropocene epoch (1950-present or the period when the Industrial Revolution began to alter climate). When we refer to dune sand types, they are informally divided into Early/Lower Quaternary (dunes formed 2.6 million-78,000 years ago) and Late/Upper Quaternary (dunes formed 12,000 years ago to the present, basically during the Holocene epoch).

The material in present-day river valleys and beaches has been mainly deposited since the last glacial stage ended, about 14 000 years ago. From then, until about 6000 years ago, there was a substantial warming of climate which caused a rise in sea level; some dune deposits are recognised as having formed at the time that sea level rise ended.

Sea level has dropped again slightly since that time. Lakes are collecting mud and sand and will eventually fill. Sand dunes naturally advance, blown by the wind until stabilised by vegetation.

Periods of cold climate occurred throughout the Quaternary, not only in New Zealand but globally. The worldwide glaciations caused sea level to drop, as much water was bound up in ice and snow. During warmer interglacial periods, the ice melted and sea level rose. The effect of these oscillating sea levels is clearly seen in uplifted coastal terraces, each flat surface marking the position of an earlier high sea level. Periods of low sea level and cold climate created expanses of bare earth and sand with little vegetation. Winds blew the coastal sand into dunes. In the North Island, there was little active glaciation except in the very highest mountain areas. The build-up of sand dunes was a result of low sea levels and cold climate.

Rare native plant - A rare plant is one that is not commonly found in the wild. It may be naturally rare or sparse or may have a restricted range. Rare plants may or may not be of conservation concern. A threatened plant is a rare plant which is at risk of extinction in the wild. An endangered plant is a category of threatened plant. It is a technical term for describing the degree of risk of extinction a plant is under. Some technical terms, such as endangered, are commonly and inaccurately used to refer to all threatened plants.

Residence time (also retention time, water age or flushing rate) – A calculated quantity expressing the mean time that water spends in a particular lake.

Riparian zone - A strip of land, usually of varying width, that is directly adjacent to a waterway and which contributes to maintaining and enhancing the natural functioning, quality, and character of the waterbody. This area is commonly planted in native species to reduce sediment and nutrient inflows.

Sp. aff. or aff. (short for "species affinis") indicates a potentially new and undescribed species has an affinity to, but is not identical to, the named species. ... spp.; short for "species") indicates potentially new species without remarking on its possible affinity.

Secchi disk - Lake clarity is measured using a Secchi disc attached to a measured line. The disc is lowered into the water until it disappears and this depth is noted. The disc is lowered a little further and then slowly raised until it reappears, this depth is noted. The average of the two readings is the final Secchi depth visibility depth.

Supertrophic - A trophic level greater than 5 meaning the water quality is very poor. The lake is fertile and saturated in phosphorus and nitrogen, often associated with poor water clarity.

Thermal stratification - Refers to a change in the lake water temperature at different depths in the lake, and is due to the change in water's density with temperature. Cold water is denser than warm water and the epilimnion, or shallower waters, generally consists of water that is not as dense as the water in the hypolimnion, or deeper waters. When stratification

occurs, the two water masses are not mixing, leading to nutrients and lower oxygen levels being captured in deeper, colder water. This generally occurs in warmer months. When the upper water cools in colder months, mixing will occur, providing nutrients throughout the lake, which can lead to algal bloom conditions.

Total Phosphorus (TP) - Total phosphorus is a measure of all forms of phosphorus that are found in a sample, including dissolved and particulate, organic and inorganic. High levels of total phosphorus in water can come from either wastewater or run-off from agricultural land. Too much phosphorus can encourage the growth of nuisance plants such as algal blooms.

Total Nitrogen (TN) - Total Nitrogen is a measure of all organic and inorganic forms of nitrogen that are found in a sample. High total nitrogen, like total phosphorus can be a cause of eutrophication in lakes, estuaries and coastal waters and can cause algal blooms.

Total Suspended Solids (TSS) - Solids in water that can be trapped by a filter for measurement. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can adversely affect aquatic life.

Trophic Level Index (TLI) - Used in New Zealand as a measure of nutrient status of lakes. The TLI is calculated from data from 4 parameters: water clarity (Secchi), chlorophyll a content, total phosphorus and total nitrogen.

Volumetric flow rate (as a mean annual total) - The amount of water entering a lake in a year, expressed in m3/s or cubic meters per second.

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