Lake Morehurehu

MANAGEMENT PLAN

Northland
REGIONAL COUNCIL

CONTENTS

LAKE MOREHUREHU MANAGEMENT PLAN

1. PURPOSE

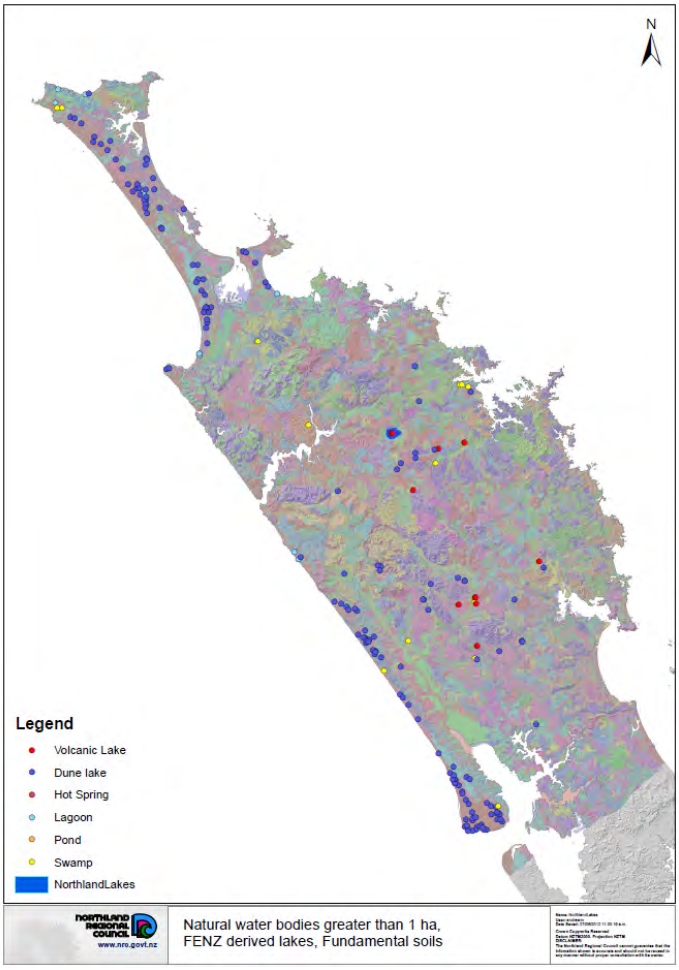
The purpose of the Outstanding Northland Dune Lakes Management Plans is to implement the recommendations of the Northland Lakes Strategy Part II (NIWA 2014) by producing Lakes Management Plans, starting with the 12 'Outstanding' value lakes, and by facilitating actions with mana whenua iwi, landowners 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.

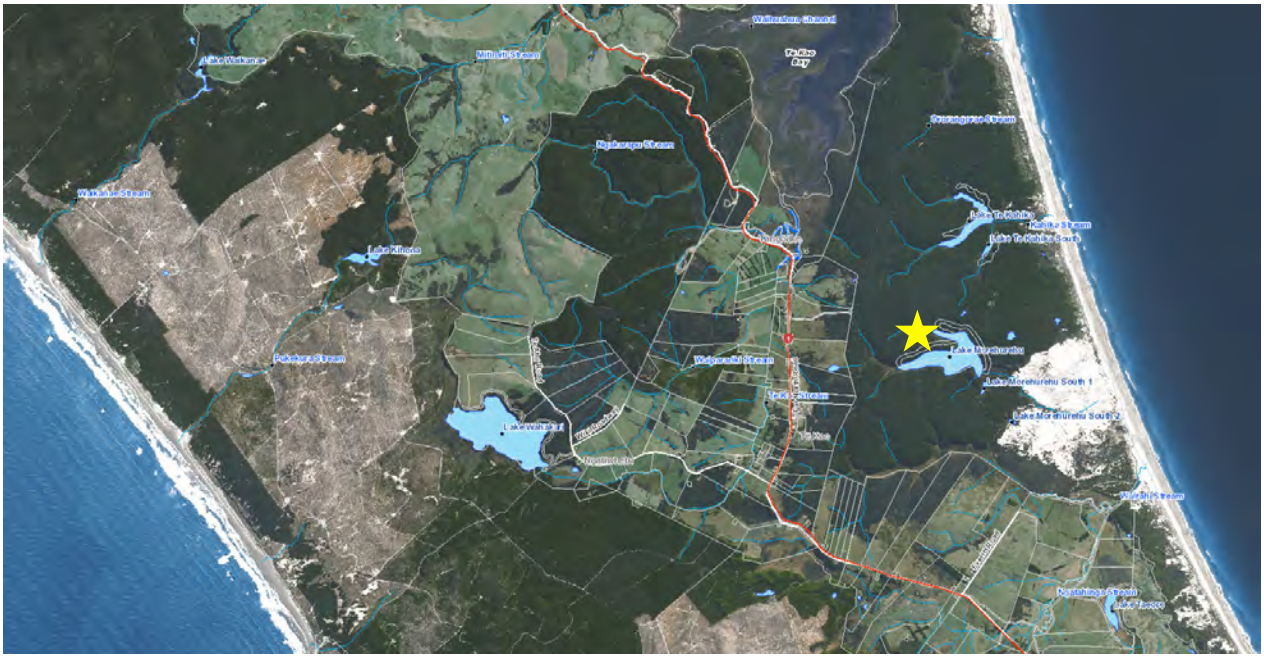
Further south within Northland, on the west coast north of Dargaville, are the three Kai Iwi Lakes (Lake Kai Iwi itself, and Lakes Taharoa and Waikare, sometimes referred to as Waikere).

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 Morehurehu (NRC Lake Number 32) is a deep, 14.0 ha (14.91 m maximum and 6.94 mean depth) dune lake located in the forestry blocks on the Northern Aupōuri Peninsula in Far North Northland, east of Route 1 and south of Parengarenga Harbour. The lake is classified as a Class 4 Dune Contact dune lake (Timms, 1982), meaning it sits with one shore in contact with coastal dunes. There are three inlet streams from the southwest, northwest and southeast. The lake is connected to Lake Morehurehu South No. 1 via a stream through a wetland. There is an outlet at the south-eastern end through wetland to the sea.

The lake is situated in a catchment dominated by harvested pine forest, exotic forest, sand or gravel, high manuka/kanuka scrub and freshwater sedgeland/ rushland. The NRC-derived catchment area, including the lake itself, is 426.7 ha. The surface area of the lake is 14.0 ha.

The lake does not thermally stratify, increasing nutrient availability through the year. Although algal blooms have declined as a trend, chlorophyll-a continues to oscillate through State B, pulsing occasionally into State C and peaking in February 2015. These periods are likely due to decreases in humic staining, allowing light to fuel phytoplankton growth. Humic staining has been an issue after forestry harvest and may be due to run off from disturbed peat gumland soils.

Nitrogen levels have historically been in state B but rose over the period from August 2011 to November 13 into State C, since returning to State B. Phosphorus follows a similar trend to nitrogen, except with greater activity in 2006 and 2008. A large mode from August 2011 until February 2013 saw only a brief peak in State C from state B. Despite these issues Morehurehu remains largely high mesotrophic (average water quality) touching upon the eutrophic (poor water quality) line.

There is a deoxygenation phase in summer and spring below 6.5 m depth. The pH has gradually dropped (increased acidity) from a starting point in 2006 being fairly neutral. This trend is likely to be due to humic acids leaching into the lake from the effects of disturbance of peat soils and iron pans during forestry harvest.

No lake level data exists for this lake. A staff gauge is due to be installed in early November 2017.
The lake hosts 30 native aquatic plants, the highest diversity of any lake on Aupōuri Peninsula, and only one exotic non-invasive plants; the bladderwort *Utricularia gibba*. Morehurehu and its margins contain four rare native plants; *Dianella haematica, Drosera pygmaea, Todea Barbara* and *Utricularia australis*. The Invasive Impact Index follows a trend in the invasion of the lake by *Uticularia gibba*. It progressively increased from 2005 to 2009, displacing the rare native *Utricularia australis*.

Extensive loss of aquatic habitat and biodiversity appears to be coupled with pine harvesting in the catchment since 2009. In 2013 all plants died back after the lake became humic-stained a dark red-brown colour to the point that light incidence limited plant growth. This staining was most likely associated with runoff and leaching associated with forestry harvest and disturbance of soils in the catchment and remains an issue.

Similar staining also occurred in the nearby lakes Te Kahika and Morehurehu South No. 2 as well as in the Parengarenga Harbour after heavy rains. Interestingly, there has been no harvest close to Morehurehu No. 2, a small lake closer to the coast, so presumably the staining was transported via shallow groundwater.

By 2014 *U. gibba* had become the dominant species. Native Condition Index and Submerged Plant Index reflect this event, declining as *U. gibba* increased in dominance and crashing along with the die-off of plants after the staining event in 2013. In 2009, the native plant community had a similar composition to what was present in a 1988 survey, except that *U. gibba* was absent in 1988. Recovery has been slow due to the persistence of the staining.

The lake has a moderate level of native fish diversity and no pest fish are present. Common bully, short-finned eel and inanga are present.

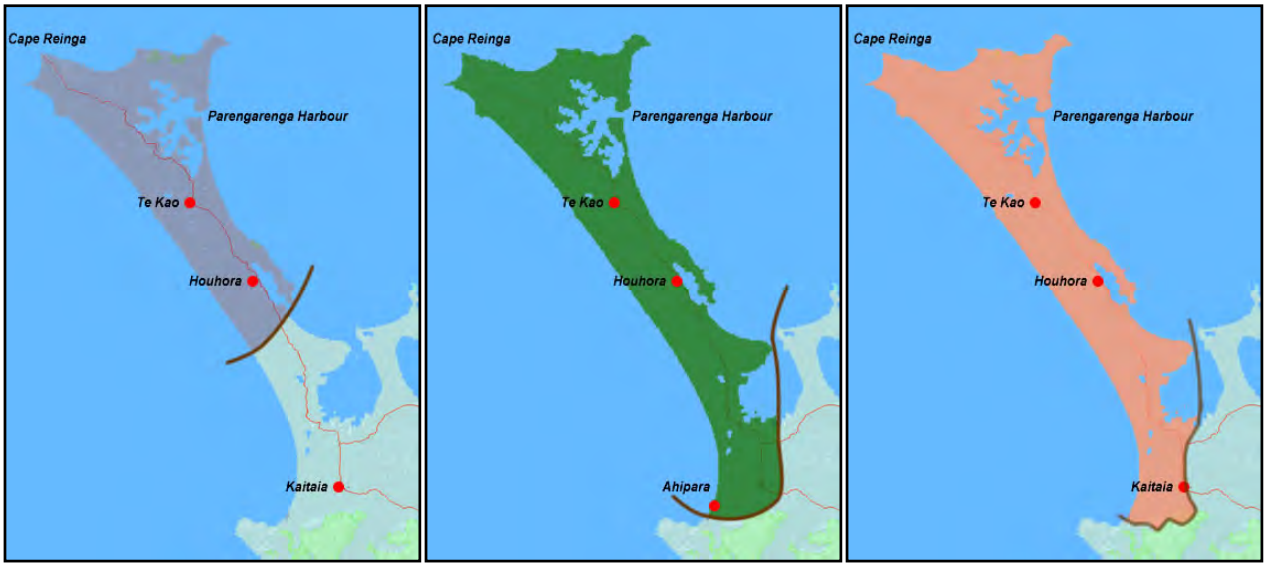
The lake has a low level of native bird diversity (fernbird and Australasian bittern) and could be a low-use game-bird hunting site (mallard) and Canada geese as a hunted non-game bird which threatens lakes with over-nutrification when numbers grow.

5. SOCIAL AND CULTURAL DIMENSION

5.1. Mana whenua

Three mana whenua groups have rohe whenua Area of Interest in the area of Lake Morehurehu; Ngāti Kurī (grey), Ngāi Takoto (green) and Te Aupōuri (pink).

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

Six landowners own six parcels within the lake catchment. The lake bed is privately owned.

5.3. Community involvement

Due to its remote nature in the forestry blocks, the lake is not part of any community activity.

5.4. Public use

5.4.1. Access

Access to the lake is difficult through forestry tracks by 4WD with steep, loose sand. Permission is required.

5.4.2. Boating

5.4.2.1. Boat access

Trailer boat access is difficult due to the loose sand at the launch point.

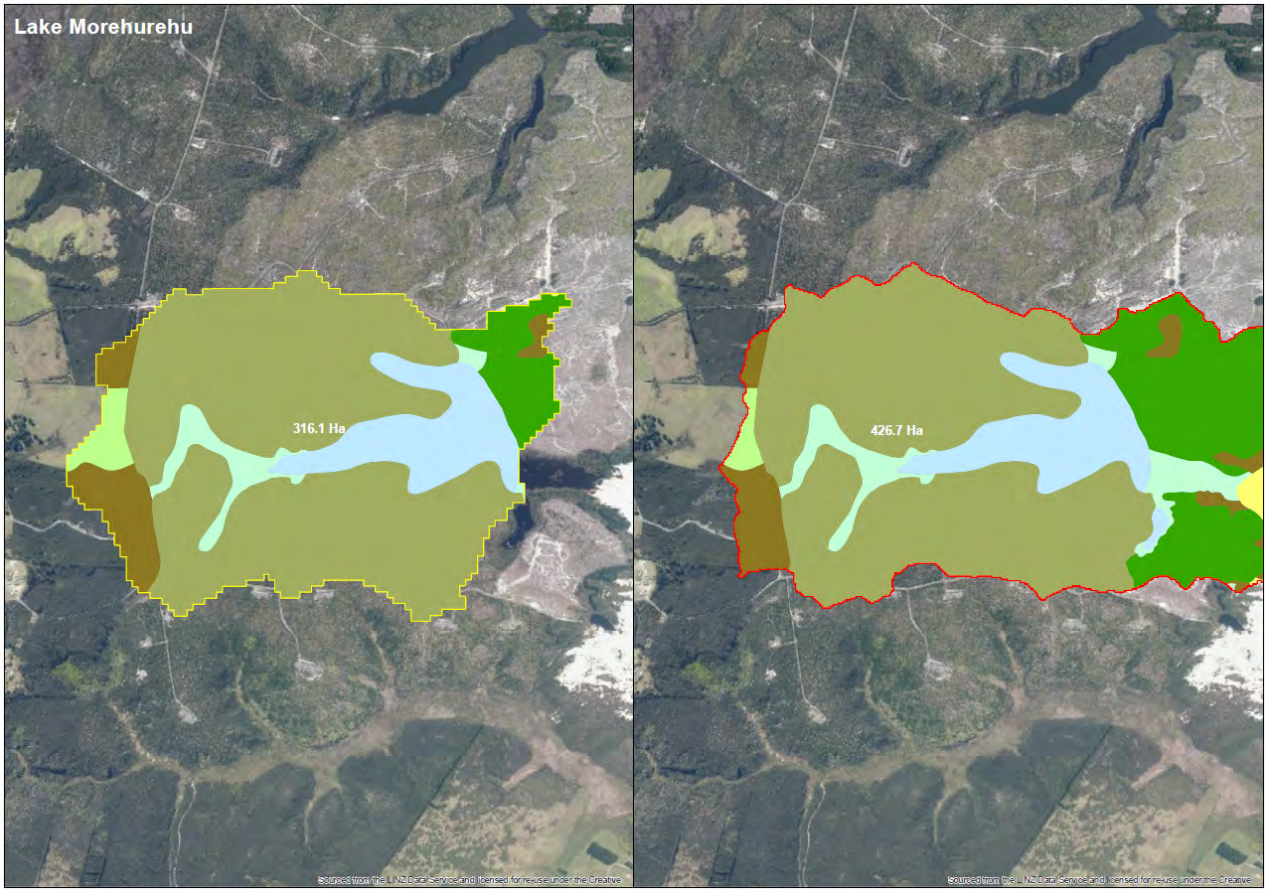
5.4.2.2. Duck shooting

Though not a specific Fish and Game Council hunting site, it is likely that hunters use the lake and that Fish and Game manage this activity on behalf of Hancock Forest Management.

6. PHYSICAL CHARACTERISTICS

6.1. Catchment Area with Map

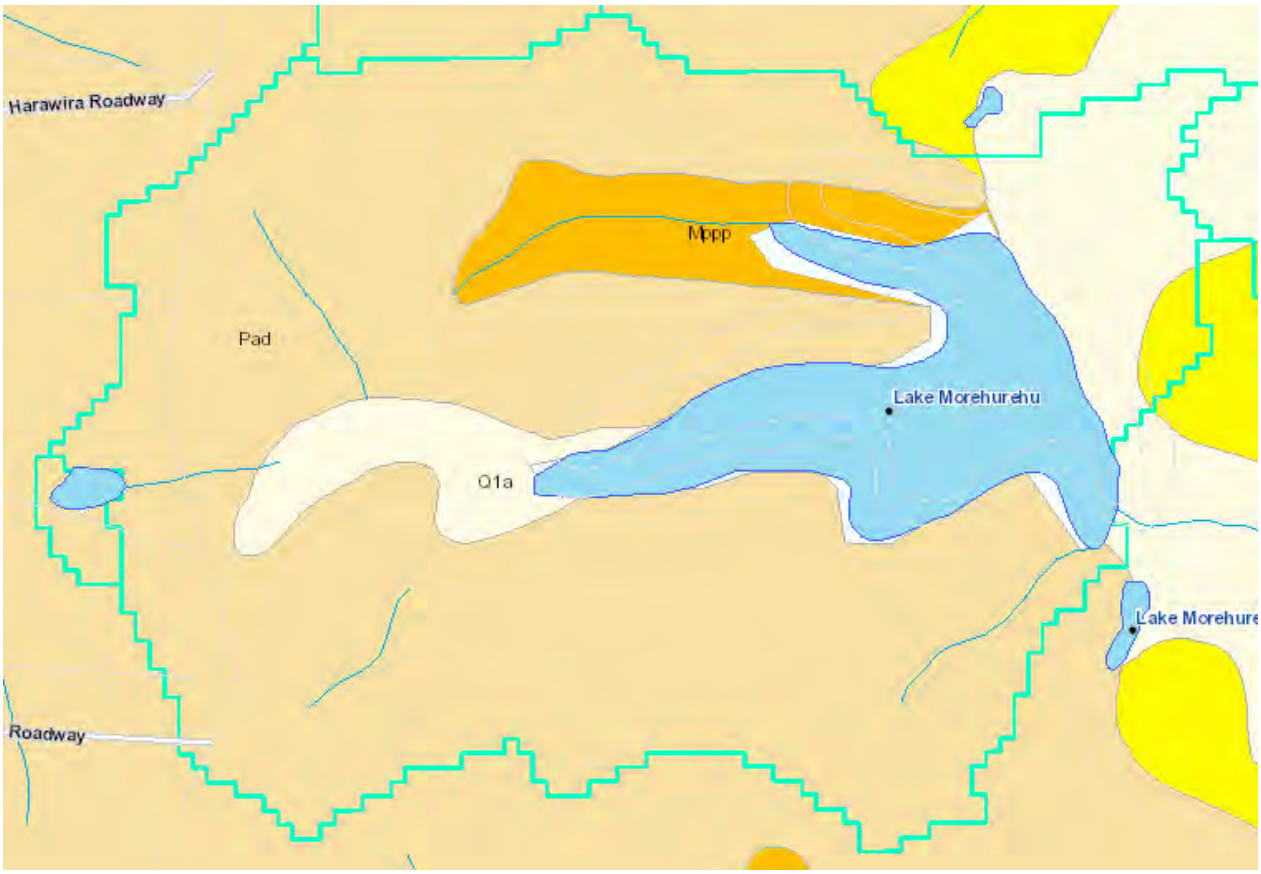
The following image shows the extent of the lake catchment. On the left is the FENZ catchment boundary and a rationalised boundary created by NRC staff appears on the right. By the end of 2018, a highly-accurate LiDAR catchment boundary will be available. The NRC-defined catchment area, including the lake itself, is 426.7 hectares.



- Built-up Area (settlement)
- Surface Mines and Dumps
- Lake or Pond
- Short-rotation Cropland
- High Producing Exotic Grassland
- Low Producing Grassland
- Herbaceous Freshwater Vegetation
- Flaxland
- Gorse and/or Broom
- Manuka and/or Kanuka
- Broadleaved Indigenous Hardwoods
- Mixed Exotic Shrubland
- Forest - Harvested
- Indigenous Forest
- Exotic Forest

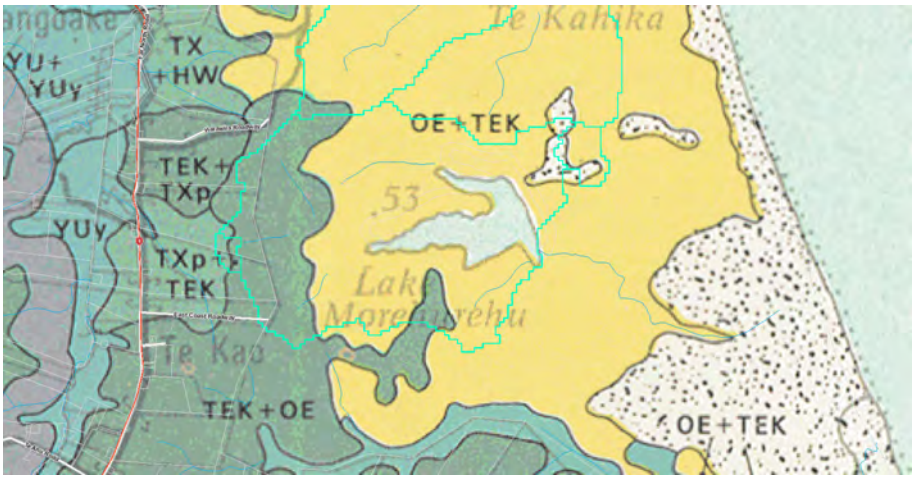
6.2. Catchment Geology and soil types

The following map ((C) GNS Science 2016) of the Aupōuri Peninsula and table, below, shows the geological history of the lake catchment. Morehurehu has a geology of Awhitu group Late Pliocene to Early Quaternary sand with the northern and western arms of the lake on Early and Late Quaternary dune sand.



Lake Name/Plot Symbol	eQd	lQd (Q1d)	lPld (lPad)
Morehurehu	x	x	x
Name	Early Quaternary dunes	Late Quaternary dunes	Awhitu Group
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.	Loose to poorly consolidated sand in mobile and fixed dunes locally with paleosols and peat. Minor sand, mud and peat in interdune lake and swamp deposits.	Cemented dune sand and associated facies.
Geologic history	Early Quaternary	Late Quaternary	Late Pliocene to Early Quaternary
Simple name	Zealandia Megasequence Terrestrial and Shallow Marine Sedimentary Rocks (Neogene)	Zealandia Megasequence Terrestrial and Shallow Marine Sedimentary Rocks (Neogene)	Zealandia Megasequence Terrestrial and Shallow Marine Sedimentary Rocks (Neogene)
Absolute minimum age (millions of years before present)	0.78	0	0.78
Absolute maximum age (millions of years before present)	2.6	0.12	3.6
Supergroup equivalent stratigraphic name	Pakihi Supergroup	Pakihi Supergroup	Pakihi Supergroup
Terrane equivalent name			
Lithology	sand	sand	sand

Soil type in the catchment is portrayed in the soil map and table below. The lake is sitting within a soil type of Ohia yellow-brown sands (OE) and Te Kopuru sand podzols (TEK) forming a silica and iron pan.



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.
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.

6.3. Catchment Hydrogeology

Although the Aupōuri sands hold an extensive groundwater aquifer, Morehurehu is a Class 4 Dune Contact dune lake, perched above the water table.

6.4. Catchment drainage and sedimentation rates

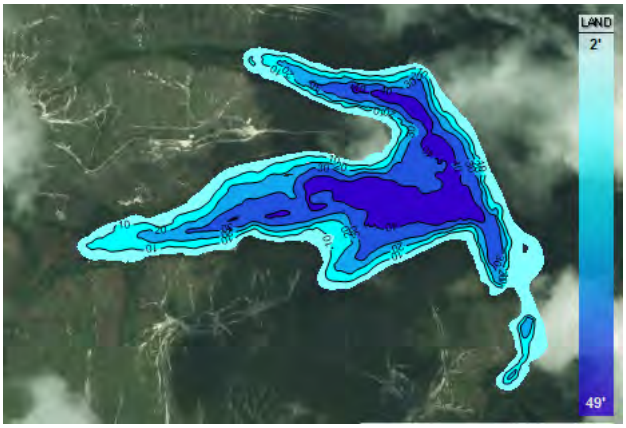
The NRC-defined catchment area, including the lake itself, is 426.7 hectares and produces a mean annual flow, based on hydrological models, of 1,309,126.7 m³/year. The lake has an estimated lake residence time of 1.281 years, meaning any water entering the lake will remain for just under 15 months. The average particle size of surface rock in the catchment is 1.95 on a scale of 5, a value of 1 being sand (FENZ database).

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

In common with other dune lakes on the Aupōuri Peninsula (Bulrush to the south, Morehurehu South 2, Te Kahika, Kihona and Pretty, Austria, Te Paki Dune, Ngakeketo south and North, Te Warahi and the Waitahora Lakes to the north), Morehurehu is a Class 4 Dune Contact dune lake. The lake has a maximum depth of 14.91 m with a mean overall depth of 6.94 m. The surface area of the lake is 14.0 hectares with a volume of 3,129,515.80 m³. The NRC-defined catchment area, including the lake itself, is 316.44 hectares.

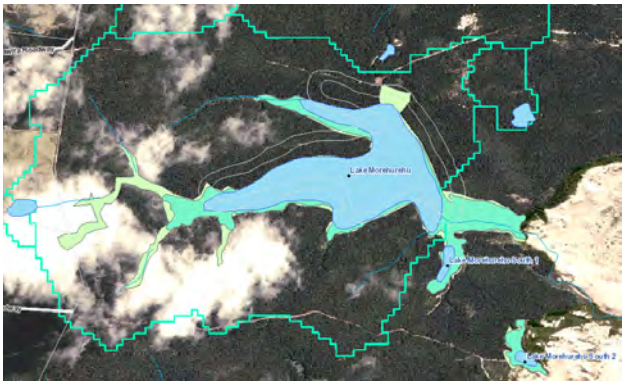
6.6. Bathymetry map

The following bathymetric depth map comes from a survey done by NIWA for the NRC. Morehurehu's deepest point is the single west-central 14.91 m basin which extends into the north-west arm.
Please note that the scale of this map is in feet, not meters.



6.7. Natural inlets and outlets

There are three inlet streams from the southwest, northwest and southeast. The lake is connected to Lake Morehurehu South 1 via wetland. There is an outlet at the south-eastern end through wetland to the sea. This outlet has become blocked within the last ten years, causing inundation of the pines and low-lying ground connected to the lake to the east.



6.8. Wetland associations

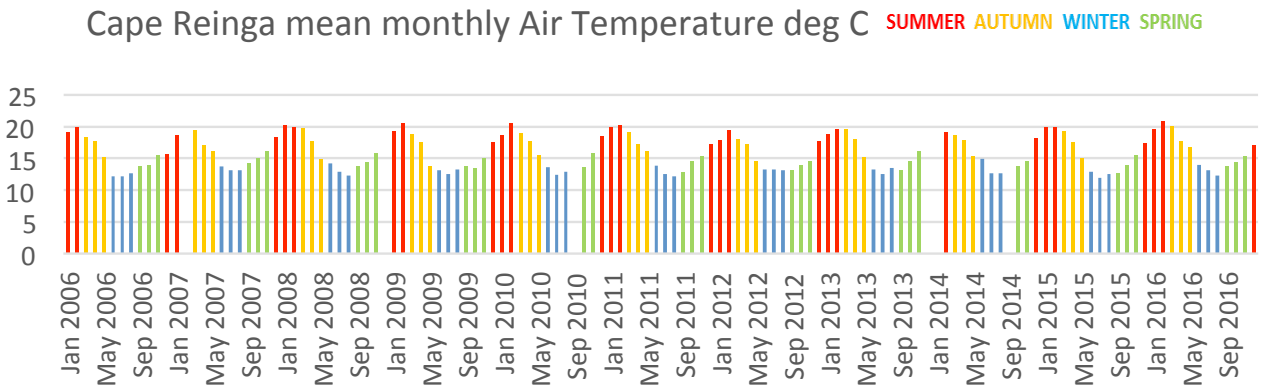
Morehurehu is fringed by a wetland, including areas of "Top 150" wetland.

6.9. Connectivity

The lake is connected to Lake Morehurehu South No. 1 via a stream within a wetland.

6.10. Air Temperature

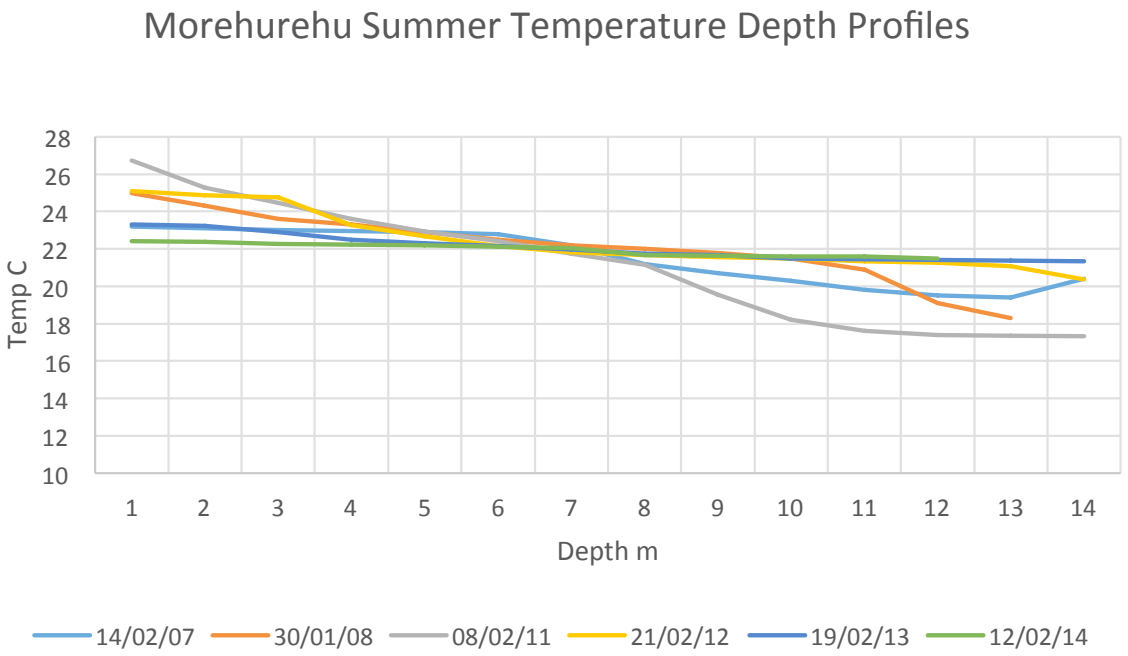
Air temperature recordings taken at Cape Reinga are used as a proxy.

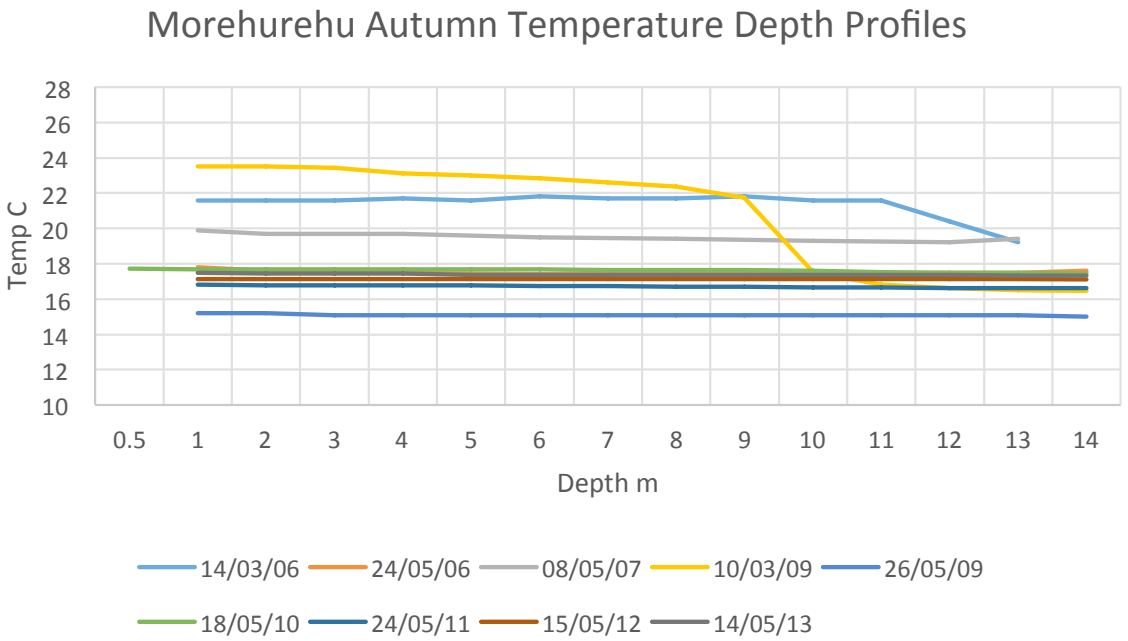


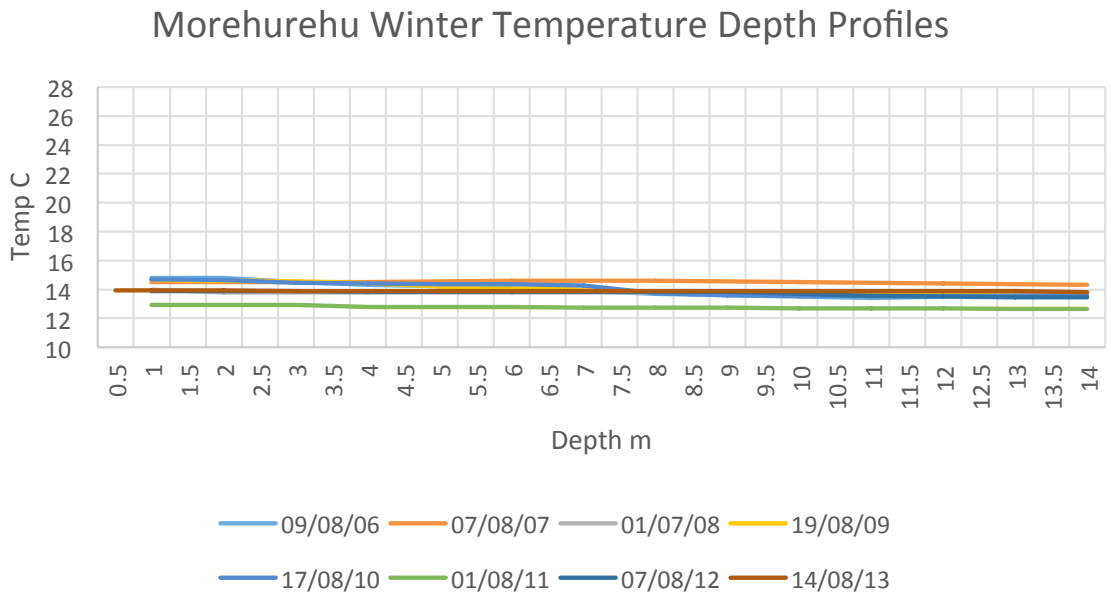
6.11. Thermal stratification

The graphs below show temperature at depth throughout the water column, by season. Each coloured line represents one sample. Water temperatures throughout the year range from 12.65 degrees C to 26.74 degrees C.

Although the lake is deeper than 10 m, at which some lakes thermally stratify, it is still relatively shallow and does not show a marked thermal stratification. Some temperature change is noted at 8-9 m in warmer months.






Morehurehu Winter Temperature Depth Profiles
Temp C
28
26
24
22
20
18
16
14
12
10
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
14
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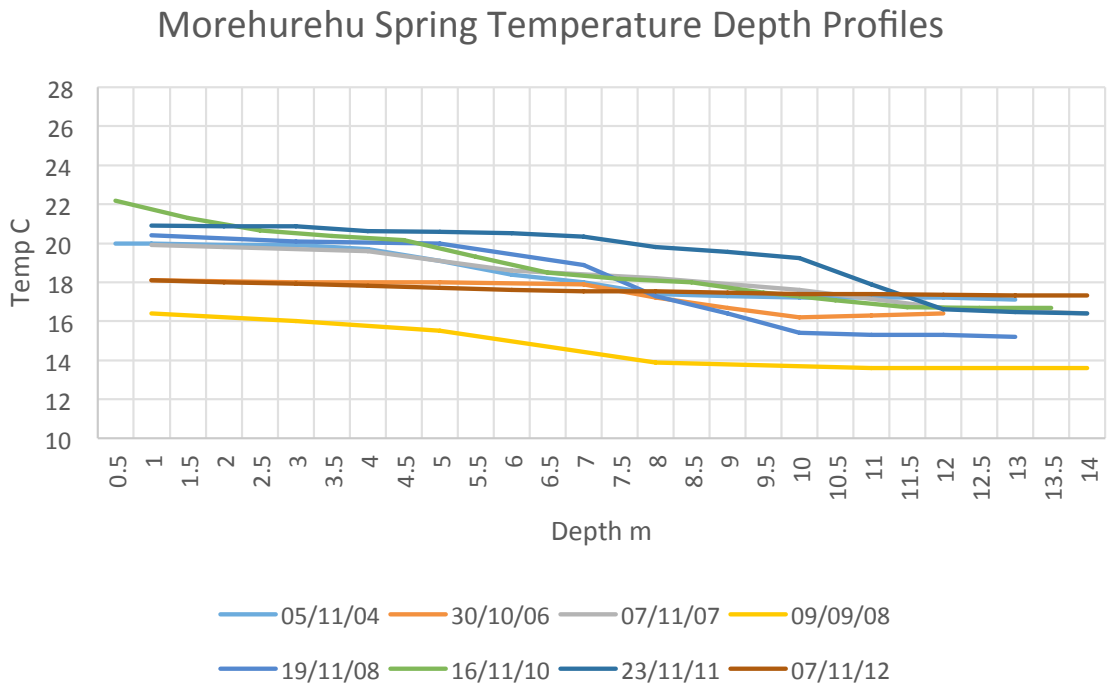
17/08/10
01/08/11
07/08/12
14/08/13


Morehurehu Spring Temperature Depth Profiles
Temp C
28
26
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22
20
18
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14
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2
2.5
3
3.5
4
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8
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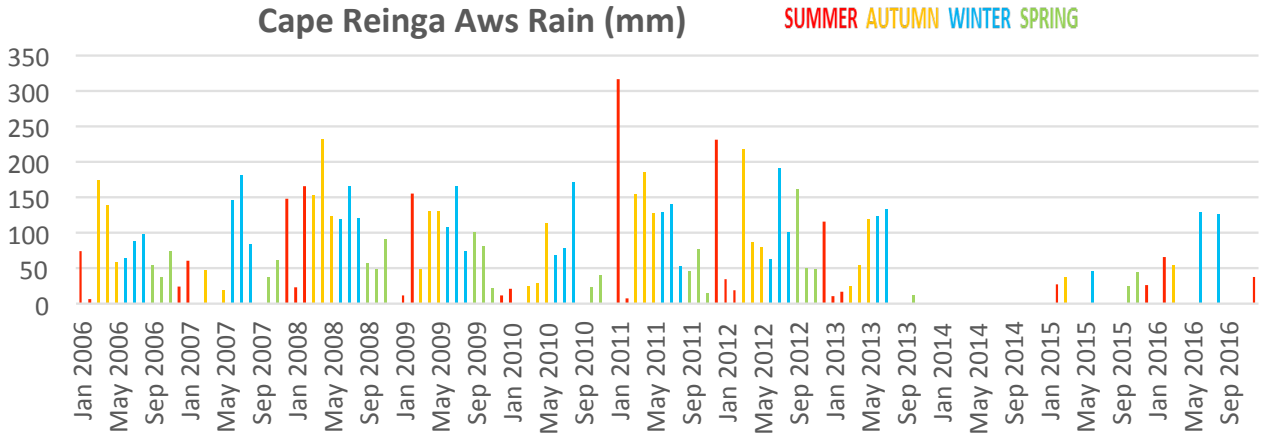
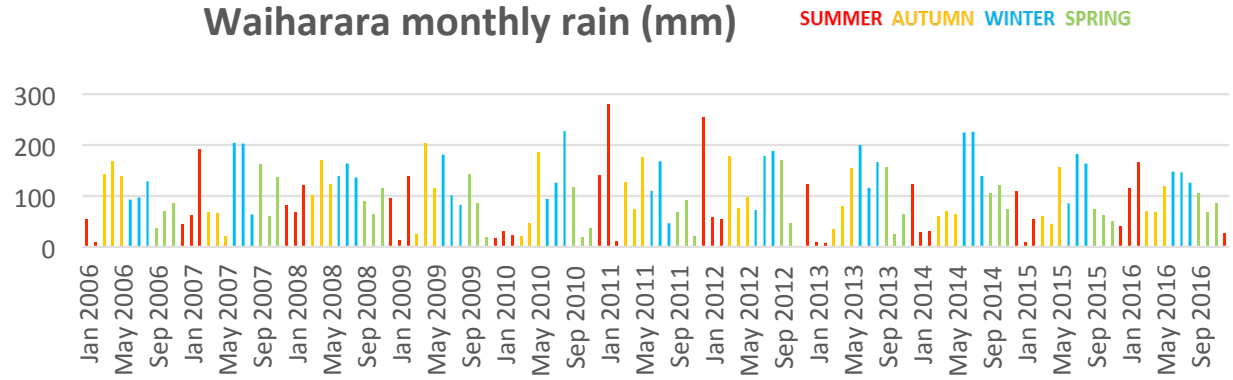
9
9.5
10
10.5
11
11.5
12
12.5
13
13.5
14
Depth m
05/11/04
30/10/06
07/11/07
09/09/08
19/11/08
16/11/10
23/11/11
07/11/12

6.12. Rainfall and drought

Local weather data recorded at Cape Reinga has major gaps. Monthly rainfall with zero values (e.g. 2014) are data gaps.

Waiharara (south) rain data, recorded approximately 38 km to the south, is shown below to show the trend missing from the Cape Reinga data gaps.





6.13. Lake level

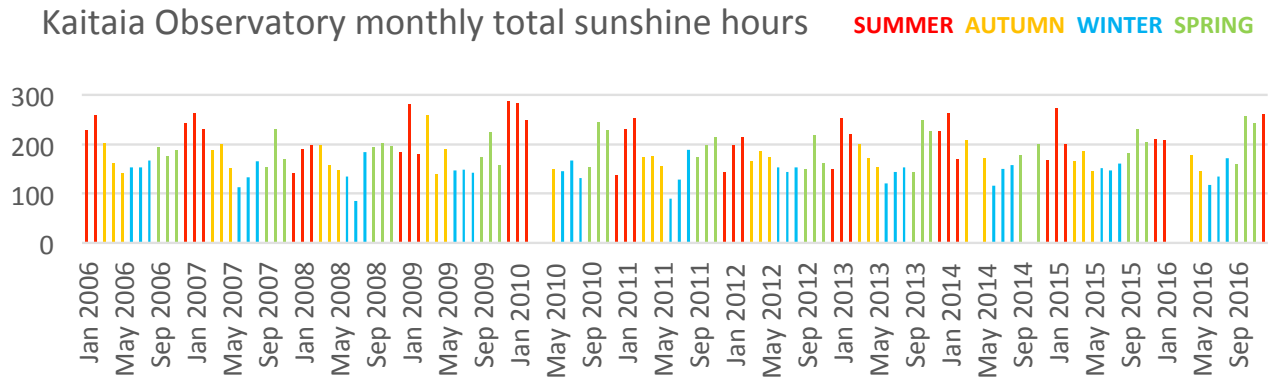
No lake level data exists for this lake. A staff gauge is due to be installed.

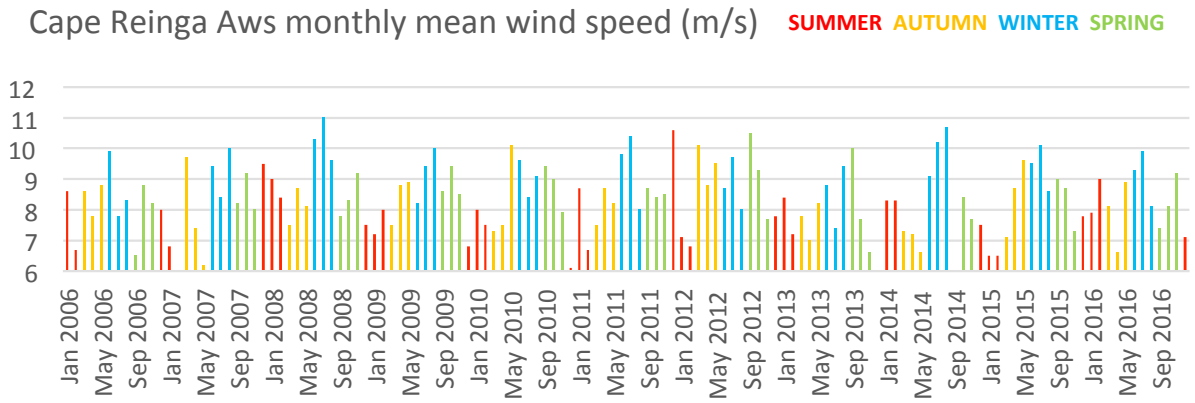
6.14. Sunshine

Recording of sunshine hours data collected at Kaitaia are used as a proxy.

6.15. Wind speed

Cape Reinga wind speed recordings are used as a proxy.

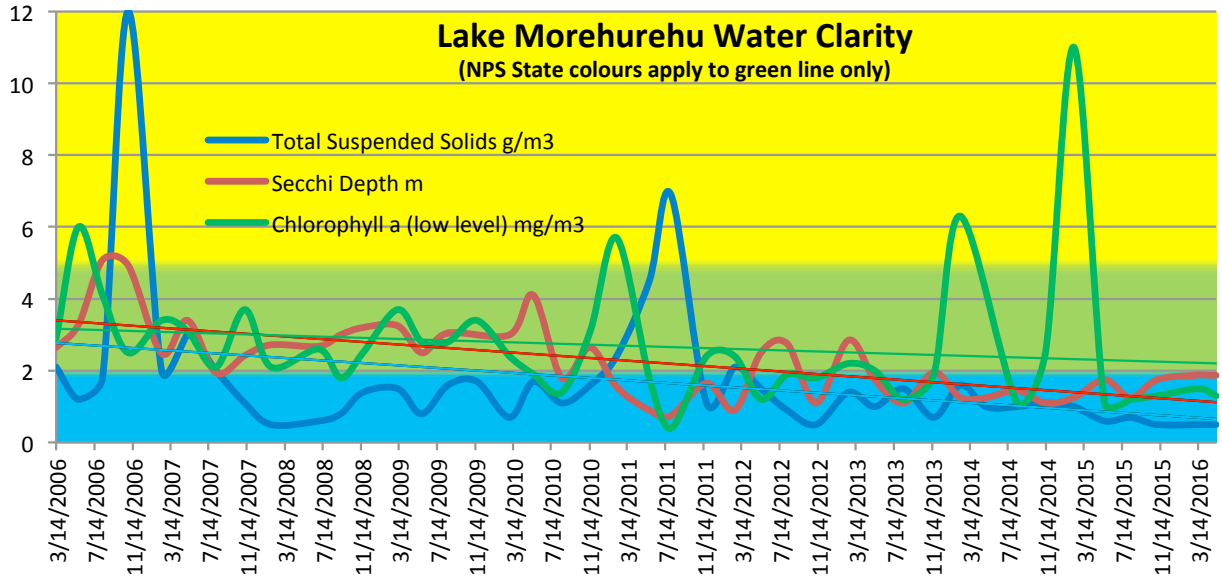




6.16. Light incidence (Secchi, Total Suspended Solids, Chlorophyll-a)

Three measures which are indicators of water clarity include chlorophyll-a (presence of micro-algal growth in the water column, total suspended solids and the direct measure of visibility at depth by lowering a black and white Secchi disk until it is no longer visible. The graph below shows that Morehurehu has experienced both a peak in algal blooms (green line) and a loss of visibility (Secchi) in February 2014. Other Chlorophyll-a (algal bloom) and Total Suspended Solids peaks occurred in the first half of 2006 and 2011. All these events are likely associated with soil disturbance from forestry activity in the catchment.

The table below the graph shows the National Policy Statement for Freshwater Management states for phytoplankton (chlorophyll-a). Chlorophyll-a tends to trend in State B, pulsing occasionally into State C, peaking in February 2015.



Attribute	Unit	Lake Type	State	Annual Median	Annual Maximum	Narrative State
Phytoplankton	mg Chlorophyll-a/m³	All	A	≤2	≤10	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Phytoplankton	mg Chlorophyll-a/m³	All	B	>2 and ≤5	>10 and ≤25	Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrients levels that are elevated above natural reference conditions.
Phytoplankton	mg Chlorophyll-a/m³	All	C	>5 and ≤12	>25 and ≤60	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrients levels that are elevated well above natural reference conditions. Reduced water clarity is likely to affect habitat available for native macrophytes.
Phytoplankton	mg Chlorophyll-a/m³	All	National Bottom Line	12	60	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrients levels that are elevated well above natural reference conditions. Reduced water clarity is likely to affect habitat available for native macrophytes.
Phytoplankton	mg Chlorophyll-a/m³	All	D	>12	>60	Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes.

7. CHEMICAL CHARACTERISTICS

7.1. Water Quality

7.1.1. Nutrients

7.1.1.1. Limiting nutrient assay

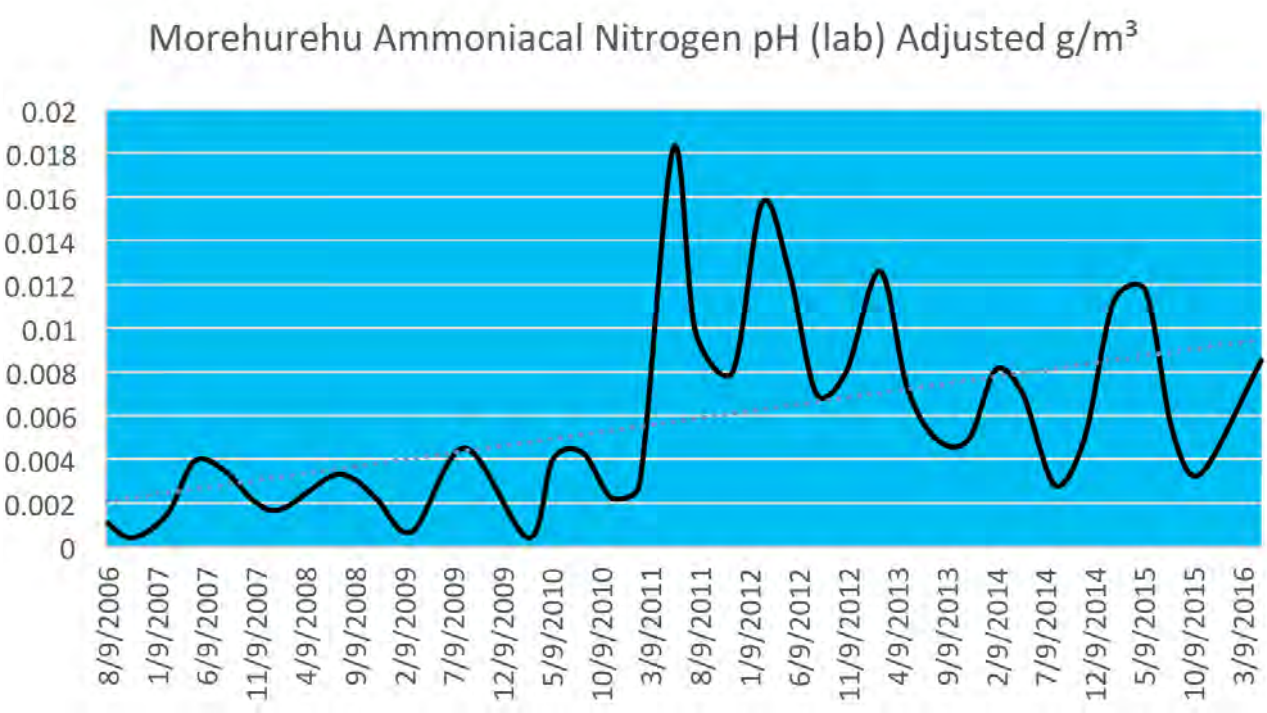
Max Gibbs (pers. comm.) from NIWA conducted limiting nutrient assays on several lakes, including Morehurehu. Significant results are highlighted. For the years and seasons assayed, phosphorus is the limiting nutrient in summer. Lack of this nutrient regulates the ability of plants to optimally grow.

7.1.1.2. Ammoniacal Nitrogen (Toxicity)

Ammoniacal nitrogen (NH4-N), also often called 'ammonium', covers two forms of nitrogen; ammonia (NH3) and ammonium (NH4). It enters waterways primarily through point source discharges, such as raw sewage or livestock effluent. It is toxic to aquatic life at high concentrations.

The table following the graph shows the National Policy Statement Freshwater Management limits for lake state. Morehurehu has remained in State A or low ammonia toxicity levels, but with an increasing trend.

	Autumn 2014	Summer 2015	Autumn 2014	Summer 2015	Autumn 2014				Summer 2015		
Lake	Initial Chla	Initial Chla	Change in	Change in	Proportional change over control				Proportional change over control		
	(mg m^{-3})	(mg m^{-3})	Control	Control	+N	+P	+N+P	NP-P	+N	+P	+N+P
Morehureru	1.5	2.6	0.81	0.92	1.01	1.08	0.98	-0.11	1.00	1.25	1.25

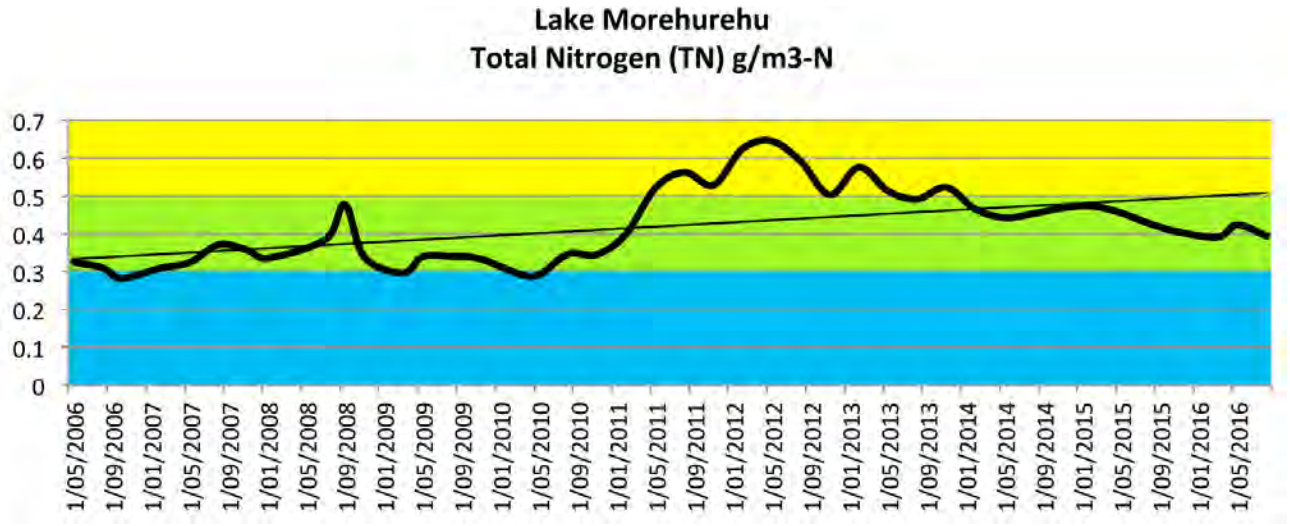


Attribute	Unit	Lake Type	State	Annual Median	Annual Maximum	Narrative State
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	A	≤0.03	≤0.05	99% species protection level: No observed effect on any species tested
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	B	>0.03 and ≤0.24	>0.05 and ≤0.40	95% species protection level: Starts impacting occasionally on the 5% most sensitive species
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	C	>0.24 and ≤1.30	>0.40 and ≤2.20	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	National Bottom Line	1.3	2.2	80% species protection level: Starts impacting regularly on the 20% most sensitive species (reduced survival of most sensitive species)
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	D	>1.30	>2.20	Starts approaching acute impact level (ie risk of death) for sensitive species

7.1.1.3. Nitrogen

Total nitrogen levels pulsed slightly in September 2008. This was followed by a multiple-year increase from August 2011 until November 2013, likely due to the effects of forestry harvest and runoff. Peak rainfall in the summers of 2011 and 2012 will have contributed to additional nitrogen transport in this runoff.

The table following the chart shows the National Policy Statement for Freshwater Management limits for lake state. The nitrogen trend is increasing with a history largely in State B, apart from a multi-modal event which took the lake into State C, peaking in February 2012.

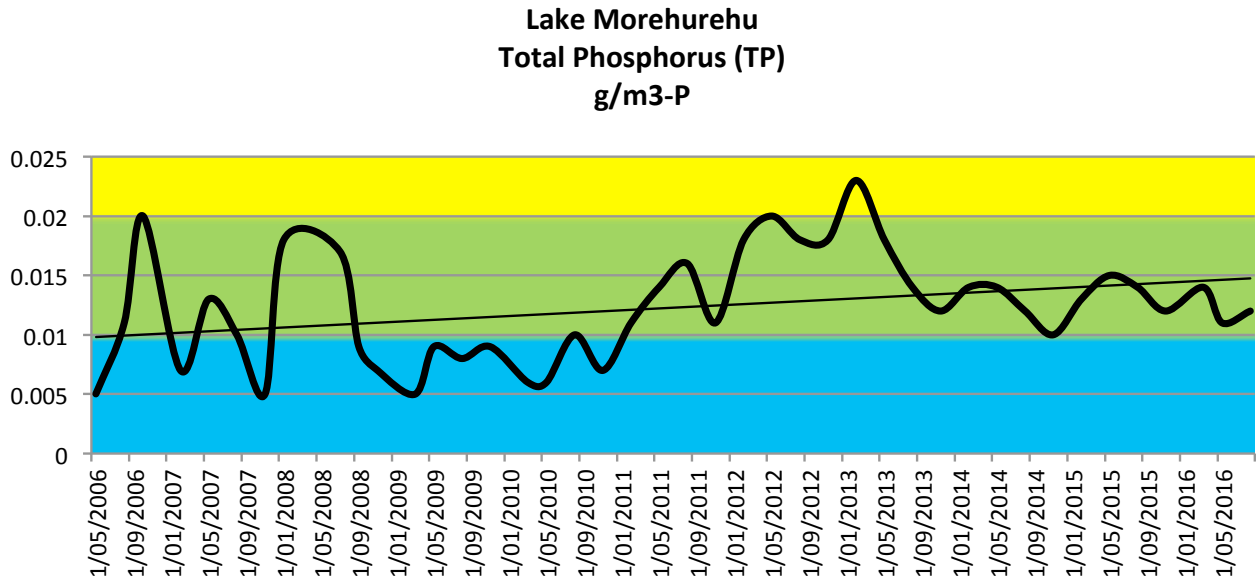


Attribute	Unit	Lake Type	State	Annual Median	Narrative State
Total Nitrogen (Trophic state)	g/m3	Polymictic	A	≤.3	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Total Nitrogen (Trophic state)	g/m3	Polymictic	B	>.3 and ≤.5	Lake ecological communities are slightly impacted by additional algal and/or plant growth arising from nutrients levels that are elevated above natural reference conditions.
Total Nitrogen (Trophic state)	g/m3	Polymictic	C	>.5 and ≤.8	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrients levels that are elevated well above natural reference conditions.
Total Nitrogen (Trophic state)	g/m3	Polymictic	National Bottom Line	0.8	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrients levels that are elevated well above natural reference conditions
Total Nitrogen (Trophic state)	g/m3	Polymictic	D	>.8	Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes.

7.1.1.4. Phosphorus

Total phosphorus follows a similar trend to nitrogen above, except with greater activity in 2006 and 2008. The large mode from August 2011 until February 2013 follows a similar trend to nitrogen. Again, soil disturbance associated with forestry harvest probably led to increased sediment runoff in the catchment, leading to phosphorus release to the lake.

The table following the chart shows the National Policy Statement for Freshwater Management limits for lake state. The phosphorus trend is increasing with levels tending to remain in State B recently, after a minor mode into State C in February 2013.

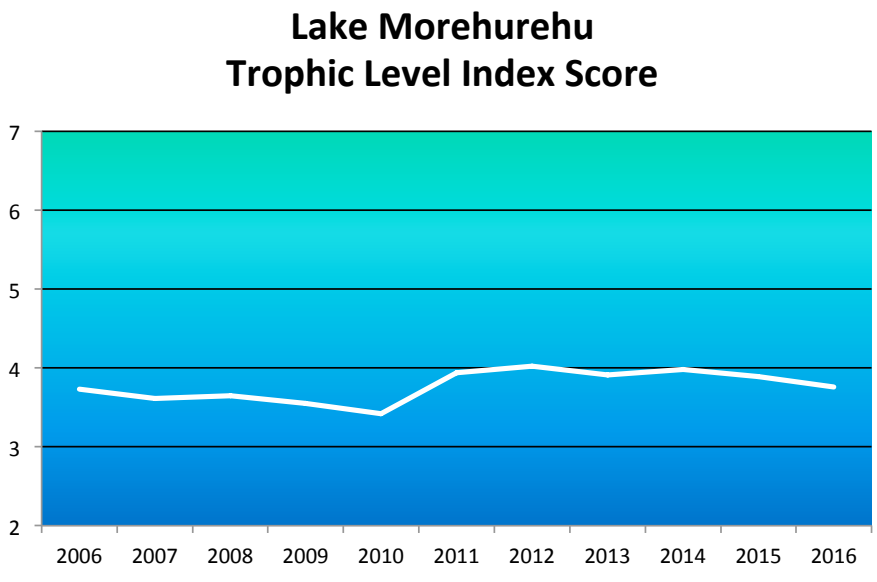


Attribute	Unit	Lake Type	State	Annual Median	Narrative State
Total Phosphorus (Trophic state)	g/m3	All	A	≤.01	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Total Phosphorus (Trophic state)	g/m3	All	B	>.01 and ≤.02	Lake ecological communities are slightly impacted by additional algal and plant growth arising from nutrients levels that are elevated above natural reference conditions.
Total Phosphorus (Trophic state)	g/m3	All	C	>.02 and ≤.05	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrients levels that are elevated well above natural reference conditions.
Total Phosphorus (Trophic state)	g/m3	All	National Bottom Line	0.05	Lake ecological communities are moderately impacted by additional algal and plant growth arising from nutrients levels that are elevated well above natural reference conditions.
Total Phosphorus (Trophic state)	g/m3	All	D	>.05	Lake ecological communities have undergone or are at high risk of a regime shift to a persistent, degraded state (without native macrophyte/seagrass cover), due to impacts of elevated nutrients leading to excessive algal and/or plant growth, as well as from losing oxygen in bottom waters of deep lakes.

7.1.2. Trophic Level Index

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 algal biomass, 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. The TLI trend for Morehurehu surprisingly remains largely high mesotrophic (average water quality) touching upon the eutrophic (poor water quality) line. The forestry harvest events which caused nutrient, especially nitrogen, surges and a decline in water clarity affecting the plant community is likely to be associated with both algal blooms and humic staining of the lake.



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	

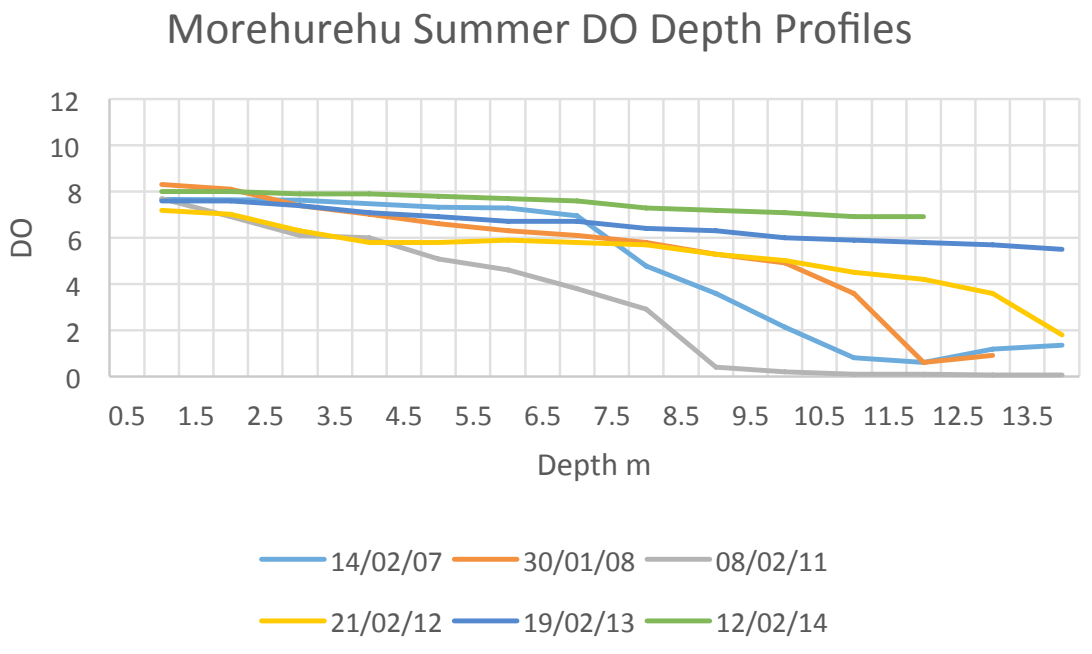
The graph below is a display of TLI scores. This allows interpretation of the four contributing variables which are combined into an overall TLI score. From this chart, Secchi disk visibility is consistently the main contributor followed by nitrogen, throughout all years, and a rise in phosphorus from 2011. The non-correspondence between Secchi and chlorophyll-a indicates that the decline in water clarity was due to humic staining (a dark red-brown colouration) after forestry harvest.

7.1.3. Dissolved Oxygen g/m³

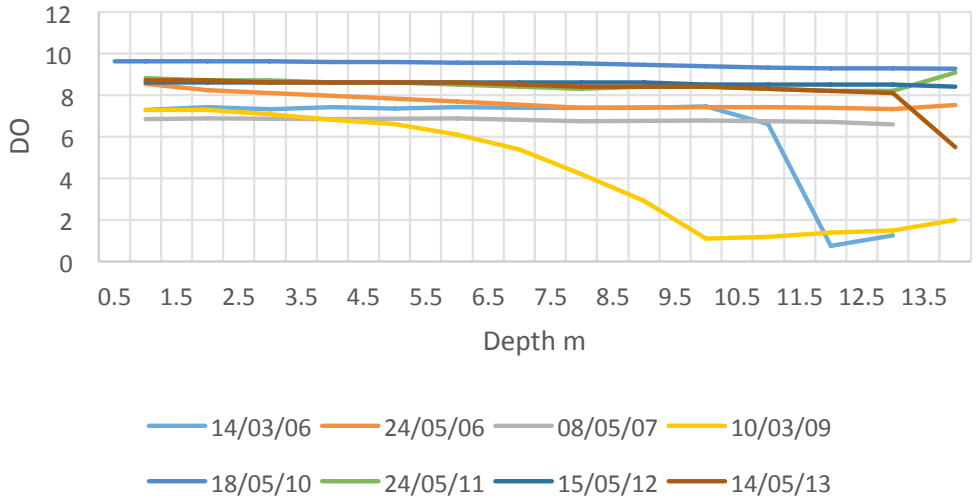
Although the lake does not thermally stratify due to its shallow nature, there is a deoxygenation phase in summer and spring in water below 6.5 m.

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

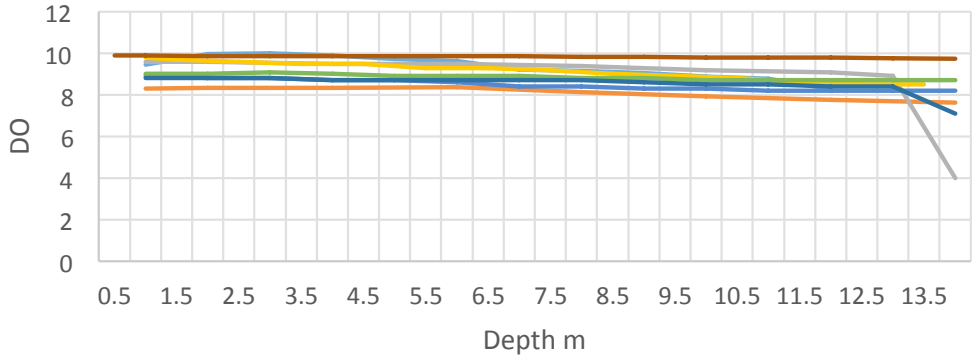


Morehurehu Autumn DO Depth Profiles



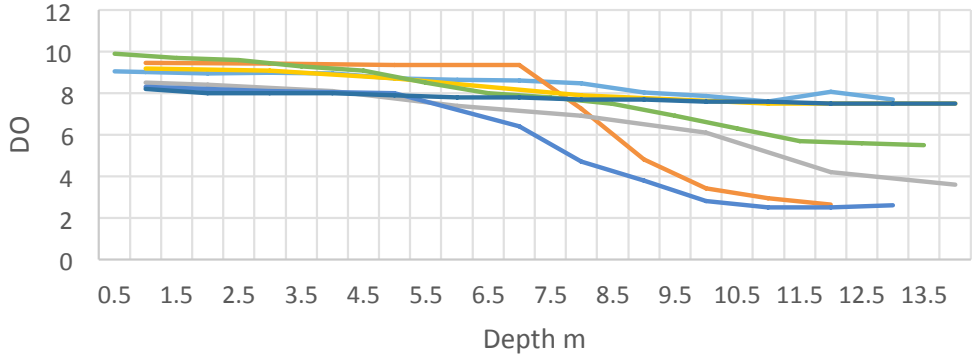
14/03/06 24/05/06 08/05/07 10/03/09
18/05/10 24/05/11 15/05/12 14/05/13

Morehurehu Winter DO Depth Profiles



09/08/06 07/08/07 01/07/08 19/08/09
17/08/10 01/08/11 07/08/12 14/08/13

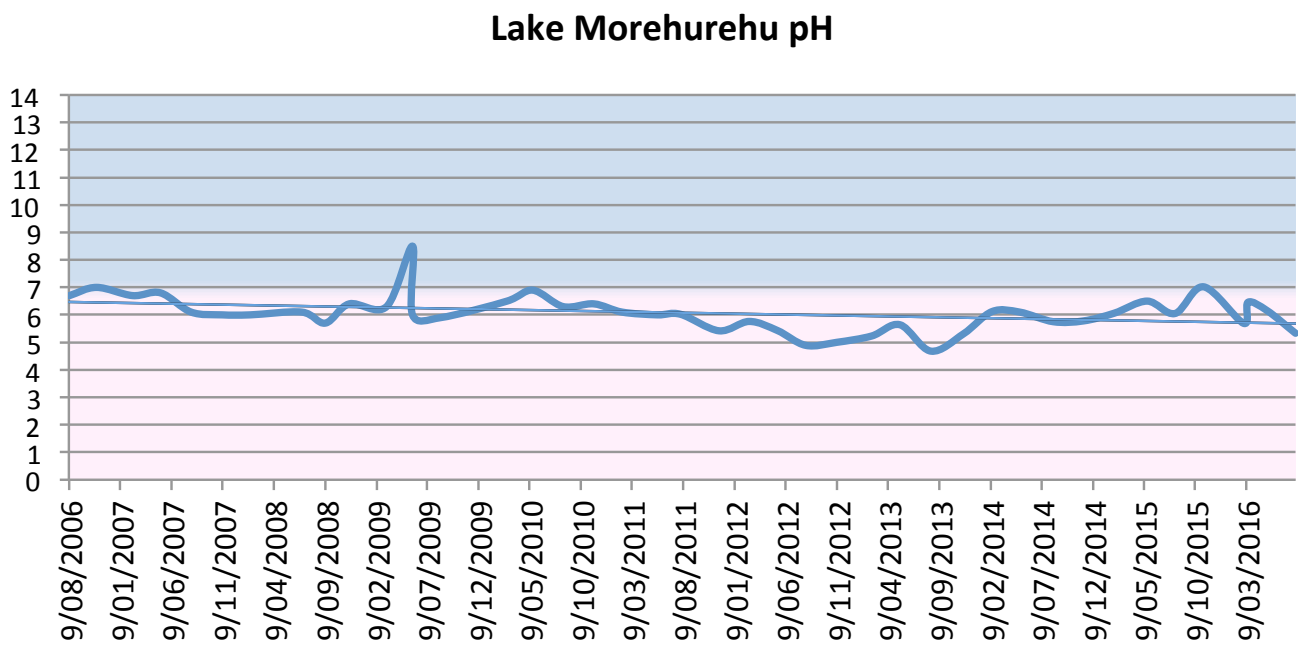
Morehurehu Spring DO Depth Profiles



05/11/04 30/10/06 07/11/07 09/09/08
19/11/08 16/11/10 07/11/12

7.1.4. pH

The lake has seen a gradual drop in pH, in other words an increased acidity. Given the starting point in 2006 being fairly neutral, this is a concern with regards to fish, which prefer basic (alkaline) conditions. The trend is likely due to humic acids leaching into the lake from the effects of forestry harvest.



8. BIOLOGICAL CHARACTERISTICS

8.1. Lake Biodiversity and Biosecurity species

8.1.1. Plants

Morehurehu hosts 30 native aquatic plants, the highest diversity of any lake on Aupōuri Peninsula, and only one exotic non-invasive plants; the bladderwort *Utricularia gibba*.

The table is organised as a depth gradient, from emergent plants to those which are submerged, for each of the invasives and natives. Rare natives are presented last. Morehurehu and its margins are home to four rare native plants; *Dianella haematica, Drosera pygmaea, Todea Barbara* and *Utricularia australis.* Of these the native bladderwort, *Utricularia australis*, is classified as Nationally Critical, which is the highest threat status. This plant is considered to be seriously at risk throughout its northern range, through habitat loss and competition with the introduced *Utricularia gibba. U. australis* has not been recorded in Lake Morehurehu since 2009 and is considered locally extinct, although recently a population was discovered in the outlet stream of Lake Te Kahika to the north.

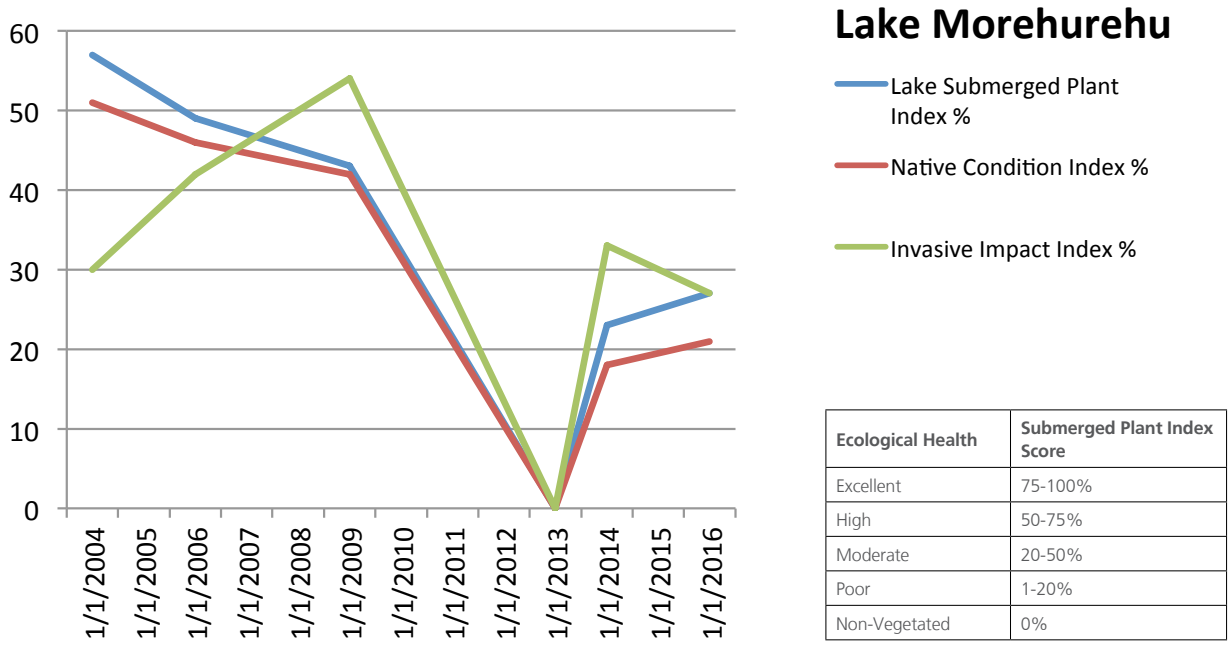
The table presents plant communities in nearby dune lakes as a comparison and indication of biosecurity species of concern which should be contained wherever possible. Data is derived from annual NIWA ecological surveys.

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						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**	**3**	**1**	**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 Impact Index.

Invasive Impact Index follows a trend of the invasion and spread of *Uticularia gibba* in the lake. It progressively increased from 2005 to 2009, displacing the rare native *Utricularia australis*. In 2013 all plants crashed after a forest harvest stained the lake a dark red-brown colour to the point that light incidence limited plant growth. This staining also occurred in the nearby lakes Te Kahika and Morehurehu South as well as in the Parengarenga Harbour after heavy rains. By 2014, *U. gibba* had become the dominant species. Native Condition Index and Submerged Plant Index mirror these events, declining as *U. gibba* rises and crashing along with it in 2013. In 2009, the native plant community was similar to a prior 1988 vegetation survey result, except that *U. gibba* was absent in 1988.



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

The table overleaf displays the fish of the upper Aupōuri Peninsula. Pest fish are shown in green and native species in pink. Lake Morehurehu appears in yellow. The lake has a moderate level of native fish diversity and no pest fish are present. Common bully, short-finned eel and inanga are present. No fish have been seen since 2009, based on diver sightings. In order to assess the current status of fish in the lake, a full fish survey should be undertaken.

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 below 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 removed from the game bird list, but able to be hunted year-round and posing a threat to lakes when numbers become too high due to nutrient enrichment. Lake Morehurehu appears in yellow. The lake has a moderate level of bird diversity and could be a low-use waterfowl game-bird hunting site.

common name	species	Conservation status (DOC: *Conservation status of NZ birds* , 2016)	Criteria / Degree of loss	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
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 Morehurehu, no species which are sensitive to poorer states of water quality are present and diversity of invertebrates is moderately low. Data is combined from NIWA and Northtec surveys.

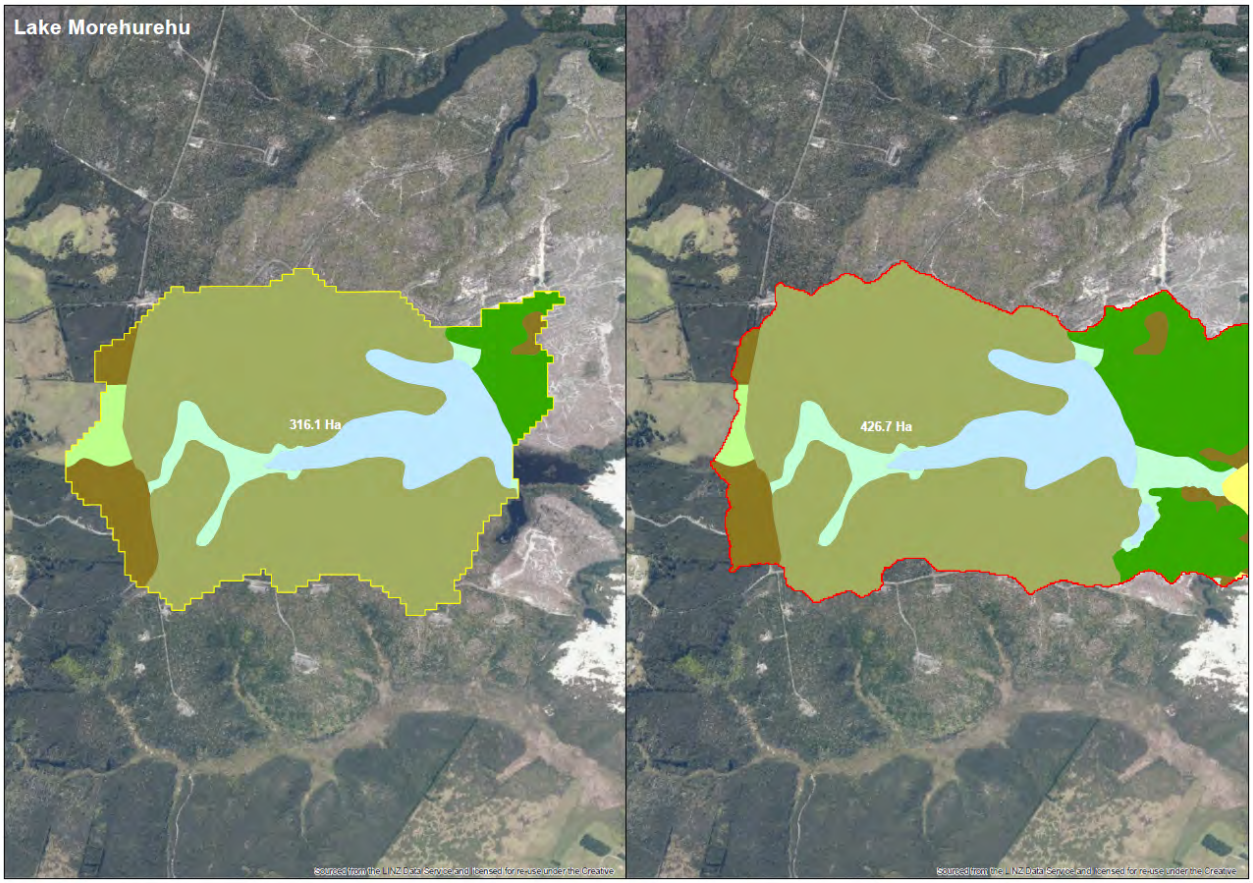
Order or phylum and common name	Family or species	Pollution minimum tolerance - Clean Water (>5.99) Mild Pollution (5.00-5.90) Moderate Pollution (4.00-4.99) Severe Pollution (<4.00)	Waitahora lagoon	Waitahora Lakes	Te Werahi Lagoon	Ngakeketa North/Te Paki	Ngakeketa South	Te Paki Dune Lake	Austria	Pretty	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
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 harvested pine forest, exotic forest, sand or gravel, high manuka/kanuka scrub and freshwater sedgeland/ rushland.

Lake	Cover Type	Total FENZ (ha)	Total Hand-drawn (ha)
Lake Morehurehu	Exotic Forest	20.15	90.46
Lake Morehurehu	Forest - Harvested	214.80	212.11
Lake Morehurehu	Herbaceous Freshwater Vegetation	13.48	22.22
Lake Morehurehu	High Producing Exotic Grassland	7.22	3.59
Lake Morehurehu	Lake or Pond	38.77	40.23
Lake Morehurehu	Manuka and/or Kanuka	21.69	25.20
Lake Morehurehu	Sand or Gravel	0.03	32.93
Lake Morehurehu Total		316.15	426.74



9.2. Fire-fighting mitigations

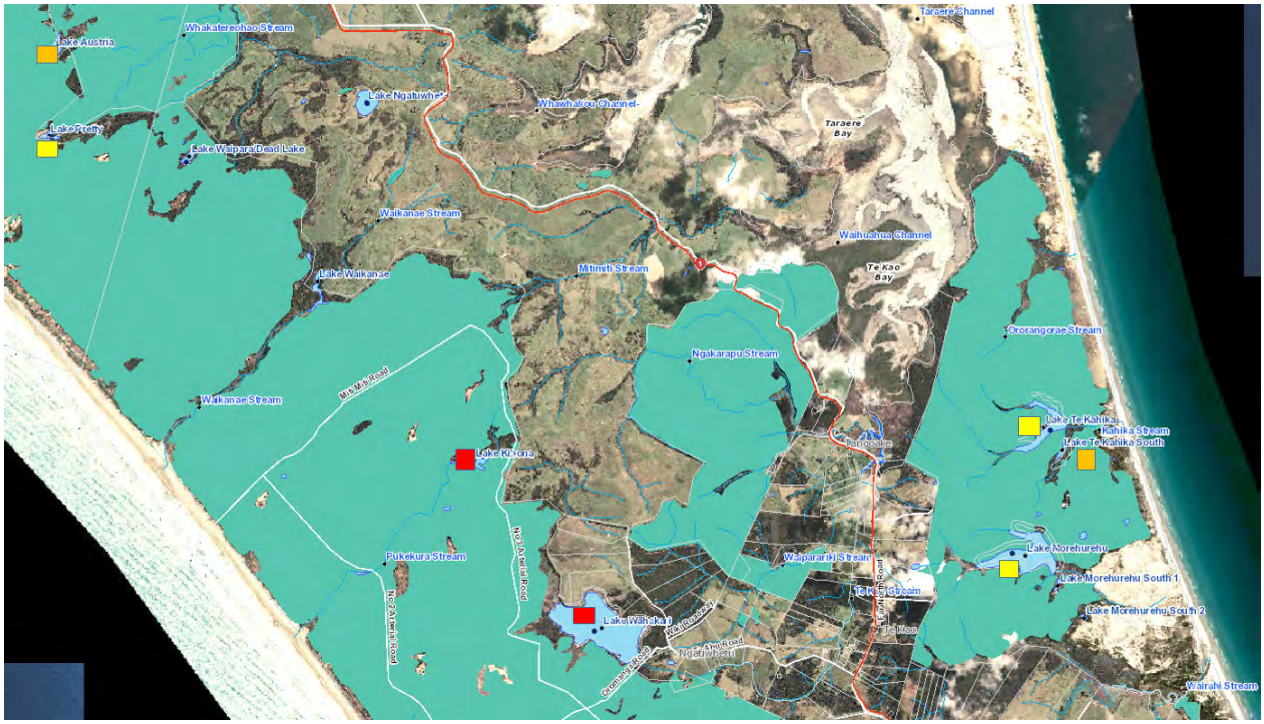
Only a small proportion of the catchment, to the west is in pastoral farm, the effects of which are likely to be minimal.(see overleaf)

9.3. Forestry

The surrounding forest has been harvested and has now been replanted. Hancock Forest Management have undertaken some terrestrial weed control around the margins of the lake, especially of nitrogen fixing weeds such as oxylobium and wattle.

9.4. Fire-fighting mitigations

Morehurehu has been assessed as a moderate-low risk (yellow square on the map) lake for the take of water by helicopter bucket for fire-fighting due to the presence of the exotic water-weed Utricularia gibba. This species is absent in nearby Lake Te Kahika South.



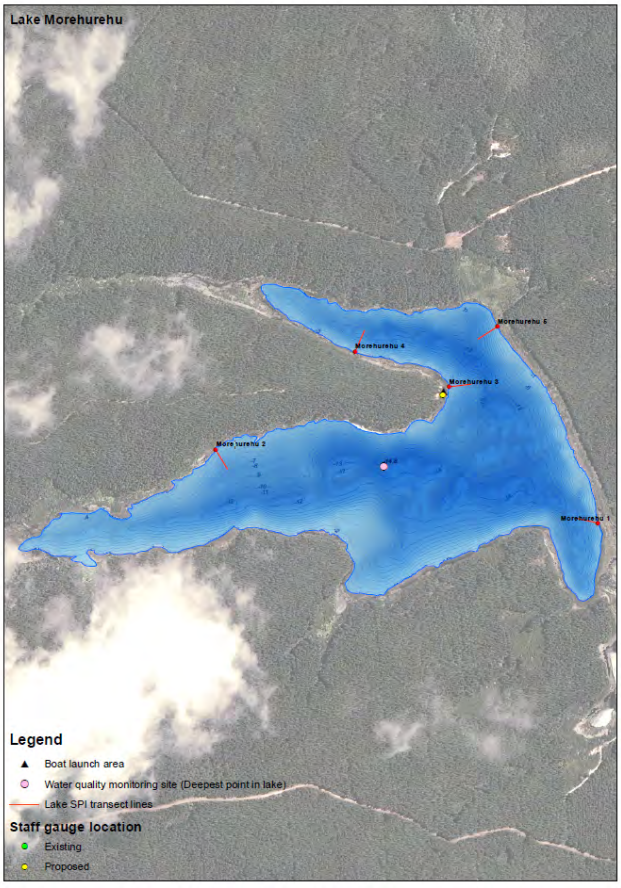
Fire-fighting mitigations

10. MONITORING PLAN

The diagram below shows the five transect lines surveyed during ecological surveys. The dark triangle on the central western shore is the access point for the NRC vessel for water quality sampling. The pink point in the south-west 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. There have been seven full surveys since 1988. The value class of the lake began at High in 2004, progressing to Outstanding in 2006 and 2009 and dropping back to High ever since. The next full survey is likely to be done in 2021.



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. Samples taken per year by depth follow.

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

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
Morehurehu lower																		4	4	4	3	4	4	4	4	4	4	5	1	45
Morehurehu surface			1					1								1		4	4	4	4	4	4	4	4	4	4	5	1	49

11. WORK IMPLEMENTATION PLAN

Ongoing work includes:

- The NRC/NIWA ecological surveys will continue every five years. The next full survey will be in 2021. Quarterly NRC water quality monitoring will continue.
- Installation of a staff gauge and a continuous electronic water-level recorder by NRC.
- Marginal terrestrial weed control by forestry managers especially of nitrogen fixing weeds.

Further mitigation work to consider includes:

- Morehurehu has been assessed as a moderate-low risk lake for the take of water by helicopter bucket for fire-fighting due to the presence of the exotic water-weed *Utricularia gibba*. Duck hunting represents a biosecurity vector risk to the lake. The Check Clean Dry protocol needs to be advocated throughout this sector.
- The Morehurehu lakes have not recovered since 2013 when pine forests were harvested in the area with loss of submerged vegetation in these waterbodies. Investigate the impacts of pine harvesting on Lakes Te Kahika, Te Kahika South, Morehurehu and Morehurehu South No. 1 and 2.
- Develop recommendations for forest managers concerning future harvest protocols to prevent these same impacts occurring again. Such recommendations could include wider setbacks for planting/harvesting on the lake margins and possible retirement of key areas in the catchment.
- Assess the current status of fish in this and other lakes in the area through a comprehensive fish survey.

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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.

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.

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.

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.

Acknowledgements

Sincere thanks to those who have generously provided their time to the twelve outstanding dune lake plans project, including:

- Lisa Forester for the guidance, support, knowledge and editing.
- Andrew Macdonald for countless analyses, data presentation and editing.
- Bruce Howse for guidance and support along the way.
- Katrina Hansen and Bruce Griffin in Biodiversity for their editing.
- Ngā Kaitiaki o ngā roto tāhuna – Each iwi/hapu/whanau and marae who have engaged in this process and in the korero and mahi to come.
- The NRC teams: Biodiversity, GIS, Biosecurity, Hydrology, State of the Environment, Area Offices in Dargaville and Kaitaia, Land Management, Consents, IS&T, Planning and Policy, Communications, Finance and our Kaiarahi who all made valuable contributions of time, information and thought.
- The Northland Regional Council councillors and our CEO Malcolm Nicolson who are passionate about our region and our lakes.
- Paul Champion and the team at NIWA for data provision and insight.
- Kevin Matthews of the Bushland Trust for local knowledge of the Aupouri and Karikari Peninsulas ecology.

- Graeme Doole at the Ministry for the Environment and Chris Tanner at the Cawthron Institute for the modelling approach to nutrient mitigation presented in the Humuhumu and Kanono plans.
- Our friends at DOC, Taharoa Domain Committee at Kaipara District Council and Lake Ngatu Action Group for collaborations.
- The Catchment Groups, especially Pōuto and Doubtless Bay, for their lakes-related planning.
- The forestry industry for their open engagement and the farmers who are taking steps to protect these lakes.
- The Ministry for the Environment and ratepayers of Northland for the Dune Lakes Freshwater Improvement Fund project which will address many of the actions in these plans over the next five years.