Lake Mokeno

MANAGEMENT PLAN

Northland
REGIONAL COUNCIL

CONTENTS

LAKE MOKENO MANAGEMENT PLAN

1. PURPOSE

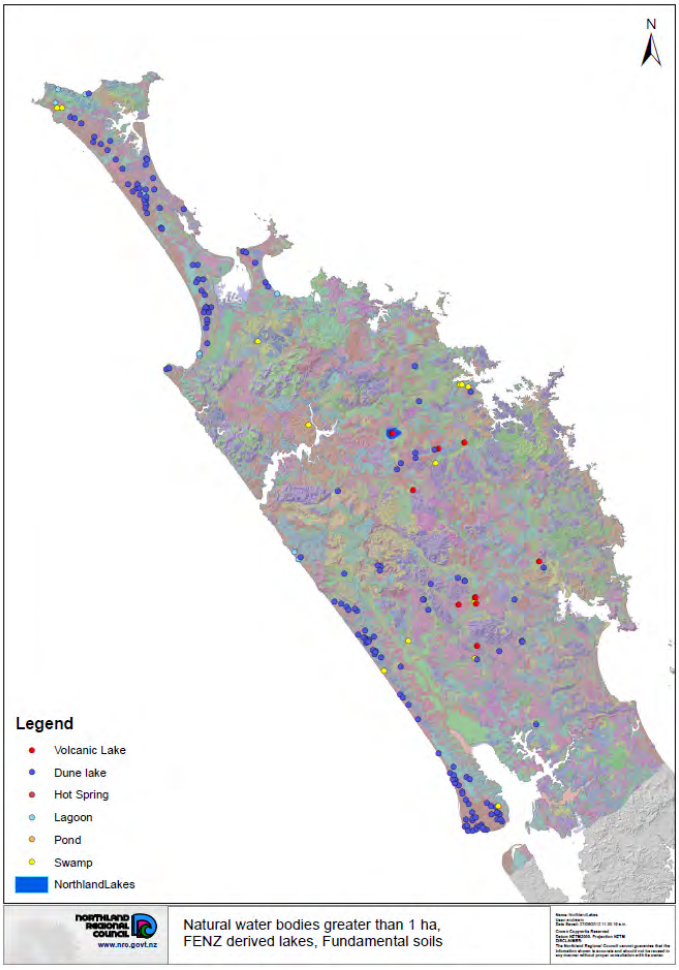
The purpose of the Outstanding Northland Dune Lakes Management Plans is to implement the recommendations of the Northland Lakes Strategy Part II (NIWA 2014) by producing Lakes Management Plans, starting with the 12 'Outstanding' value lakes, and by facilitating actions with mana whenua iwi, landowners 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 Mokeno (NRC Lake Number 356) is a shallow (6.53 m max, 2.51 m mean depth) 168.03 ha lake located on the western edge of the Pōuto Peninsula in south-western Northland, beyond the forestry blocks. The lake is classified as a Class 2 Not Perched - Swampy dune lake (Timms, 1982) sitting within an extensive wetland system which spans the southern head of the Pōuto Peninsula.

The lake is situated in a catchment dominated by exotic pine forest, manuka/kanuka scrub and harvested forest. There are extensive unconsolidated dunes bordering the lake to the west. The LiDAR-derived catchment area, including the lake, is 1075.9 ha. The surface area of the lake is 168.03 ha based on NIWA bathymetric survey.

The lake, being very shallow, does not thermally stratify. Mokeno experienced a series of algal blooms (National Policy Statement for Freshwater Management (NPS) chlorophyll-a activity in state D) and corresponding peaks in total suspended solids between February 2012 and June 2015 after a seven-year period of stability. This is likely due to a rapid growth and dieback of the macrophyte community from 2007 onward. Water clarity, based on Secchi depth, is very poor. This is a shift from macrophytes to plankton bloom dominance. Toxic ammonia has spiked four times into NPS state C.

Nitrogen and phosphorus each pulsed in 2005 into State D as well. A smaller pulse of phosphorus occurred in March 2011 into State D followed by a longer-term residence between States C and D. Native macrophytes experienced rapid growth, using up the nutrients, while overgrowing the lake. This resulted in a crash (total dieback) of the plant community, followed by this plant material rotting and releasing their nutrients. This then resulted in a biomass-flop to micro-algal conditions from 2011 onward, ending by 2016. Nitrogen is trending upward based on pulses between November 2011 and June 2015. This corresponds with increases in algal blooms and total suspended solids.

The 2005-2016 Trophic Level Index trend indicates an average to poor (mesotrophic to eutrophic) trend from 2005 until 2010 when the lake water quality degraded to a low point in 2012, entering very poor (supertrophic) condition. It took until 2016 for water quality to re-equilibrate back to mesotrophic level. There was a single prominent deoxygenation event in waters below 4.5 meters in March 2005 as a result of the large-scale phosphorus pulse.

The lake has an estimated lake water residence time of just over three months.

The lake hosts 19 native aquatic plants including the rare marsh fern, *Thelypteris confluens* and only one exotic invasive plant, royal fern. The Invasive Impact Index is consistently at zero because there are no exotic invasive plants other than royal fern. In April 2007, both Submerged Plant Index and Native Condition Index dropped to zero by January 2015. This was due to Mokeno experiencing a classic biomass "flip" from macrophyte (native plants) dominance until 2007 to microplankton algal dominance from 2011. Both indices rebounded in 2016, showing the ability of native plants to thrive from seedbanks and remnant survivors. Lakes Wairere and Karaka to the north experienced similar events earlier than Mokeno, suggesting that not only is this chain of swampy lakes interconnected through the extensive wetland in which they sit, but also that the direction of the water flow is north to south.

There are no pest fish recorded. Common bully and short-finned eel are present and the lake is the only one in Pōuto with inanga (*Glaxias maculatus*), landlocked smelt and grey mullet. Interestingly, lake Mokeno lacks dwarf inanga, common at other Pōuto lakes.

The lake has a very high level of non-game bird diversity and shoveler and grey duck are present as game species. Dabchicks, Australasian bittern and New Zealand scaup occur widely in this sub-region.

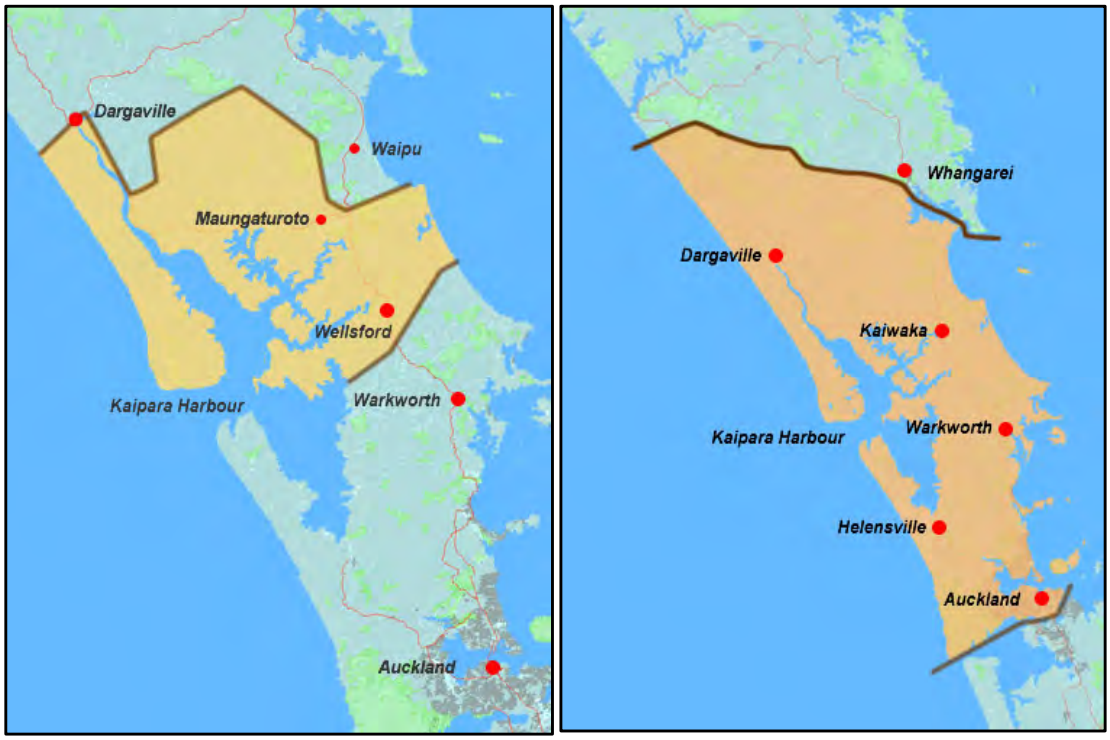
5. SOCIAL AND CULTURAL DIMENSION

5.1. Mana whenua

Te Uri o Hau (yellow) and Te Runanga o Ngāti Whātua (orange) have rohe whenua Area of Interest in the area of Lake Mokeno. Te Uri o Hau has reached Deed of Settlement with the Crown and there appears to have been no specific vesting of the lake bed, which remains privately owned.

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).

Two iwi organisations have rohe whenua Area of Interest in the area of Lake Mokeno; Te Uri o Hau (yellow) and Te Runanga o Ngāti Whātua (orange). Te Uri o Hau has reached Deed of Settlement with the Crown over this area. A planning initiative called Future Pōuto has recently been undertaken by Te Uri o Hau and an Iwi Environmental Management Plan has been written.



5.2. Land Tenure

5.2.1 Catchment landowners and Lake bed owners

Five landowners own six land parcels within the lake catchment. The lake bed is owned by Crown Forestry – National Manager Forest Assets, Ministry for Primary Assets.

5.3. Community involvement

The Pōuto Catchment Group was formed in mid-2013 to help determine how the Pōuto Peninsula's freshwater resources should best be managed into the future. The group comprises representatives from tangata whenua, forestry, drystock and dairy industries and recreational, community and environmental interests. It also includes representatives from the Department of Conservation, Kaipara District Council and the Northland Fish and Game Council. The chair is a councillor from Northland Regional Council.

5.4. Public use

5.4.1. Access

Access is found to the northern end of the lake via forestry and Māori land over 7 km of well-formed tracks. There is a locked gate.

5.4.2. Boating

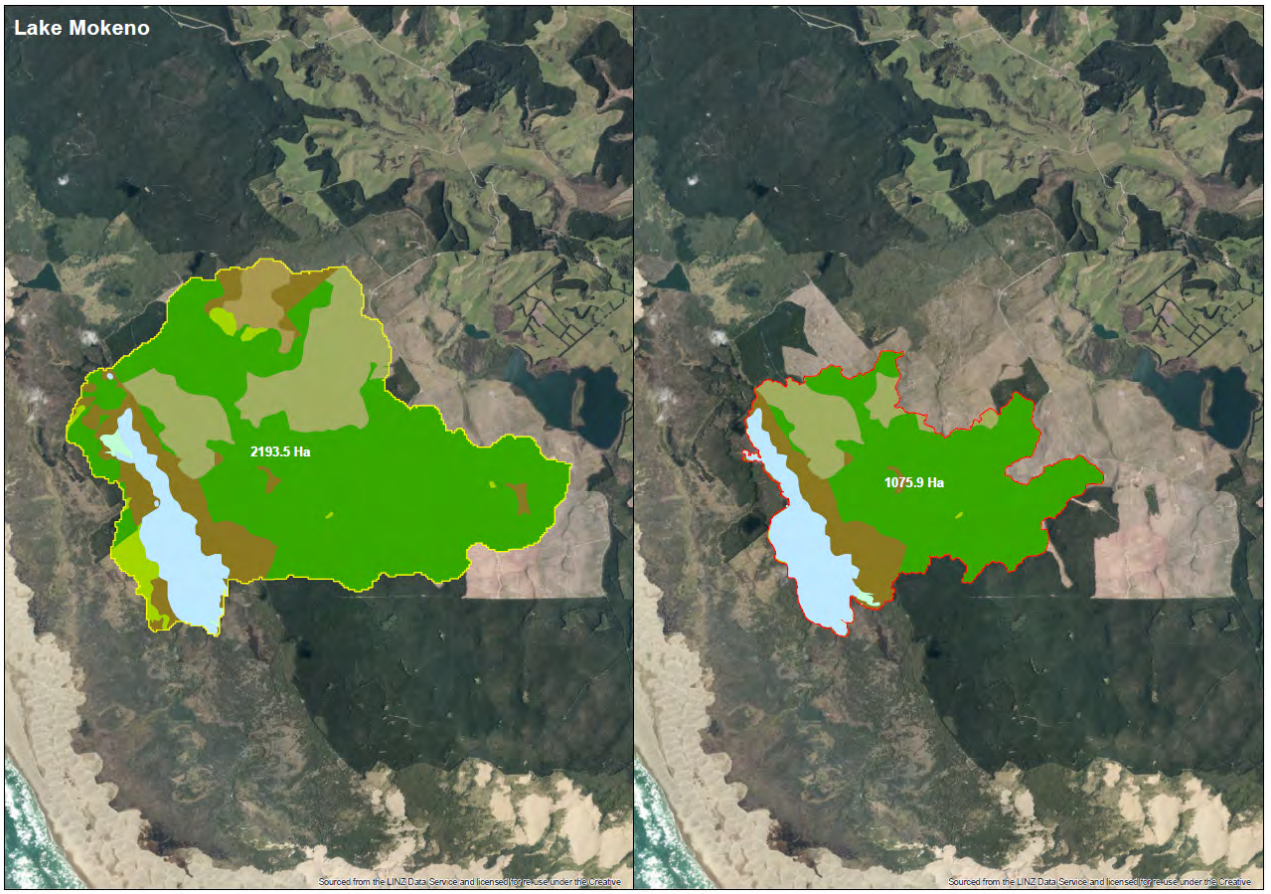
5.4.2.1. Boat access

Boat access to the lake is difficult due to a steep drop off from the lake margin, by 4WD only and by permission.

6. PHYSICAL CHARACTERISTICS

6.1. Catchment Area with Map

The following map shows the extent of the lake catchment. The image on the left is the FENZ boundary a rationalised boundary based on more-accurate LiDAR is on the right. The LiDAR catchment area, including the lake itself, is 1075.9 ha.

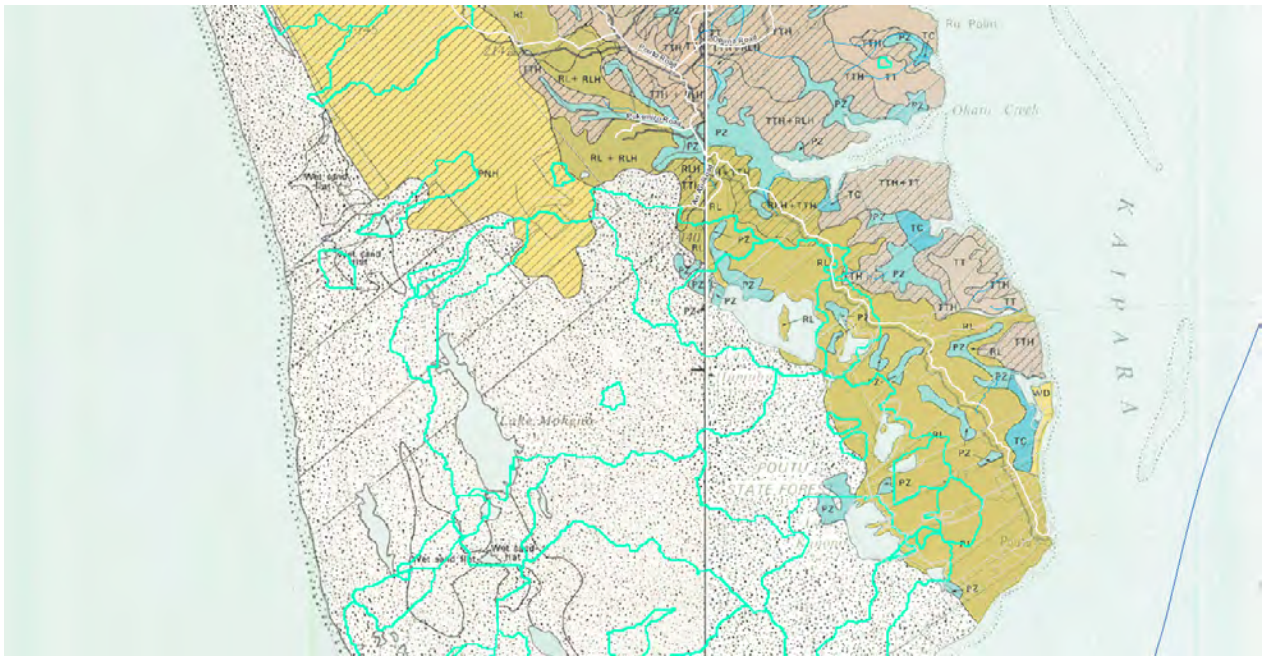


6.2. Catchment Geology and soil types

The following map ((C) GNS Science 2016) of the Pōuto Peninsula and table below it shows the geological history of the lake catchment. Mokeno has a geology comprised of Late Quaternary dunes (lQd). These ancient dunes are now poorly consolidated sand.

Lake Name/Plot Symbol	lQd (Q1d)
Mokeno	x
Name	Late Quaternary dunes
Description	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.
Geologic history	Late Quaternary
Simple name	Zealandia Megasequence Terrestrial and Shallow Marine Sedimentary Rocks (Neogene)
Absolute minimum age (millions of years before present)	0
Absolute maximum age (millions of years before present)	0.12
Supergroup equivalent stratigraphic name	Pakihi Supergroup
Terrane equivalent name	
Lithology	sand

Soil type in the catchment is portrayed in the soil map and table below. The lake is dominated by yellow-brown sands of the Pinaki series (PNH).



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.

6.3. Catchment Hydrogeology

Only a conceptual understanding of the hydrogeology of Pōuto Peninsula is available as no specific investigations have taken place and bore-logs offer little information of use. The geology of the dune lakes relies on strata of cemented and uncemented dune sands. Paleo-channels and iron pans likely allow water flow collecting in cemented areas to provide water to the non-perched lakes occurring at lower elevations. Lake Mokeno is a Class 2 Not Perched (swampy) lake of this type.

6.4. Catchment drainage and sedimentation rates

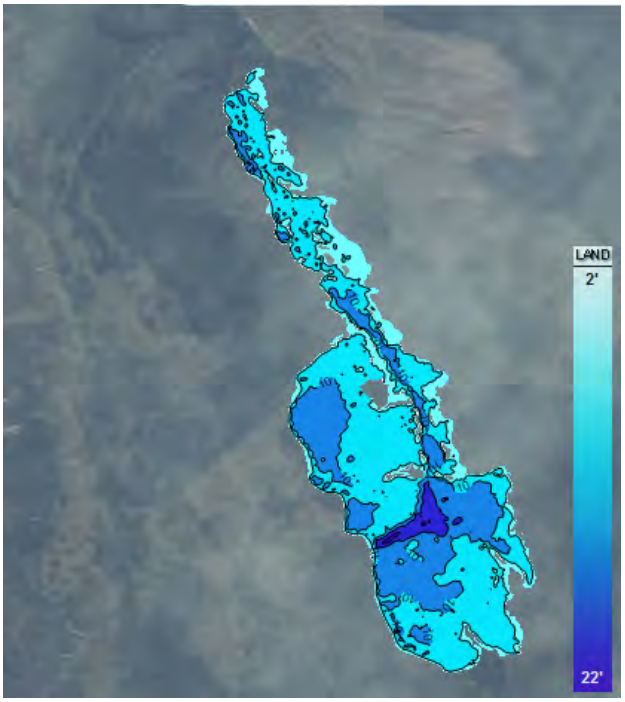
The LiDAR-defined catchment area, including the lake itself, is 1075.9 hectares and produces a mean annual flow, based on hydrological models, of 2,219,345.5 m³/year. The lake has an estimated lake residence time of 0.281 years, meaning any water entering the lake will remain for just over three months. The average particle size of surface rock in the catchment is 1.98 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 western Pōuto Peninsula (Whakaneke to the south, Karaka to the north and Wairere further north), Mokeno is a Class 2 Not-Perched (swampy) dune lake close to the sea and associated with extensive swamp. The lake has a maximum depth of 6.53 m with a mean overall depth of 2.51 m. The surface area of the lake is 168.03 hectares with a volume of 4,429,437.90 m³ (NIWA bathymetric survey). The LiDAR-defined catchment area, including the lake itself, is 1075.9 hectares.

6.6. Bathymetry map

The following bathymetric depth map comes from a survey done by NIWA for the NRC. Mokeno's deepest point is the single 6.53 m basin to the central south of the lake. The lake has islands. The narrow arm to the north is deepest along the western edge at up to 4.3 m. Please note that the scale of this map is in feet, not meters.



6.7. Natural inlets and outlets

There are no inlets or outlets, but water flows south to Lake Whananeke then on to the Kaipara Harbour.

6.8. Wetland associations

The lake sits within an extended "Top 150" wetland, connecting it to other lakes. The shallowest zones of the lake have been colonised by emergent vegetation and appear as a series of islands. To the southeast is an extensive swamp characterized by an unusual mix of sedges and the rare fern *Thelypteris confluens.*

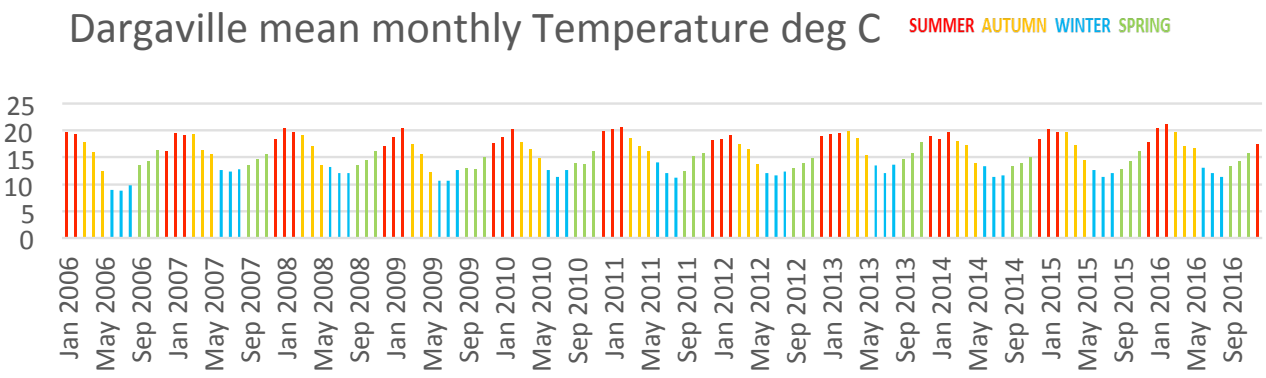
6.9. Connectivity

Water flows southwest from Lake Mokeno to Lake Whananeke via interconnecting wetland. There is also a wetland connection to Lake Otapuiti to the south.

Based on the phosphorus pulse of 2005, Mokeno receives water from the northern chain of Class 2 Not-Perched lakes to the north, Wairere and Karaka.

6.10. Air Temperature

Dargaville air temperature data is used as a proxy for Pōuto.

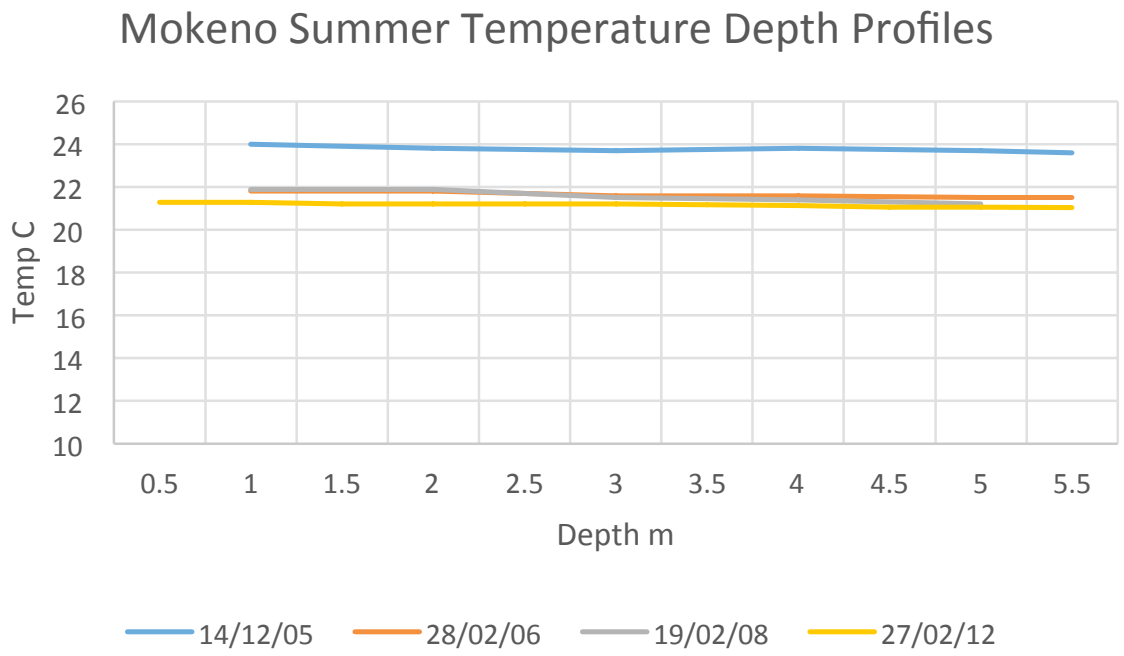


6.11. Thermal stratification

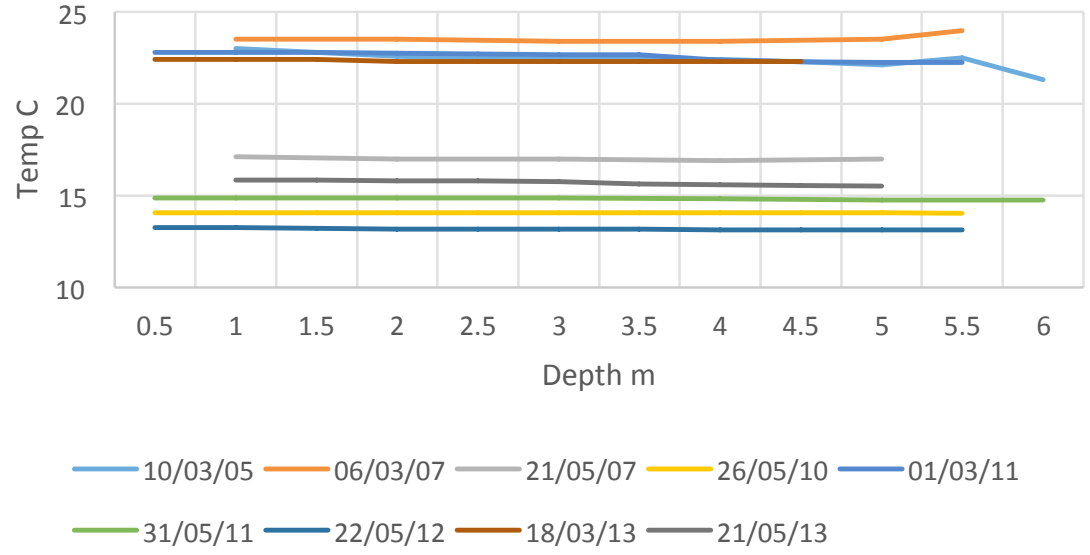
The graphs below show temperature at depth throughout the water column, by season. Each coloured line represents one sample. Water temperatures throughout the year range from 12.3 degrees C to 24.0 degrees C.

The lake, being very shallow, does not thermally stratify and temperature is fairly uniform at all depths year round.

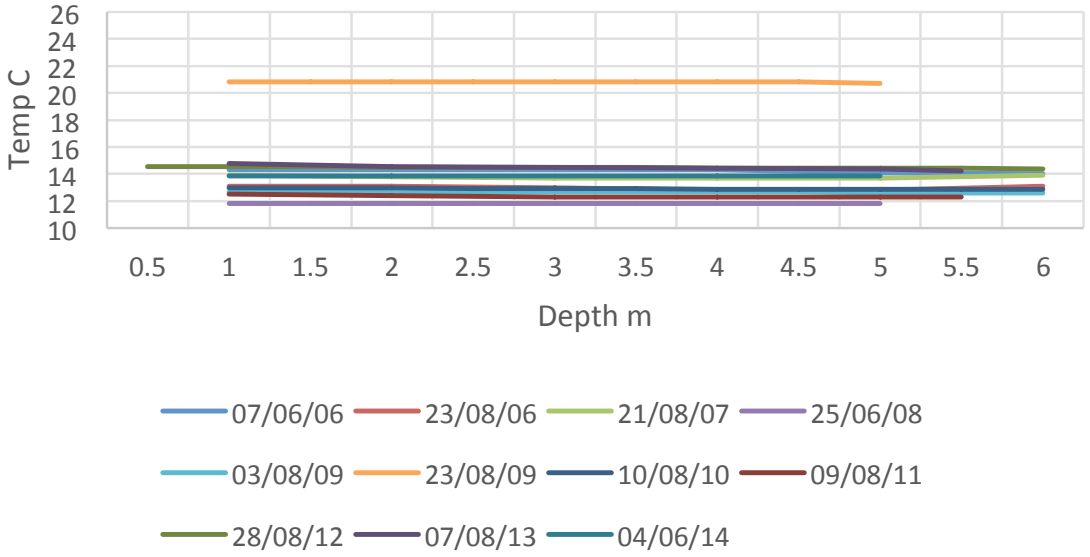
Due to lack of stratification, nutrients are available throughout the water column throughout the year due to wind mixing.



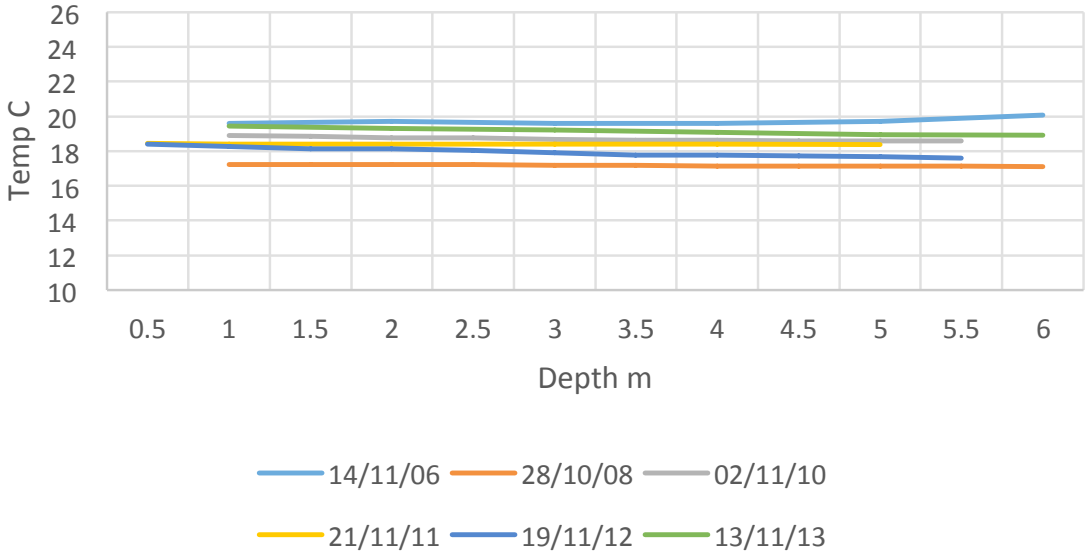
Mokeno Autumn Temperature Depth Profile



Mokeno Winter Temperature Depth Profiles

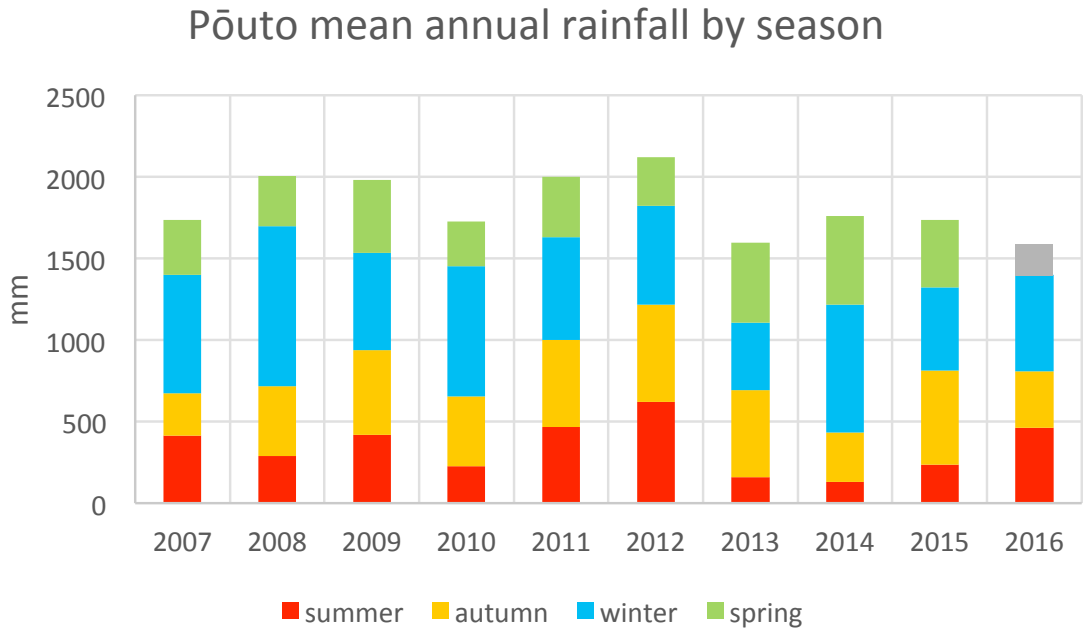


Mokeno Spring Temperature Depth Profiles



6.12. Rainfall and drought

The graph below shows cumulative rainfall by year displayed as seasons within each bar. Note that summer includes December from the year prior along with January and February of the year shown on the X axis. Greyed season indicates that a one month of the three months for that season, has no data available so this portion of the bar in underestimated.



6.13. Lake level

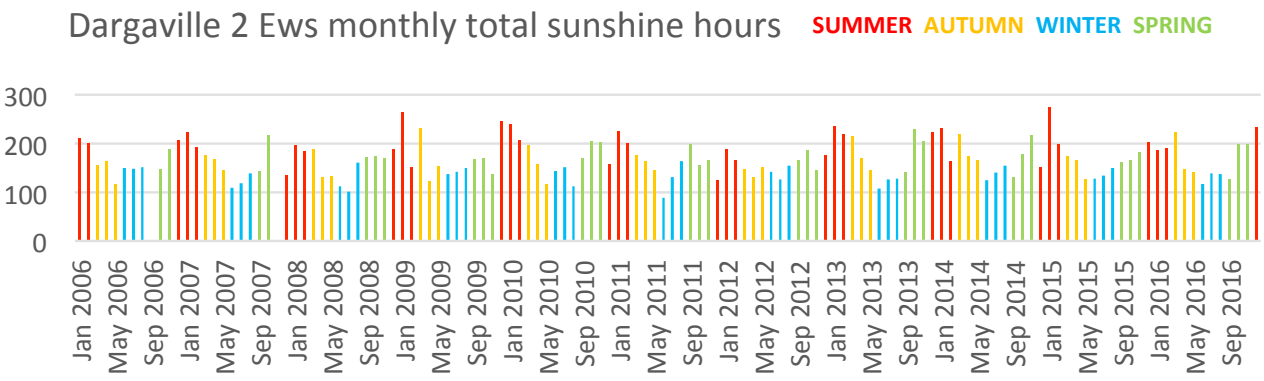
No lake water level data is available for Lake Mokeno. A staff gauge is to be installed.

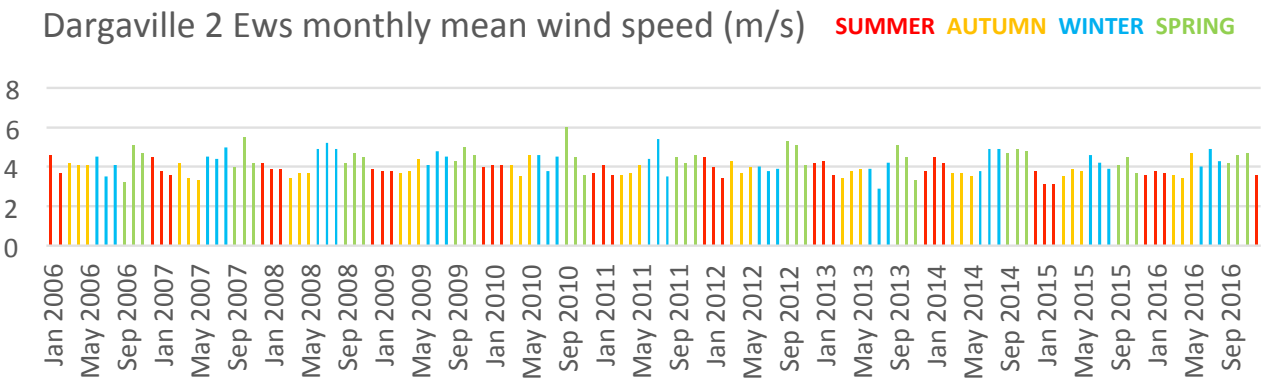
6.14. Sunshine

Dargaville sunshine recordings are used as a proxy.

6.15. Wind speed

Dargaville wind speed recordings are used as a proxy.

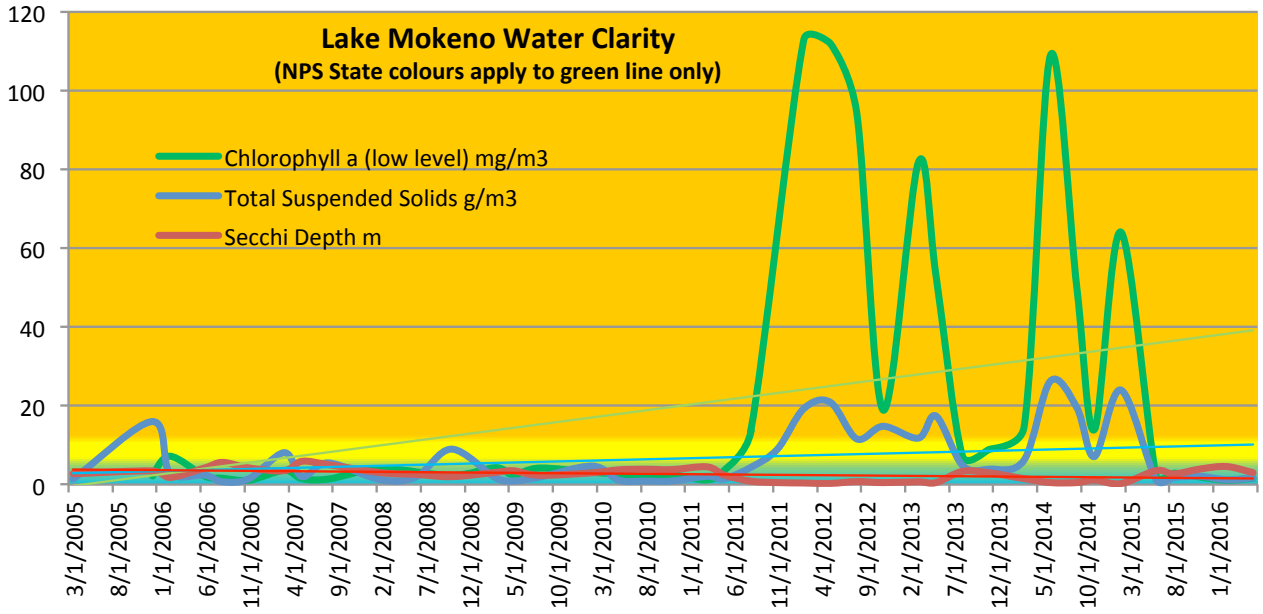




6.16. Light incidence (Secchi, Total Suspended Solids, Chlorophyll-a)

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. As seen from the graph below, Mokeno experienced a series of algal blooms (green line) and increases in total suspended solids after a seven-year period of stability, between February 2012 and June 2015. This is likely due to a rapid growth and dieback of the macrophyte community from 2007. Water clarity, based on Secchi depth, is very poor.

The table below the graph shows the National Policy Statement for Freshwater Management states for phytoplankton (chlorophyll-a). A great bulk of the phytoplankton chlorophyll-a activity is in State D. This is a shift from a macrophyte community to plankton bloom dominance.



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

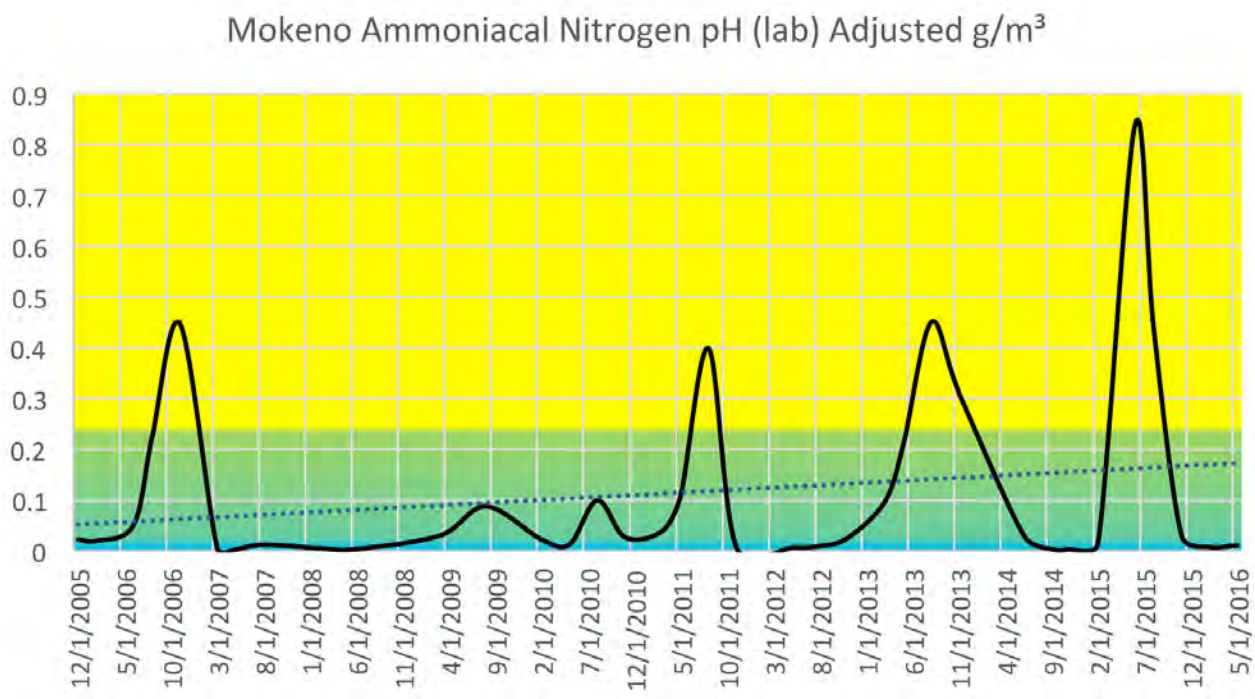
7.1.1.1. Limiting nutrient assay

Max Gibbs (pers. comm.) from NIWA conducted limiting nutrient assays on several lakes, including Mokeno. Significant results are highlighted. For the years and seasons assayed, nitrogen plus phosphorus is the limiting nutrient combination in summer. Lack of these nutrients regulate 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. As Mokeno has minimal farming in its catchment, the pulses seen in the graph below may be due to influences from either forestry or from flow-through of water from Lake Karaka to the north, which is influenced by pastoral farming. 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. Mokeno has surged into State C during four major pulses.

	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
Mokeno	99.5	173.0	0.85	1.12	1.01	1.00	1.02	0.02	1.05	1.09	1.23

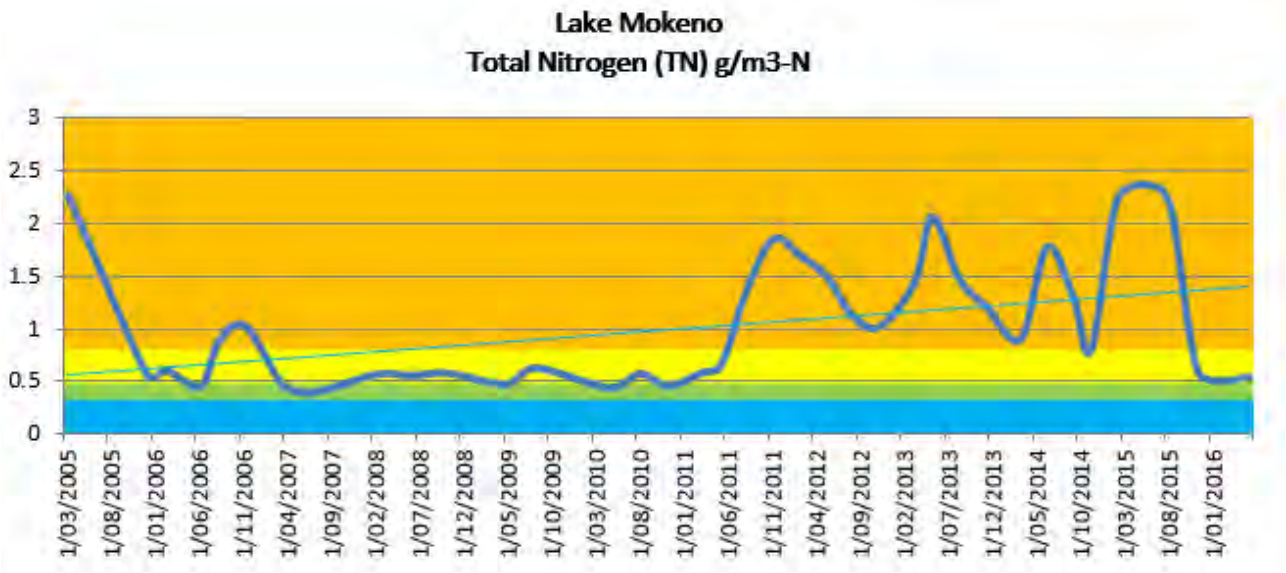


Attribute	Unit	Lake Type	State	Annual Median	Annual Maximum	Narrative State
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	A	≤0.03	≤0.05	99% species protection level: No observed effect on any species tested
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	B	>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, like phosphorus (below), pulsed in 2005 or earlier. Native macrophytes experienced rapid growth, used up nutrients and overgrew the lake. This was followed by a crash of this plant community which rotted down and released its nutrients. This is seen in the nitrogen pulse between November 2011 and June 2015. This rise in nitrogen corresponds with increases in algal blooms and total suspended solids.

The table following the chart shows the National Policy Statement for Freshwater Management (NPS) limits for lake state. As the lake does not thermally stratify, it is defined as polymictic, or being constantly mixed by wind. Recent trends have this lake solidly in State D.



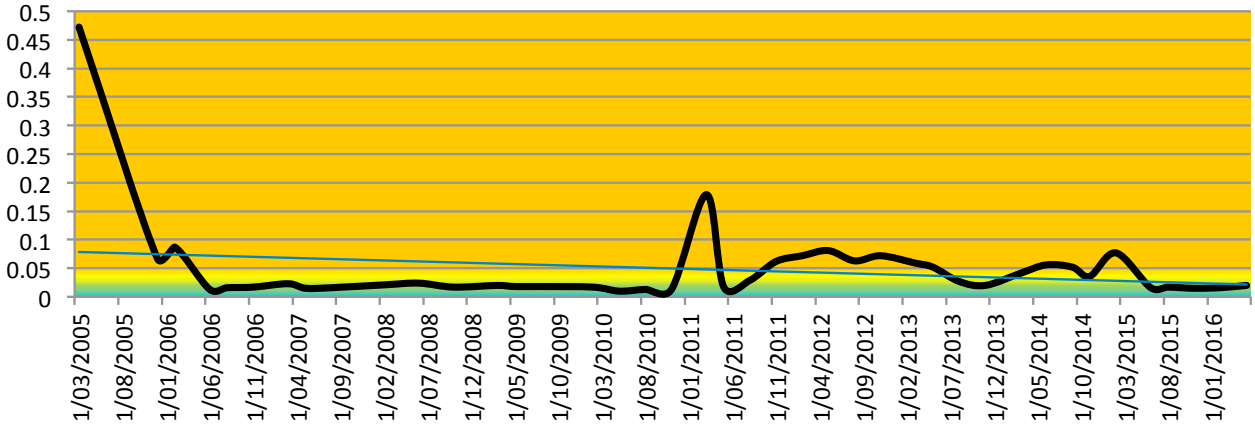
Attribute	Unit	Lake Type	State	Annual Median	Narrative State
Total Nitrogen (Trophic state)	g/m3	Polymictic	A	≤.3	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Total Nitrogen (Trophic state)	g/m3	Polymictic	B	>.3 and ≤.5	Lake ecological communities are 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 peaked in March 2005, promoting a growth response in the native macrophytes in the lake. By 2007, it is likely that these plants reached their carrying capacity and crashed, which resulted in a biomass-flop to micro-algal conditions from 2011 onward, ending by 2016.

The table following the chart shows the National Policy Statement for Freshwater Management limits for lake state. The lake had a large phosphorus peak the early peak into State D in December 2005 and a small pulse in March 2011 into State D followed by a longer-term residence between States C and D.

Lake Mokeno
Total Phosphorus (TP)
g/m3-P

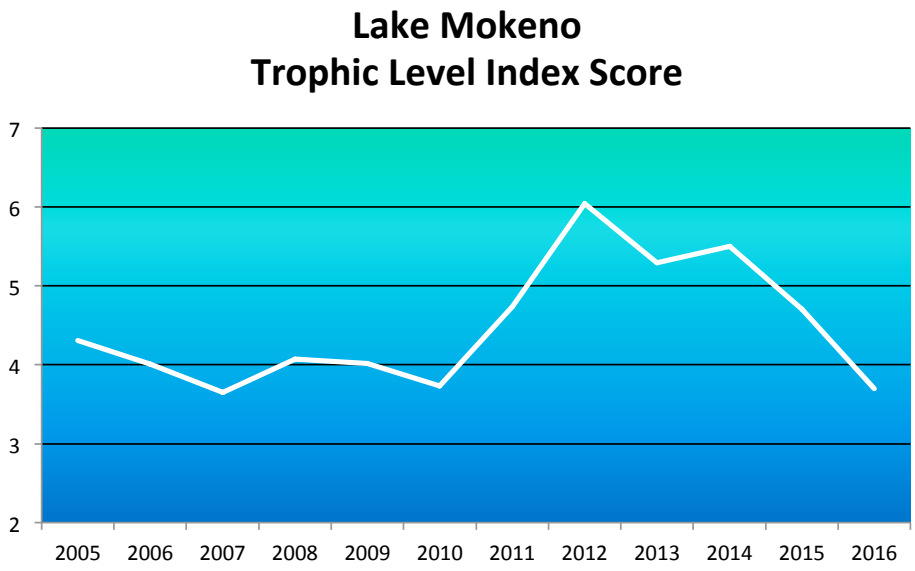


Attribute	Unit	Lake Type	State	Annual Median	Narrative State
Total Phosphorus (Trophic state)	g/m3	All	A	≤.01	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Total Phosphorus (Trophic state)	g/m3	All	B	>.01 and ≤.02	Lake ecological communities are slightly 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.

7.1.1.5. Trophic Level Index

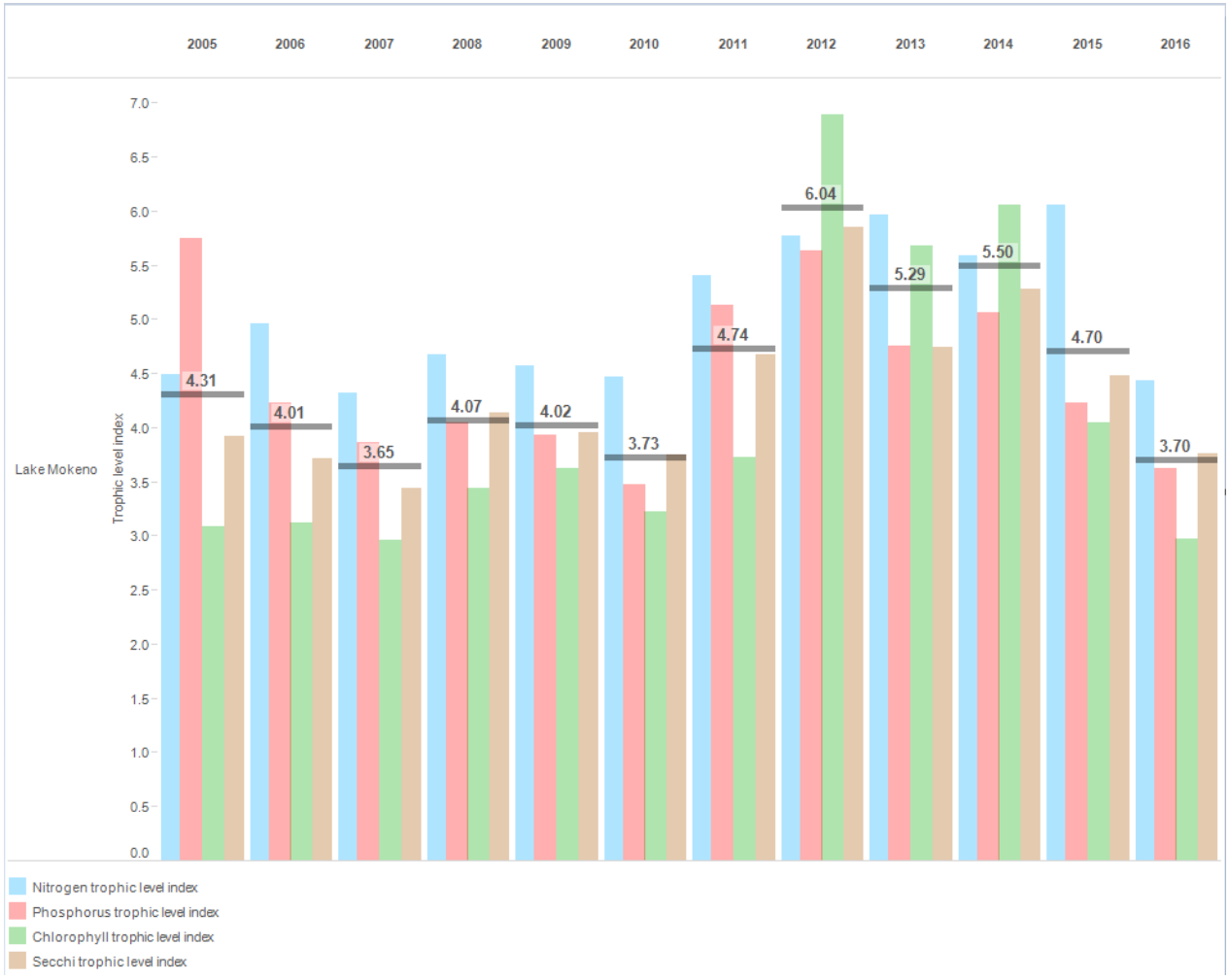
The trophic level index (TLI) is used in New Zealand as a measure of the nutrient status of lakes. The index combines four variables; phosphorus, nitrogen, visual clarity (Secchi disk depth) and algal biomass, each weighted equally.

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 2005-2016 TLI trend, shown below, indicates an average to poor (mesotrophic to eutrophic) trend from 2005 until 2010 when the lake water quality degraded to a low point in 2012, entering very poor (supertrophic) condition. It took until 2016 for water quality to re-equilibrate back to mesotrophic level.



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 displays the TLI scores comparatively. This allows interpretation of the four contributing variables which are combined into an overall TLI score. From this chart, the early phosphorus event in 2005 began the cycle of water quality decline. Nitrogen remained dominant after this event until 2011-2012 when both nutrients pulsed, leading to a nitrogen/ chlorophyll-a dominance through the period 2013-2014, tailing into nitrogen dominance since. With nitrogen + phosphorus being the limiting nutrient combination for this lake, it is not surprising that algal blooms occurred when both nutrients peaked simultaneously.

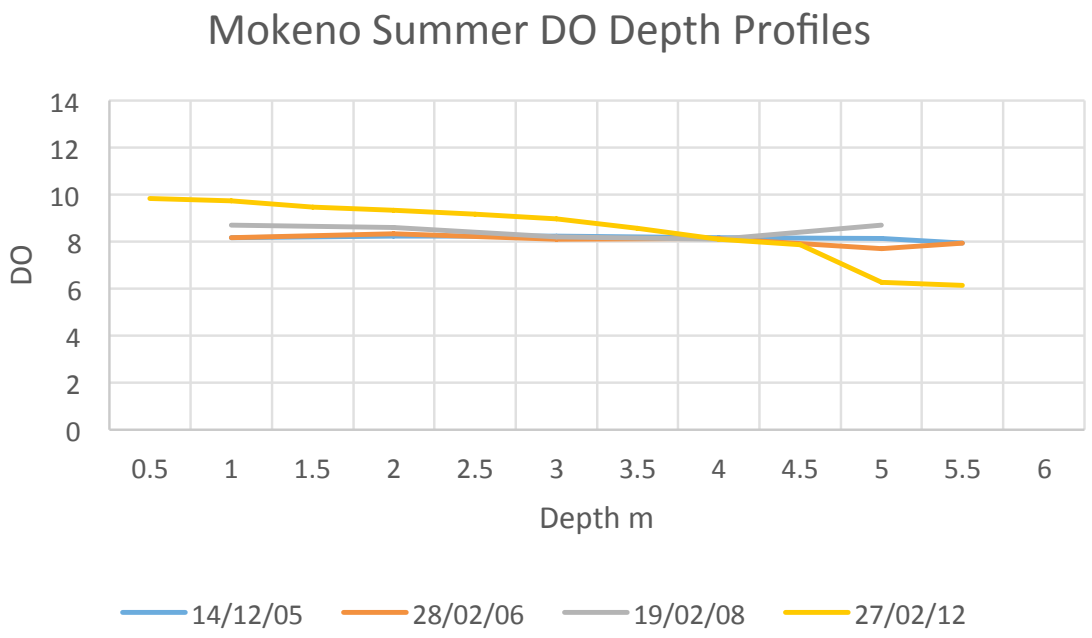


7.1.2. Dissolved Oxygen g/m³

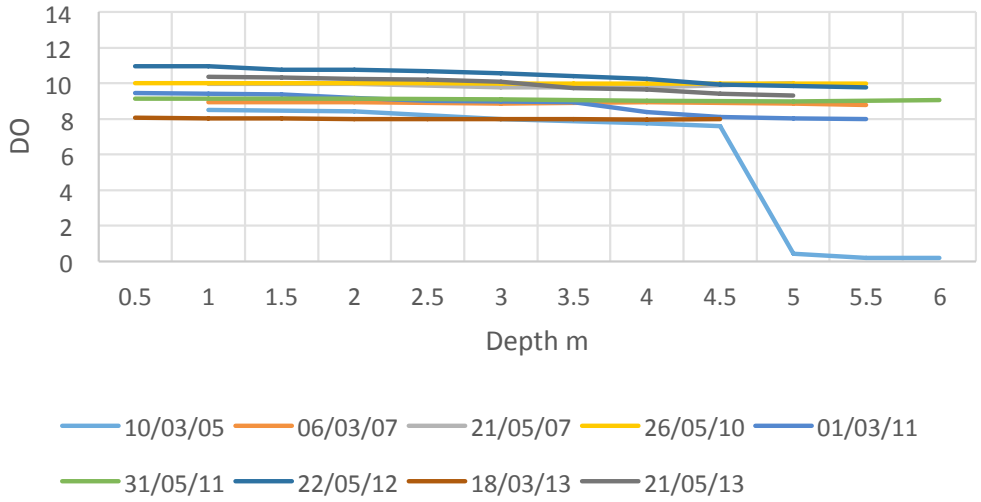
Although the lake does not thermally stratify due to its shallow nature, there was a single prominent deoxygenation event in March 2005 as a result of a large-scale phosphorus pulse. Oxygen depletion occurred in waters below 4.5 meters, as seen in the graphs below.

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

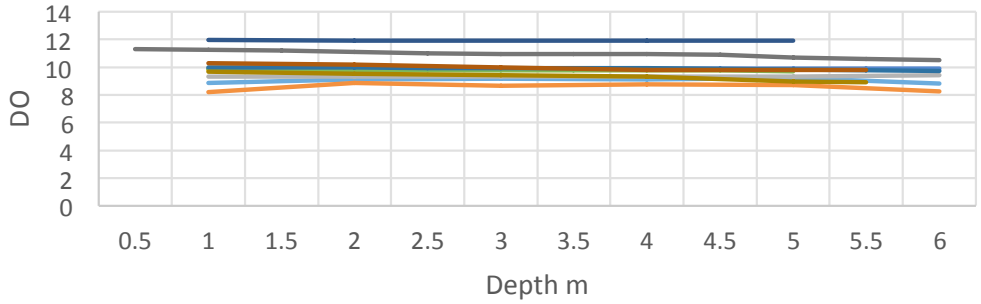


Mokeno Autumn DO Depth Profiles



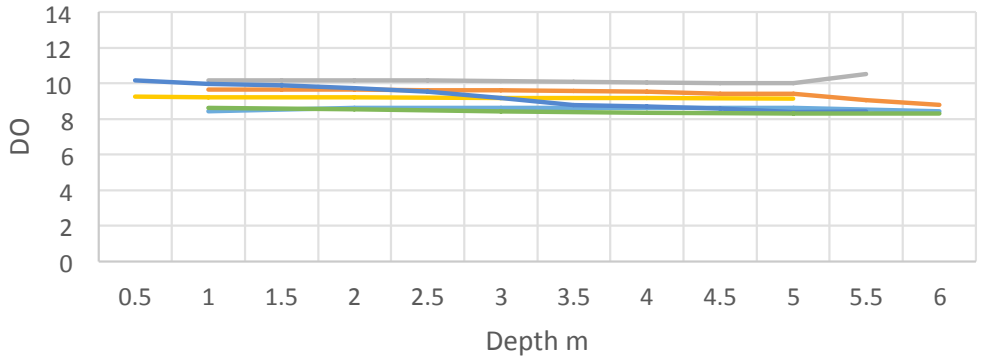
10/03/05 06/03/07 21/05/07 26/05/10 01/03/11
31/05/11 22/05/12 18/03/13 21/05/13

Mokeno Winter DO Depth Profiles



07/06/06 23/08/06 21/08/07 25/06/08
03/08/09 23/08/09 10/08/10 09/08/11
28/08/12 07/08/13 04/06/14

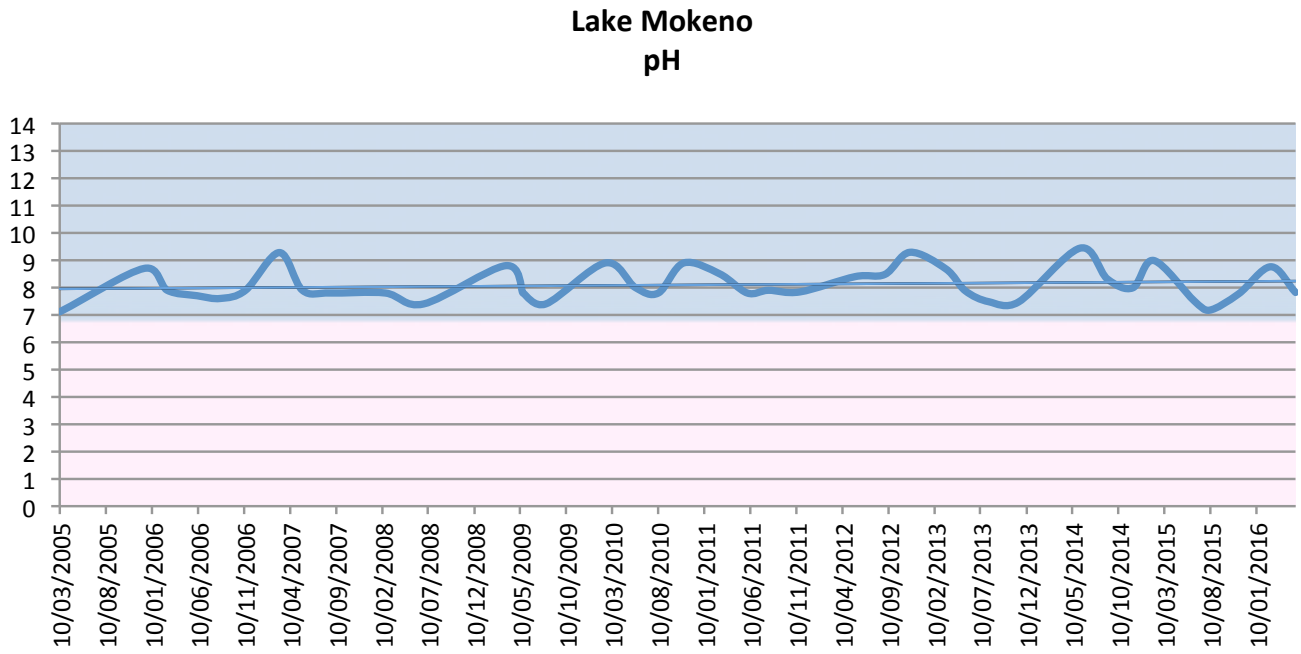
Mokeno Spring DO Depth Profiles



14/11/06 28/10/08 02/11/10
21/11/11 19/11/12 13/11/13

7.1.3. pH

The pH levels in Mokeno vary around 8, between 7.1 and 9.44. These alkaline conditions are preferred by native fish.



8. BIOLOGICAL CHARACTERISTICS

8.1. Lake Biodiversity and Biosecurity species

8.1.1. Plants

Mokeno hosts 19 native aquatic plant species, shown in the table below. 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. Mokeno contains one rare native, the marsh fern (*Thelypteris confluens*).

In addition to the natives, there is only one invasive exotic species present, royal fern.

Lakes Roto-otuauru/Swan and Waingata (Pōuto) have grass carp (green column colouration on the table below) which were introduced to rid these lakes of *Egeria densa* (from Swan) and Elodea (from Waingata). These operations were successful, with grass carp due for removal. Other species of plants in these lakes have been largely de-vegetated, but will likely return once the carp are removed.

Phoebe's Lake has been successfully treated with endothall for the eradication of *Lagarosiphon* major (purple absence on the chart).

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.

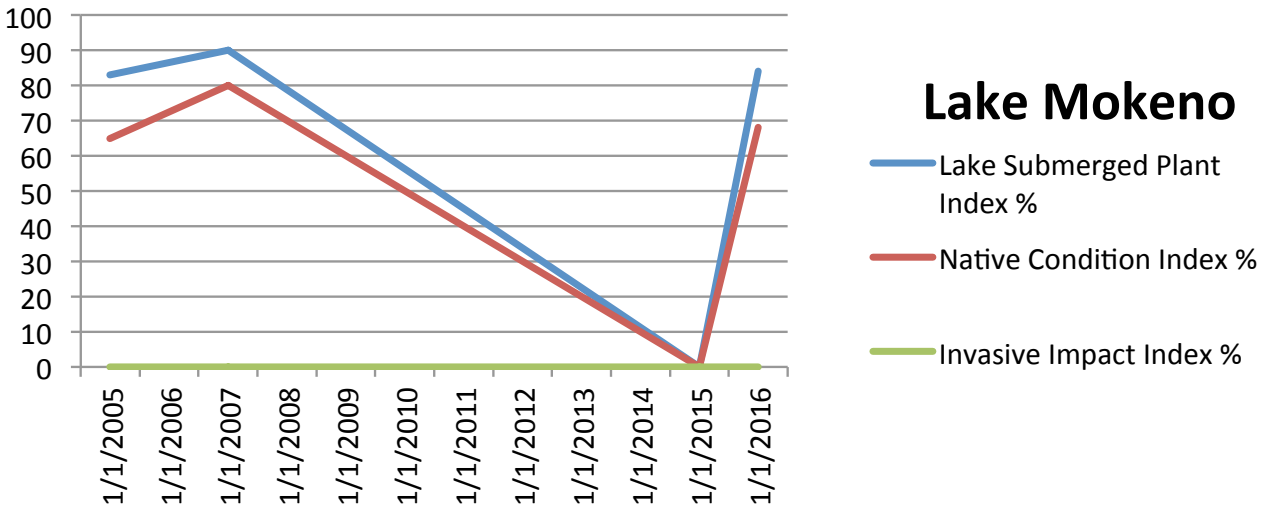
	Depth and Plant Type Zone	Biogeography	Common Name	Species	Grevilles Lagoon	Kapoai	Parawanui	Waimui	Rototuna	Wairere	Phoebe's	Rotopouua	Humuhumu	Roto-otauuru/Swan	Rotokawau (P)	Waingata (P)	Kanono	Kahuparere	Karaka	Mokeno	Whakaneke	Frequency
1	Erect emergent	Invasive exotic	African feather grass	Cenchrus macrourus		x																1
1	Erect emergent	Invasive exotic	royal fern	Osmunda regalis									x		x					x		3
1	Erect emergent	Invasive exotic	Manchurian wild rice	Zizania latifolia							x											1
1	Erect emergent	Non-invasive exotic	bulbous rush	Juncus bulbosus					x						x							2
2	Sprawling emergent	Invasive exotic	alligator weed	Alternanthera philoxeroides	x								x	x		x						4
2	Sprawling emergent	Invasive exotic	glyceria, swamp grass, water meadow grass	Glyceria maxima					x													1
2	Sprawling emergent	Invasive exotic	primrose willow, water primrose	Ludwigia peploides				x														1
2	Sprawling emergent	Invasive exotic	mercer grass, paspalum	Paspalum distichum						x												1
2	Sprawling emergent	Non-invasive exotic	water purslane	Ludwigia palustris									x		x			x				3
4	Floating leaved	Non-invasive exotic	swamp lily	Ottelia ovalifolia				x														1
5	Free floating	Non-invasive exotic	ferny azolla	Azolla pinnata									x									1
5	Free floating	Non-invasive exotic	bladderwort, yellow bladderwort	Utricularia gibba						x	x	x	x	x	x			x				7
7	Submerged tall pondweed	Invasive exotic	lakeweed, egeria	Egeria densa										x	x							2
7	Submerged tall pondweed	Invasive exotic	canadian pondweed	Elodea canadensis											x	x						2
7	Submerged tall pondweed	Invasive exotic	lagarosiphon, lakeweed, oxygen weed	Lagarosiphon major																		0
7	Submerged tall pondweed	Non-invasive exotic	curly leaved pondweed, curled pondweed	Potamogeton crispus			x		x				x				x					4
1	Erect emergent	Native	oioi, jointed wire rush	Apodasmia similis									x		x					x		3
1	Erect emergent	Native	marsh clubrush	Bolboschoenus fluviatilis									x				x	x				3
1	Erect emergent	Native	maori sedge	Carax maorica						x										x		2
1	Erect emergent	Native	pukio	Carex secta						x		x						x	x	x		5
1	Erect emergent	Native	swamp sedge, pukio, toitoi, toetoe	Carex virgata						x												1
1	Erect emergent	Native	giant umbrella sedge, Upokotangata	Cyperus ustulatus						x			x				x	x	x			5
1	Erect emergent	Native	sharp spike sedge	Eleocharis acuta				x	x	x			x	x	x		x	x	x	x	x	11
1	Erect emergent	Native	bamboo spike sedge, tall spike sedge	Eleocharis sphacelata		x		x	x	x	x	x	x	x	x			x		x	x	12
1	Erect emergent	Native	leafless rush	Juncus pallidus						x			x		x			x	x			5
1	Erect emergent	Native	manuka, tea tree, kahikatoa	Leptospermum scoparium																x		1
1	Erect emergent	Native	sedge	Machaerina arthrophylla (syn. Baumea arthrophylla)						x			x						x	x		4
1	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	13
1	Erect emergent	Native	sedge, tussock swamp twig rush	Machaerina juncea (syn. Baumea juncea)						x		x	x		x				x	x		6
1	Erect emergent	Native	baumea	Machaerina rubiginosa (syn. Baumea rubiginosa)																x		1
1	Erect emergent	Native	flax, harakeke, korari	Phormium tenax																x		1
1	Erect emergent	Native	softstem bulrush, grey club-rush, great bulrush	Schoenoplectus tabernaemontani	x	x	x	x	x	x		x	x	x	x		x	x	x	x	x	15
1	Erect emergent	Native	raupo	Typha orientalis	x			x	x	x	x	x	x	x	x		x	x	x	x	x	14
1	Erect emergent	Rare native	Fimbristylis	Fimbristylis velata		x	x															2
1	Erect emergent	Rare native	Marsh fern, swamp fern	Thelypteris confluens								x	x						x	x		4
2	Sprawling emergent	Native	nahui	Alternanthera nahui		x																1
2	Sprawling emergent	Native	centella	Centella uniflora											x							1
2	Sprawling emergent	Native	swamp millet	Isachne globosa						x			x						x		x	4
2	Sprawling emergent	Native	swamp willow weed	Persicaria decipiens						x								x			x	3
2	Sprawling emergent	Rare native	New Zealand sneezewort	Centipeda aotearoana		x																1
3	Low growing turf	Native	starwort	Callitriche petriei		x																1
3	Low growing turf	Native	waterwort	Elatine gratioloides												x						1
3	Low growing turf	Native	none known	Glossostigma elatinoides					x				x	x	x	x	x			x		7
3	Low growing turf	Native	gratiola	Gratiola sexdentata										x								1
3	Low growing turf	Native	none known (sedge)	Isolepis prolifera						x			x		x					x		4
3	Low growing turf	Native	Zelandiae chain sword	Lilaeopsis novae-zelandiae					x				x		x	x	x			x		6
3	Low growing turf	Native	mudwort	Limosella lineata		x							x		x		x					4
3	Low growing turf	Native	arrow grass	Triglochin striata									x	x	x							3
3	Low growing turf	Rare native	hydatella	Trithuria inconspicua (syn Hydatella inconspicua)									x	x	x							3
4	Floating leaved	Native	red pondweed	Potamogeton cheesemanii	x			x	x	x			x		x		x		x	x		9
6	Submerged milfoil	Native	common water milfoil	Myriophyllum propinquum		x							x		x			x				4
6	Submerged milfoil	Native	water milfoil	Myriophyllum triphyllum				x	x	x			x				x	x		x	x	8
6	Submerged milfoil	Rare native	small water milfoil	Myriophyllum votschii									x		x							2
7	Submerged tall pondweed	Native	blunt pondweed	Potamogeton ochreatus	x	x		x	x	x	x	x	x		x		X	x		x		12
7	Submerged tall pondweed	Native	horses mane weed, lakeweed	Ruppia polycarpa									x				x					2
7	Submerged tall pondweed	Native	fennel-leaved pondweed, sago pondweed	Stuckenia pectinata					x								x					2
8	Submerged charophyte	Native	stonewort	Chara australis	x			x	x	x		x	x		x	x	X	x	x	X	x	13
8	Submerged charophyte	Native	stonewort	Chara fibrosa									x		x		x					3
8	Submerged charophyte	Native	stonewort	Chara globularis				x		x			x				X		x	x		6
8	Submerged charophyte	Native	stonewort	Nitella hyalina					x													1
8	Submerged charophyte	Native	stonewort	Nitella leonhardii											x							1
8	Submerged charophyte	Native	stonewort	Nitella pseudoflabellata					x				x		x		x					4
8	Submerged charophyte	Native	stonewort	Nitella sp. aff. cristata	x			x	x		x	x	x		x		X					8
				Total Plant Diversity	**7**	**10**	**3**	**13**	**18**	**22**	**7**	**11**	**36**	**12**	**30**	**6**	**20**	**16**	**17**	**20**	**9**	
				Exotic Plant diversity	**1**	**1**	**1**	**2**	**3**	**2**	**2**	**1**	**6**	**3**	**6**	**2**	**1**	**2**	**0**	**1**	**0**	
				Native Plant Diversity	**6**	**9**	**2**	**11**	**15**	**20**	**5**	**10**	**30**	**9**	**24**	**4**	**19**	**14**	**17**	**19**	**9**	

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. From the timeline below, Invasive Plant Index is consistently at zero because royal fern is the only invasive exotic plant. In April 2007, both Submerged Plant Index and Native Condition Index began to drop to zero by January 2015. This was due to Mokeno experiencing a classic biomass "flip" from macrophyte (native plants) dominance until 2007 to microplankton algal dominance from 2011. Both indices rebounded in 2016, showing the ability of native plants start over from seedbanks and remnant survivors.

A high phosphorus pulse occurred in 2005 or earlier. The only known event this could be linked to is forestry harvest. This phosphorous pulse promoted a rapid growth of native plants in the lake until it was choked with plants. When this phosphorus was used up, the very high biomass of natives collapsed and rotted, releasing their nutrients into the lake. Next, anoxic conditions caused by the rotting plants pulled further legacy phosphorus from the lake-floor sediments, allowing micro-algae to take advantage. Shading by algal conditions prevented recolonization by light-limited native plants. The ability of the lake to recover is a sign of its resilience probably due to a very short water residence time of just over three months. Lakes Wairere and Karaka to the north experienced a similar related event before Mokeno, suggesting that not only is this chain of swampy lakes interconnected through the extensive wetland in which they sit, but also that the direction of the water flow is north to south.

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 below displays the fish of the Pōuto Peninsula. Pest fish are shown in green and conservation species in pink. Lake Mokeno appears in yellow. The lake has a high level of native fish diversity and is free from pest fish.

Gambusia are found at Lake Rototuna to the north and pose a threat to the lakes of the rest of the peninsula to the south.

Common bully and short-finned eel are commonly found in the Pōuto lakes, including Lake Mokeno and the lake is the only one in Pōuto with inanga (*Glaxias maculatus*). Mokeno lacks dwarf inanga, common at other Pōuto lakes.

Lake Mokeno is also the only Pōuto lake with landlocked smelt and grey mullet. The lake is linked to Lake Karaka to the north through interconnected wetland, and drains south into Whakaneke through wetland.

The common bully of Lake Karaka, to the north, have parasites also found in Lake Te Riu well to the north in Waipoua. Common bully parasites in Lake Karaka may pose a threat to common bully in Lakes Mokeno and Whakaneke.

common name	species	Conservation status	Degree of loss	Kapoai	Parawanui	Wainui	Rototuna	Wairere	Phoebe's	Rotopouua	Humuhumu	Roto-otuauru/Swan	Rotokawau (P)	Waingata (P)	Kanono	Kahuparere	Karaka	Mokeno	Whakaneke	frequency
golden bell frog	Litoria Aurea								x											1
grass carp	Ctenopharyngodon idella											x		x						2
goldfish	Carassius auratus			x																1
koi carp	Cyprinus carpio				x															1
Gambusia	Gambusia affinis						x													1
orfe	Leuciscus idus				x															1
rudd	Scardinius erythrophthalmus			x	x		x													3
tench	Tinca tinca			x																1
shortfinned eel	Anguilla australis			x	x			x	x			x	x				x	x		8
longfinned eel	Anguilla dieffenbachii	at risk	declining					x									x			2
giant kokopu	Galaxias argenteus	at risk	declining														x			1
dwarf inanga	Galaxias gracilis	at risk	naturally uncommon				rare			x	x	rare	rare	extinct	x	x				8
inanga	Galaxias maculatus	at risk	declining															x		1
common bully	Gobiomorphus cotidianus			x	x		x			x	x	x	x	x	x	x	x parasites	x	x	13
grey mullet	Mugil cephalus																	x		1
smelt	Retropinna retropinna																	x		1
	diversity pest fish			3	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	
	diversity native			2	2	0	2	2	1	2	2	3	3	2	2	2	4	5	1	

8.1.3. Waterbirds

The table below displays the waterbirds of the Pōuto Peninsula. Game birds are shown in green and non-game bird native species in pink. Lake Mokeno appears in yellow. The lake has a very high level of native bird diversity. Shoveler and grey duck are present as game species. Dabchicks, Australasian bittern and New Zealand scaup occur widely in this sub-region. The remoteness of Lakes Mokeno, Karaka and Whakaneke, being off-road and isolated in the forestry blocks as well as being associated with the extensive west-Pōuto wetlands explains the high bird biodiversity at this lake cluster.

common name	species	Conservation status (DOC, *Conservation status of NZ birds*, 2016)	Criteria / Degree of loss	Grevilles Lagoon	Kapoai	Parawanui	Wainui	Rototuna	Wairere	Phoebe's	Rotopouua	Humuhumu	Roto-otuauru/Swan	Rotokawau (P)	Waingata (P)	Kanono	Kahuparere	Karaka	Mokeno	Whakaneke	frequency
Australasian (NZ) shoveler	Anas rhynchotis (resident native (not introduced) on game bird list)	Not threatened (resident native)																	x		1
grey duck	Anas superciliosa (resident native (not introduced) on game bird list)	threatened	nationally critical		x														x		2
grey duck - mallard hybrid	Anas superciliosa x platyrhynchus (resident native (not introduced) on game bird list)	Not threatened																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				1
paradise shelduck	Tardorna variegata (resident native (not introduced) on game bird list)	Not threatened					x	x		x				x							4
Cape Barren goose	Cereopsis novaehollandiae (Introduced & naturalised)	Introduced & naturalised												x							1
brown teal	Anas chlorotis	at risk	recovering															x		x	2
New Zealand scaup	Aythya novazeelandiae	not threatened			x		x	x	x			x		x	x	x	x	x	x	x	12
Australasian bittern	Botaurus poiciloptilus	threatened	nationally critical	x			x	x	x		x	x	x	x		x	x	x	x	x	13
North Island fernbird	Bowdleria punctata vealeae	at risk	declining									x	x					x	x	x	5
banded rail	Gallirallus philippensis assimilis	at risk	declining															x	x	x	3
Caspian tern	Hydroprogne caspia	threatened	nationally vulnerable									x				x	x		x		4
black shag	Phalacrocorax carbo novaehollandiae	at risk	naturally uncommon		x																1
shag spp.	Phalacrocorax spp.																		x		1
New Zealand dabchick	Poliocephalus rufopectus	at risk	recovering	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	17
marsh crake	Porzana pusilla affinis	at risk	declining															x			1
spotless crake	Porzana t. tabuensis	at risk	declining						x		x	x				x	x		x	x	7
Eastern little tern	Sternula albifrons sinensis		migrant													x	x				2
	diversity resident native (not introduced) on game bird list			0	2	0	2	2	0	1	0	0	1	1	0	1	1	1	2	0	
	diversity introduced & naturalised			0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
	diversity native			2	3	1	3	3	4	1	3	6	3	3	2	6	6	7	8	7	

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 Mokeno, the presence of the Ceratopogonidae and Tanypodinae biting midges, which cannot tolerate more than clean water and the two Acarna mites, not tolerant of worse than mild pollution, is encouraging. Koura/kewai, however, are absent and torowai (freshwater mussels) were last recorded in 2012.

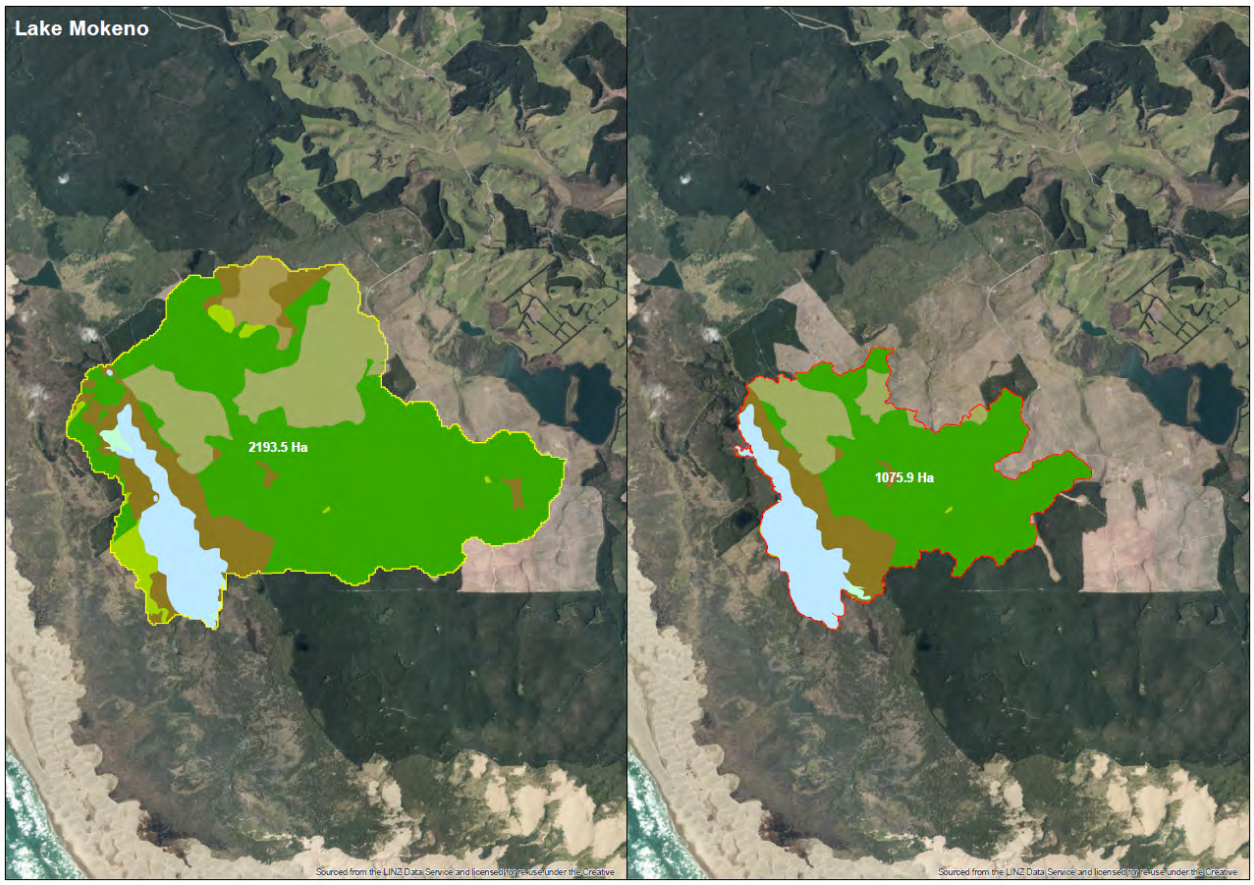
Order or phylum and common name	Family or species	Pollution minimum tolerance - Clean Water (>5.99) Mild Pollution (5.00-5.90) Moderate Pollution (4.00-4.99) Severe Pollution (<4.00)	Parawanui	Wainui	Rototuna	Rotopouua	Humuhumu	Roto-otuauru/Swan	Rotokawau (P)	Kanono	Kahuparere	Karaka	Mokeno	Whakaneke	frequency
Hydrozoa, freshwater jellyfish medusae	*Craspedacusta sowerbyi*						x						x		2
Mollusc, snail	*Physa (Physella) acuta*	0.1			x										1
Mollusc, snail	*Physa (Physella) sp*	0.1		x							x			x	3
Acarna, mite	Hydrachnidae	5.2							x		x		x		3
Acarna, mite	Oribatida	5.2		x					x	x	x		x		5
Acarna, mite	Oxidae	5.2							x		x				2
Amphipoda, hopper	Paracalliope sp			x											1
Crustacea, Cladocera	sp	0.7		x					x		x		x		4
Crustacea, Copepoda	sp	2.4		x					x		x		x		4
Crustacea, Ostracoda, koura	*Paranephrops planifrons*	8.4					x			x	x				3
Crusteacea, Ostracoda	*Herpetocypris*	1.9		x					x	x	x				4
Diptera, house fly	Muscidae	1.6							x						1
Diptera, midge, biting	Ceratopogonidae	6.2							x	x	x		x		4
Diptera, midge, non-biting, Chironomid	Tanytarsini	4.5		x					x		x		x		4
Diptera, midge, non-biting, Chironomid	*Chironomas sp*	3.4		x					x	x	x		x	x	6
Diptera, midge, non-biting, Chironomid	Orthocladiinae	3.2		x					x	x	x		x		5
Diptera, midge, non-biting, Chironomid	Tanypodinae	6.5									x		x		2
Ephemeroptera, mayfly	*Deleatidium*	5.6							x						1
Hemiptera, bug	*Microvelia macgregori*	4.6											x		1
Hemiptera, bug, backswimmer	*Sigara arguta*	2.4		x							x			x	3
Hemiptera, bug, waterboatman	*Diaprepocoris sp*	4.7									x				1
Hirudinea, leech	Hirudinea			x							x		x		3
Hirudinea, leech	*Richardsonianus mauianus*			x					x						2
Hydrozoa, hydra	*Hydra* sp					x							x		2
Lepidoptera, aquatic moth	*Hygraula nitens*	1.3									x		x		2
Mollusca, bivalve	Sphaeridae			x					x						2
Mollusca, freshwater mussel	*Echyridella menziesi*					shells	x	x	x				x		5
Mollusca, freshwater mussel	*Hyridella menziesi*	6.7	x							x	last 2001				3
Mollusca, snail	*Gyraulus corinna*	1.7		x											1
Mollusca, snail	Lymnaea sp			x											1
Mollusca, snail, native	*Glyptophysa variabilis*	0.3					x			x	x				3
Mollusca, snail, native	*Potamopyrgus antipodarum*	2.1				x			x			x		x	4
Nematoda, roundworm	sp	1.8		x					x	x			x		4
Nemertea, proboscis worm	sp	1.8		x							x				2
Odonata, damselfly	*Xanthocnemis sp*	1.2		x							x				2
Odonata, dragonfly	*Aesha brevistyla*	1.4		x					x						2
Odonata, dragonfly	*Hemianax papuensis*	1.1		x							x				2
Odonata, dragonfly	*Hemicordulia australiae*	0.4		x					x	x	x				4
Oligocheate worm	Oligochaeta sp	3.8							x	x	x		x		4
Ostracod crusteacean	*Cypretta*										x				1
Ostracod crusteacean	Cypridopsis								x	x					2
Ostracod crusteacean	*Ilyodromus*								x	x	x		x		4
Platyhelminthes, flatworm	sp	0.9		x					x	x	x				4
Porifera, freshwater sponge	sp					x									1
Trichoptera, caddisfly	*Paroxyethira hendersoni*	3.7		x					x	x	x				4
	diversity invasive		0	1	1	0	1	0	0	0	1	0	1	1	6
	diversity native		1	22	0	4	3	1	24	15	27	1	17	3	

9. LAND USE

9.1. Catchment land cover table and map

The catchment (hand-drawn) is dominated by exotic pine forest, manuka/kanuka scrub and harvested forest.

Lake	Cover Type	Total FENZ (ha)	Total LiDAR (ha)
Lake Mokeno	Broadleaved Indigenous Hardwoods	64.09	0.00
Lake Mokeno	Exotic Forest	1267.85	617.65
Lake Mokeno	Forest - Harvested	370.62	139.87
Lake Mokeno	Herbaceous Freshwater Vegetation	10.40	5.66
Lake Mokeno	Lake or Pond	170.83	169.94
Lake Mokeno	Low Producing Grassland	56.51	1.23
Lake Mokeno	Manuka and/or Kanuka	253.23	141.57
Lake Mokeno Total		2193.53	1075.91

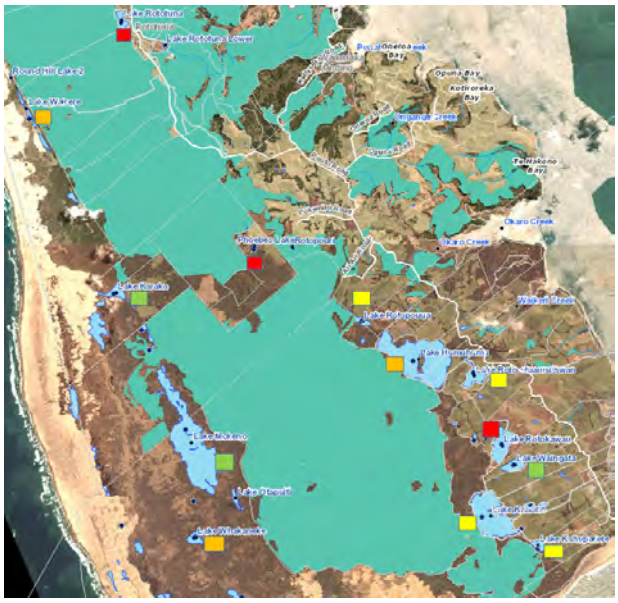


9.2. Fire-fighting mitigations

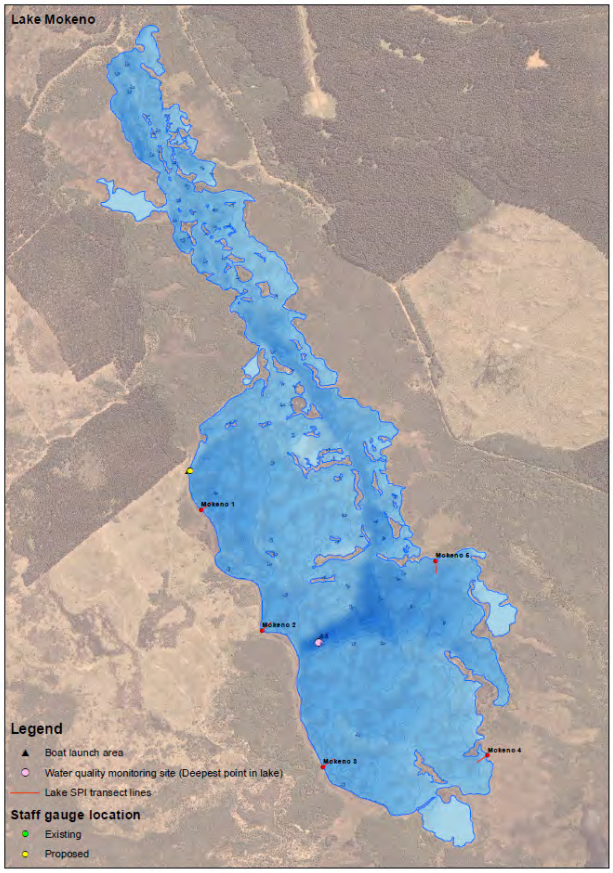
Mokeno, due to its low level of invasive exotic plants, along with Karaka to the north, offers opportunity for use as a water source in the event of forest fire. Optimal location of take by fire bucket is at the deepest basin to avoid bottom damage to this otherwise shallow lake. (see overleaf)

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.



Fire-fighting mitigations



Monitoring plan

10.1. NIWA ecological monitoring

The lake is scheduled to be fully ecologically monitored every five years with weed surveillance every five years as well. There have been five full surveys since 2005. The value class of the lake began at Outstanding and progressed to Medium-High in 2015 due to algal dominance, improving to High in 2016. The next full survey is likely to be done in 2018.

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
Grevilles Lagoon															M																
Humuhumu	5	1													O		O					O		O							
Kahuparere	5														H		H					H			O						
Kanono	5	3-5													O		O						O		O			?			
Kapoai	5														L-M		L-M							L				?	?	?	
Karaka	10	5-10													H		H					H			O			?			
Mokeno	5	5													O		O					O			M-H	H					
Parawanui															L											M-H		?			
Phoebe's																		L													
Rotokawau (P)	5														H		H					H			O						
Roto-otuauru/Swan		1													M				M carp	M	M	M	M		carp			carp	carp	carp	carp
Rotopouua	5																	O				O									
Rototuna	5														H		H					H		M				?			
Waingata (P)															L					L					L						
Wainui	5														M-H		M-H							H				?			
Wairere and Round Hill Lake 2	10														M-H									M-H							
Whakaneke															H							M						?			

10.2. NRC Ecological monitoring

10.2.1.Water quality and quantity monitoring

Water quality sampling occurs quarterly in February, May, August and November.
Number of samples taken per year are display 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
Mokeno lower																	2	4	3	3	3	4	4	4	4	4	4	4	2	45
Mokeno surface													1				2	4	3	3	3	4	4	4	4	4	4	4	2	46

11. WORK IMPLEMENTATION PLAN

Ongoing work includes:
The NRC/NIWA ecological surveys and weed surveillance will continue every five years. The next full survey will be in 2018. Quarterly NRC water quality monitoring will continue.

Further mitigation work to consider includes:

- Assessment of the effects of forestry harvest on the drivers of nutrient enrichment. Work with forestry industry during next harvest cycle to minimise impacts.
- Mokeno, due to its low level of invasive exotic plants, along with Karaka to the north, offers opportunity for use as a water source in the event of forest fire. Optimal location of take by fire bucket is at the deepest basin to avoid bottom damage to this otherwise shallow lake. Water take from the sea is preferred.
- Installation of a staff gauge and a continuous electronic water-level recorder.
- Investigate eradication of royal fern

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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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