Lake Ngatu
MANAGEMENT PLAN

Northland
REGIONAL COUNCIL

CONTENTS

LAKE NGATU MANAGEMENT PLAN

1. PURPOSE

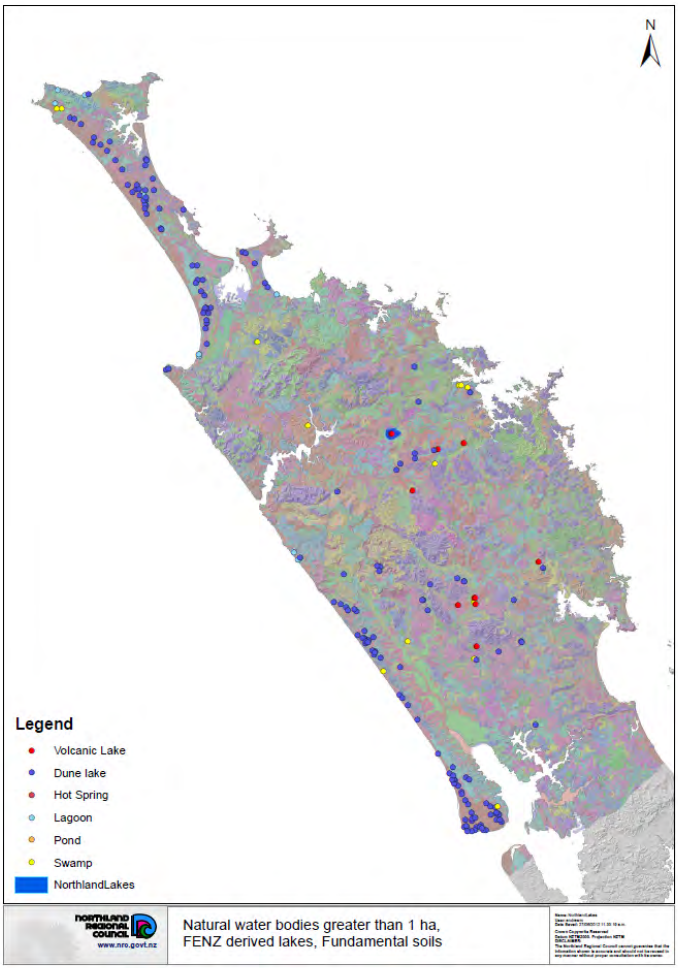
The purpose of the Outstanding Northland Dune Lakes Management Plans is to implement the recommendations of the Northland Lakes Strategy Part II (NIWA 2014) by producing Lakes Management Plans, starting with the 12 'Outstanding' value lakes, and by facilitating actions with mana whenua iwi, landowners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

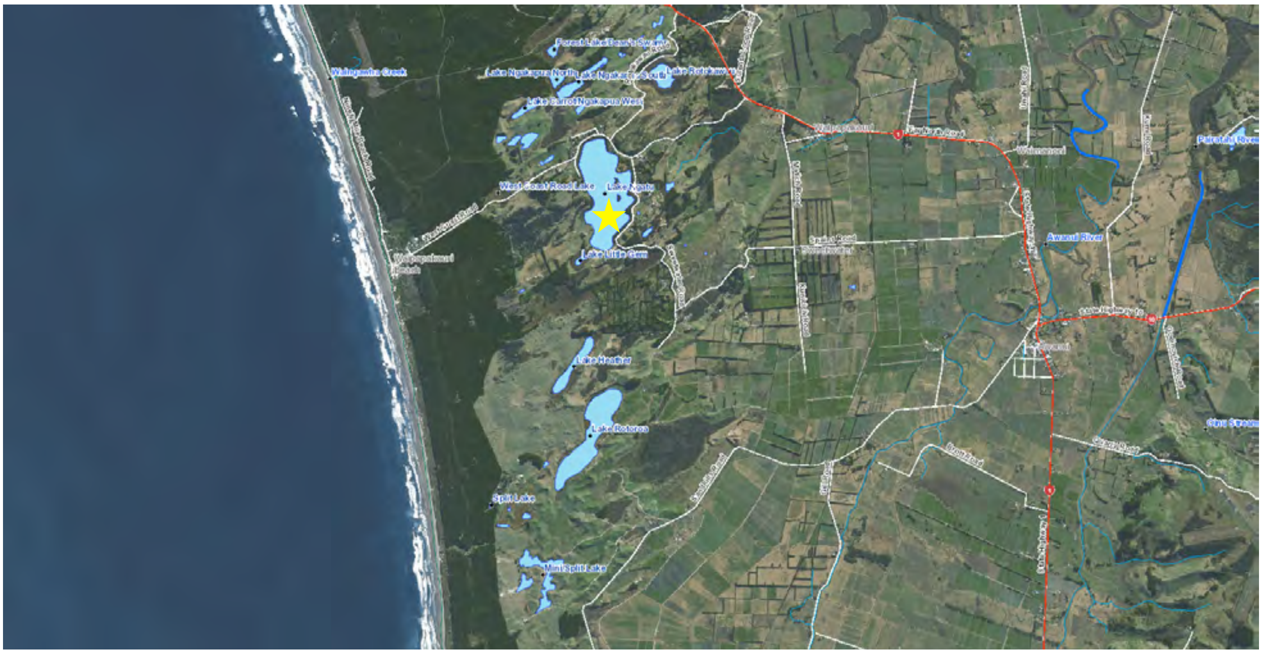
Further south within Northland, on the west coast north of Dargaville, are the three Kai Iwi Lakes (Lake Kai Iwi itself, and Lakes Taharoa and Waikare, sometimes referred to as Waikere).

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 Ngatu (NRC Lake Number 120) has a shallow northern half and three deep basins to the south (6.26 m max and 2.67 mean depth) and is a 55.54 ha in area. Lake Ngatu is located at the corner of Sweetwater and West Coast Road in the lower Aupōuri Peninsula of Northland. The lake is classified as a Class 1 Perched dune lake (Timms, 1982), meaning it sits above ground water level and relies on rainfall and overland flows for recharge.

The catchment is largely influenced by high and low producing exotic grassland and freshwater sedgeland/rushland. Other influences, although at lower percentage covers, include short rotation cropland and orchard, other perennial crops and built-up settlement, all of which will be contributing to nutrient inputs to the lake. The NRC-defined catchment area, including the lake, is 177.9 hectares. The surface area of the lake is 55.54 ha.

Of significance is the influence of built up settlement area, orchard and other perennial crops and short-rotation cropland which drain into the lake. There is historic urban development overlooking the lake with possible effects from septic tanks, some of them being older systems, increased road runoff, a school nearby with an older septic system and DOC toilets close to the road on northern side, also with an older septic system. The reserves at either end are used regularly by freedom campers who also use the lake for bathing, and cleaning cooking equipment. The lake is popular for swimming and bathing over summer, with use of soap products. These cumulative effects add to the overall decline of water quality.

The shallow water is wind-mixed and does not thermally stratify, mixing excess nitrogen and phosphorus making them available to phytoplankton throughout the year. Algal blooms have occurred in 2009 and 2015. Chlorophyll-a levels are in National Policy Statement for Freshwater Management (NPS) States C and D and push well into State D during blooms. If this continues, the lake may "flip" to an algal dominated state causing blooms to shade submerged vegetation leading to dieback of bottom-rooted plants. Recent results from 2017 (available after this plan was written) are showing substantial improvements in water quality.

Nitrogen levels are trending upward and have remained well into a consistent State D since late 2012 and phosphorus has seen a long-term decline, currently in State B with smaller event modes than in the past. Toxic ammonia levels peaked in November 2015. The lake was mesotrophic (average water quality) for some time before degrading to eutrophic (poor water quality) since 2015. There is an occasional oxygen depletion in water deeper than 4-4.5 meters between August and February. The pH has historically been neutral, but has risen (more alkaline), most likely from phytoplankton using up carbon dioxide. Lake levels are variable for this perched dune lake due to the influences of inter-annual rainfall and drought patterns as the lake largely receives water from rainfall. The range in levels varies by 1.8 m. The overall trend is of slight increase in level, largely due to early historic low levels. Water retention time is just over 18 months.

One of the reasons that Lake Ngatu is among the top outstanding dune lakes in Northland is because of its diverse aquatic plant community. The lake supports 20 native plant species, including five rare natives. Lake Submerged Plant Index is high at 55%. There are five exotic species recorded, three of these being invasive, and including yellow flag iris (eradicated by the NRC in 2007), alligator weed and *Lagarosiphon*, which was first recorded in 1988. *Lagarosiphon* is highly invasive and is capable of occupying the entire lake bed. The Invasive Impact Index is high at 47%.

Gambusia, goldfish, rudd, perch and even introduced trout, in the past, suggest there has been a range of vectors for pest fish entry. Common bully and inanga are still present as native fish, but their survival will be under sustained pressure given the deterioration of water quality.

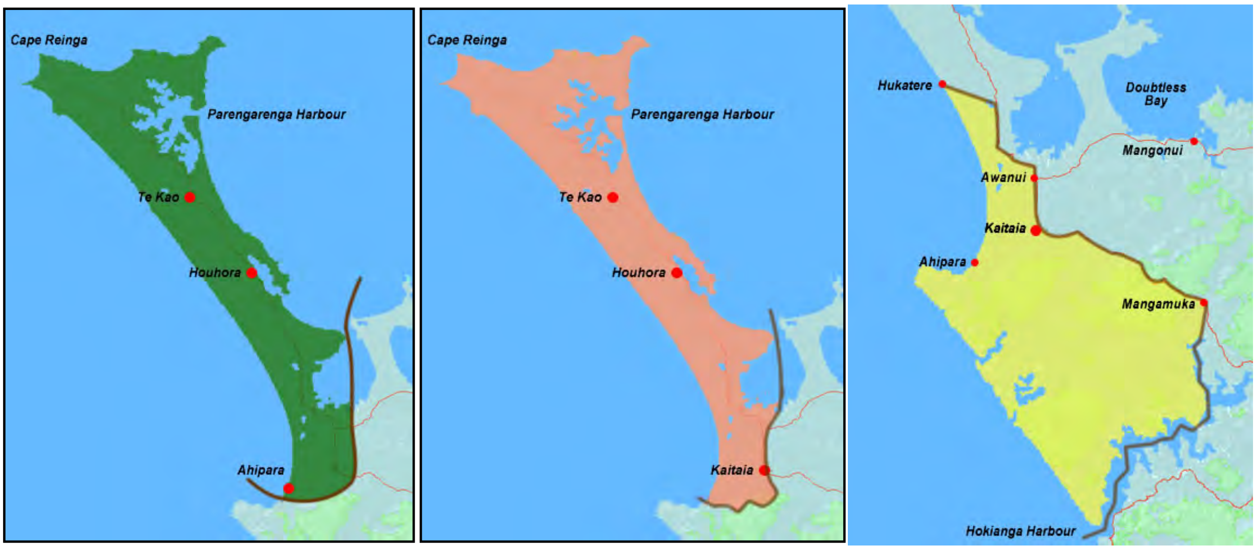
The lake has a moderate level of non-game bird native bird diversity at four species. Of interest is the sole occurrence of the Caspian tern in the area.

5. SOCIAL AND CULTURAL DIMENSION

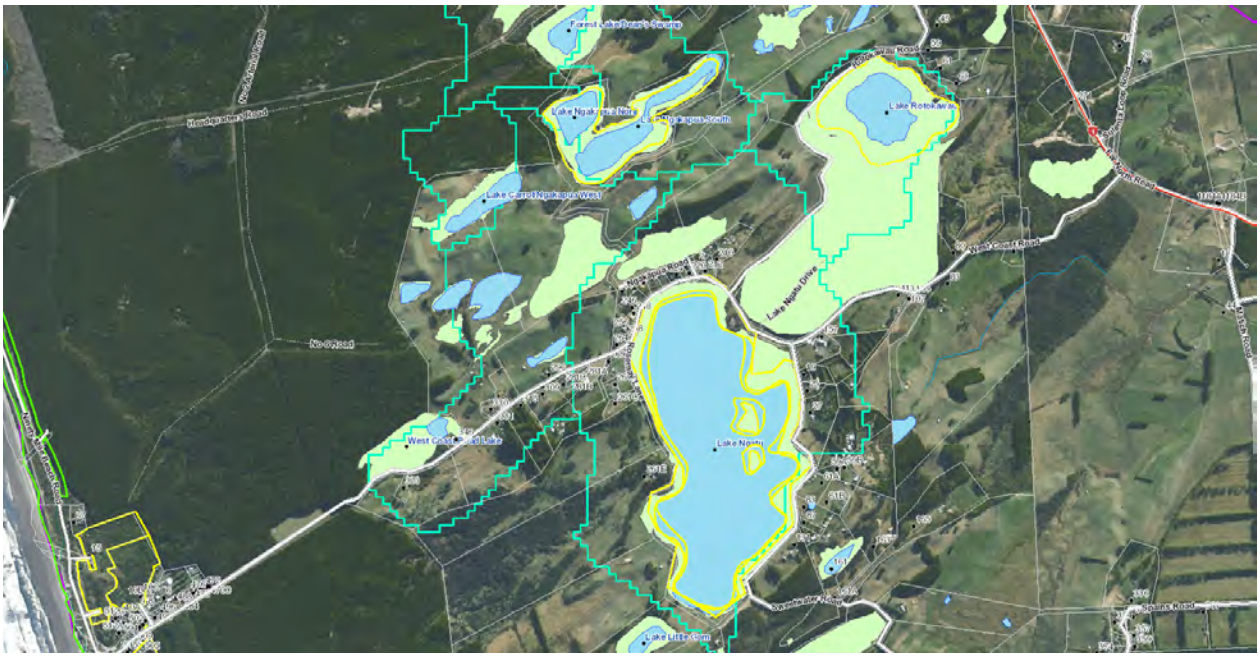
5.1. Mana whenua

Three iwi/hapu have rohe whenua Area of Interest in the area of Lake Ngatu; Ngāi Takoto (green), Te Aupōuri (pink) and Te Rarawa (yellow). All three iwi/ hapu have reached Deed of Settlement with the Crown and Ngāi Takoto has been given ownership of Lake Ngatu, along with lakes Ngakapua North and South and Rotokawau (Sweetwater) by way of cultural redress. The lake is largely managed by Ngāi Takoto.

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



The yellow line on the following map shows Ngāi Takoto ownership of the four lakebeds. The light green areas are wetland.



5.2. Land Tenure

5.2.1 Catchment landowners and Lake bed owners

Thirty-eight landowners own 49 parcels within the lake catchment. The lake bed is owned by Ngāi Takoto. There is a paper road which encircles the lake.

5.3. Community involvement

Restoration activity in this area has been undertaken by Bushland Trust and the local school and community. An active management group called Lake Ngatu Action Group is in place comprised of Ngāi Takoto, the Department of Conservation, Far North District Council, Northland Regional Council, Bushland Trust and local landowners.

Ngāi Takoto have installed bollards at entry points to exclude power boats and the public using the lake to wash vehicles after coming off the beach. They have also discouraged the use of the lake for bathing with soap products and have erected informational signage. Riparian planting has been underway for a number of years.

5.4. Public use

5.4.1. Access

Public access is easy via West Coast Road and Sweetwater Road.

5.4.2. Boating

5.4.2.1. Boat access

Boat access is easy to the northern and southern end of the lake but is now limited mainly to waka ama. Bollards stop access to trailer or power boats, although access through chained launch points for events and management purposes is possible by permission through Ngāi Takoto

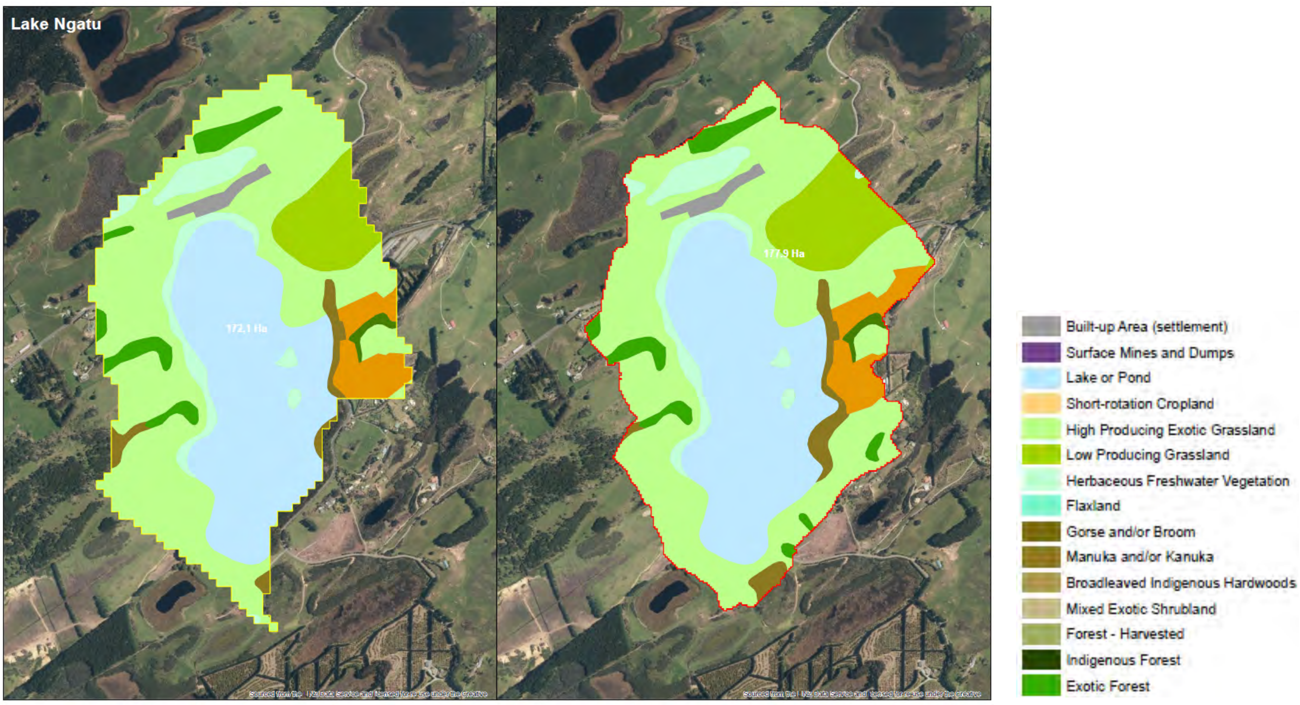
5.4.3. Events

Summer events are periodic including concerts and World Wetlands Day celebrations.

6. PHYSICAL CHARACTERISTICS

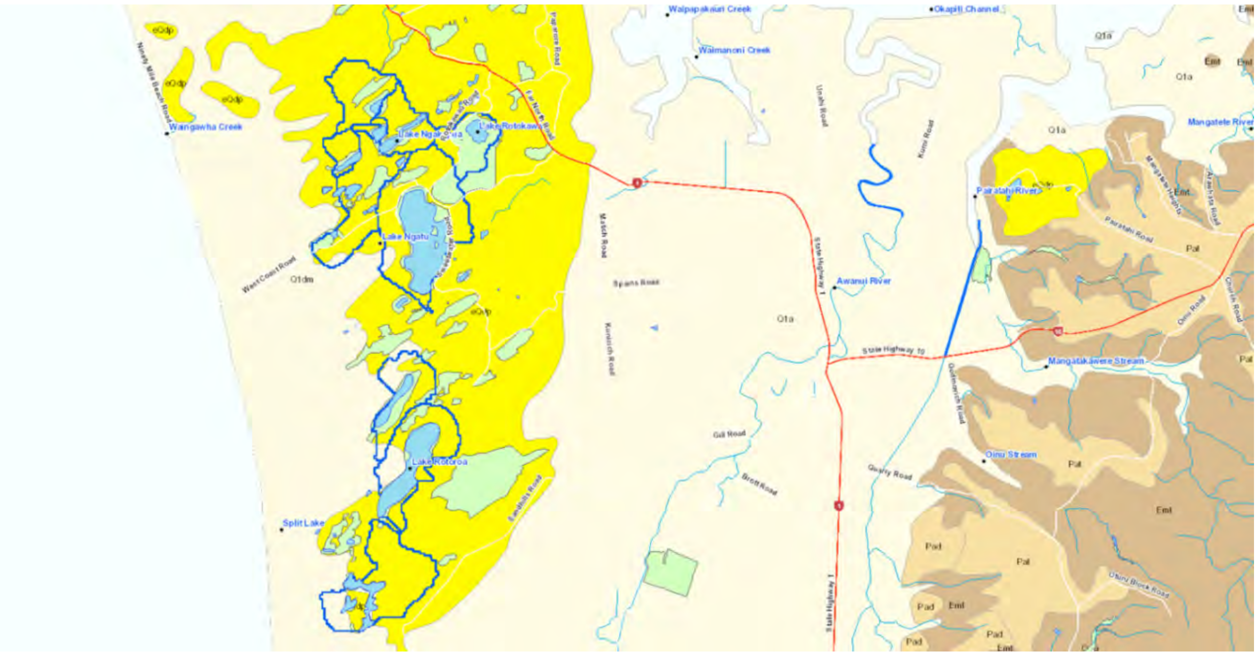
6.1. Catchment Area with Map

The following map shows the extent of the lake catchment. On the left is the FENZ boundary and a is a rationalised boundary created by NRC staff is on the right. By the end of 2018, a highly-accurate LiDAR boundary will be available. The NRC-defined catchment area, including the lake itself, is 177.9 hectares.



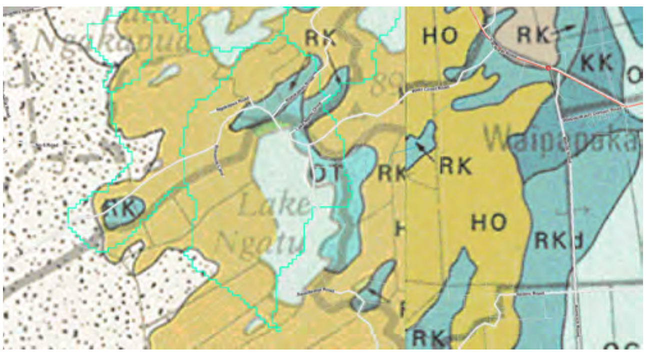
6.2. Catchment Geology and soil types

The following map ((C) GNS Science 2016) of the Sweetwater area and the table below it shows the geology of the lake catchment. Lake Ngatu has a uniform geology comprised solely of Early Quaternary dunes (eQd) which formed during higher sea levels 12,000 years ago and earlier. These ancient dunes are now weakly cemented to uncemented.



Plot Symbol	eQd
Name	Early Quaternary dunes
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.
Geologic history	Early Quaternary
Simple name	Zealandia Megasequence Terrestrial and Shallow Marine Sedimentary Rocks (Neogene)
Absolute minimum age (millions of years before present)	0.78
Absolute maximum age (millions of years before present)	2.6
Supergroup equivalent stratigraphic name	Pakihi Supergroup
Lithology	Sand

Soil types in the catchment are portrayed in the soil map adjacent and table below. The eastern shore of the lake is dominated by organic soils of the One Tree Point series (OT) and the western shore is organic soils of the Ruakaka series (RK) with a northern area of the catchment with patches of yellow brown sands of the Houhora series (HO). The One Tree Point peaty sands have deposited an iron pan which creates an impermeable water-holding layer.



Soil Symbol	Genetic soil group	Geological origin	Suite	Subgroup	Series	Soil name	Description
OT	Organic soils		Ruakaka		One Tree Point	One Tree Point peaty sand	**One Tree Point peaty sand (OT)** is a 'groundwater podzol', its development has been similar in many ways to that of the pakahi soils of Westland. It will have carried kauri forest at some stage in its development but not since human settlement in New Zealand. A typical profile has up to 75 mm of dark reddish brown slightly peaty loamy sand with weakly developed structure and containing bits of kauri gum, on 100 mm of very dark grey peaty sand also with little structure, over 100 mm of very dark grey peaty sand with increasing proportions of white silica sand grains. The boundaries between the layers are indistinct to this point but beneath this last layer is a distinct, iron-cemented layer which acts as a barrier to further root penetration and to the drainage of water on through the profile. Water drains horizontally along this pan. Wind erosion of dust and peat has been a problem during development of this land for urban and industrial use at One Tree Point., causing both onsite problems and difficulty of revegetation, and air quality off-site nuisance problems.
RK	Organic soils		Ruakaka		Ruakaka	Ruakaka peaty sand loam	**Ruakaka peaty sand loam** (**RK**) is found throughout Northland (except around the Kaipara where there is PZ) in what were swampy basins adjoining dunes, for example, in inter-dune swamps and the fringes of peaty sand plains. A representative profile of this low to very low fertility soil would have 150 mm of black fine sandy peaty loam, on 450 mm of black to reddish brown fine sandy peaty loam, on black loamy peat, which will contain wood fragments. There may well be ash layers where the swamp has been burnt and then peat has developed on top.
HO	Yellow-brown sands	Sands of Upper Quaternary dune series	Pinaki	Moderately to strongly leached	Houhora	Hourhora sand	**Houhora series** – on older west coast dunes, more mature than Pinaki series, having more soil development, more organic matter and stronger structure. Can have iron cementing but generally iron content is a much lower than Red Hill series. [Either developed on sand from a separate source – (Central North Island rhyolitic/feldspathic sand rather than Taranaki iron sands) or the iron had settled out before this sand reached the Aupouri Peninsula.] A typical profile of Houhora sand (HO & HOH) may include: 80 to 150 mm of very dark greyish brown to olive brown loamy sand, on 80 to 150 mm of yellowish brown to pale brown sand, on brownish yellow to strong brown loamy sand.

6.3. Catchment Hydrogeology

Although the Aupōuri sands holds an extensive groundwater aquifer, Ngatu is a perched lake unaffected by the water table. The lake sits to the southern edge of the Aupōuri aquifer range.

6.4. Catchment drainage and sedimentation rates

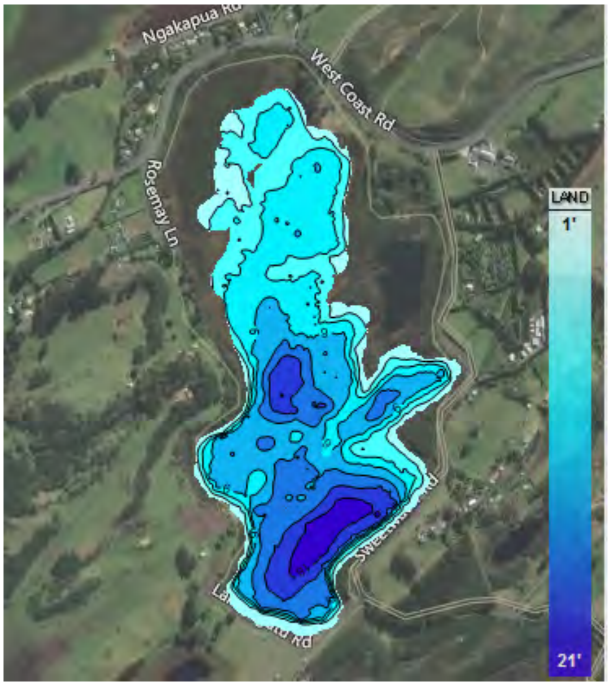
The NRC-defined catchment area, including the lake itself, is 177.9 hectares and produces a mean annual flow, based on hydrological models, of 715,552.5 m³/year. The lake has an estimated lake residence time of 1.565 years, meaning any water entering the lake will remain for over 18 months. This residence time is similar to nearby Ngakapua North (2.268 years) and Rotoroa (1.805 years) with other lakes in this sub-region having considerably shorter residence times. The average particle size of surface rock in the catchment is 1.63 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 in the Sweetwater area, Lake Ngatu is a shallow Class 1 perched lake originating as an elevated deflation hollow with a sealed organic basin with humic characteristics. The lake has a maximum depth of 6.26 m with a mean overall depth of 2.67 m. The surface area of the lake is 55.54 hectares with a volume of 1,548,165.50 m³ (NIWA bathymetric survey). The NRC-defined catchment area, including the lake itself, is 177.9 hectares.

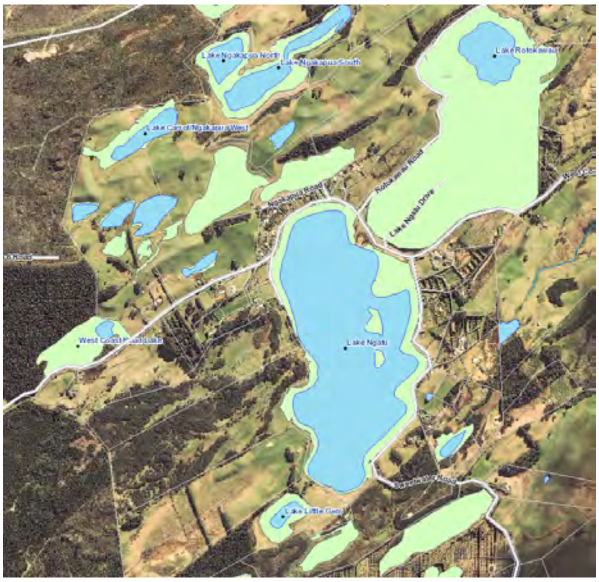
6.6. Bathymetry map

The bathymetric depth map adjacent comes from a survey done by NIWA for the NRC. The deepest point is within the southern-most basin followed by central and eastern basins. Please note that the scale of this map is in feet, not meters.



6.7. Natural inlets and outlets

Several drains enter the lake (please see section 10.2 Drains). There are no outlets.



6.8. Wetland associations

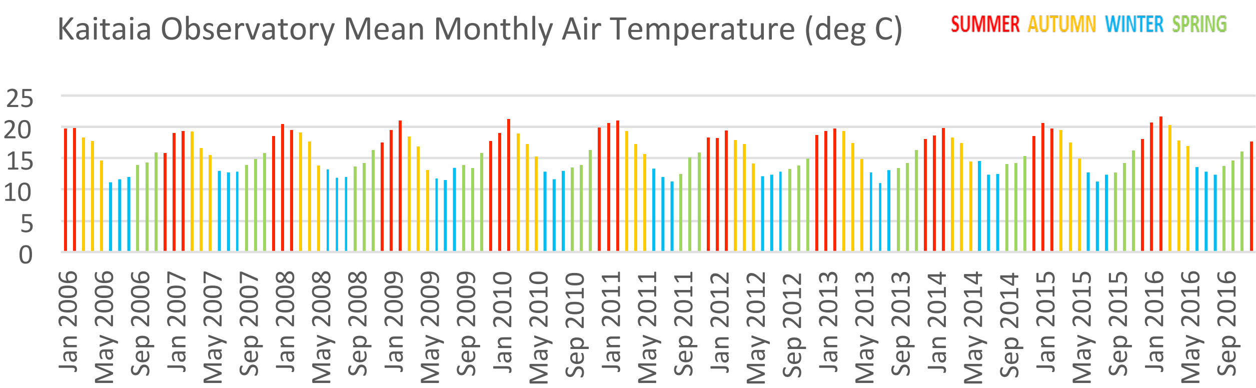
A shallow water wetland surrounds the lake edges, shown in the map below in light green. This is not a "Top 150" wetland meaning that it is not ranked as one of the region's best wetlands. The subregion contains a mosaic of such wetlands and dune lakes.

6.9. Connectivity

The lake is not connected to any other waterbody although there are smaller dune lakes nearby, including Lake Gem to the south, which has a walking track around it from Lake Ngatu carpark and has been fenced and replanted.

6.10. Air Temperature

Temperature appears to be reflecting a cyclic pattern like based on El Nino/La Nina oscillations. Lake level drops follow summer droughts due to evaporation.

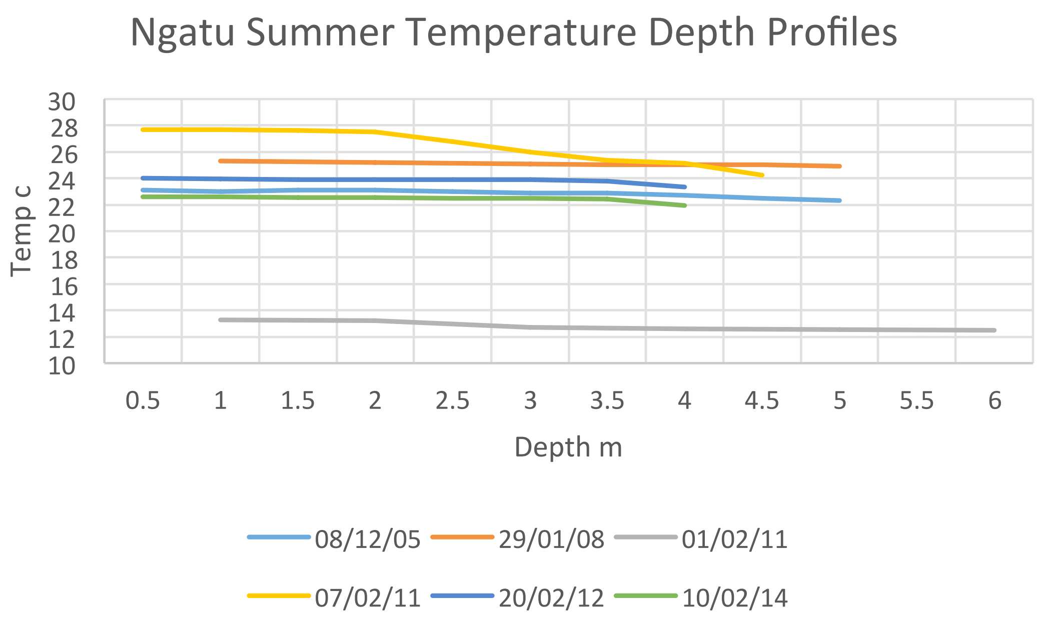


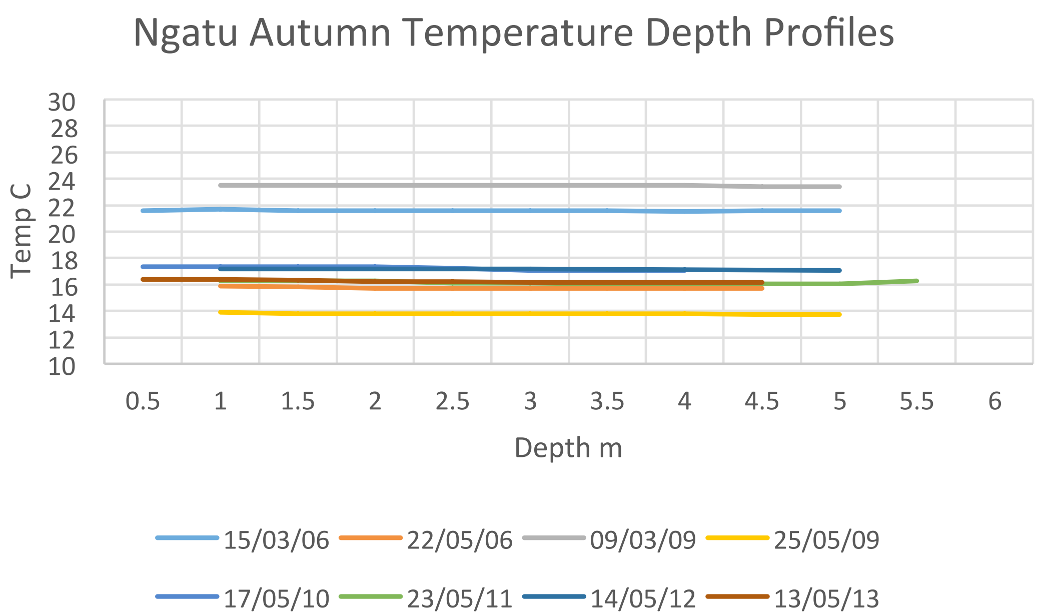
6.11. Thermal stratification

The graph below shows temperature at depth throughout the water column. Each coloured line represents one sample. Water temperatures throughout the year range from 12.6 degrees C to 27.67 degrees C.

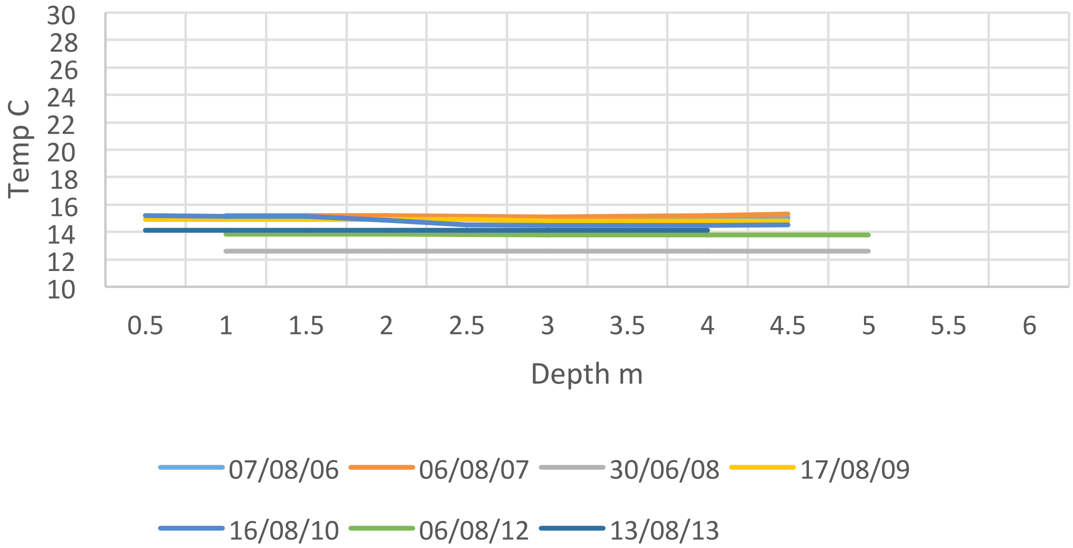
The lake, being very shallow at 2.67 m mean depth, does not thermally stratify in summer and temperature is fairly uniform at all depths, year-round. In order for a lake to stratify, water depth must exceed 10 meters.

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

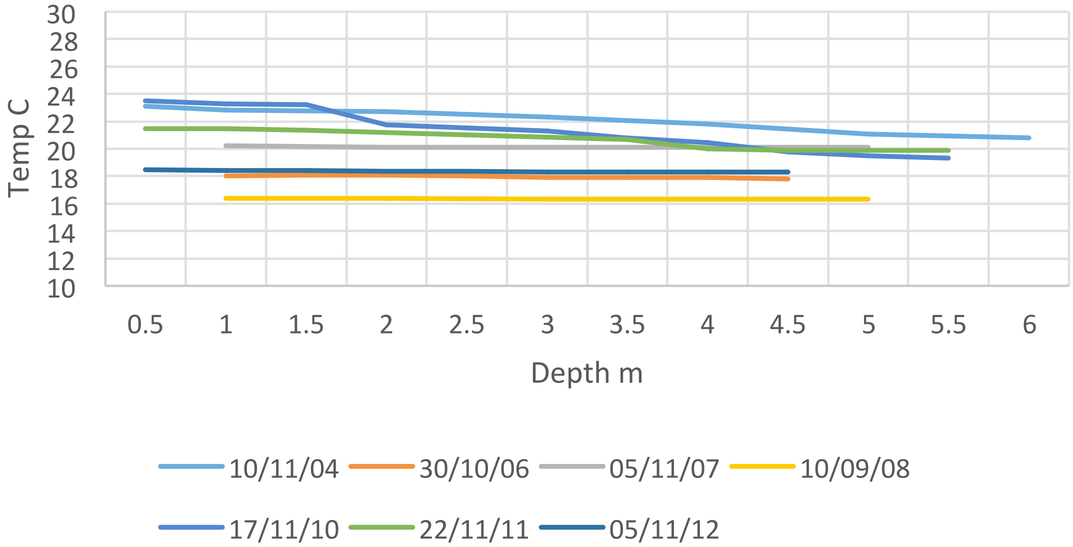




Ngatu Winter Temperature Depth Profiles

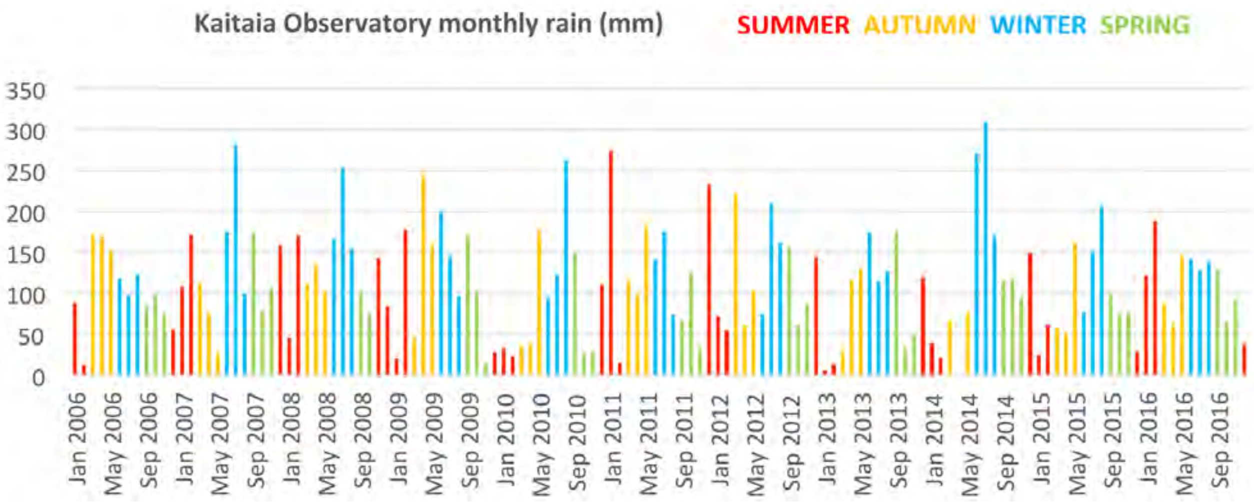


Ngatu Spring Temperature Depth Profiles



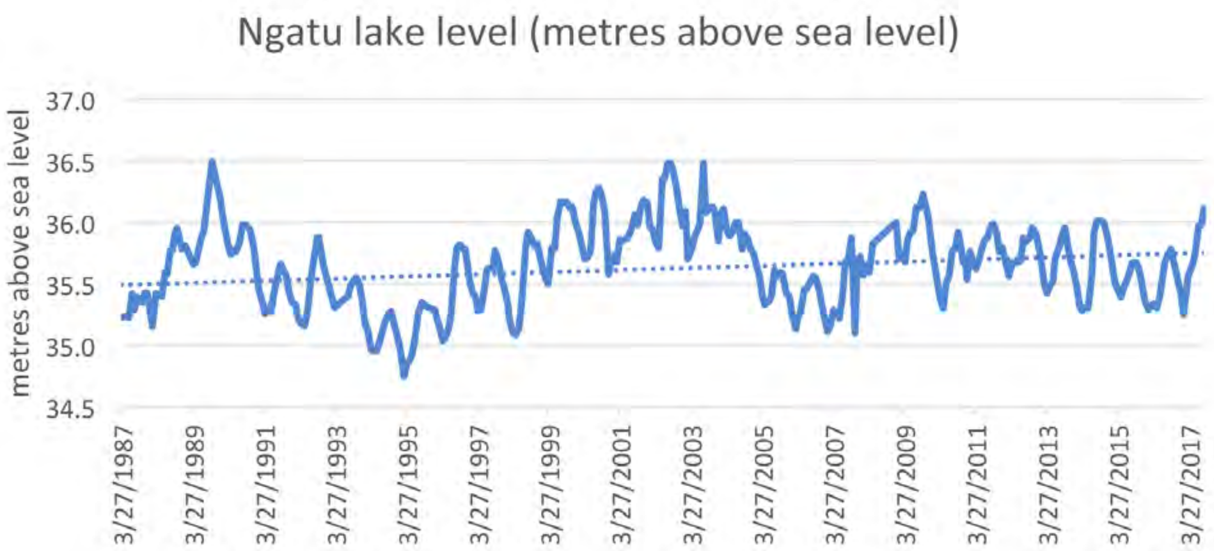
6.12. Rainfall and drought

The graph below shows how many summers are experienced as drought. This will result in a reduction in lake level. Peak sustained rainfall events result in an influx of new nutrients from the many inflow drains.



6.13. Lake level

Lake levels are variable for this perched dune lake due to the influences of inter-annual rainfall and drought patterns as the lake largely receives water from rainfall. The range in levels varies by 1.8 m. The overall trend is of slight increase in level, largely due to the low levels in 1995.



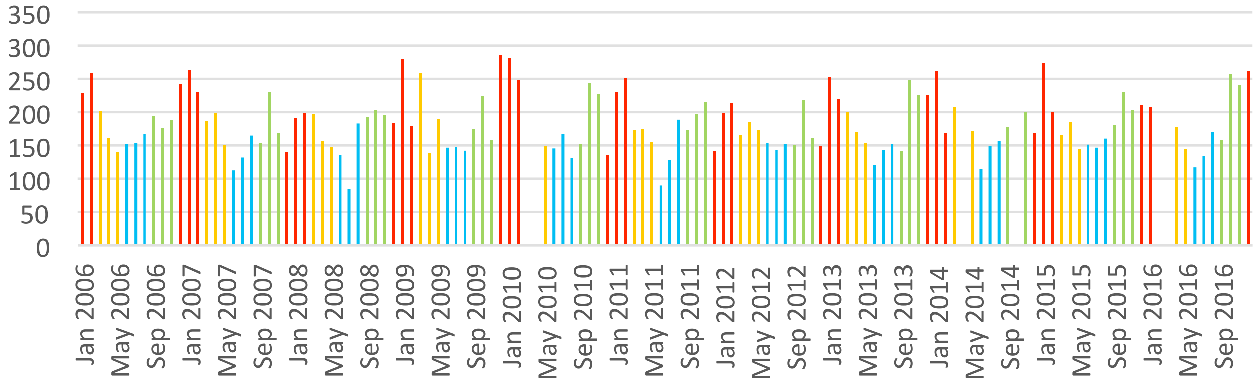
6.14. Sunshine

Peak summer sun seasons likely increase the evaporation rates of the lake resulting in lake level decrease.

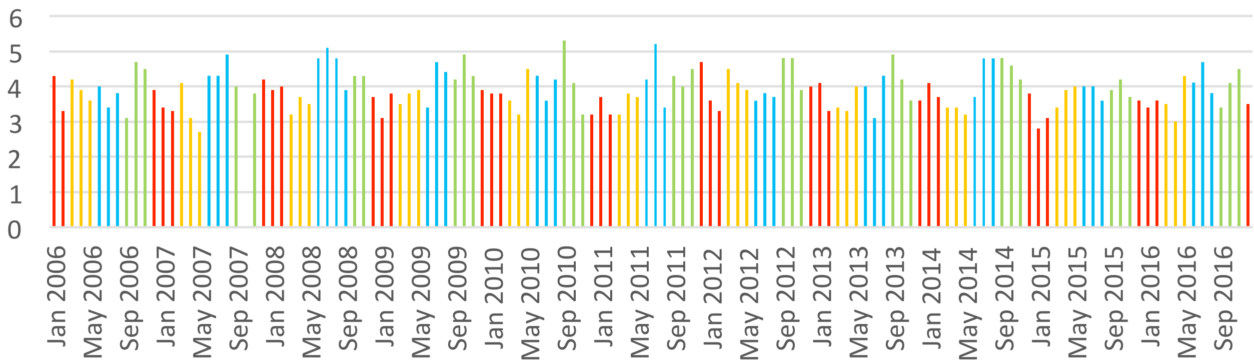
6.15. Wind speed

Although wind stirs up nutrient-loaded sediment and mixes nutrients in the water column, Ngatu is more likely to be affected by influx of new nutrients during peak rain events.

Kaitaia Observatory monthly total sunshine hours SUMMER AUTUMN WINTER SPRING



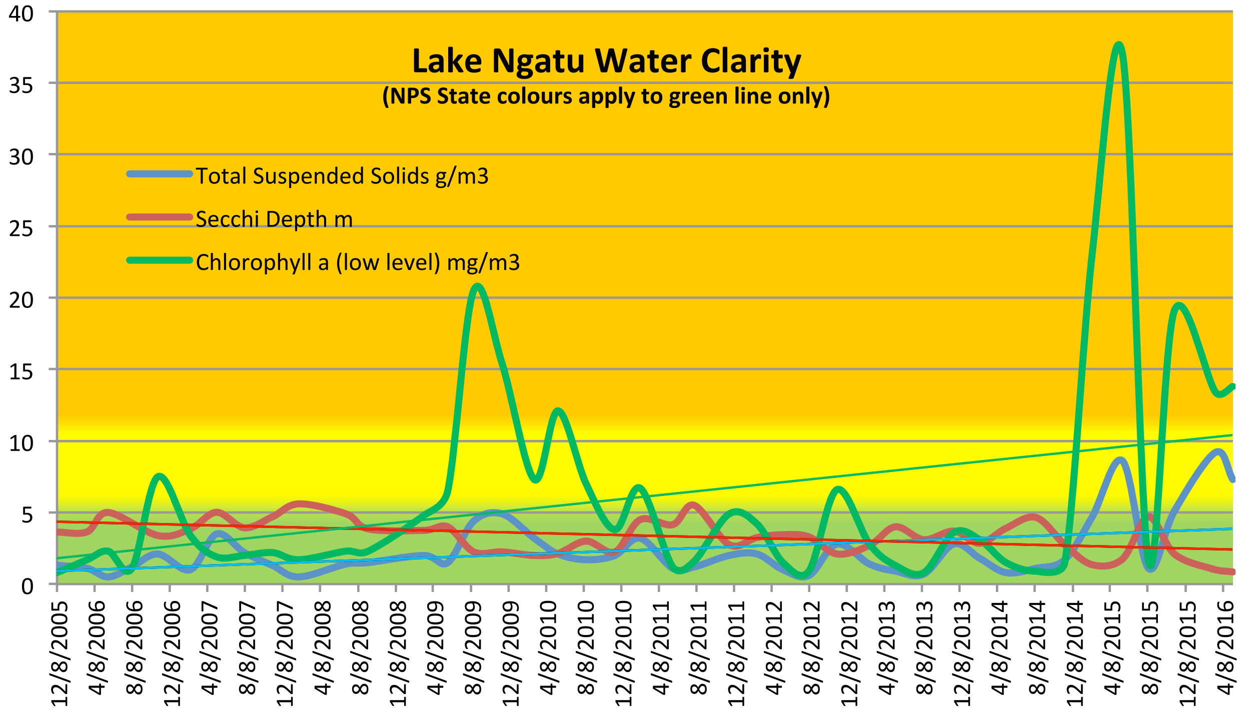
Kaitaia Ews monthly mean wind speed (m/s) SUMMER AUTUMN WINTER SPRING



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, the lake experiences a sporadic pattern of algal blooms (green line), occurring in late spring and summer as well as in autumn. A peak bloom occurred in May 2015 at 37 mg/m³ chlorophyll-a with a smaller bloom following in November 2015. This lake has a number of external influences and possible nutrient inputs which can result in algal blooms. Without better information on land use practices, it is difficult to point to a single cause of these events.

The table below the following graph shows the National Policy Statement for Freshwater Management states for phytoplankton (chlorophyll-a). A sharply increasing trend in chlorophyll-a, with recent algal blooms pushing into State D is related to increasing nitrogen levels.



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

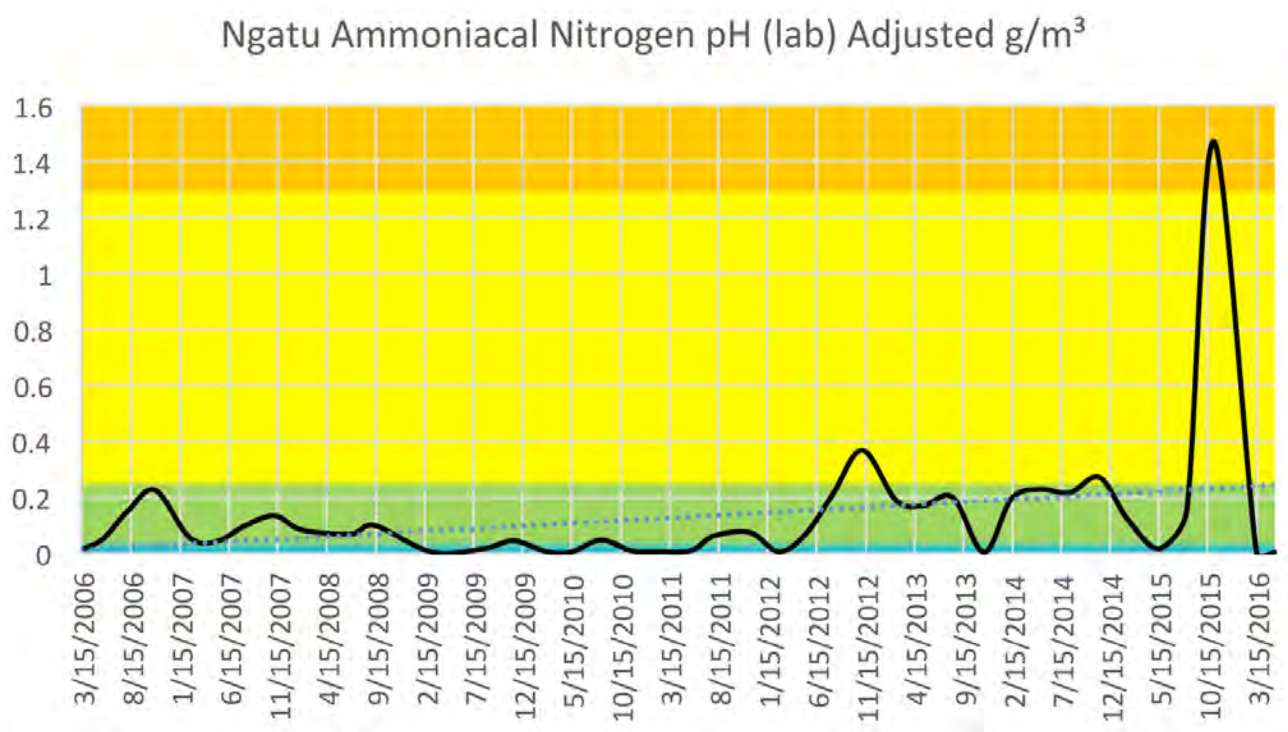
Max Gibbs (pers. comm.) from NIWA conducted limiting nutrient assays on several lakes including Ngatu. Significant results are highlighted. For the years and seasons assayed, both phosphorus and nitrogen plus phosphorus are the limiting nutrient combination in summer with no limiting nutrients in autumn. The summer 2015 sample contained peak chlorophyll a (from algal bloom).

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 below, shows the National Policy Statement Freshwater Management limits for lake state. Ngatu has an increasing trend and has recently seen a marked increase in ammonia spiking into State D in November 2015. Earlier on it moved from State A into State B. If this trend continues, acute impacts on native aquatic fauna are likely.

Lake	Autumn 2014 Initial Chla (mg m^{-3})	Summer 2015 Initial Chla (mg m^{-3})	Autumn 2014 Change in Control	Summer 2015 Change in Control	Autumn 2014 Proportional change over control +N	+P	+N+P	NP-P	Summer 2015 Proportional change over control +N	+P	+N+P
Ngatu	1.25	13.7	1.06	1.01	0.96	0.91	0.87	-0.04	1.03	1.10	1.17

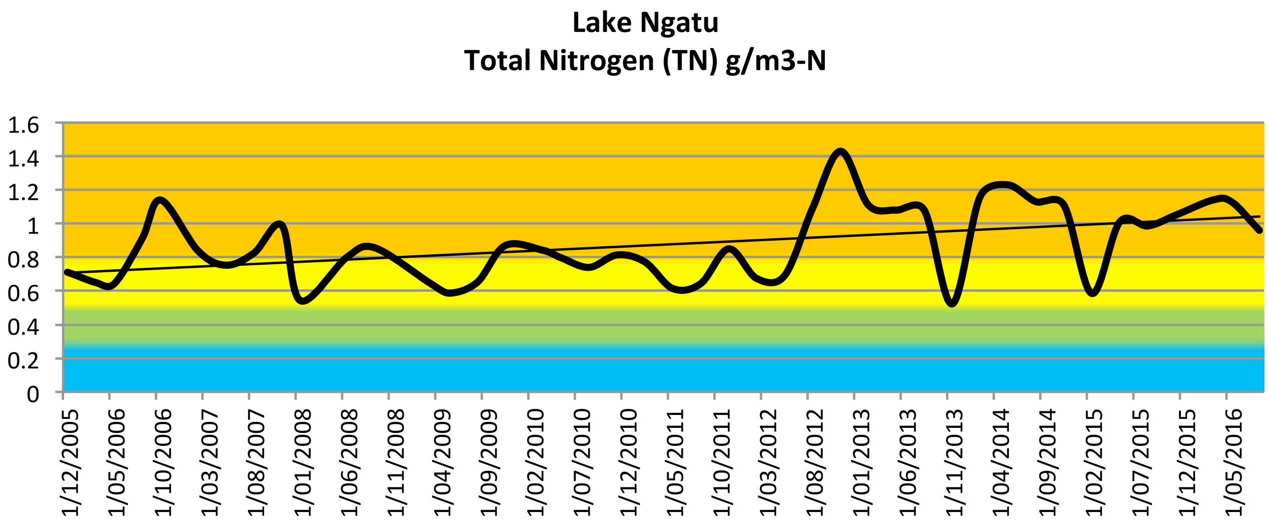


Attribute	Unit	Lake Type	State	Annual Median	Annual Maximum	Narrative State
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	A	≤0.03	≤0.05	99% species protection level: No observed effect on any species tested
Ammonia (Toxicity)	mg NH4-N/L (mg ammoniacal-nitrogen per litre)	All	B	>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

The following graph shows a total nitrogen timeline for the lake from 2005-2016. The trendline shows a gradual rise, which is mainly due to peaks in November 2012 and May 2014. This is most likely a sign of intensified land use in the catchment.

The table, following the chart below, shows the National Policy Statement for Freshwater Management limits for lake state. Ngatu has an increasing trend well into State D after an earlier history between States C and D. The trend shows a regime shift from macrophytes to phytoplankton.

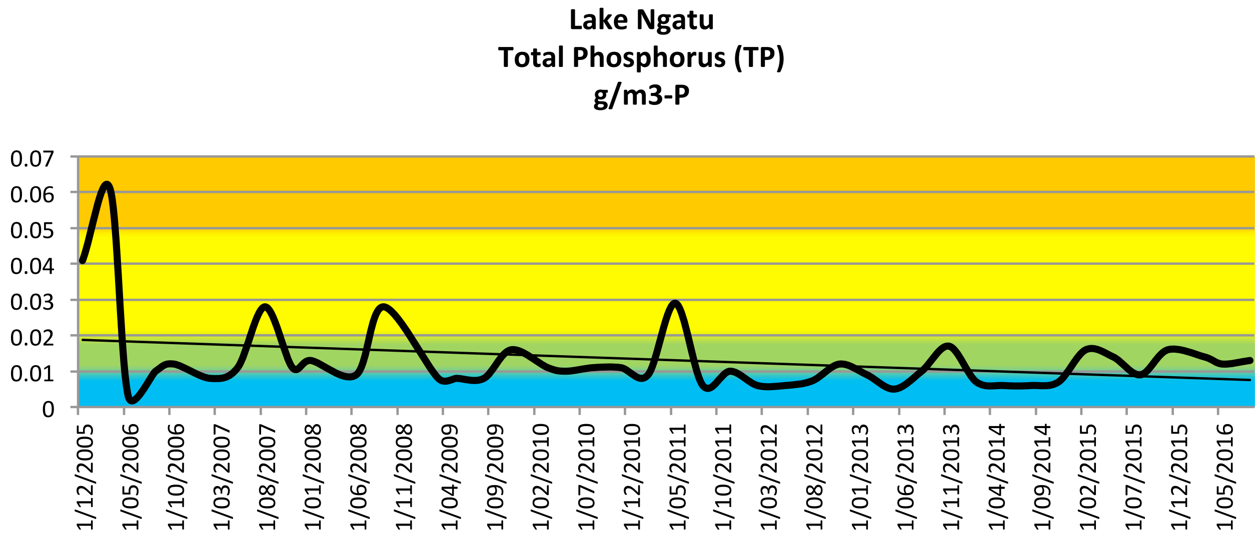


Attribute	Unit	Lake Type	State	Annual Median	Narrative State
Total Nitrogen (Trophic state)	g/m3	Polymictic	A	≤.3	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Total Nitrogen (Trophic state)	g/m3	Polymictic	B	>.3 and ≤.5	Lake ecological communities are 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 levels are showing long term decline with periodic modes still occurring as late as 2015. As phosphorus is a limiting nutrient, this is a hopeful trend.

The table, following the chart below, shows the National Policy Statement for Freshwater Management limits for lake state. More recently, phosphorus ranged between States A and B, with an earlier history of peaks into State C.



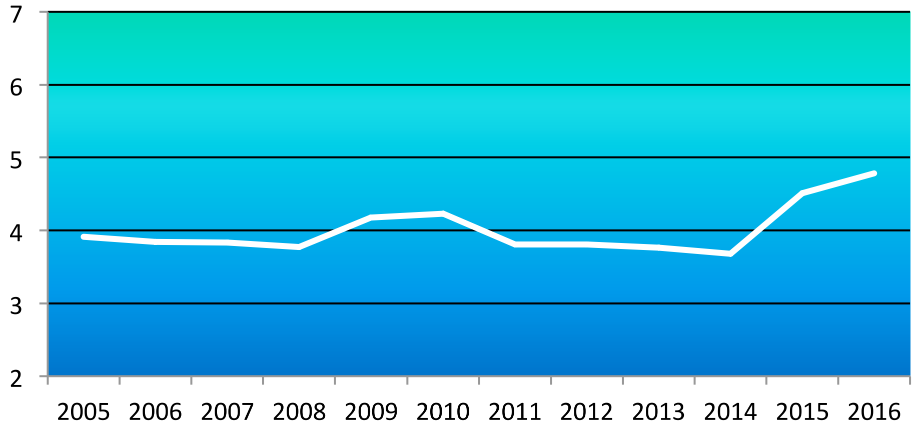
Attribute	Unit	Lake Type	State	Annual Median	Narrative State
Total Phosphorus (Trophic state)	g/m3	All	A	≤.01	Lake ecological communities are healthy and resilient, similar to natural reference conditions.
Total Phosphorus (Trophic state)	g/m3	All	B	>.01 and ≤.02	Lake ecological communities are slightly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

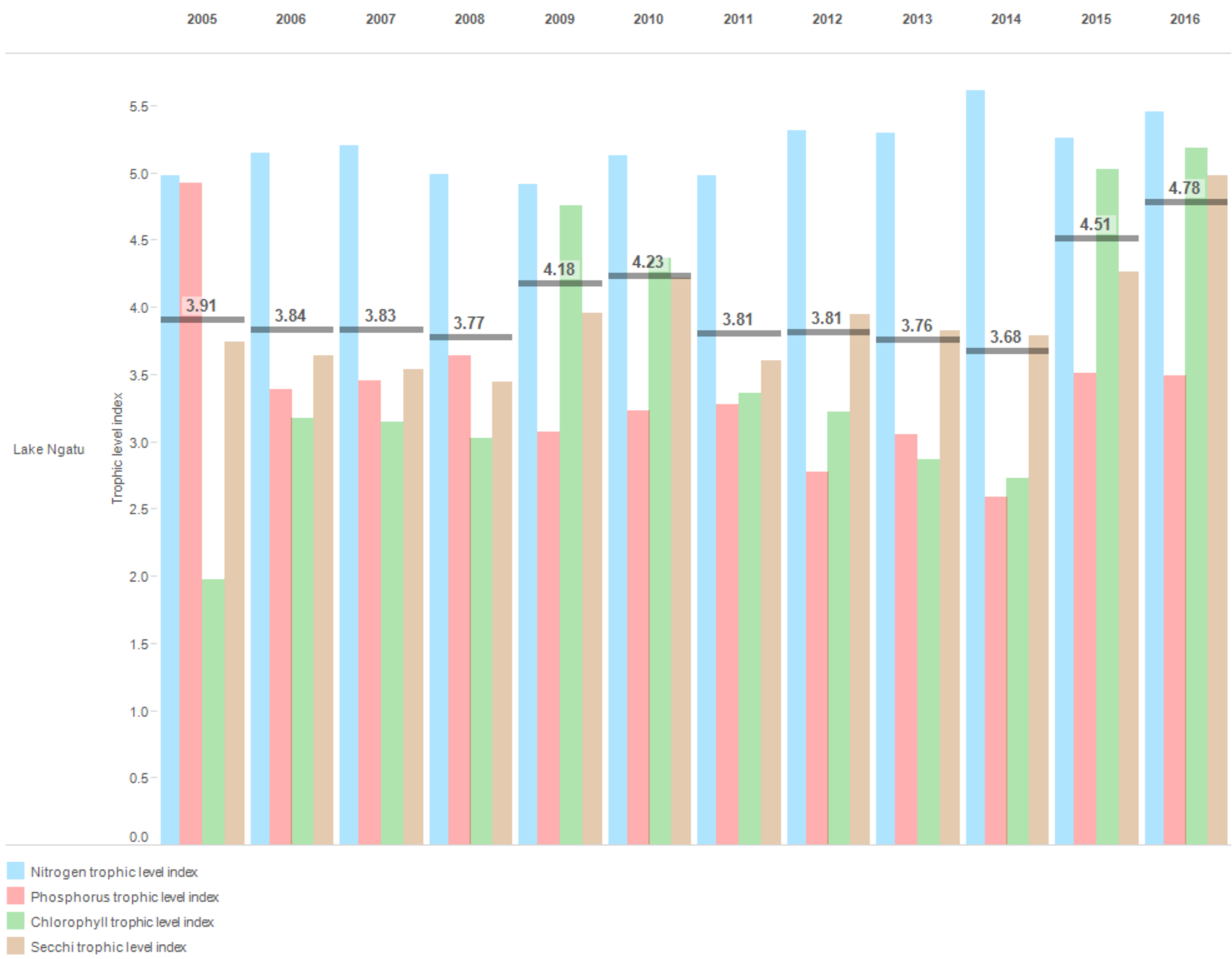
The trophic level index (TLI) is used in New Zealand as a measure of the nutrient status of lakes. The index combines four variables; phosphorus, nitrogen, visual clarity (Secchi disk depth) and algal biomass, each weighted equally.

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 2005-2016 TLI trend, shown below, indicates a decline since 2015 with the lake moving from a mesotrophic to a eutrophic state, although 2017 data (not shown) is showing improvement. The lake had been low level eutrophic before in 2009-2010. Anecdotal reports and old photographs suggest that the lake was historically a clear water lake. Visibility was described during an ecological survey in 2001 as 4-5m with meadows of vegetation across the entire lake bed.

Lake Ngatu Trophic Level Index Score



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	

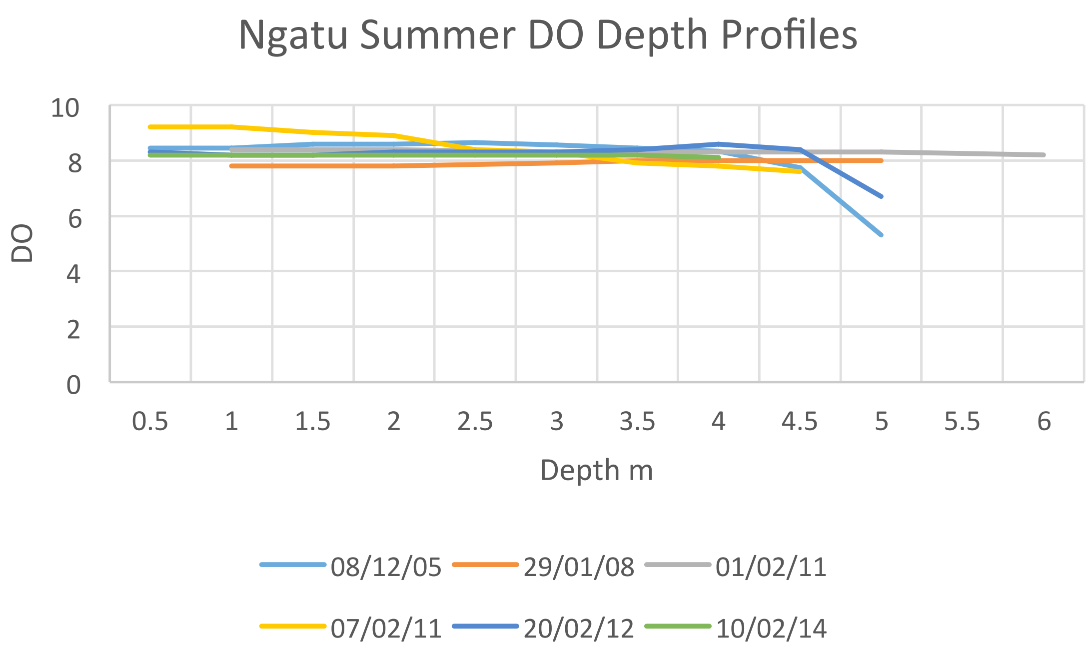


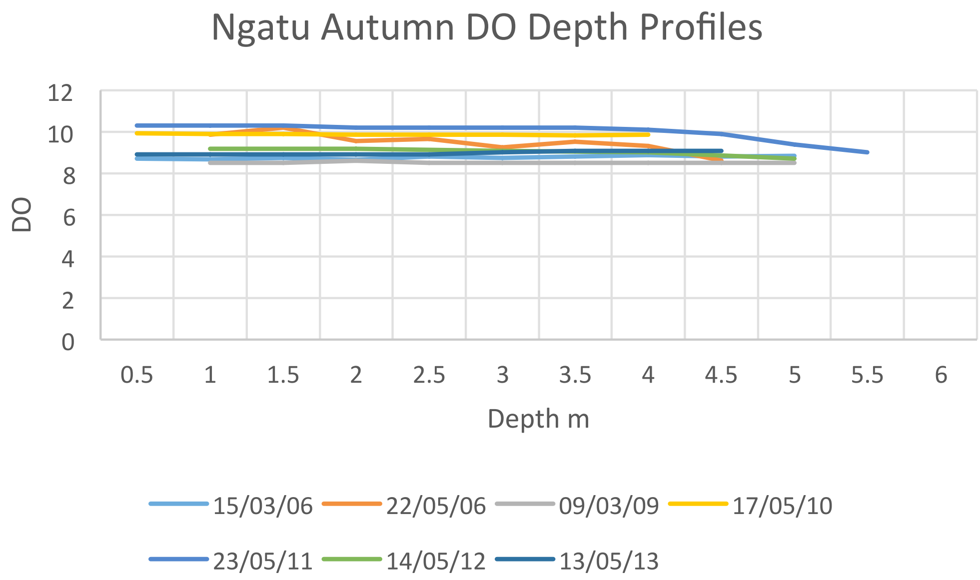
7.1.3. Dissolved Oxygen g/m³

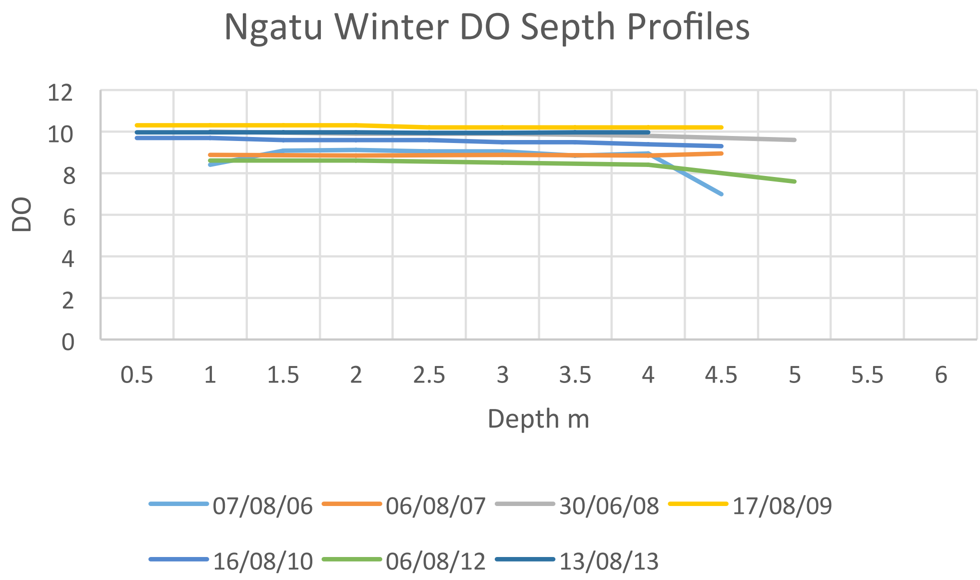
Although the lake does not thermally stratify due to its shallowness, there is an occasional oxygen depletion in water deeper than 4 - 4.5 meters between August and February.

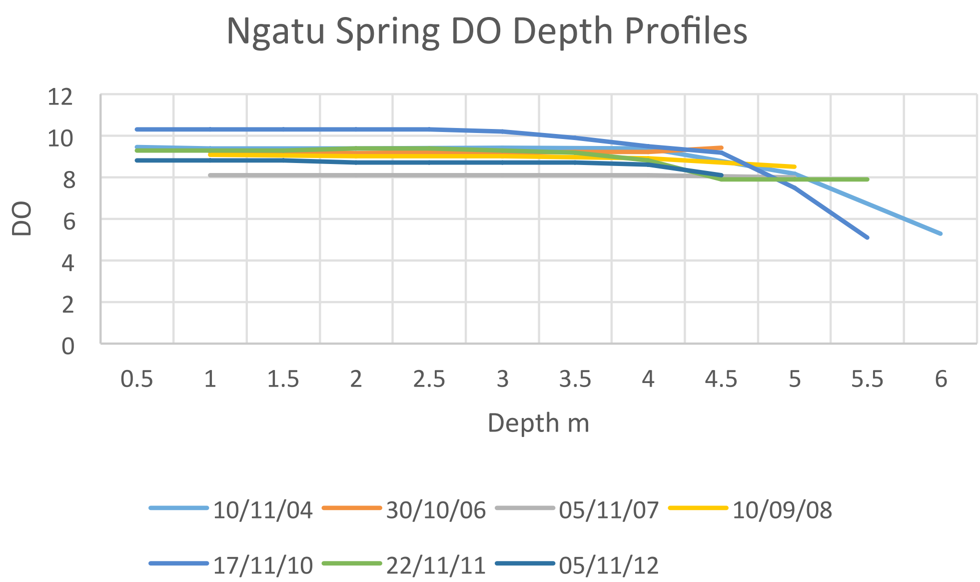
The table below shows the dissolved oxygen (at 15 degrees C) limits for New Zealand freshwater fish from **https://www.niwa.co.nz/freshwater-and-estuaries/research-projects/dissolved-oxygen-criteria-for-fish.** These guidelines help interpret the depth profiles as to the depth of the water column usable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




Ngatu Autumn DO Depth Profiles
DO
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Depth m
15/03/06
22/05/06
09/03/09
17/05/10
23/05/11
14/05/12
13/05/13


Ngatu Winter DO Septh Profiles
DO
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Depth m
07/08/06
06/08/07
30/06/08
17/08/09
16/08/10
06/08/12
13/08/13


Ngatu Spring DO Depth Profiles
DO
12
10
8
6
4
2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Depth m
10/11/04
30/10/06
05/11/07
10/09/08
17/11/10
22/11/11
05/11/12

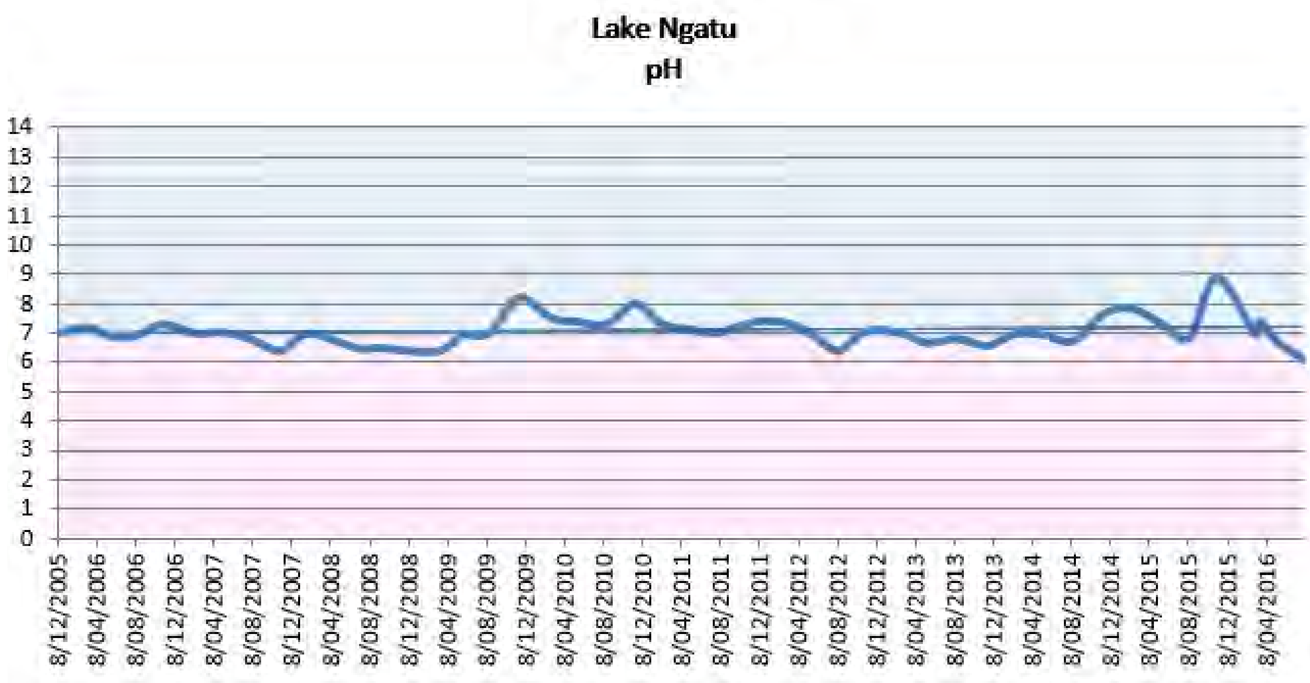
7.1.4. pH

The lake has a very slightly increasing trend to higher pH (increased alkalinity conditions). This is most likely a result of algal bloom activity using up dissolved carbon dioxide which would otherwise make the lake water relatively more acidic. As the lake has inanga present, this is a positive indicator as these fish are basophilic (preferring alkaline over acidic water).

7.2. Lake and catchment water and nutrient dynamic drivers

7.2.1. Influence of nutrient loading

In general, the persistence of new nitrogen from the many culverts and drains entering the lake do not offer a chance for natural recovery unless these sources are mitigated. An NRC Freshwater Improvement Fund project will assist with sediment and nutrient detention structures to mitigate this.



8. BIOLOGICAL CHARACTERISTICS

8.1. Lake Biodiversity and Biosecurity species

8.1.1. Plants

One of the reasons that Lake Ngatu is among the top outstanding dune lakes in Northland is due to its diverse aquatic plant community. The lake supports 20 native plant species, including five rare natives, shown in the table below.

Of note is the large population of the Nationally Endangered *Trithuria inconspicua*, a tiny rush-like submerged plant which has become extinct in a most of the Northland lakes where it was found previously.

Native bladderwort (*Utricularia australis)*, listed in the highest threat category as Nationally Critical, has not been recorded in Lake Ngatu since 2004. Its decline is most likely related to competition with the introduced yellow bladderwort (*Utricularia gibba*) and to increasing pH (alkalinity) as a result of algal blooms consuming dissolved carbon.

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

In addition to the natives, there are five exotic species recorded, three of these being invasive, three being invasive and including yellow flag iris (eradicated by the NRC in 2007), alligator weed and *Lagarosiphon.*

The latter is highly invasive and is capable of covering the entire lake floor and overgrowing the lake. There is also a patch of planted water lilies which do not appear to have spread and are being eradicated by NRC.

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.

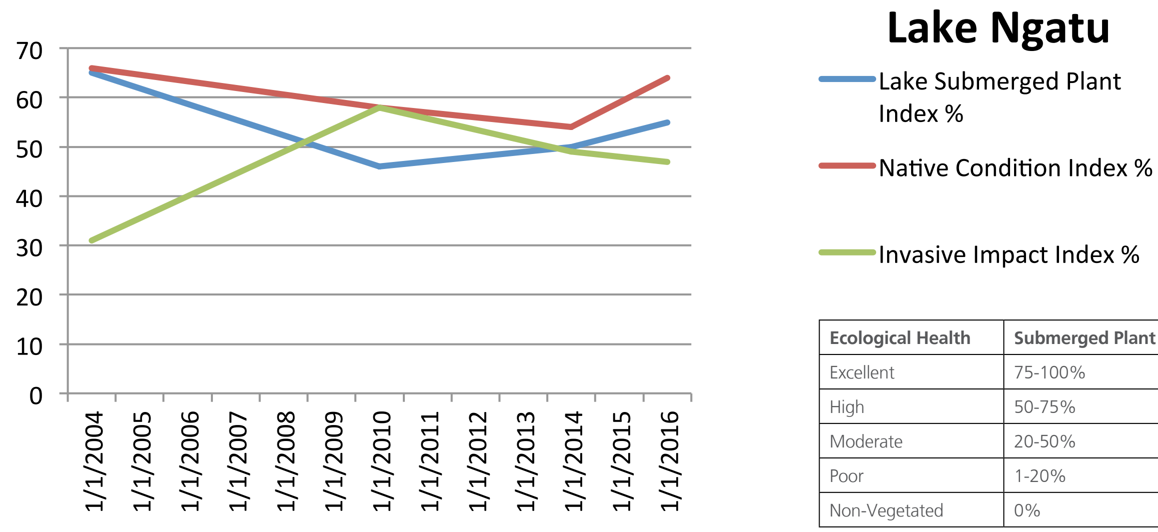
Nearby Lake Heather was a risk to Ngatu and other lakes because it was infested with *Egeria* and hornwort, but the introduction of grass carp has eradicated both plants (Heather appears green to signify that grass carp have now eaten all species, but natives will regrow once the fish are removed). These pest-weed species are still present in three other lakes in the region, however.

Lake Ngakapua South was treated with herbicide for *Lagarosiphon* and is due to be signed off as a successful eradication (Ngakapua South *Lagarosiphon* is in purple in the table to indicate its former presence). An NRC Freshwater Improvement Fund project is seeking to work with the community to control or eradicate these species from lakes Ngatu, Mini/Split, Rotoroa and Waimimiha North.

Depth and Plant Type Zone	Biogeography	Common Name	Species	Forest Lake/Dean's Swamp	West Coast Rd	Carrot/Ngakapua West	Heather	Little Gem	Ngakapua	Ngatu	Rotokawau (SW)	Rotoroa	Mini/Split	Waimimiha North	Waimimiha South	Frequency
Erect emergent	Invasive exotic	yellow flag iris	Iris pseudacorus							x						1
Erect emergent	Non-invasive exotic	bulbous rush	Juncus bulbosus						x	x						2
Sprawling emergent	Invasive exotic	alligator weed	Alternanthera philoxeroides				x			x		x	x			4
Sprawling emergent	Invasive exotic	glyceria, swamp grass, water meadow grass	Glyceria maxima												x	1
Sprawling emergent	Non-invasive exotic	water purslane	Ludwigia palustris				x									1
Free floating	Non-invasive exotic	bladderwort, yellow bladderwort	Utricularia gibba	X	x	x	x	x	x	x	X	x	x			10
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
Erect emergent	Native	oioi, jointed wire rush	Apodasmia similis							x	x					2
Erect emergent	Native	sharp spike sedge	Eleocharis acuta				x				x					2
Erect emergent	Native	bamboo spike sedge, tall spike sedge	Eleocharis sphacelata	x	x	x	x	x	x	x	x	x	x	x	x	12
Erect emergent	Native	manuka, tea tree, kahikatoa	Leptospermum scoparium					x								1
Erect emergent	Native	sedge	Machaerina arthrophylla (syn. Baumea arthrophylla)						x	x	x					3
Erect emergent	Native	jointed baumea, jointed twig rush	Machaerina articulata (syn. Baumea articulata)	x	x		x	x	x	x	x		x			8
Erect emergent	Native	sedge, tussock swamp twig rush	Machaerina juncea (syn. Baumea juncea)							x	x					2
Erect emergent	Native	flax, harakeke, korari	Phormium tenax					x								1
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	7
Erect emergent	Rare native	none known	Cyclosorus interuptus							x						1
Erect emergent	Rare native	Marsh fern, swamp fern	Thelypteris confluens				x									1
Sprawling emergent	Native	pennywort	Hydrocotyle pterocarpa					x								1
Sprawling emergent	Native	swamp millet	Isachne globosa					x								1
Sprawling emergent	Native	swamp willow weed	Persicaria decipiens		x											1
Low growing turf	Native	gratiola	Gratiola sexdentata						x		x					2
Low growing turf	Native	none known (sedge)	Isolepis prolifera		x		x	x					x			4
Low growing turf	Native	Zelandiae chain sword	Lilaeopsis novae-zelandiae							x		x				2
Low growing turf	Native	mudwort	Limosella lineata							x						1
Low growing turf	Native	arrow grass	Triglochin striata						x	x	x					3
Low growing turf	Rare native	hydatella	Trithuria inconspicua (syn Hydatella inconspicua)							x		x				2
Floating leaved	Native	red pondweed	Potamogeton cheesemanii	x		x	x	x	x	x						6
Submerged milfoil	Native	common water milfoil	Myriophyllum propinquum		x	x	x	x		x						5
Submerged milfoil	Rare native	small water milfoil	Myriophyllum votschii							x						1
Submerged tall pondweed	Native	blunt pondweed	Potamogeton ochreatus				x					x				2
Submerged tall pondweed	Rare native	bladderwort, yellow bladderwort	Utricularia australis	x		x	x		x	x	x					6
Submerged charophyte	Native	stonewort	Chara australis	x		x	x	x	x	x	x	x	x			9
Submerged charophyte	Native	stonewort	Chara fibrosa							x	x					2
Submerged charophyte	Native	stonewort	Nitella leonhardii	x						x						2
Submerged charophyte	Native	stonewort	Nitella pseudoflabellata							x						1
Submerged charophyte	Native	stonewort	Nitella sp. aff. cristata			x		x	x	x			x			5
			Total Plant Diversity	**7**	**6**	**9**	**17**	**14**	**11**	**25**	**13**	**9**	**11**	**3**	**3**	
			Exotic Plant diversity	**1**	**1**	**1**	**5**	**1**	**2**	**5**	**1**	**3**	**4**	**1**	**1**	
			Native Plant Diversity	**6**	**5**	**8**	**12**	**13**	**9**	**20**	**12**	**6**	**7**	**2**	**2**	

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 2004-2016 timeline below, the lake's Native Condition Index and Submerged Plant Index are increasing and the Invasive Impact Index is decreasing. In short, this means that desirable native plants are improving while invasive plants, which were becoming dominant, are now declining.



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 Sweetwater area of the Aupōuri Peninsula. Pest fish are shown in green and conservation species in pink. Lake Ngatu appears in yellow. The lake has a low level of native fish diversity, yet has among the highest diversity of pest fish of all Northland lakes, largely due to its accessibility and history of multiple recreational uses. Data has been derived from annual NIWA ecological surveys.

common name	species	Conservation status	Degree of loss	Forest Lake/Dean's Swamp	West Coast Rd	Carrot/Ngakapua West	Heather	Little Gem	Ngakapua	Ngatu	Rotokawau (SW)	Rotoroa	Mini/Split	frequency
grass carp	Ctenopharyngodon idella						x							1
rainbow trout	Oncorhynchus mykiss									x				1
goldfish	Carassius auratus								x	x				2
Gambusia	Gambusia affinis				x			x	x	x	x	x		6
perch	Perca fluviatilis									?				1
rudd	Scardinius erythrophthalmus									x				1
shortfinned eel	Anguilla australis						x					x		2
longfinned eel	Anguilla dieffenbachii	at risk	declining										x	1
inanga	Galaxias maculatus	at risk	declining					x		x	x	x		4
common bully	Gobiomorphus cotidianus			x		x	x		x	x	x	x		7
smelt	Retropinna retropinna											x		1
	diversity pest fish			0	1	0	0	1	2	4	1	1	0	
	diversity native			1	0	1	2	1	1	2	2	4	1	

8.1.3. Waterbirds

The table below displays the waterbirds of the Sweetwater area of the Aupōuri Peninsula. Game birds are shown in green and non-game bird native species in pink. Lake Ngatu appears in yellow. Canada goose is an exception, having been taken off the game bird list but able to be hunted year-round and posing a nutrient risk to lake when numbers swell. The lake has a moderate level of bird diversity and the area is popular with duck-hunters. Caspian tern are probably feeding on schools of fish in the lake and account for their sole occurrence in the general area. Data has been derived from annual NIWA ecological surveys.

common name	species	Conservation status (DOC: *Conservation status of NZ birds*, 2016)	Criteria / Degree of loss	Forest Lake/Dean's Swamp	West Coast Rd	Carrot/Ngakapua West	Heather	Little Gem	Ngakapua	Ngatu	Rotokawau (SW)	Rotoroa	Mini/Split	Waimimiha North	Waimimiha South	frequency
black swan	Cygnus atratus (resident native (not introduced) on game bird list)	Not threatened							x			x	x			3
paradise shelduck	Tardorna variegata (resident native (not introduced) on game bird list)	Not threatened					x		x			x				3
Canada goose	Branta canadensis (Introduced & naturalised, not protected, able to be hunted at any time)	Introduced & naturalised					x						x			2
New Zealand scaup	Aythya novazeelandiae	not threatened								x		x				2
Australasian bittern	Botaurus poiciloptilus	threatened	nationally critical		x	x		x	x	x	x	x	x		x	9
North Island fernbird	Bowdleria punctata vealeae	at risk	declining								x			x	x	3
Caspian tern	Hydroprogne caspia	threatened	nationally vulnerable							x						1
New Zealand dabchick	Poliocephalus rufopectus	at risk	recovering		x	x	x	x	x	x	x	x	x			9
spotless crake	Porzana t. tabuensis	at risk	declining		x									x	x	3
Australasian little grebe	Tachybaptus n. novaehollandiae		coloniser	x		x	x		x		x	x				6
diversity resident native (not introduced) on game bird list				0	0	0	1	0	2	0	0	2	1	0	0	
diversity introduced & naturalised				0	0	0	1	0	0	0	0	0	1	0	0	
diversity native				1	3	3	2	2	3	4	4	4	2	2	3	

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 Lake Ngatu, the presence of the Tanytarsini midge, which cannot tolerate more than moderate pollution is encouraging, but other sensitive species are absent. Freshwater crayfish (koura/kewai) are absent. Data is a compilation of NIWA and Northtec surveys. The lake has two species of non-native snails.

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)	Forest Lake/Dean's Swamp	West Coast Rd	Carrot/Ngakapua West	Heather	Little Gem	Ngakapua North basin	Ngakapua South basin	Ngatu	Rotokawau (SW)	Rotoroa	Mini/Split	Waimimiha North	Waimimiha South	frequency
Hydrozoa, freshwater jellyfish medusae	*Craspedacusta sowerbyi*						x									1
Mollusc, ramshorn snail	*Planorbarius corneus*				x			x		x						3
Mollusc, snail	*Physa (Physella) acuta*	0.1		x		x					x	x				4
Mollusc, snail	*Planorbella scalaris*							x	x	x						3
Mollusc, snail	Pseudosuccinea			x		x					x	x				4
Acarna, mite	Oribatida	5.2			x											1
Coleoptera, dytiscid diving beetle	*Onychohydrus hookeri*					x	x	x		x	x					5
Coleoptera, whirigig beetle	*Gyrinus*					x										1
Crustacea, Cladocera	sp	0.7			x											1
Crustacea, Copepoda	sp	2.4			x											1
Crustacea, Ostracoda, koura	*Paranephrops planifrons*	8.4														0
Crusteacea, Ostracoda	*Herpetocypris*	*1.9*			x											1
Diptera, midge, non-biting, Chironomid	Tanytarsini	4.5			x					x						2
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		x								3
Hemiptera, bug	sp					x										1

Hemiptera, bug, backswimmer	*Anisops*	2.2										x				1
Hemiptera, bug, backswimmer	*Sigara arguta*	2.4		x		x		x								3
Hemiptera, bug, waterboatman	Corixidae sp					x		x	x		x	x				5
Hirudinea, leech	Alboglossiphonia			x												1
Hirudinea, leech	*Richardsonianus mauianus*							x								1
Lepidoptera, aquatic moth	*Hygraula nitens*	1.3						x	x							2
Mollusca, freshwater mussel	*Hyridella menziesi*	6.7						x				x				2
Mollusca, pea mussel	*Musculium novazelandiae*									x						1
Mollusca, pea mussel	*Sphaerium novaezelandiae*											x				1
Mollusca, snail	*Planorbella sp*				x											1
Mollusca, snail, native	*Glyptophysa variabilis*	0.3										x				1
Mollusca, snail, native	*Potamopyrgus antipodarum*	2.1										x				1
Nemertea, proboscis worm	sp	1.8			x											1
Odonata, damselfly	*Ischnura*	3.1								x						1
Odonata, damselfly	*Xanthocnemis sp*	1.2				x		x	x			x				4
Odonata, dragonfly	*Hemicordulia australiae*	0.4		x				x			x	x				4
Odonata, dragonfly	sp					x		x								2
Odonata, dragonfly	*Tramea loewii*							x								1
Oligocheate worm	Oligochaeta sp	3.8			x											1
Oligocheate worm	Tubificidae			x												1
Ostracod crusteacean	*Ilyodromus*				x											1
Porifera, freshwater sponge	sp				x											1
Trichoptera, caddisfly	*Oecetis unicolor*	6.8										x				1
Trichoptera, caddisfly	*Paroxyethira hendersoni*	3.7			x							x				2
	diversity invasive		0	2	1	2	1	2	1	2	2	2	0	0	0	15
	diversity native		0	5	13	9	1	12	4	5	4	10	0	0	0	

8.1.5. Catchment weeds

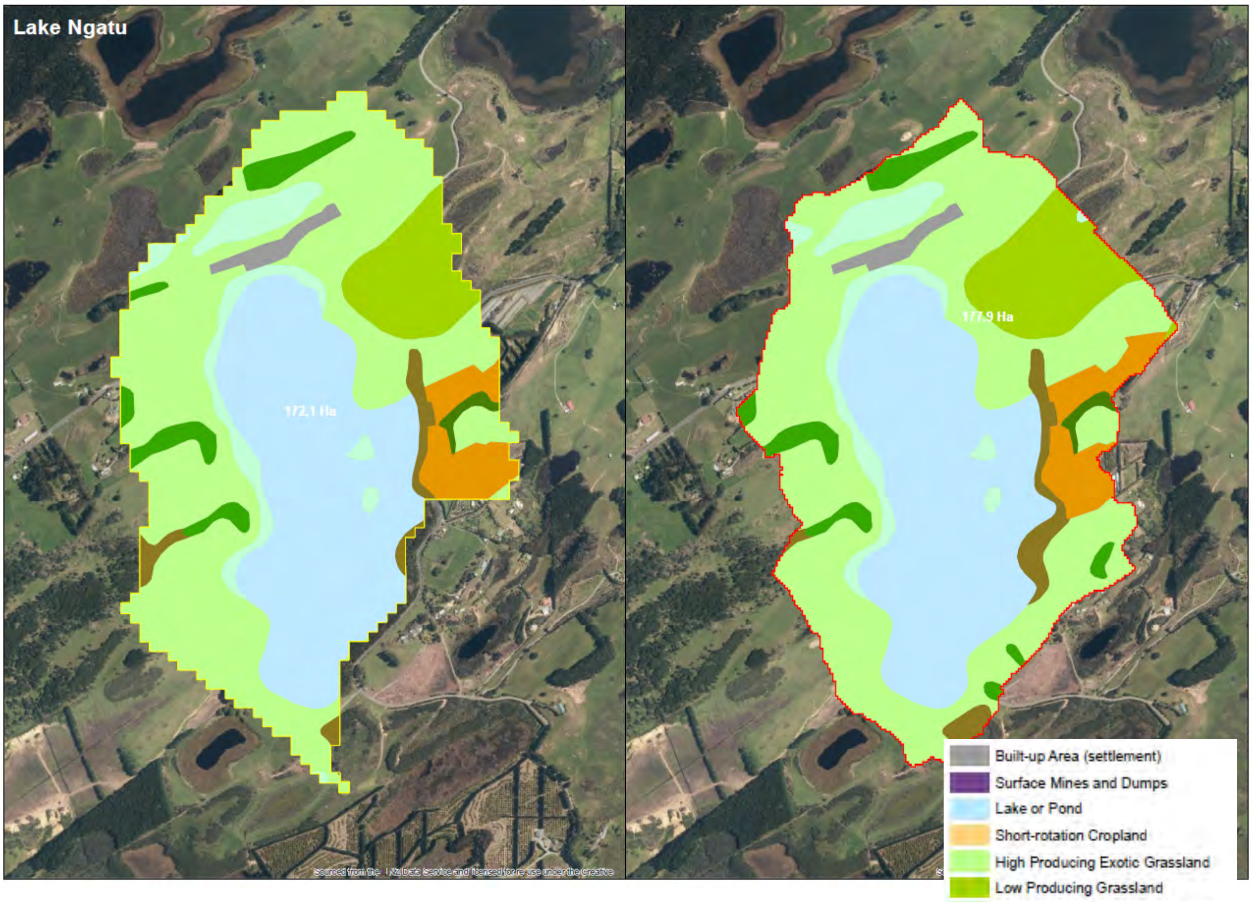
A range of exotic tree species should be removed from the catchment. Efforts should be focused first on nitrogen-fixing weeds such as brush wattle, wattle, oxylobium and gorse.

9. LAND USE

9.1. Catchment land cover table and map

The catchment is largely influenced by high and low producing exotic grassland and freshwater sedgeland/rushland. Other influences, although at lower percentage covers, include short rotation cropland and orchard, other perennial crops and built-up settlement, all of which will be contributing to nutrient inputs to the lake. There is little native vegetation in the catchment, though most of this is on the lake margins with replanted areas to the east and west.

Lake	Cover Type	Total FENZ (ha)	Total Hand-drawn (ha)
Lake Ngatu	Built-up Area (settlement)	2.14	2.14
Lake Ngatu	Deciduous Hardwoods	0.86	0.79
Lake Ngatu	Exotic Forest	5.85	6.04
Lake Ngatu	Herbaceous Freshwater Vegetation	10.40	10.16
Lake Ngatu	High Producing Exotic Grassland	75.31	75.52
Lake Ngatu	Lake or Pond	54.93	55.77
Lake Ngatu	Low Producing Grassland	11.89	14.73
Lake Ngatu	Manuka and/or Kanuka	3.46	5.18
Lake Ngatu	Orchard, Vineyard or Other Perennial Crop	7.22	7.56
Lake Ngatu Total		172.07	177.89



9.2. Road drains

The drains, culverts, septic systems and land-use affecting this lake have been mapped, overleaf. It is yet unclear what level of nutrients any of these structures and uses have contributed, but they may collectively form the key issue for nutrient management in this lake which suffers from over-nitrification. A systematic assessment of each input is required and unique mitigations put in place. The NRC Freshwater Improvement Fund will address this study and its mitigations.

9.3. Pastoral farming

Pastoral farming affects the northern, western and southern areas of the lake. These paddocks are fenced, however. Some of the fence-lines on the western side of the lake are on the boundary of the paper road which surrounds the lake. These could be set back further and replanted to provide more of a buffer between lake and farmland.

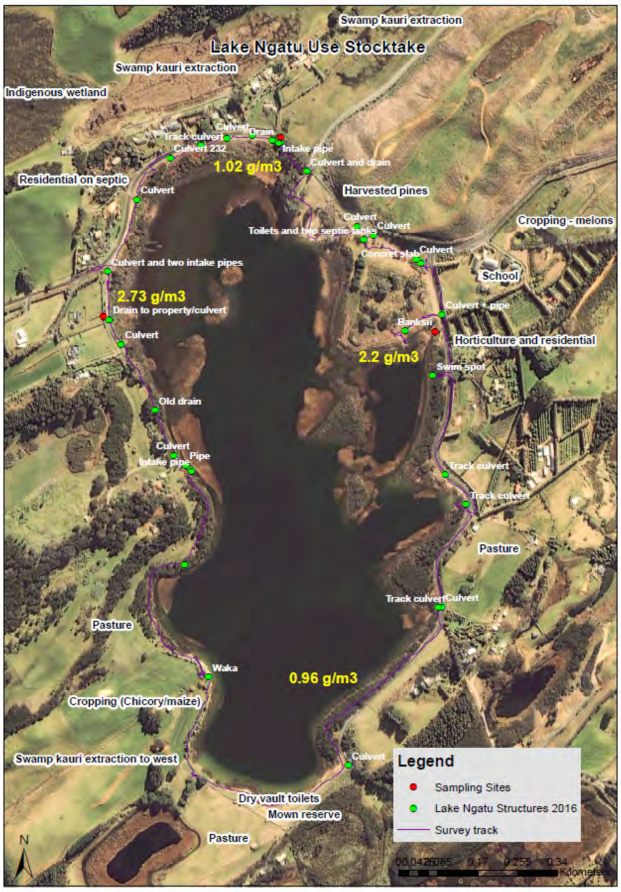
9.4. Forestry

Forestry is not a major impact on the catchment.

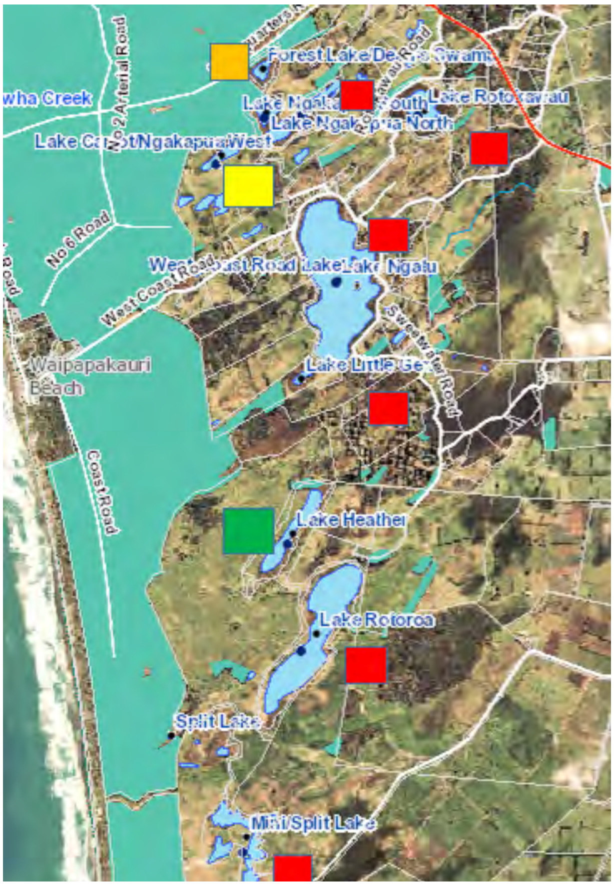
9.5. Fire-fighting

The lake is a potential source of water for forest fire-fighting. NRC and the forestry industry are working towards mitigation of lake-bed disturbance and biosecurity pathways by identifying the most suitable sources of water for this purpose.

From the map overleaf, Lake Ngatu is identified as a high-risk water source due to the presence of *Lagarosiphon* oxygen weed, a highly invasive water weed and a range of pest fish species not present in all waterbodies in the area. Therefore, if a helicopter hurricane bucket or other firefighting equipment were to move between lakes for sourcing water, there is an unacceptable risk of transfer of these species. Depth cut-off for lake bed disturbance is 4 m and Lake Ngatu is 6.26 m deep in the deepest basin, so that feature does not apply to this risk ranking. Lake Heather (green square) is a preferred source due to the removal of weed species by grass carp in this lake.



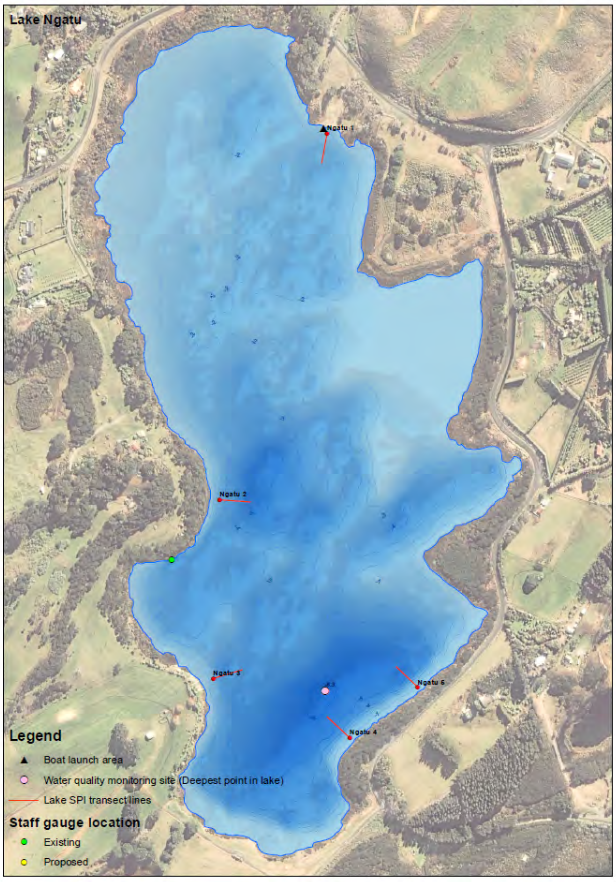
Road drains



Fire-fighting

10. MONITORING PLAN

The adjacent map shows the five transect lines surveyed during ecological assessments. The dark triangle is the access point for the NRC vessel for water quality sampling. The pink point in the south of the lake is the water quality sampling point, corresponding to the deepest point in the lake.



10.1. NIWA ecological monitoring

The lake is scheduled to be fully ecologically monitored every five years with a weed survey annually. There have been eight full surveys since 1984 with weed surveillance recommended every 1-2 years and has been undertaken most years since 2007. The value class of the lake has held at Outstanding. The next full survey is likely to be done in 2021 with continuation of 1-2 yearly weed 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
Carrot/Ngakapua West		1													M					M											
Forest Lake/Dean's Swamp															L					M											
Heather	5	1													H			H		carp	carp	carp	carp			carp					
Little Gem	5																O			M-H											
Mini/Split															L																
Ngakapua	5	1													M-H					M-H				O2 weed	Endoth	Endoth					
Ngatu	5	1												O						O				O		O					
Rotokawau (A)	5													M-H					H					M-H							
Rotoroa	5														H																
Waimimiha North															L																
Waimimiha South															L																
West Coast Rd	5														H		H			L											

10.2. NRC Ecological monitoring

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

10.2.1. Water quality and quantity monitoring

Water quality sampling occurs quarterly in February, May, August and November.

Samples taken by year are shown 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
Ngatu lower																	1	4	4	3	3	4	4	4	4	4	4	5	1	45
Ngatu surface	1							1		1				1			1	4	4	3	4	4	4	4	4	4	4	5	1	50

11. WORK IMPLEMENTATION PLAN

The NRC's Freshwater Improvement Fund (FIF) Dune Lakes project includes several work-streams at Lake Ngatu, including:

- Set-back fencing the slopes of pasture to the south-east. This fence would run 295 m at a cost of ~$2655.
- Lake Ngatu has been selected for a more detailed modelling benefit-cost analysis for nutrient mitigation. This process involves walking the catchment and its sub-catchments, documenting required works. The model, based on monitoring of nutrient loads in each drain will estimate the nutrient load mitigated by works such as sediment detention structures and compare it to the cost of the work. The FIF work commits to investigating and mitigating eight drains to a total of $30,000. Further voluntary reductions of fertiliser use by landowners in the catchment will further mitigate loads.
- Eradicating Lagarosiphon with Aquathol K Endothall, budgeted at $96,576. This will require a consultation with the local community.
- Goldfish are found in both Lake Ngatu and neighbouring Lake Little Gem. Ngatu also contains rudd and likely perch. Eradication of the species will require sustained netting. The FIF work seeks to address these species.

Further mitigation work to consider includes:

- The elevated wetland to the north has been historically disturbed by kauri stump removal. Any proposals for future swamp kauri extractions in the catchment need to be considered carefully to reduce any risk of effects on Lake Ngatu.
- A range of exotic tree species, targeting nitrogen-fixing weeds such as oxylobium, gorse, brush wattle and wattle, should be removed from the catchment.
- A Check Clean Dry campaign for waka ama users
- Installation of an electronic continuous water level recorder
- Set back of fencing and planting along the paper road boundary

- A field audit of sewage leachate from the public toilets
- Kuta (tall spike sedge or *Eleocharis sphacelata*) restoration for harvesting for cultural material
- Eradication of water lily, alligator weed, mile-a-minute and Christmas berry.
- Notify the rural fire service to avoid water take from the lake due to pest species present. Lake Heather is a nearby alternative.
- The last full fish survey of native and exotic species was undertaken in 2014 and should be repeated
- Trialled control of *Gambusia* by Gee minnow trapping
- Planting of the FIF fenced area through the Million Metres project

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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.

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.

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.

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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