THE ROTORUA LAKES
Protection and Restoration Action Programme

A **Bay of Plenty Regional Council, Rotorua District Council** and **Te Arawa Lakes Trust** joint project

Lake Ōkataina water quality
Background information 2012

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This document is prepared to assist with development of a Lake Ōkataina Action Plan – a non-statutory document for improving water quality in Lake Ōkataina.

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Cover photo: Lake Ōkataina at Tauranganui Bay

A brief historical background

Ngāti Tarāwhai and Ngāti Kohuūpoko tribes both lived around Lake Ōkataina for many years in the early history. Once, Te Whanapokia (the son of Titi, a Kahuūpoko chief) gifted land and a famous fishing place in Ōkataina to Ngāti Tarāwhai chief Tarāwhai II as highly valued treasures.

Lake Ōkataina (Te moana-i-kataina-ā-Te Rangitakaroro) is an important place for Ngāti Tarāwhai, as it has partially defined their role in history, as celebrated woodcarvers, whose artworks are sought after. The homeland of Ngāti Tarāwhai provided them with extensive stands of totara, which is suitable for canoe and house building, as well as good rimu and matai timber (Neich, 2001).

The location of Ōkataina allowed Ngāti Tarāwhai to trade their canoes widely and regulate that trade. Men came from other tribes and usually had to pay Ngāti Tarāwhai for the timber, or work with Ngāti Tarāwhai experts. Ngāti Tarāwhai traded finished canoes for valuables or commodities not otherwise available to them.

On January 29, 1921, Ngāti Tarāwhai gifted their treasured shores of Lake Ōkataina to be set aside as a Scenic Reserve (Gosling, 2002). The Ngāti Tarāwhai chief did this to ensure the treasured place would continue to be looked after. Since then, the reserve has been administered by the Lake Ōkataina Scenic Reserve Board, a committee comprising representatives from Ngāti Tarāwhai and the Department of Conservation.

Today, Lake Ōkataina provides some of the most scenic views in the area and is a valued fishing destination enjoyed by many.

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Introduction

This background information includes known physical characteristics of Lake Ōkataina and its catchment, likely sources of nutrients going into the lake and some actions which could manage these sources.

The Lake Ōkataina community and stakeholders can comment on and add information by contacting Bay of Plenty Regional Council during development of the Lake Ōkataina Action Plan. The plan is a non-statutory document required under the Operative Bay of Plenty Regional Water and Land Plan.

Figure 1. Information panel by Lake Ōkataina

(Photo taken and modified in January 2012)

Part 1: Physical features

The catchment of Lake Ōkataina is covered predominantly with indigenous vegetation. Unlike many other lakes in the region, Lake Ōkataina is completely encircled by native forest. This leaves approximately 19 percent of the surface catchment for other land uses:

- About 10% of the land in the catchment is used for dry-stock farming which, at its closest point, is about 150 m from the lake.
- Exotic forests cover 8% and are as close as 600 m to the lake, with three streams flowing through this land to the lake.
- Road, car parks and buildings cover 1% of the catchment, with one lake access route to the north.

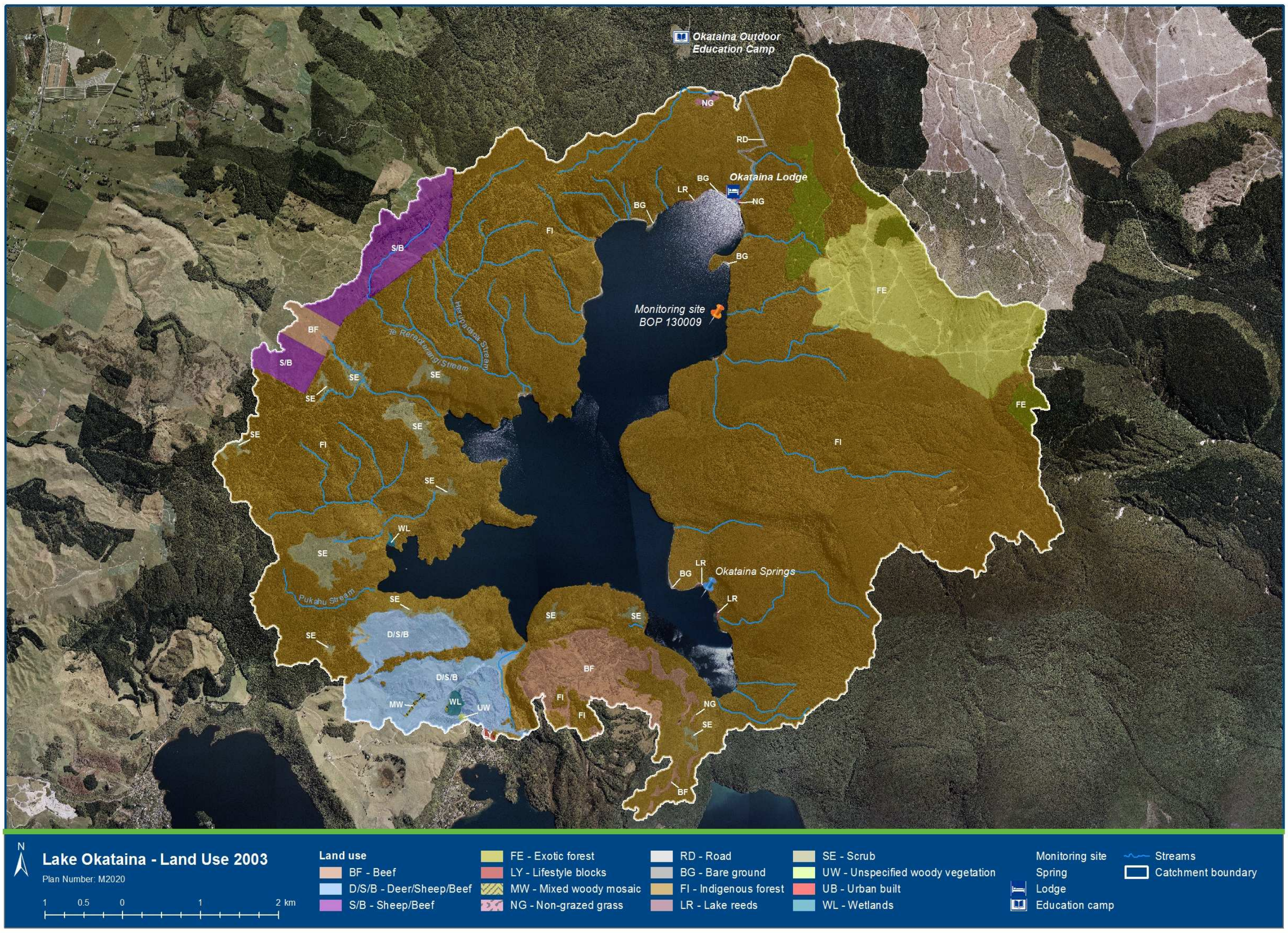


Figure 2. Lake Ōkataina surface catchment (2006) and land-use (2003) indicative map

1.1 Characteristics of lakes

Lakes are generally more vulnerable to water pollution and eutrophication than other water bodies, for example, rivers (PCE, 2012). Lakes are fragile environments that can be easily influenced by both natural and human factors (Sigee, 2005). They act like sinks, accumulating pollutants (especially sediment and phosphorus) that come from the catchment (PCE, 2012) and water gradually becomes enriched with nutrients. Lakes can retain water for a long time.

1.2 Characteristics of Lake Ōkataina

Lake Ōkataina has no surface outlet, instead draining southward by seepage towards Lake Tarawera. Because the level of Lake Ōkataina is not controlled by overflow, water levels fluctuate dramatically, depending on rainfall. A rise of 10 m has occurred in the last 100 years or so and a rise of 3 m was recorded in 1971 (Gosling, 2002).

The steep surrounding terrain and loose pumice soils in the Lake Ōkataina catchment make the lake prone to erosion during periods of heavy rain, both from the rainfall itself and rapid water level fluctuations.

Lake Ōkataina has a number of characteristics that help maintain high water quality. It is the only lake (of the 12 Te Arawa lakes in the Rotorua area) that is almost completely surrounded by native bush, which also covers the majority of its catchment. Native bush is considered to be the best type of land use for a vulnerable catchment like Lake Ōkataina. The lake has limited access and so has fewer pressures from visitors and boats. The lake is also protected under the Rotorua District Plan, with bans on jet-skiing and water-skiing.

1.3 Rainfall in the catchment

The Lake Ōkataina catchment has a mean annual rainfall of 1,600-2,200 mm, whereas most of Rotorua city generally has an annual rainfall of 1,400-1,600mm. In comparison, Tauranga and Whakatāne townships have a mean annual rainfall of 1,200-1,400 mm. The amount of rain Lake Ōkataina receives a year is lower than Lake Rotomā (2,000-2,400 mm) but higher than Lake Tikitapu (1,400-1,600 mm). Most Rotorua lakes have a higher annual rainfall than Lake Taupō, which receives about 1,000-1,200 mm of rain every year.

1.4 Terrains around Lake Ōkataina

The land surrounding Lake Ōkataina is typically hilly, rising steeply from the lake with slopes approaching 45^0. There is more steep land surrounding Lake Ōkataina than any other Te Arawa lake. Some parts of the lake also have steep drops under the water.

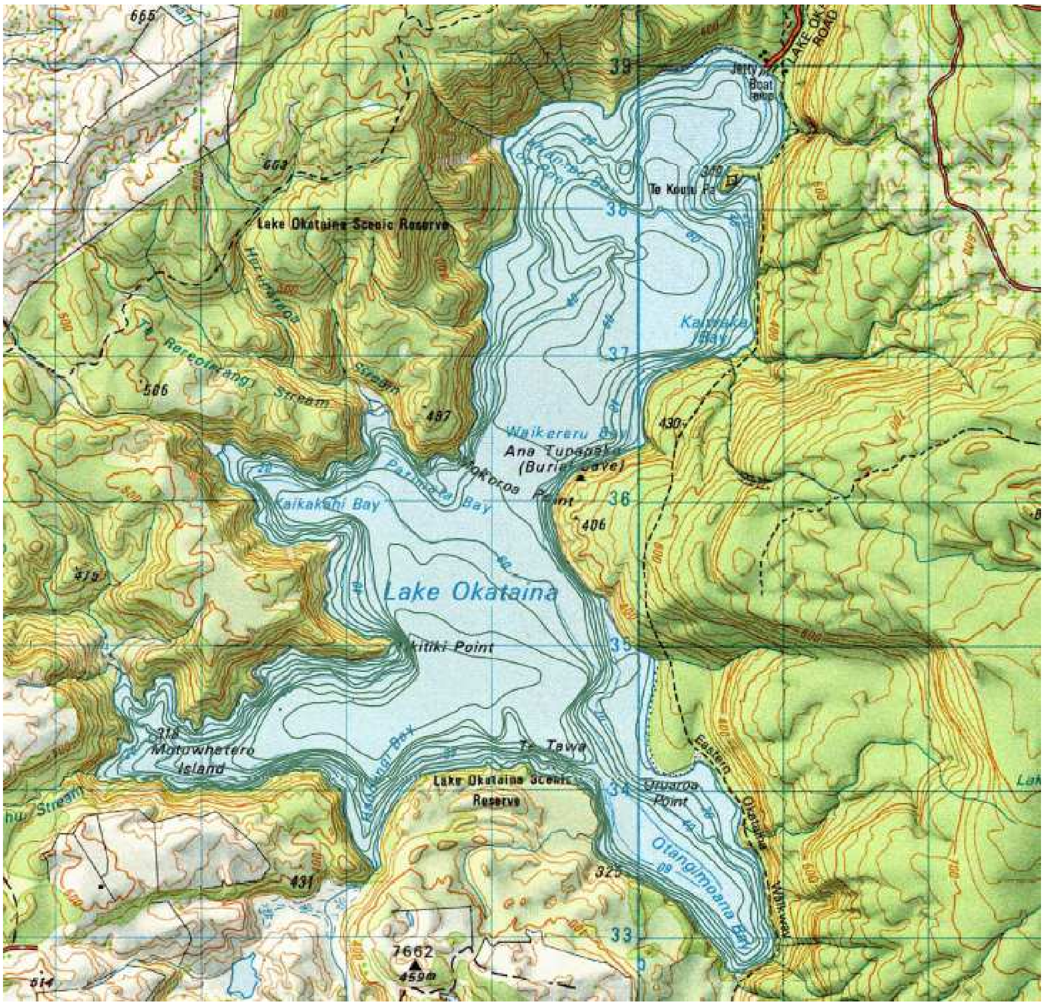


Figure 3. Topographical map and photo showing steep landscape surrounding Lake Ōkataina

1.5 Soils in the Lake Ōkataina catchment

The soils in Lake Ōkataina's surface catchment are characterised by the effects of past volcanic episodes. The catchment is comprised of well-drained 'recent soils' and 'pumice soils' with rapid permeability (that rain can soak into or pass through quickly, Landcare Research, 2012). When saturated with water, pumice soil tends to erode easily (Rijkse and Guinto, 2010). Maintaining a good vegetative cover protects the soil from such erosion.

A high level of soil organic matter is also important as it binds soil particles to prevent erosion (Bay of Plenty Regional Council, 2011).

Spring water from these volcanic deposits is usually rich in phosphorus (Hamilton, 2005) which is drawn from the underlying layers of pumice and rock. Much of the surface phosphorus is retained in the clay minerals of the soil. Most soil types in the Lake Ōkataina catchment have a moderate degree of phosphorus retention.

Figure 4. Photo showing organic matter holding the soil together, Eastern Lake Ōkataina walkway, December 2011

1.6 Physical characteristics contributing to erosion

Rainfall can cause shore erosion due to rapid changes in water level, as well as landslides in the surrounding steep terrain. Both of these types of erosion bring phosphorus to the lake, with sediment being a major source of phosphorus. Beneath the native forest, water travels easily through the coarse pores of the loose pumice and recently-deposited soils and drains to Lake Ōkataina. Phosphate tends to stick ('absorb') to the surface of soil particles carried into water (PCE, 2012).

Erosion is a natural process, but without healthy forest covers it can become much faster on exposed soil (PCE, 2012).

Much of the phosphorus in rivers and lakes in New Zealand is a legacy of erosion caused by forest clearance and fertilising for farming (PCE, 2012).

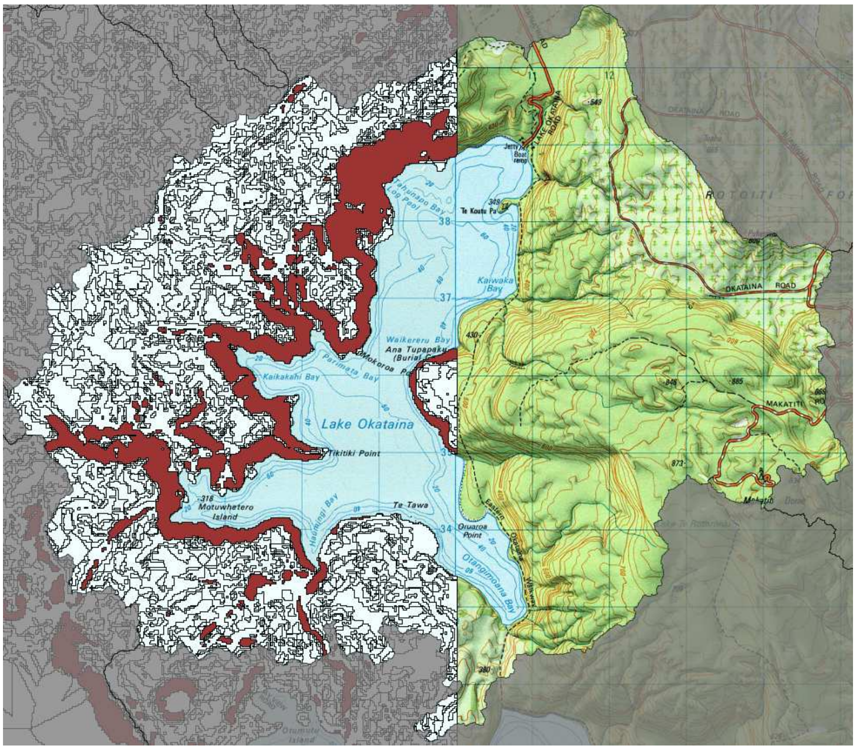


Figure 5. Map of Lake Ōkataina Catchment showing areas susceptible to landslides (brown).

Most land on the edge of Lake Ōkataina is highly susceptible to landslides (GNS Science, 2011). The data available cover only half of the Lake Ōkataina catchment shown in the map.

Figure 6. Photos showing landslides and erosion, January 2012

1.7 Streams in the Lake Ōkataina catchment

Lake Ōkataina is surrounded by steep land. It has no visible surface outlet and just two permanent streams feeding in. Even these streams are sometimes only trickles (Gosling, 2002) and most of its streams flow only briefly. In fact, the base flow rate in the streams is very small compared to what might be expected, given the catchment's rainfall. Storm flows and sub-surface springs are assumed to be the major source of water entering the lake.

It is generally assumed that the phosphorus entering the lake via groundwater is mostly in dissolved form as a result of changes from underlying geological material rather than from land-use effects (McIntosh, 2011). Steep flow paths allow rain to enter the lake rapidly. In less steep areas volcanic soils absorb the rain water rapidly to flow underground.

Figure 7. Pukahu Stream during summer.

Streams are seasonal in the Lake Ōkataina catchment. The Pukahu Stream was dry in January 2012.

1.8 Lake Ōkataina water level

Lake Ōkataina's water level fluctuates greatly and this can influence the quality of water (Lake Ecosystem Restoration New Zealand, 2012; Gibbons-Davies, 2002).

Marked lake level fluctuations, because there is no surface outlet, cause erosion and leaching of nutrients from the inundated shoreline where wave action can re-suspend sediment particles and nutrients. Long-term rainfall trends correlate closely with the lake level (Department of Conservation) but better rainfall measurement within the catchment would add greater accuracy to hydrological assessments.

During the past 30 years, the lake level has had a range of about 5 m (Department of Conservation). Between 1962 and 1971 the lake rose 3 m, submerging beaches, damaging bush and causing major erosion around the lake (Gosling, 2002; Department of Conservation). A rise of more than 10 m has occurred in the last 100 years or so. During dry spells, the lake bed can be exposed. Better understanding of the causes of natural fluctuations in water levels will help our interpretation of water quality in Lake Ōkataina.

Figure 8. High water levels in Lake Ōkataina submerge a sign post at Otangimoana Bay, November 2011

Figure 9. A slip by the lake edge, Eastern Ōkataina Walkway between Oruaroa Bay and Otangimoana Bay, November 2011

Once saturated by water, the pumice soil tends to erode easily causing landslides into Lake Okaitana (Rijkse and Guinto, 2010).

1.9 About Lake Ōkataina

Lake Ōkataina is a deep, oligotrophic lake (Lake Ecosystem Restoration New Zealand, 2011; Deely et al. 1995) with its deepest point at 79 m (about the height of a 24-storey building). The average depth of the lake is 39 m with over 62% (667.5 ha) deeper than 40 m. Adult divers normally begin to develop serious illnesses below 30 m.

The depth of the lake is one of the factors affecting its natural processes. Deep highland lakes with infertile soils and undisturbed catchment areas are often oligotrophic (Sigee, 2005) – low in nutrients, rich in oxygen and generally hosting little or no aquatic vegetation.

Figure 10. Lake Ōkataina, Tauranganui Bay, April 2011

1.10 Summary of physical characteristics

The soil types and steep landscape surrounding Lake Ōkataina are sensitive to erosion. Vegetation plays an important role in holding soil and nutrients and not letting them be washed into the lake to cause possible eutrophication (an abundance of aquatic plants and algae) and poor water clarity.

Part 2: Water quality

2.1 Trophic level

The trophic level index (TLI) is widely used to measure changes in the nutrient (trophic) status of lakes, and includes phosphorus and nitrogen levels, how clear the water is and the presence of biomass of planktonic algae. Lower TLI is generally associated with higher water quality.

The trophic level of Lake Ōkataina has been fluctuating between TLI 2.5 and TLI 3 in the last two decades. Putting together an action plan will help direct what actions need to be taken to improve water quality to meet the target (TLI 2.6) for the lake.

In the past, the Te Arawa Rotorua lakes' communities have said that the expected water-quality target should be no less than its 1994 level, so the TLI target for Lake Ōkataina has been set at TLI 2.6.

Nitrogen and phosphorus are essential plant nutrients. In large quantities, however, they can encourage nuisance aquatic plants such as algal blooms. High levels of water-bound nitrogen and phosphorus most often come from agricultural run-off and urban wastewater, but can also come from geothermal inputs and deep springs that leach phosphorus from the bedrock.

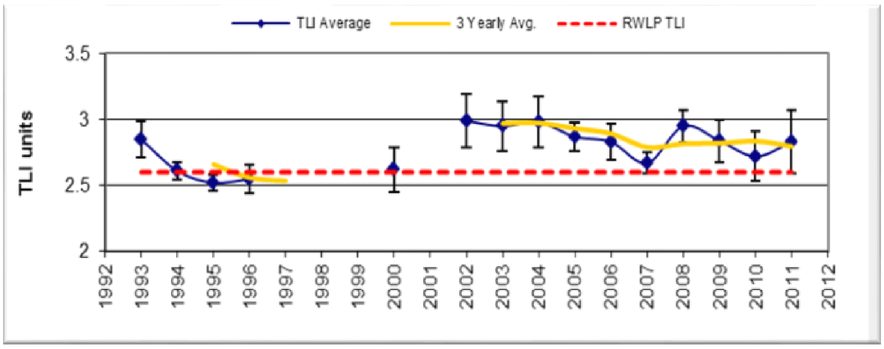


Figure 11. Annual average TLIs, three-yearly average TLIs and the target TLI set in Regional Water and Land Plan

The trend in the last 10 years shows the concentration of total phosphorus has been going up slightly, while the concentration of total nitrogen has been coming down slightly.

In aquatic systems, nutrients (nitrogen and phosphorus) are important links to the growth of plant and algae, while algal blooms are important indicators of poor water quality. The Regional Council has set a water-quality goal for each of the Rotorua lakes in the Regional Water and Land Plan, with one objective being to keep the lakes free of algal blooms.

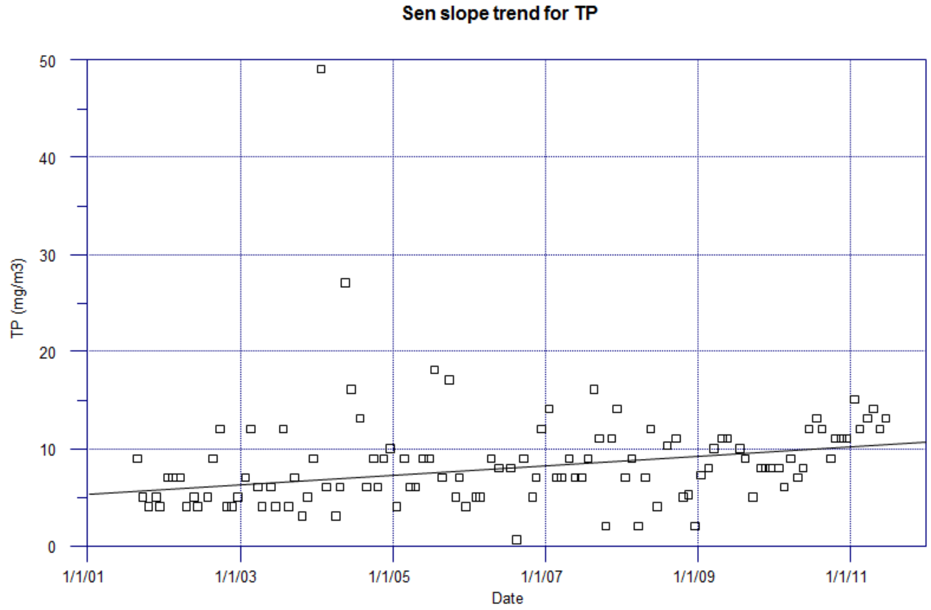


Figure 12. Phosphorus concentration in Lake Ōkataina (2001-11)

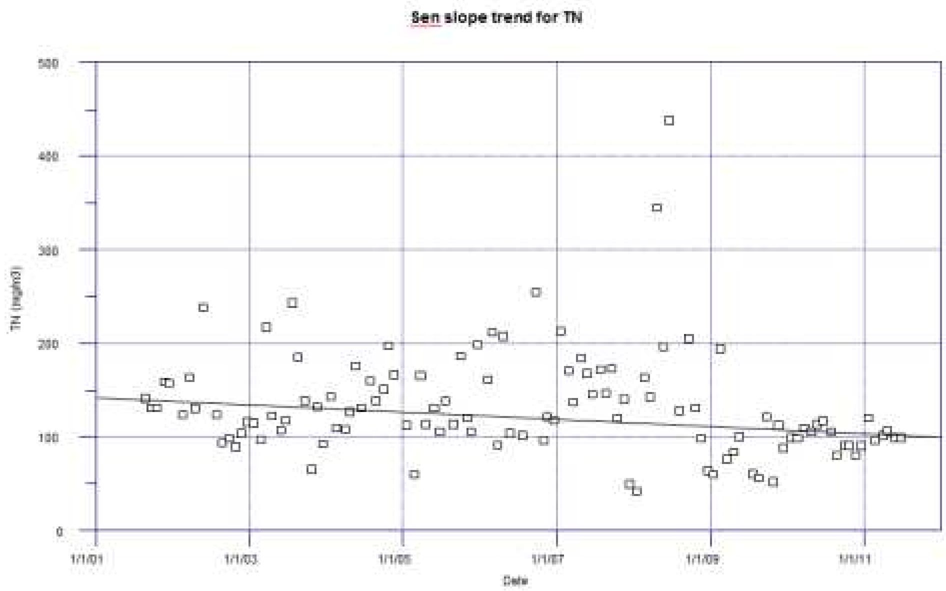


Figure 13. Nitrogen concentration in Lake Ōkataina (2001-11)

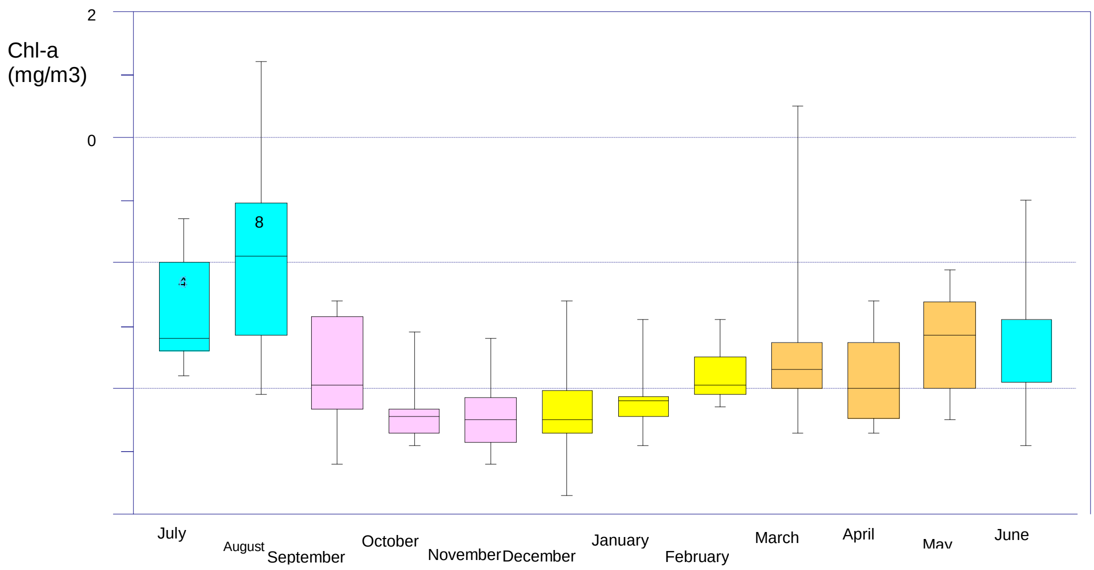


Figure 14. Concentration of chlorophyll-*a* in Lake Ōkataina showing seasonal variation

Concentrations are high in winter and low in summer. Box and whisker plot shows average, upper and lower quartile and maximum and minimum chlorophyll-*a* concentrations from 2000 – 2011.

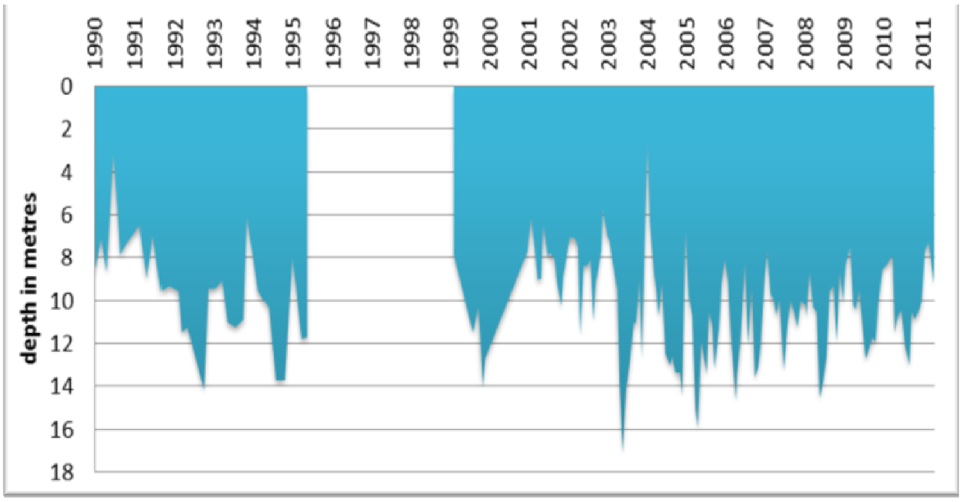


Figure 15. Water clarity in Lake Ōkataina

The monthly Secci depth reading from a central lake monitoring station reveals seasonal variation with a long-term decreasing trend in water clarity since 2004.

2.2 Lake water level and the trophic level

A high lake level is generally followed by a higher TLI about two years later. The recorded lake level in the last 15 years has fluctuated within a 3 m range.

Observation shows Lake Ōkataina is an unstable lake. It is presumed to have one of the most potentially active underground plugs that affects the underground flow to Lake Tarawera (Gosling, 2002).

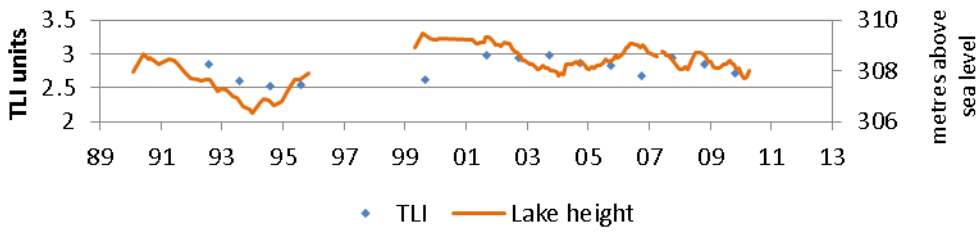


Figure 16. Annual average TLIs and monthly lake height

Higher levels of rainfall result in run-off from, and inundation of, soils around the lake shore. The amount of annual rainfall appears to have an effect on the phosphorus concentration in Lake Ōkataina's water. Nutrients flowing in from storm events impact the trophic status as well as the lake level, and are a possible link between lake level changes and TLI.

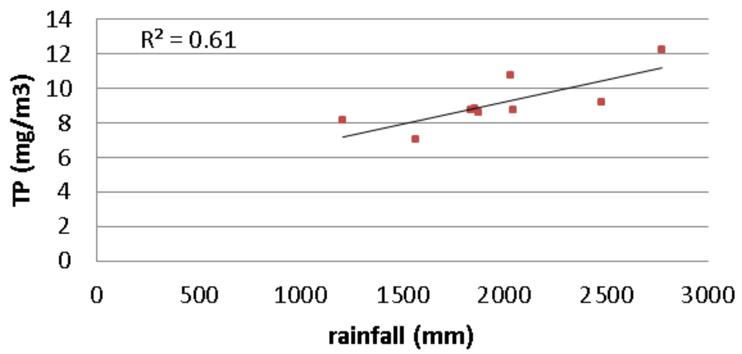


Figure 17. Annual rainfall versus annual Lake TP (Total Phosphorus)

2.3 Lake oxygen levels and stratification

Lake Ōkataina stratifies in October when the temperature warms – separating into distinct layers with the coldest water at the bottom. The water can remain stratified until mid-June when the mixing of the surface and bottom waters occurs. Current research shows that during that warm period, there is a marked depletion of oxygen in the deeper water of Lake Ōkataina.

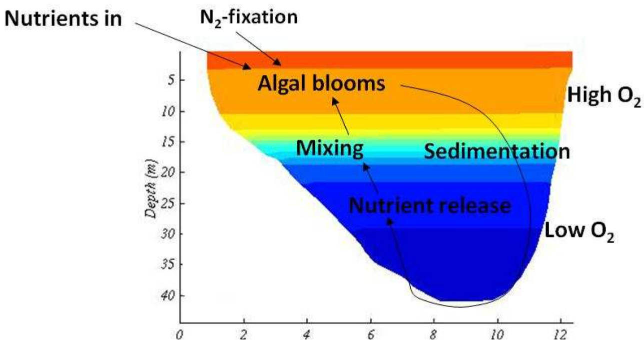


Figure 18. Stratification of Lake Ōkataina

The lake has a different process when it stratifies (separating into layers) during warm and calm periods

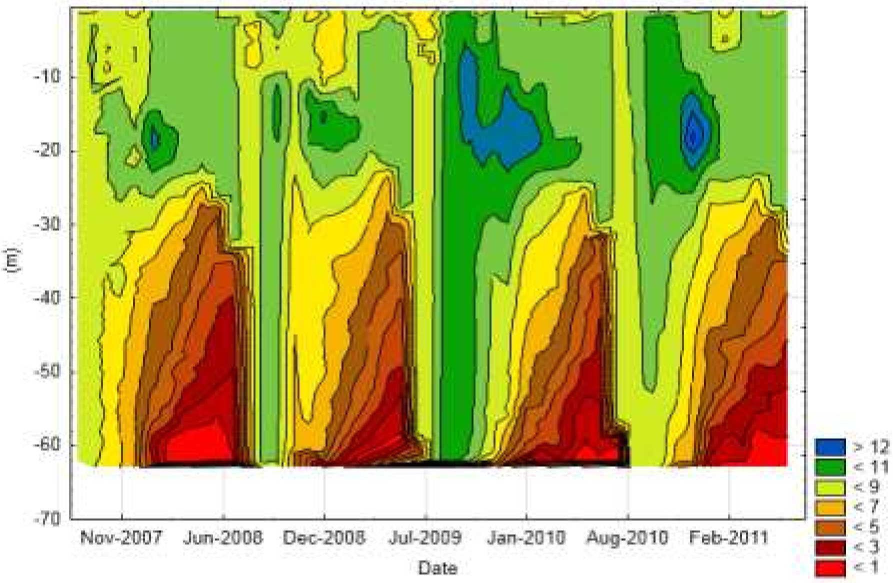


Figure 19. Dissolved Oxygen (g/m^3) in Lake Ōkataina

The bright red shows oxygen levels are very low at the bottom of Lake Ōkataina at certain times of the year.

The oxygen depletion rate in Lake Ōkataina is higher than any of the other nearby oligotrophic lakes, such as Lake Rotomā and Tarawera, while water at the bottom of Ōkataina has shown lower oxygen levels than previously measured.

Lakes are fragile environments that can be easily influenced by both natural and human factors. Lakes are also nutrient sinks, especially those retain water for a long time – the longer the water is held, often the richer it becomes in nutrients.

2.4 Is the water drinkable?

The Bay of Plenty Regional Council samples water at 80 popular swimming spots from October to March each year and counts the number of *Escherichia coli* (*E. coli*) bacteria in the test sample.

If the *E. coli* level is 260 (or under) units per 100 ml, the water is considered safe for swimming. The Council's monitoring in the 2009/2010 testing season showed Lake Ōkataina had an average 2.5 *E. coli*/100 ml with the highest reaching 9 *E.*

coli/100ml. This shows it is good quality for swimming, but would not meet the legal standards for potable water (drinking-water).

The presence and amount of *E. coli* is also one of the many standards used for to rate drinking water quality. If there is more than one *E. coli* per 100 ml, water is considered not safe to drink (Ministry of Health, 2008). Generally, supplies with more than 10 *E. coli* per 100 ml of drinking water would cause illness. Lake Ōkataina's water would be fine for drinking so long as it was treated with chlorine. Drinking water generally requires close monitoring and careful examination to ensure it meets public health standards.

Figure 20. Looking across to the shores of Lake Ōkataina, December 2011

2.5 Lake Ōkataina nutrient budget

A nutrient budget is the sum of nutrient inflows and outflows from a lake over a specified period (Gibbs, 2009). Generally, measurements of the nutrients in lake inflows and in the lake itself are collected to produce a nutrient budget (Gibbs, 2009).

The nutrient budget is used by the Bay of Plenty Regional Council to analyse and identify the key processes controlling supply, form and availability of essential nutrients, including those that might cause lake enrichment and algal blooms (Gibbs, 2009).

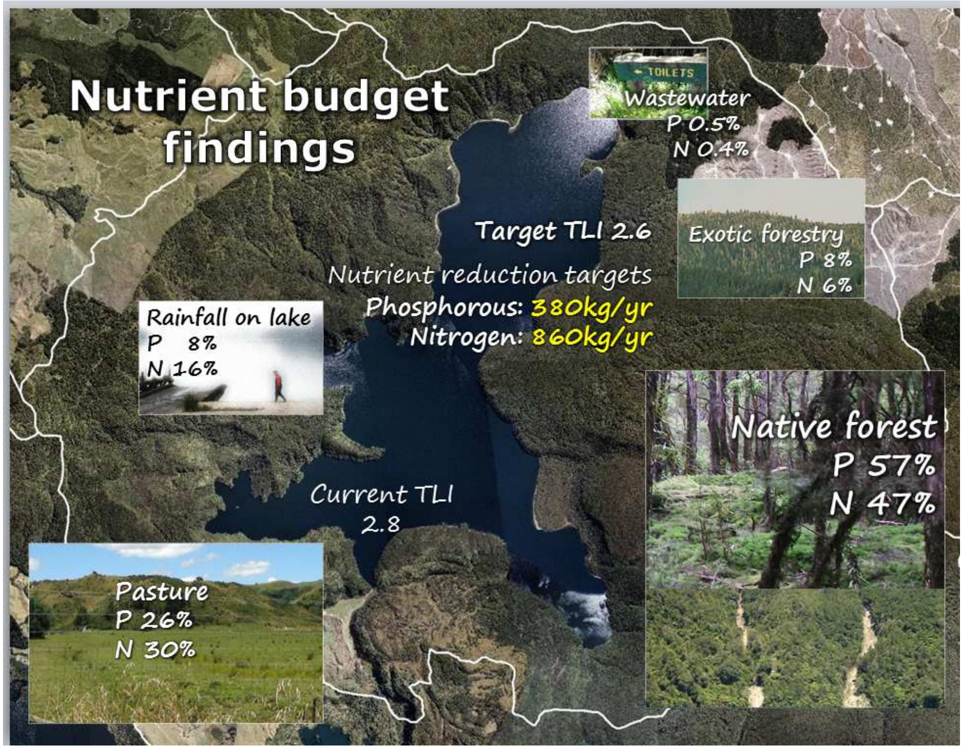
The draft nutrient budget for Lake Ōkataina (December 2011) estimates that Lake Ōkataina has a little over 2 tonnes (2079 kg) of phosphorus and 27 tonnes (27,112 kg) of nitrogen coming into the lake each year.

- The estimated total phosphorus load to Lake Ōkataina is 2079 kg/yr
- The estimate total nitrogen load to Lake Ōkataina is 27,112 kg/yr.

The lake nutrient budget is based on the following available information:

- Lake water samples in the last 14 years
- A few water samples from streams coming into the lake

- 2003 land-use data within the surface-water catchment
- Wastewater discharge, such as septic tanks.



To devise a nutrient budget, scientists must make certain assumptions, including:

- The amount of nutrient that stays in the lake
- That lake levels vary little
- The rate of nutrients that come from land uses to the lake at a similar rate as recorded in other Rotorua lakes
- The amount of nutrients that come from sewage and storm water
- The water flow of Lake Ōkataina catchment is similar to other Rotorua lakes' catchments.

Based on these assumptions, scientists estimated that for Lake Ōkataina to reach its target TLI of 2.6, an annual reduction in phosphorus of 380 kg and nitrogen of 860 kg is required.

However, the accuracy of the nutrient budget (Shallenberg, 2012) is limited by:

- The difficulty in separating the amount of nutrient coming from natural sources (geological) and artificial sources (land use)
- Lack of information on groundwater flows
- The most recent land-use data being from 2003
- The fact there is no surface outflow from the lake, so assumptions about the rate of loss of nutrients may be in error
- Limited local storm event data.

Part 3: Nutrient sources

To achieve the water-quality target (TLI 2.6) for Lake Ōkataina, based on the nutrient budget, scientists estimated that an annual reduction in the inflow of phosphorus (380 kg) and nitrogen (860 kg) is needed.

Scientists estimate that a large proportion of nutrients in Lake Ōkataina come from natural sources. Native forest and rainfall on the lake's surface together form 63% of the annual input of phosphorus, and 47% of the annual input of nitrogen. There are limited options for managing nutrients from these sources.

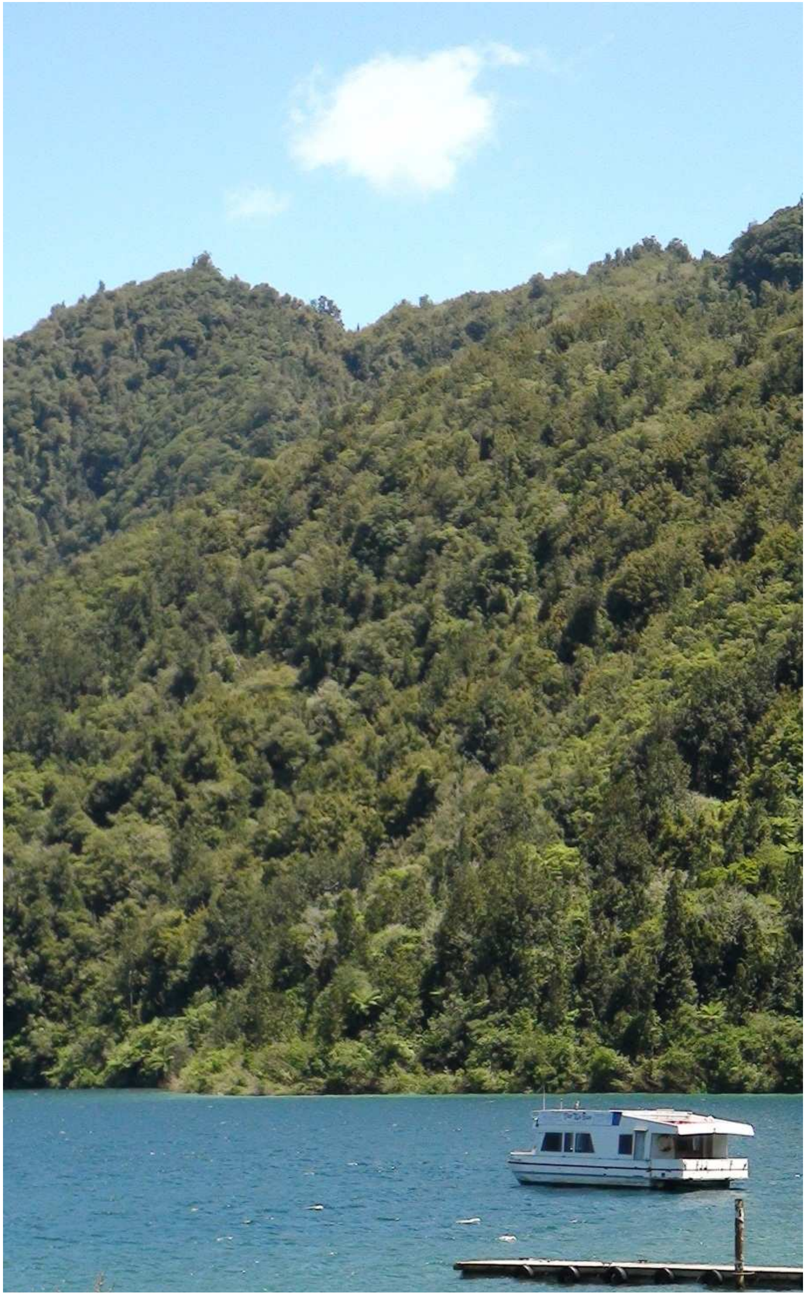


Figure 21. Lake Ōkataina, view from Tauranganui Bay, November 2012

Over one-third of the nutrient input to Lake Ōkataina is from manageable sources – an estimated nearly 35% of phosphorus and 37% of nitrogen from pasture and exotic forest land.

We estimate that about 0.5% of phosphorus and 0.4% of nitrogen are from wastewater. This is based on the estimated number of visitors to the lake, and assuming the wastewater system is similar to that at Lake Tikitapu before 2010.

There are small areas of bare ground and built areas in the Lake Ōkataina catchment, but it is thought that only a trace amount of nutrient input (10 g of phosphorus and 110 g of nitrogen) a year is generated from these.

These estimates of nutrient sources have been based on a number of assumptions, including:

- Lake Ōkataina receives nutrient only from its surface catchment (defined by surface elevations)
- No specific estimation is made for nutrient input from gorse
- Land use today is similar to that of 2003
- Indigenous forest in the catchment releases 0.28 kg of phosphorus and 3 kg of nitrogen per hectare annually
- Rainfall contributes 0.15 kg of phosphorus and 4 kg of nitrogen per hectare of lake surface annually
- Pastoral land releases 1 kg of phosphorus and 15 kg of nitrogen per hectare annually
- Exotic forest contributes 0.4 kg of phosphorus and 4 kg of nitrogen per hectare annually.

Nutrients from natural sources

- Native forest is thought to be the main nutrient source
- Rainfall on the lake is another main source of nutrients
- The health of the forest is related to its ability to retain nutrients

3.1 Nutrient input from native bush

It is thought that about 57% of the annual phosphorus input and 47% of annual nitrogen input comes from land with indigenous bush cover. However, it is thought difficult to reduce nutrients from this source. Pest control could restore the understory growth, which could be one way of retaining more sediments and associated nutrients on the land.

The best estimate for the catchment phosphorus run-off concentration for forest land use coincided with lower concentration in the small inflowing streams (McIntosh, 2011).

Figure 22. Native Forest, Lake Ōkataina

Nearly 80 percent of the land cover in the Ōkataina catchment is native forest.

According to the Department of Conservation, the Ōkataina Scenic Reserve forest has been damaged at all levels by a variety of pest animals, from the ground to the canopy. Native bush in Ōkataina is infested with wallabies and deer, which graze the forest understory. An experimental site is showing how forest can regenerate and provide dense cover.

Figure 23. Photos showing the difference between animal-grazed (left in 1995) and non-grazed forest (right in 2011 with pest exclusion), near Lake Ōkataina

We also note that the New Zealand Forest Service and the Department of Conservation undertook some larger scale terrestrial pest control in 1987, 1989 and 1991, and 1999. So it is possible that the terrestrial pests may have a growing presence given it has been a decade since the last larger scale control, but there is very limited information on current pest densities on site (Speedy, C and Singers, N., 2012).

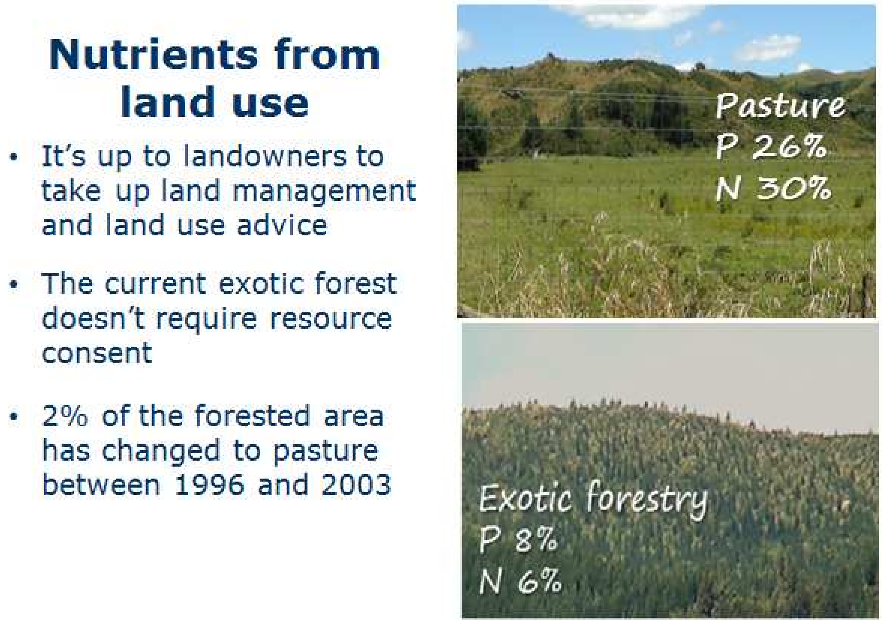
3.2 Nutrient input from rainfall

It is estimated that about 8% of the annual phosphorus input and 16% of nitrogen comes from rainfall on the lake. This input cannot be managed.

Research has found that rainfall carries nutrients from the air into a lake (Gibbs and Vant, 2006, Timperley et al. 1985, Rutherford et al. 1987, Nichol et al. 1997). Some factors that determine the loads of nitrogen in rainfall include:

- The use of fossil fuel and the nitrogen oxides it produces
- Ammonia released from agriculture into the air
- Winds that redistribute pollution in the air (Gibbs and Vant, 2006).

The rate of nutrient input from rainfall to Lake Ōkataina is assumed to be similar to that measured at Lake Taupō in 2006, and to that measured at Lake Rotorua in the mid-1970s by the Ministry of Works.



3.3 Nutrient input from pasture

About 26% of the lake's annual phosphorus intake and 30% of the nitrogen is believed to come from pasture land.

However, since these figures were estimated, it is possible that land-use practices in the Lake Ōkataina catchment are already more sustainable. For example, an audit surveyed an approximate 50 ha farm block and estimated that about 490kg of nitrogen enters the lake every year (almost 10 kg per hectare), which is lower than the nutrient budget estimate for average beef and sheep farms (15 kg of nitrogen per hectare).

Figure 24. Most pasture land is located at the top (elevated) part of this catchment, January 2012

Land use is constantly changing in the catchment. For example, a 50 hectare beef/sheep farm block is being converted to forestry and a smaller nutrient input to Lake Ōkataina is an expected as a result. Conversely, if other landowners converted to dairy, that would be likely to result in higher nutrient yields.

Some restoration practices on pasture land that have benefits for lake water quality include:

- Using fences to keep stock out of the waterways including wetland
- Managing existing wetlands as sustainable areas
- Riparian planting and indigenous planting where groundwater seeps to the surface.

3.4 Many of these practices are already carried out by famers around Lake Ōkataina. However, more could still be done by fencing all streams to prevent stock access and considering more sustainable land-use options for steep areas (for example, forestry).Nutrient input from exotic forest

About 8% of the annual phosphorus intake and 6% of nitrogen are thought to come from exotic forest land.

The nearest area of forestry land is about 600m from the lake, buffered by indigenous forest. No logging occurs around the lake. Maps show three streams starting from the exotic forestry areas, travelling through steep land covered by indigenous forest, before entering the lake.

Forestry and harvesting are currently permitted activities in the catchment and no resource consents are required. Factors likely to affect the lake's water quality would relate to forest harvest practices. These are governed by industry regulations with a proposed National Environmental Standards for Forestry under development (Ministry for the Environment, 2012).

Figure 25. Forestry land on the top of the Lake Ōkataina catchment, January 2012

3.5 Dynamics in land-use change

Aerial photography analysis shows that about 2% of the land cover has changed between 1996 and 2003 (latest land use data available) with the forested area reduced by 97 ha (about 33 ha from indigenous forest and 64 ha from exotic) and pasture land increasing by 93 ha (2003 is the most recent land-use data available).Land use in areas of the catchment continues to change.

The surface cover of both pastoral and exotic forest land could change rapidly as economic returns from these primary industries change. The following three images show the surface changes of the Lake Ōkataina catchment between 2003 and 2009.

Figure 26. Lake Ōkataina catchment aerial mosaic image, 2003

Figure 27. Lake Ōkataina catchment aerial photo image, 2006/2007

Figure 28. Lake Ōkataina catchment satellite image, 2009

3.6 Nutrient input from wastewater

It is estimated that about 0.5% of the annual phosphorus input to the lake and 0.4% of the nitrogen comes from wastewater.

It is expected that there is some nutrient contribution from two septic tanks (or wastewater treatment systems) near the lake (the Lake Lodge Ōkataina and public toilets beside the car park). Due to the limited information available, we could only make an estimate from our experiences with other Rotorua lakes.

Lake Ōkataina and Lake Tikitapu are similar in that both have wastewater facilities near the lake to accommodate daytime and overnight visitors and tourists[1]. The public toilet and tourist accommodation nearby are the key wastewater sources.

A 2010 survey (ARC Consultants) recorded 227 vehicles at Lake Ōkataina (on an average of 17 visits to Rotorua lakes), compared to 1,494 at Lake Tikitapu.

[1] Lake Ōkataina is identified as a water body of national tourism importance. Its pristine environment attracts tourists, picnickers and fishermen.

If it is assumed that the amount of wastewater is related to the number of visitors, then Lake Ōkataina receives less wastewater than Lake Tikitapu as Lake Ōkataina receives an average of 30 visitors per day, about 15.7% of the number of visitors of Lake Tikitapu.

If Lake Ōkataina's wastewater system accommodates 15.7% of the amount of wastewater of the system at Lake Tikitapu, then up to 11 kg of phosphorus and 110 kg of nitrogen per year from visitors could be flowing in to Lake Ōkataina.

The above estimate includes the on-site effluent treatment system of the commercial operation Lakes Lodge Ōkataina, as well as the public toilet. Both systems are within the 200 m buffer of Lake Ōkataina as set out in the effluent treatment concentration rule coming into force from December 2012.

However, Lakes Lodge Ōkataina is permitted under a resource consent to discharge its wastewater to land until 2024. The consent allows discharge of up to 12.5m3 per day through 150 m (90 m^2) of soakage trenches on the property. Its water-use information shows only half of the permitted amount of effluent is discharged daily. If this is the average daily rate, the annual discharge would near 2,000 m^3.

The Ōkataina public toilet did not need a resource consent and is not used frequently enough to require one. However, a rule is in place to ensure that from December 2012, the owner of the septic tank must ensure that the total nitrogen discharge from its septic tank is less than 15g/m^3 in concentration before discharge to land.

3.7 Nutrient input from reserves, buildings and car park

The Ōkataina catchment has a limited built-up area, which contributes a small amount of nutrients to the lake every year.

Figure 29. Stormwater drain in the car park next to Tauranganui Bay

3.8 Groundwater feeding into Lake Ōkataina

There are geothermal inflows to Lake Ōkataina and these inflows, such as Ōkataina Springs (on the eastern shore of the lake, south of Oruaroa), contribute gas and seeping warm water to the Lake (Donovan and Donovan, 2003). We have limited information on the quality and quantity of geothermal water flowing into the lake (Donovan and Donovan, 2003).

Scientists are unsure if the groundwater catchment has the same boundary as the surface-water catchment. More land could be contributing water to Lake Ōkataina than contained by the surface contour.

Currently there are some groundwater bore investigations being carried out. A three phase investigative drilling program has been carried out to improve our understanding of the flow direction, hydraulic properties, quality and age of groundwater within the 'greater' Lake Tarawera groundwater catchment. This catchment includes water inputs from Lakes Rerewhakaaitu, Rotomahana, Rotokakahi, Tikitapu, Ōkāreka and Ōkataina.

The focus of the Phase Three drilling program was on groundwater near Lakes Rotokakahi, Tikitapu and Ōkāreka. The drilling identified several high flowing aquifer layers, but only at Lake Rotokakahi was an aquifer identified that showed elevated nitrate levels indicating the effects of land use activity. The remaining aquifers had low nitrate concentrations consistent with pristine oxidised groundwater systems. Groundwater age was moderate to high (50 to 150 years) in most of the aquifers sampled.

The drilling program has now been largely completed. The next phase is to construct a conceptual geological model for the greater Lake Tarawera groundwater catchment. The model will be used to develop groundwater flow and nutrient models for the area.

Figure 30. Tarawera waterfall

Tarawera waterfall (Figure 30) and Earthquake Flat are two good examples showing groundwater dynamics in the district.

3.9 Gorse in the catchment

The Council is looking into[2] the impact of gorse on water quality and policy options for managing gorse. Early indications are that gorse may add substantially more nitrogen (but not phosphorus) to lake water compared to other types of vegetation.

There are some areas of the catchment are covered in gorse, the findings of this study may prove important. The Regional Council adopt an adaptive approach when new evidence becomes available.

[2] This work is commissioned by the Bay of Plenty Regional Council, undertaken by an independent consultant.

Part 4: Key stakeholders' comments

4.1 Meeting with Ngāti Tarāwhai Iwi Trust

11am – 12.30pm, April 15, 2012, at Te Kotahitanga o Te Arawa Waka (Te Arawa Fisheries Trust Board)

The objectives of the meeting were to share experiences, values and aspirations for Lake Ōkataina, and work in interactive groups to focus on identifying pressures on water quality, and anything else we need to know about or do, to improve water quality at Lake Ōkataina.

Attendees**:** Ngāti Tarāwhai Iwi Trust: Joseph Te Poroa Malcolm (Chairman), Manu Pene, Rangitukehu Paora, Tera Malcolm, Angela Malcolm, Cyrus Hingston and Manu Malcolm.

Bay of Plenty Regional Council: Jane Waldon (Māori Policy Advisor) and Michelle Lee (Planner).

What are the pressures on water quality at Lake Ōkataina?

- Recreation – walking tracks
- Farm on the southern side – sheep, beef and deer
- Lodge wastewater diverted
- Forest
- Wharepaku (toilet).

The future of Lake Ōkataina - what would you like see in 2020?

- Drinkable water and edible koura supported by a plan that maintains the water quality
- The cultural and heritage sites left alone
- Safe for swimming
- Pristine area
- Protect the native fauna and flora around the lake
- Septic tank mitigation
- Lake back to us – title back to Māori people.

In the Trust's view, what are the key issues for the lake's water quality?

- Need to control the levels of phosphorus and nitrogen
- Identified pasture and native forest are sources of N and P
- Native forest as a method to reduce N and P
- Diverting farm pollution
- Need to note that some land is already retired from farming.

What was your first reaction when you heard the information on current lake water quality?

- Data is hard to understand and needs stories to go with it
- Trophic level.

What other types of facts do we need?

- Research showing other cases
- Examples of oxygenation in lake
- Research to reduce N and P
- Source of N and P, such as farming
- Actions
- Better overview.

What are the alternatives?

- Improve forest undergrowth
- Alternative to farming is to replace farmland with forest
- Action on pest eradication is urgently needed, not using chemicals but using iwi labour.

What didn't you like about what you've heard?

- The water quality is a wake-up call
- Now the lake is under threat from pollution
- Deterioration of the lake is getting worse since 1994.

What's great about what you heard?

- Now we know we can do something about water quality – it's not too late
- We can see what actions are committed.

4.2 Workshop with key stakeholders

10am – 2.30pm, April 3, 2012, at Conference Room, Holdens Bay Top 10 Holiday Park

Attendees: John Green, Shane Grayling, Helen Crawford (Whakapoungakau 4K2A), Matt Osborne (Fish & Game NZ), Paul Skinner (Rotorua District Council), Nick Berryman, Tony and Joanna Carr, Jenny and Paddy Sands, Hera Smith, John Ransfield, Paul Scholes, Joshua O'Rourke, Michelle Lee.

The objectives of the meeting were to share experiences, values and aspirations for Lake Ōkataina, and work in interactive groups to focus on identifying pressures on water quality at the lake, and anything else we need to know about or do to improve water quality at Lake Ōkataina.

The best possible future for Lake Ōkataina: What would you like people to say about Lake Ōkataina in 2020?

(Bold text shows what each workshop group selected as the top three).

- **Wilderness feel and remoteness**
- **Unspoilt**
- **Historical and cultural sites**
- Surrounded with bush, history and water quality
- "Outstanding picture; deep clear water reflecting natural bush"
- "Stunning, unbelievable, memorable"
- People will say – a great place to see natural NZ flora
- "Native bush around lake"
- Protect current values
- A highly regarded fishing destination – perfect world big trout
- Outstanding feature – fishing
- **Quiet recreation** - enjoy environment
- Swim, fish and low-impact recreation
- Isolation
- **No decline in current water quality**
- Clean water
- Clear water, natural bush
- **Stop pests (aquatic and terrestrial)**
- No aquatic pest incursions
- No invasive weeds
- Possum rates and wallaby numbers decrease - In a **perfect world**, Lake Ōkataina would be **vermin free**
- People's impact (e.g. events) managed with control and infrastructure support
- Continue existing direction.

The pressures on water quality at Lake Ōkataina – what activities are putting pressure on Lake Ōkataina?

(Bold text shows what each workshop group selected as the top three)

- **What impacts are natural activities having on water quality** e.g. geothermal, rainfall washing foliage into lake.
- **Terrestrial and aquatic pests**
  - ➔ Wallaby damage to undergrowth preventing bush from filtering rainwater runoff before it enters the lake
  - ➔ Pest include rats, mice, deer, pigs, wallabies, possums, stoats, ferrets, feral cats and dogs.
- **Need planning for increased use** (tourism, commercial, recreational use and events on water and land), such as infrastructure
- Land use of primary industry
- No composting toilets around lake infrastructure
- Poaching (deer and cattle) from boats
- Tourism pressures.

Figure 31. Lake Ōkataina, November 2011

How the current water quality has affected the lake environment

(Bold text shows what each workshop group selected as the top three)

- Current water looks clear and deep and is an attractive environment
- Perception of the lake is that it is unspoiled - is the perception a problem as a lack of awareness about natural process and human impact on water quality
- Water levels (currently very high) affecting erosion and recreational use
- Natural thermal activity/climate change effect on water quality?
- What is the science of the water quality?
- Lack of affected parties (around lake) – lack of 'voice'
- High water level has driven out mosquitos and wasps
- Weed incursion → weed cordons/ fenced off 'no go' areas.

What impact does the current water quality have on the Lake Ōkataina community?

(Bold text shows what each workshop group selected as the top three)

- People looking for a pristine environment
- Encourage recreational use (for Ōkataina community and regional community)
- What impact is the community (recreational users) having on the lake quality: increasing recreational use needs suitable sewage and rubbish support
- Community needs greater communication and awareness of water quality and action plans /pollution prevention
- Activities on the lake have changed, water-skiing is not allowed on the lake.

Comments on the water quality information

In your view, what's the key point in the presentation?

- Understanding aspirations from a variety of stakeholders
- Gaps in science – geology and inflows
- The lake is stable
- State not bad, do not want further deterioration
- High natural loading to lake, hard to manage
- Pests and weeds are key threats to lake
- Weed problem - need to take away.

What's your first reaction when you heard the information on current lake water quality?

- Is there a 'problem' with Ōkataina other than weed?
- Generally not surprised (water quality still good and stable as expected)
- Surprised that TLI is deteriorating.

What didn't you like about what you've heard?

- Water quality compared to other lakes, Lake Tarawera and Lake Ōkataina
- No easy answer to manage pests in and around the lake
- Weed issues – concerned what could happen to Lake Ōkataina
- Weed and vermin issues
- Need a lot more science info to understand the lake dynamics.

What's great about what you heard?

- Monitoring - being proactive
- Current state is reasonably good
- Consensus that want to keep Ōkataina in its current state
- Good to see comparisons between lakes
- Nutrient budget isn't huge – economic cost.

Could we go in a totally new direction?

- Community to understand what the issues are
- Monitoring – check and balance to see is there a problem
- Stay on course – existing process in place
- Be flexible and allow for dynamics
- Providing appropriate infrastructure for events and recreation.

What other types of facts might make the science clearer?

- Quantifying natural vs. introduced inputs
- Input from indigenous forest – intact vs. impacted --> what would the difference to the lake be?
- More investigation into groundwater influences (geology, underground water flows)
- Land-water integration

- Climate change
- Geothermal inflow
- Effect of herbicides (to control aquatic weeds – ecosystem impacts)
- Information about all types of pollution going into the lake
- More comparative data with other lakes
- Other science avenues to be explored.

4.3 Workshop with Lake Ōkataina Scenic Reserve Board

March 26, 2012, at Conference Room, Department of Conservation, Rotorua

Attendees: Lake Ōkataina Scenic Reserve Board: Don Bennett (Chairman), Anaru Rangiheua, Cheryl Roberts (Board Secretary), Nicki Douglas (DoC), Manu Pene, Manu Rangiheua, Ruka Hughes, Charles Hemana.

University of Waikato: David Hamilton.

Bay of Plenty Regional Council staff: Paul Scholes, Kerry Gosling, Michelle Lee.

The best possible future for Lake Ōkataina

The foundation: "For us, the history, lake and land are the foundation."

- Recognising the history, the water and land history of Lake Ōkataina
- Lake Ōkataina and the meaning behind the name
- History, land and lake is the foundation for us
- Sunken pa site and bed of lake
- Museum
- Taonga
- Wāhi tāpu areas
- Rangitakeao
- Te Koutū Pa
- Part of the traditional roadway
- Ōkataina 10 block is part of the traditional roadway.

The best possible future for Lake Ōkataina: What do you want to see happen?

- Keep the lake unique
- Keep vista – building free
- Keep environment
- Maintain the quality of the lake
- Prevent Lake Ōkataina from becoming polluted like other lakes
- Serene
- Tranquil for all
- Healthy ecosystem
- Better-quality forest ecosystem to support the lake health
- Area above the lake retired
- Custodians
- Te Ao Māori – reasonable job
- Recreation use BUT only if not detrimental to the lake
- Restrict boating use – speed
- Larger signs for boaties to take pest plants off their boats
- Toilet facility along the way
- Used to have 3-4 buses of visitors a day to see the lake
- The Board has rights – responsibilities and funding
- Monitoring (during and after) event activities
- Keep updated
- TLI water quality, monitoring.

The pressures on water quality at Lake Ōkataina: What activities are putting pressure on Lake Ōkataina?

- Tourism, events.
- Aquatic pests (weeds from boats)
- Ecosystem in the forest is damaged by pests, such as possums, pigs and wallabies
- History to be kept in the Trust
- Māori management system – people can say what they think more directly if the managing people are local
- Meeting with Lake Trust on the ownership back to the Board - issue outside the scope of the water quality action plan?
- Scenic Reserve used to include the lake and its bed. We need to manage the whole holistically.

Comments on the water-quality information

We think the key messages are:

- Inform

- Create an awareness
- Learning about the water quality and its technical aspect
- Keep the lake pure
- We try to keep the water as clean as possible
- We better stay where we are – concentrate on water quality
- Become more proactive in water management
- Role as the trustees has rights/responsibilities, links between land and lake
- More tourists means it will need more facilities.

Our first reaction to the water-quality information:

- Informed – different levels in the water, need you to keep us up-to-date
- Shocked – were not aware of the lake water quality
- Not surprised – we know the water is affected by run-off, the water quality is affected by man-made and natural factors
- Worried – the impacts and treat to water quality
- Can't afford to relax
- The reasoning
- How to keep the water quality at the top (forest ecosystem and pests)
- How do we keep the pollutants out of the lakes.

We did not like it when we heard about:

- The threats
- The pests (including pest animals on land, and pest plants in the water)
- Aquatic weed has effect on the lake
- The state of the forest
- The state of the forest ecosystem
- That the water quality is not improving
- More people need to be aware of the water quality
- All the pollution is still running into the lake
- Haven't thought about potential impacts.

We think it is great that:

- There are people around concerned about the lake's condition
- Like to be kept informed – good to hear from scientists and hear about the changes
- Like to become more proactive in water management.

Could we go in a totally new direction?

- Water conservation (in town to reduce waste water)
- Pest destruction programmes

- Looking into the gaps
- Resources (give iwi the resource and recognition to run management programmes)
- Give Board the right and authority
- Respect for the land.

What other types of facts might make the science clearer?

- Koura, koaro
- The biological information
- More information about the forest
- How to address the problems
- A full list of what things have impact on the water quality
- A list on how to prevent these impacts.

Interim session: Magic Wand - what would you do if the Board had unlimited resources?

- Pest management – in water and on land
- Pest destruction programme
- Conservator spent time liaising with the Board
- Looking after our own taonga
- Have, and utilise the local resource
- Recognised the ownership
- List of things that create impact
- Management process
- Programme process.

4.4 Other community concerns

Any impacts from motorboats?

There have been two studies looking into the potential impact of motorboats on water quality. A literature review shows that normal levels of motorised recreational boating activity do not have a significant impact on the toxicity of the water quality (Depree, C., 2007). The Waikato University has recently conducted water disturbance study on Lake Tikitapu by using "velocity metres" in the bottom of the Lake during the height of the water ski season to assess the impact motorboats may have on the sediments of the lake. No disturbance was registered from motorboat activities.

The condition of the boat ramp and jetty at Lake Ōkataina

The boat ramp and jetty at Lake Ōkataina is provided and maintained by the Rotorua District Council. The District Council has made the decision that it will try and get one boat launching site operational in each lake affected by high lake levels. The jetty at Lake Ōkataina is on the list of those that need to be attended.

Part 5: Preliminary consideration of nutrient reduction options

The unique situation of Lake Ōkataina – that there are no changes that obviously explain the degradation in water quality between 1994 and today – make it difficult to decide what actions we should focus on.

Lake Ōkataina is a vulnerable catchment that is sensitive to sediments that come from erosion (see Part 1 of this document). A number of actions could be considered at this preliminary stage, including those that have proven effective at managing human impacts in other Rotorua lakes, like Lake Rotoiti.

Not all treatment options that worked for other lakes will work for Lake Ōkataina, a deep, oligotropic lake. In-lake treatments – such as chemical dosing, engineering structures, mechanical weed harvesting and floating-wetland options – and stream treatments, for instance, wetland construction, are costly, ineffective and not consistent with the relatively pristine water of the lake.

Not all treatment options that worked effectively for other Rotorua lakes will work or be necessary for Lake Ōkataina. Water quality in Lake Ōkataina isn't as bad as Lake Ōkaro or Rotorua.

Figure 32. Chemical dosing at Lake Ōkareka (top left); floating wetland in Lake Rotorua (top right); diversion wall in Lake Rotoiti (bottom)

Wastewater reticulation is an option that has worked well for Lakes Ōkāreka and Tikitapu, but, unlike those lakes, Lake Ōkataina has only a small number of residents and visitors. The two septic tanks in the catchment are a long way from the district's main sewerage system. It would be costly to reticulate the wastewater from Lake Ōkataina to a treatment station given the small amount of nutrient reduction achieved.

Actions for managing the sources of nutrient pollution seem to be the most sensible option. These options are aimed at keeping the nutrients on the land rather than going into the lake.

A preliminary estimation and comparison of proven options (see the tables in this chapter) indicates that land-use change (from pasture to forest) is the most cost-efficient action. The fact that there are willing landowners in the Lake Ōkataina catchment represents a good opportunity; however, the financial cost of the change stops it from happening. The former Afforestation Grant Scheme (a Ministry of Agriculture and Forestry scheme) has helped this land-use change in recent years.

There are tools to help with managing nutrient sources on-farm, like voluntary property benchmarking and developing an on-farm nutrient budget. These tools help farmers see their nutrient trends, get best use of fertilisers, save money and look after their environment.

Members of the Lake Ōkataina community have told us that the state of the native bush around the lake is an obvious problem. Pest animals, such as Dama wallabies, graze on younger, low-level plants (forest understory) leaving fewer plants to cover the forest floor.

Restoring native bush could be a long-term solution for water quality at Lake Ōkataina. Freshwater scientists found the relationship between the state of native forest and its ability to hold phosphorus and nitrogen is intriguing (see page 26) but a topic still largely unexplored. The state of native forest and its effects on water quality are now identified as an area for further research.

5.1 Preliminary consideration of proven nutrient reduction options

Actions considered for reducing nutrients in Lake Ōkataina	Will this action be effective for Lake Ōkataina?	Why
Treating the nutrients in the lake directly		
Diversion Structures To divert a nutrient-enriched tributary around the lake	No	No one single nutrient-enriched tributary (surface or groundwater) has been identified at Lake Ōkataina
Geothermal water treatment Construct a treatment plant at the geothermal water source	No	No significant geothermal water inflow to Lake Ōkataina is observed
Floating wetland Construct a wetland on the surface of the lake at the lake's mouth(s)	No	No one single nutrient-enriched tributary has been identified at Lake Ōkataina and the nitrogen concentration in Lake Ōkataina is low
Sediment capping Spread a chemical locking material on the lake to create a barrier layer preventing the release of phosphorus from bottom sediments	Maybe but unlikely. Only considered if the lake has lost its pristine nature	Unlike Lake Rotorua, Lake Ōkāreka and some parts of Lake Rotoiti, Lake Ōkataina has better water quality and a valued "natural" environment
Weed harvesting Use a weed-harvest machine to collect aquatic weed 1.5 m from below the lake surface	Maybe but unlikely. Only considered if weeds were prolific in shallow areas	Unlike Lake Rotoehu, very little weed is found in Lake Ōkataina due to its depth and bathymetry. Commercial-scale harvesting risks spreading the weed. Voluntary community small-scale manual weed collection is possible
Lake oxygenation Install a machine in the lake to pump oxygen into deeper water to prevent nutrient release from sediments	Maybe but unlikely Only considered if the anoxia in sediments is prolonged	The low oxygen level in Ōkataina's deep water could cause the water quality to become worse due to the release of nutrients from sediments Oxygenation is expensive, and installation might not be possible.
Treating the nutrient input from the catchment		
Phosphorus locking Construct a treatment plant adding a chemical flocculation agent to phosphorus-rich stream water to bind up and settle out phosphorus	No	Unlike Lake Rotorua and Lake Rotoehu, no one single nutrient-enriched tributary has been identified in Lake Ōkataina
Community wastewater schemes	No	Unlike Lake Rotorua, Rotoiti, Ōkāreka, Rotomā and Tikitapu, septic tanks are thought to be a very low nutrient contributor because of the number of people using them
Enhanced on-site wastewater systems	Yes but low impact	It is a rule that septic tanks within 200 m of the lake edge have to meet the nitrogen concentration standard. But it will have little impact on the lake due to low

Actions considered for reducing nutrients in Lake Ōkataina	Will this action be effective for Lake Ōkataina?	Why
		loading from this source
Constructed wetland Construct a wetland at the lake edge areas that are rich in nutrients	Maybe but unlikely	The highest nitrate-nitrogen level in Lake Ōkataina catchment is 0.05mg/l – too low (3%) for wetlands to be effective.
Land-use management/change	Yes	A range of land-use management options, each designed to assist landowners to implement best practices to reduce nutrient losses from land use
Restore native bush Control pest animals in the native bush around Lake Ōkataina to restore forest health and conserve soil Control pest plants in the native bush around Lake Ōkataina to restore forest health	Maybe	The poor state of the native bush around Ōkataina is mostly caused by animal pests and pest plants. Current knowledge cannot tell us of the difference in nutrient retention abilities between a healthy forest and a forest damaged by pest animals.

Not all options that worked for other Rotorua lakes will be as effective or necessary for Lake Ōkataina.

Figure 33. Diversion wall in Lake Rotoiti

5.2 Indicative[3] estimation and comparison of options

Estimated options for Lake Ōkataina catchment	Estimated cost and who would have to pay?	Area in Ōkataina catchment (reach)	Estimated potential nutrient reduction per year[4] (impact and cost efficiency) Move TLI 2.9 to 2.6 = -380kgP/yr, -860kgN/yr			
			Phosphorus 380kg/yr = 100%		**Nitrogen** 860kg/yr = 100%	
Changing from pasture to exotic forest (completed)	Landowners with AGS[5]	61.0ha Estimation based on reduction ratio: P -0.6kg/ha/yr N -11kg/ha/yr	36.6kg	9.6%	671.0kg	78.0%
			Supported by AGS programme		Supported by AGS programme	
Changing from pasture to exotic forest for meeting nitrogen reduction target	Landowners with agencies targeted support	17.2ha Estimation based on reduction ratio: P -0.6kg/ha/yr N -11kg/ha/yr	10.3kg	2.7%	189.2kg	22.0%
			at $4,174/kg		at $227/kg	
Changing from pasture to exotic forest for reducing phosphorus	Landowners with agencies targeted support	200ha Estimation based on reduction ratio: P -0.6kg/ha/yr N -11kg/ha/yr	120 kg	31.6%	2,200 kg	255.8%
			at $4,483/kg		at $250/kg	
Removing sewage	The on-going cost of daily removal could be $146,000 or more a year. Possibly paid for by business owners and RDC[6]	Up to two septic tanks: One public; one private Estimation based on 100% removal	0.01kg	0.003%	0.11kg	0.01%
			at $14.6m/kg/yr or more		at $1.3m/kg/yr or more	
Restoring natural wetland on pasture land	Cost estimate $795,000. Possibly paid for by landowners	Up to 5.8ha Estimation based on reduction ratio: P –1.0kg/ha/yr N -36.0kg/ha/yr[7] $137k/ha	5.8kg	1.5%	208.8kg	24.3%
			at $137,069/kg		at $3,807/kg	
Constructing wetland on pasture land	Cost estimated $2450k but feasibility highly dependent on geological conditions. Possibly paid for by landowners	Up to 14.0ha Estimation based on reduction ratio: P -1.0kg/ha/yr N -36.0kg/ha/yr $175k/ha	14.0kg	3.7%	504.0kg	59.0%
			at $175,000/kg		at $4,861/kg	

[3] Indicative – the figures used in the preliminary estimation are indicative only, so could change depending on the specific methods.
[4] The estimated potential nutrient reduction may be lower in this catchment in practice. For example, many parts of the pasture area are covered by scrub (including manuka, kanuka, naturalised broadleaf), which has lower nutrient leach than the estimated ratio for deer/beef/sheep pasture land.
[5] AGS refers to the Afforestation Grant Scheme provided to landowners to establish forestry within sensitive catchments by the Ministry of Agriculture and Forestry (merged into the Ministry for the Primary Industry since 2011).
[6] RDC refers to Rotorua District Council.
[7] Nutrient removal rate used in the Lake Rerewhakaaitu Nutrient Budget 2012, based on Rutherford and Nguyen (2004) and Sukias (2010). However, Hamill's report (2010) shows wetlands are effective nutrient reduction options only when the nitrogen concentration is higher than 1.50mg/l, with high hydraulic load and high vegetation cover. The highest nitrate-nitrogen level in Lake Ōkataina catchment is 0.05mg/l, which is too low for wetlands to be an effective nutrient reduction option.

Estimated options for Lake Ōkataina catchment	Estimated cost and who would have to pay?	Area in Ōkataina catchment (reach)	Estimated potential nutrient reduction per year[4] (impact and cost efficiency) Move TLI 2.9 to 2.6 = -380kgP/yr, -860kgN/yr			
			Phosphorus 380kg/yr = 100%		**Nitrogen** 860kg/yr = 100%	
Native forest restoration possible actions include: Dama wallaby animal pest control Silver wattle pest plant control	Cost for controlling animal pests in the forest varies between $345,000 to $1,800,000 over five years[8], depends on the chosen method/s. 1080 drop has proven to be effective but highly unpopular. Tree injection is about $3,500/ha. Possibly paid for by landowners (including DoC [9]) with potential Regional Council support.	Lake Ōkataina Scenic Reserve – 2315.9ha including adjacent DoC reserve (1085.2ha) = up to 3401.1ha **Estimation reduction ratio unknown**	Unknown	**Potentially high due to poor forest understorey health**	Unknown	Don't know

[8] Speedy, C. and Singers, N. (2012) Lake Okataina Scenic Reserves: Issues and Options for an Effective Pest Management Programme – initial draft for comment, Prepared for Department of Conservation – Rotorua Lakes Area
[9] DoC refers to The Department of Conservation

Part 6: Other actions

6.1 New actions for consideration to build knowledge and awareness of water quality

- Investigate and quantify the flow-on effects of forest understory health to lake water quality. Scoping of the work to be led by the Chair in Lakes Management and Restoration, University of Waikato
- Update stakeholders on Lake Ōkataina's water quality trends, including Lake Ōkataina Scenic Reserve Board and Ngāti Tarāwhai Iwi Trust.

A number of actions are already in place that will improve water quality in general:

- Septic tanks within 200 m of lakes are required to install an Aerated Wastewater Treatment System with nutrient reducing capabilities or obtain a resource consent by 1 December 2013
- Voluntary land-use change and management.

The Regional Council's On-Site Effluent Treatment Regional Plan 2006 requires existing conventional septic tank systems located within 200 metres of a lake edge to discharge less than 15 mg/l in total nitrogen concentration. This rule is effective from December 1, 2012. If a conventional septic tank system cannot meet this condition, the owner would need to work out ways to mitigate its impact and apply for a resource consent.

Plans have been drafted for soil conservation for some farms in the Lake Ōkataina catchment.

Some property owners/managers in the catchment have voluntarily discussed with land management advisors how to manage their land more sustainably. Some farmers in the Lake Ōkataina catchment have developed and drafted plans to reduce their impacts on the environment.

6.2 A stocktake of actions

Actions related to Lake Ōkataina	Timeframe	Lead
Reduce nutrients from human impact		
Look into animal pest control options in the catchment	Initiated, continue if the funding is available	Department of Conservation, supported by local iwi and the lake community
Propose a policy direction that requires nutrient discharge limits to be set in the Regional Water and Land Plan for all of the Rotorua Te Arawa lakes	Proposed Regional Policy Statement (water quality and land use) Regional Council Decisions Report, March 2012	Bay of Plenty Regional Council
Review regulatory interventions for all Rotorua Te Arawa lake catchments	Ongoing	Bay of Plenty Regional Council and Rotorua District Council
An effluent treatment rule: septic tanks within 200m of lakes are required to install nutrient reduction capabilities or obtain a resource consent	The rule is enforceable from 1 December 2013	Bay of Plenty Regional Council
Provide sustainable land-use information through holding or supporting workshops, field days and discussion groups with farmers. Workshops have also been held with forestry sector about earthworks and harvest practices	Ongoing	Bay of Plenty Regional Council and partners
Voluntary land-use and farm management reducing the potential for erosion or sediment loss into waterways	Ongoing	Landowners
Voluntary change of the use of land to which leach less nutrient	Ongoing	Landowners
Enhance the amenity of the lake		
Compulsory rule: jet-skis and recreational towing (e.g. water-skiing) not allowed on the lake. Other boats must travel 5 knots within 200 m of the shore	Completed	Rotorua District Council
Control aquatic weed in Lake Ōkataina. A hornwort incursion response plan was formulated in response to a 2010 hornwort problem	Completed with on-going observation	Bay of Plenty Regional Council

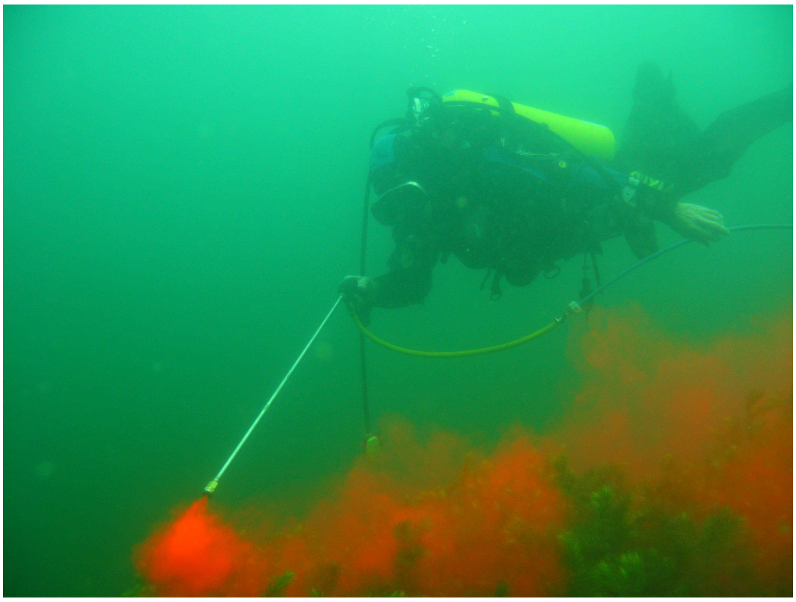


Figure 34. Controlling aquatic weeds in Lake Ōkataina by manually applying tracer-dyed herbicide on Hornwort (photo by courtesy of NIWA)

Building knowledge and awareness of nutrient sources		
Invite Rotorua Lakes stakeholders to forums presenting lake science information	Ongoing	Bay of Plenty Regional Council
Monitor the Trophic Level Index and de-oxygenation rates at Lake Ōkataina	Ongoing, monthly	Bay of Plenty Regional Council
Report to the lakes community on Lake Ōkataina water quality	Ongoing, annually	Bay of Plenty Regional Council
Benchmarking on-farm	On-going	Farmers who farm across the border between Lake Ōkataina and Lake Rotorua catchments, supported by the Bay of Plenty Regional Council

In addition to improving water quality, the lake weed hornwort is being managed and monitored in Lake Ōkataina.

Lake Ōkataina is protected under the Rotorua District Plan as part of the Lakes A Zone. The Lakes A Zone, under variation 12 of the District Plan, does not allow waterskiing, wakeboarding, ski biscuiting, jet skiing, hovercraft movements, or aircraft movements on Lake Ōkataina.

Glossary

All the definitions in this Glossary have been adapted from the Parliamentary Commissioner for the Environment's 2012 publication *Water Quality in New Zealand*, which adopted some definitions given in Harding et al*.,* 2004.

Algal bloom Dense growths of microscopic *algae* or *cyanobacteria* in response to high nutrient levels and warm temperatures. Often makes water discoloured and turbid, sometimes including scum on the surface of the water.

Catchment The area of land feeding a river system. All the precipitation within the catchment combines and flows down to form a single interconnected network of water bodies, including streams, rivers, lakes, wetlands, and aquifers.

Chlorophyll A pigment used by plants, algae*,* and cyanobacteria to harvest energy from light as part of photosynthesis.

Escherichia coli (*abbr. E. coli*)

A type of bacteria that lives in the guts of humans and other warm-blooded animals. Although usually harmless themselves, high levels of *E. coli* indicate that other pathogens are present.

Nitrogen A chemical element, symbol N. Common forms of nitrogen in water include ammonia and nitrate. 'Nitrogen gas' N_2 also makes up about 78% of the Earth's atmosphere. All life needs nitrogen for molecules such as proteins and DNA.

Nutrient A substance, element or compound that organisms need to live and grow.

Nutrient budget A calculation comparing nutrients brought on to a farm in fertiliser, feed and new stock with nutrients lost in produce, leaching, runoff, and into the atmosphere as gas. The calculation is also applied to lakes for estimating the nutrient loads coming in and out the lake.

Phosphorus A chemical element, symbol P. The most common form of phosphorus is (ortho)phosphate PO_4^{3-}, which is only slightly soluble in water. Phosphates are constituents of bone and of molecules like DNA.

Run-off Water moving overland, carrying fine *sediment* and dissolved pollutants.

Sediment Material transported by water. Sediment is generally inorganic material, but can include organic material such as plant fragments, and dead algae.

Sedimentation Settling or depositing of sediment within waterways.

Stratification Formation of two distinct layers within a lake over summer; a bright, warm upper layer, or 'epilimnion', and a denser, cooler lower layer, or 'hypolimnion'.

Box G.1 The trophic level of a lake or river describes the amount of biological activity (productivity), such as plant growth, that is happening in the water. The trophic level can be measured using the TLI, which combines information on the clarity of the lake and the amounts of nitrogen, phosphorus, and chlorophyll (and thus plant growth) in the lake.

Increasing degree of *eutrophication* ↓

Trophic Level	TLI	Lake condition
Microtrophic	1	Clear, very low in nutrients, very slow-growing plants, few algae.
Oligotrophic	2	Low in nutrients, usually clear and blue, slow plant growth, may support periphyton.
Mesotrophic	3	Moderately clear and with moderate nutrient levels, usually blue-green, supporting plant growth, typically macrophytes.
Eutrophic	4	Increasingly green and turbid, with high nutrient levels supporting rapid macrophyte or phytoplankton growth that sometimes leads to oxygen depletion.
Supertrophic	5	Very high nutrient levels, usually with poor water clarity, often with severe oxygen depletion, probably no macrophytes, may be dominated by bacteria.

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Appendix One

Lake Ōkataina Nutrient Budget

Prepared for Bay of Plenty Regional Council

May 2012

Prepared by John McIntosh (Lochmoigh)

Science reviewed by:
Professor David Hamilton (University of Waikato)
Dr Marc Schallenberg (Hydrosphere Research)
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Introduction

Once a lake's Trophic Level Index (TLI) has exceeded the Regional Water and Land Plan's (three year average) TLI target specified in Objective 11 by 0.2 for two consecutive years, Stage 3 of Method 41 of the Plan is initiated. Stage 3 is development of an Action Plan for the lake catchment which includes quantifying the reduction of nitrogen and phosphorus to achieve the Objective 11 TLI. Target TLI for Lake Ōkataina is 2.6.

A nutrient budget has been estimated for Lake Ōkataina based on nutrient export coefficients calculated from measured stream nutrient concentrations. These have been modified to match similar export coefficients from the scientific literature (Menneer *et al*. 2004). To verify the magnitude of the total nutrient budget a separate assessment has been carried out. In this case the total catchment input of nitrogen and phosphorus has been estimated from the in-lake nutrient levels. A budget from Hoare (1980) is used for this assessment as per the method of Rutherford and Cooper (2002) in proposing targets for the Lake Ōkataina Action Plan.

Nutrient budget

Nutrient export calculations in Table 1 were based on nutrient analyses of streams flowing into Lake Ōkataina. The final landuse nutrient coefficients chosen were based on the best fit to the scientific literature values derived from local studies.

The catchment boundary and land use portions have been supplied from the latest version created by the GIS section of the Bay of Plenty Regional Council.

Table 1 Nutrient budget based on land-use nutrient loss estimates.

	Area	**Rate of P loss**	**Rate of N loss**	**P Load**	**N Load**
	ha	***kg/ha/yr***	***kg/ha/yr***	***kg/yr***	***kg/yr***
Bare ground	2.7	0.15	4	0.4	10.8
Exotic forest	436.0	0.40	4	174.4	1744.0
Indigenous forest	4224.8	0.28	3	1182.9	12674.4
Pastoral land	548.7	1.00	15	548.7	8230.5
Reserve, buildings, parking	2.8			0.9	71.0
wetlands	7.6			0.0	0.0
Sewage, septic waste (30 persons/d; 3.65 kgN/p/yr, 0.37 kgP/p/yr)				11.00	110.00
Rainfall on lake	1067.9	0.15	4	160.2	4271.6
TOTAL	**6291**			**2079**	**27112**

Stormwater (reserve and parking area) estimates are from Williamson (1985).
Rainfall nutrients to lake (Hoare, 1987)

The flow rate in the streams was very small compared to the discharge expected of the catchment and it was assumed that the median phosphorus concentration would represent geologically derived phosphorus rather than landuse derived phosphorus. The lowest discharge load of the stream phosphorus was chosen as best approximation for the catchment phosphorus runoff concentration for forest land use. A greater rate of phosphorus loss was expected to derive from the exotic forestry (Hamilton 2005). A higher level of phosphorus export is characteristic of pastoral land. The export coefficient calculated from the median total phosphorus level in the stream samplings was very close to the commonly used pastoral phosphorus export coefficient. This has been used for pastoral phosphorus export. It may be high for the intensity of pastoral use in the Ōkataina catchment but compensates for geologically derived phosphorus discharged in the small springs which may have 'old-age' groundwater.

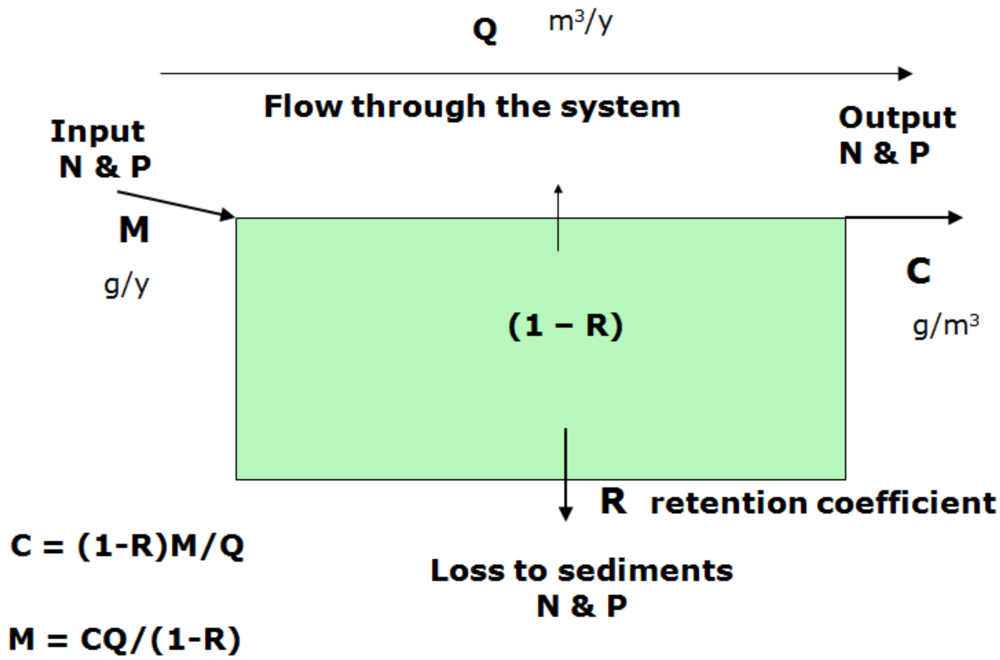
The low to median range of nitrogen concentration in the streams is equivalent to a nitrogen export range of 3 - 4 kg/ha/yr, which is within the commonly used export coefficient range for forest land. This has been used for native and exotic forest. The highest nitrate-nitrogen levels were about 0.5 g/m^3. It is assumed that these relatively high levels would arise from a landuse leaching more nitrogen than forestry and this concentration has been used to calculate the export coefficient for pastoral landuse around the Ōkataina catchment. The export coefficient of 15 kg N/ha/yr is commonly used to represent nutrient loss for moderate intensity sheep and beef farming.

In-lake nutrient levels

Catchment nutrient load can be modelled based on in-lake nutrient concentrations (C), flow through the system (Q), and nutrient retention within the lake (R). This 'back calculation' is based on a method used by Hoare (1980) for Lake Rotorua. The general concept is shown in the figure below.

At Ōkataina it is not possible to measure an outflow so it is assumed that the out-flowing water is the same concentration as average lake water. The flow rate through the lake cannot be measured so rainfall – evapo-transpiration is calculated and added to the quantity of water falling directly on the lake. There are empirical formulae for calculating the retention coefficient. In this case R is calculated to be 0.62 based on the method of Nurnberg (1984) as described in Rutherford and Cooper (2002).

Figure 1 Schematic of lake model.



With these assumptions the catchment nutrient load (M) in the equation above can be calculated.

Average annual rainfall at Okere (BOPRC data summaries 2005) = 1927 mm.

Average annual evapo-transpiration (Et) for catchment 980 mm (Rutherford et al 2009, 2011) (Whitehead and Kelliher 1991).

Evaporation from lake surface = 500 mm (Rutherford and Cooper, 2002)

In the calculations below, the average lake concentration is assumed to be the average concentration from mid 2007 to mid 2010, from Scholes (2010).

The estimate of the catchment load, from in-lake nutrient concentrations (Table 2) is of a similar order to the estimate from land use export coefficients, septic tank and stormwater input, with phosphorus being 27 % lower and nitrogen 24 % lower.

Table 2 Nutrient budget derived from in-lake nutrient concentrations based on the average lake nutrient levels from mid 2007 – mid 2010 (Scholes 2010).

	TP	**TN**		
lake concentration mg/m^3	8.75	119.77		**C**
	land	**lake**	**total**	
Lake volume (m^3)		466010000		
Area (ha)	5222.6	1067.9	6290.5	
(rain -evt)m	0.947	1.427		
flow (l/sec)	1568.3		2051.5	
flow/yr(m^3)	49458022	15238933	64696955	**Q**
Hydraulic loading (Q/lake area A) m/y			6.1	**Q/A**
Retention R (15/(18+Q/A))			0.62	**R**
	TP	**TN**		
M=CQ/(1-R) kg/yr	1504	20580		**M**

Rainfall 1927 mm/yr, evaporation (catchment) 980mm/yr (Rutherford et al, 2009, 2011) Whitehead and Kelliher 1991), evaporation (lake) 500 mm/yr (Rutherford and Cooper, 2002).

Hoare (1980) found that the R value in Lake Rotorua was similar for nitrogen and phosphorus. This has been assumed for Lake Ōkataina and the same R value used for both nitrogen and phosphorus. Results from this and several other lake nutrient budgets suggest that the R value is likely to be similar but not equal.

Sensitivity analysis

The spreadsheet model in Figure 2 is tested for its sensitivity by adjusting the R value by ± 0.10 and rainfall by ± 0.1 m.

Table 3 shows that the calculation is sensitive to changes in the retention coefficient. A retention coefficient of 0.72 better matches the spreadsheet nutrient load output in Table 1. It is possible that the equation used to calculate the retention R underestimates the actual retention in Lake Ōkataina.

Table 3 Comparison of predicted annual nutrient input to Lake Ōkataina by varying the retention coefficient.

	Total Phosphorus kg/yr	*Total Nitrogen kg/yr*
R = 0.52	1180	16140
R = 0.62	1500	20500
R = 0.72	2020	27700

Table 4 Comparison of predicted annual nutrient input to Lake Ōkataina by varying the rainfall in the rainfall – evapotranspiration (ET).

Rain – ET m	*Total Phosphorus tonne/yr*	*Total Nitrogen tonne/yr*	*R*
0.747	1350	18560	0.65
0.847	1430	19590	0.64
0.947	1500	20580	0.62
1.047	1570	21530	0.61

There is poor rainfall data for the Ōkataina catchment although there are four rain gauges in adjoining catchments. A lower rainfall (or higher ET) than used for the calculation in Table 2 produces a lower output than Table 2 calculates, and higher rainfall a higher output and the R value decreases.

The rainfall estimate has no confirmation from a gauge in the Ōkataina catchment. Nevertheless, the agreement between Tables 1 and 2 is reasonable considering that the pasture export coefficients in Table 1 are estimates for relatively productive systems and at least some of the pasture in the Okataina catchment appears to be of low productivity.

Nutrient reduction target

The objective TLI for Lake Ōkataina is 2.6 and the median TLI for the three years period 2007 – 2010 was 2.8. A reduction in lake nitrogen and phosphorus of 5 and 2.2 mg/m^3 is required to lower the TLI to 2.6. This can be converted to a catchment load.

- Target load reduction for phosphorus 380 kg/yr
- Target load reduction for nitrogen 860 kg/yr

That is about one/tenth of the estimated nitrogen load from pasture but over half the phosphorus load. Nitrogen tends to be the nutrient that has a greater effect on algal growth in Lake Ōkataina so a reduction in nitrogen may lower the other components of the TLI (secchi disc clarity and chlorophyll *a*) sufficiently to attain the target TLI without fully meeting the phosphorus target.

Conclusion

A nutrient budget has been derived from the latest determination of landuse for the Okataina catchment. About one third of the catchment nutrient load, calculated in Table 1, comes from pastoral landuse. It is possible that reductions could be made in nutrient loss from these areas but a survey of the properties would be needed to provide recommendations for remedial action.

At the north end of the lake there is a Lodge and public toilet facilities. The impact of wastewater from these facilities has been estimated from visitor figures. There is a nutrient contribution from septic tanks and wastewater treatment systems at these sites, which is in the order of 10% of the nitrogen reduction target and 3% of the phosphorus reduction target.

An engineer's report on the sewage treatment plant at the lodge, referenced to the resource consent, could be requested from Rotorua District Council as well as the public toilet disposal systems. Catchment monitoring of springs and streams could be continued while the planning process was initiated.

Pastoral land use and septic tank effluent disposal would be the two primary land uses where investigations into methods of nutrient control could lead to a reduction in the nutrient load on the lake.

There is a lack of raingauge data between Rotorua airport and Lake Rotoma and at least one site in the Ōkataina catchment would assist future hydrological studies.

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