Rotorua Lakes Summary Report

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Executive Summary

1 Purpose

The purpose of this report is to summarise information on the Rotorua Lakes to provide input into the development of the Rotorua Lakes Strategy. The report is organised by lake with general information and summaries of water quality, land cover and consented activities in each catchment. From this information trends in water quality are described and a ranking of restoration priority has been developed. The report concludes with a discussion of water quality management options for the lakes.

2 Land cover

With the exception of Lake Okataina, all of the lakes have experienced significant catchment modification within this century. While the initial modification was for pastoral development, there has been an overall increase in exotic forest of 8.9% (7,723 ha) since the 1970's. This has been at the expense of indigenous vegetation (6.3% decline, 5,467 ha) and pasture (3.7% decline, 3,211 ha).

In some of the lake catchments the extent of exotic forest development has been dramatic. For example, since 1977 the area of exotic forestry in the catchment of Lake Rotoma has increased by 30% due to the conversion of pastoral land. In others the extent of pastoral land has remained stable (e.g. Lakes Rotorua, Okataina and Okareka). As might be expected, there is some relationship between the water quality of each lake and the pattern of land cover in the catchment. For example, Lake Okataina has very high water quality (oligotrophic) and a catchment composed almost entirely of indigenous forest. In comparison, the catchment of eutrophic Lake Okaro is almost entirely pastoral.

3 Resource consents

Summaries of resource consents administered by Environment B·O·P give a useful indication of activities in the lake catchments. Of the 325 consents identified, 215 (66%) are held in the catchment of Lake Rotorua. This is largely a reflection of the large area of the Rotorua catchment (49% of the total Rotorua Lakes land catchment). Lake Rerewhakaaitu has the highest density of consents in the catchment (8.3 consents/1,000 ha of land) followed by Rotorua (5 consents/1,000 ha) and a group of lakes at around 3 consents/1,000 ha.

4 Water quality trends

A summary of the recent water quality trends in the Rotorua Lakes is given below.

Summary of water quality trends in the Rotorua Lakes.

Water quality trend		
Improving	**Stable**	**Declining**
Okareka Rerewhakaaitu Rotoiti Rotorua	Okataina Okaro Rotokakahi Rotoma Rotomahana Tarawera Tikitapu	Rotoehu

Only the water quality of Lake Rotoehu has obviously declined in the last ten years. Lake Rotorua is the only lake for which water quality restoration goals have been set and these measures have been effective. Of the other lakes in this group, Rotoiti has improved because of the influence of Rotorua while Rerewhakaaitu and Okareka have probably improved because of catchment works carried out in the 1970's.

Note that the stable lakes include the most eutrophic (Lake Okaro) and the most oligotrophic (Okataina, Rotoma, Tarawera). Lake Okaro is now probably in equilibrium with its catchment and is unlikely to deteriorate further unless there is a change in land cover which increases the input of nutrients to the lake.

5 Restoration priorities

The following table gives a ranking of restoration priority for each of the lakes based on water quality (trophic status) alone. Note that the eutrophic lakes, those with the lowest water quality, have been given the highest priority. While the high quality oligotrophic lakes are given a low priority, management action will still be required to ensure that the water quality of these lakes is maintained.

Preliminary restoration priorities based on water quality.

Restoration priority		
Low	**Medium**	**High**
Okataina Rotoma Tarawera Tikitapu	Okareka Rerewhakaaitu Rotoiti Rotokakahi Rotomahana	Okaro Rotoehu Rotorua
Oligotrophic	**Mesotrophic**	**Eutrophic**
Trophic status		

This prioritisation is preliminary and is intended as a starting point for discussion on how each of the lakes should be managed. Although water quality issues must be given high weighting, the final prioritisation will be determined by a consideration of the major issues for each of the lakes.

6 Options for achieving restoration

The restoration and maintenance of the water quality of the Rotorua Lakes can be achieved by controlling the release of contaminants from land based activities. The following practical measures are discussed and it is suggested that these should be adopted to manage water quality.

- Stream and lake margin protection works
- Protection of lake margin wetlands
- Off site treatment of domestic effluent
- Land-use controls

7 Lake classification

Under the Resource Management Act regional councils may classify waters for specific purposes (Section 69). The Third Schedule of the RMA gives a range of classes with associated water quality standards. These are intended to set the background for considering applications for resource consents by setting minimum standards. Regional councils may adopt these classes and standards in a plan or specify new ones if these are not adequate or appropriate.

Seven of the Rotorua lakes have been classified in the Proposed Regional Plan for the Tarawera River Catchment. Lakes Tarawera, Rotokakahi, Tikitapu, Okareka, Rotomahana and Okataina are classified to be managed in their "natural state" (NS). Natural state is defined as the water quality of the lakes as at 1994. Lake Okaro has been classified to meet contact recreation standards (CR), with water quality standards that are lower than the NS classification.

The classification of the Rotorua Lakes will need to be considered during the development of the Rotorua Lakes Strategy. The following options are suggested;

1) Retain the status quo

2) Retain the existing classifications and extend these to the remaining lakes as appropriate

3) Classify each of the lakes using a new classification scheme. A result of this could be that the Tarawera catchment lake classifications are altered.

Of the twelve Rotorua lakes, five do not have any form of water quality classification. As with the determination of priority lakes the purpose and structure of any classifications will depend on community aspirations for the lakes. This will be determined during the Rotorua Lakes Strategy consultation process.

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Algae

In this report the term algae refers to microscopic plants that are suspended in the water of lakes (also known as phytoplankton). Excessive quantities of these can result in algal blooms.

Algal biomass

The amounts of algae present in the water. The concentration of chlorophyll-*a* is the most widely used method to describe algal biomass.

Ammonia

Ammonia (NH_4) is the form of nitrogen that is easiest for plants to take up. It may be released from the sediment of lakes during periods when the dissolved oxygen concentrations in the bottom waters are low.

Clarity

Often determined in lakes using a secchi disc. This gives a measure of the vertical distance that objects can be seen from the surface of the lake.

Chlorophyll-*a*

Abbreviated in parts of this report as Chl-*a*. Chlorophyll-*a* is the major plant pigment responsible for photosynthesis. It is used to give an indirect measure of the amount of algal biomass in the water.

Dissolved reactive phosphorus

Phosphorus is an important plant nutrient. Dissolved reactive phosphorus is often measured in water as it simulates the growth of algae.

Eutrophic

Eutrophic lakes have a high concentration of nutrients. This results in high algal biomass that in turn gives poor water clarity.

Eutrophication

Lakes develop from an oligotrophic state (high water quality) to a more eutrophic state (lower water quality) over geological time. Eutrophication is thought to be a natural part of lake development but the rate is increased by human activities which increase the input of nutrients, specifically phosphorus and nitrogen.

Mesotrophic

The water quality of mesotrophic lakes is intermediate between oligotrophic and eutrophic lakes.

Nitrate

Nitrate (NO_3) is a form of nitrogen readily available for plant growth.

Oligotrophic

Oligotrophic lakes have a low concentration of nutrients. This results in low algal biomass and high water clarity.

Total Kjeldahl nitrogen

A measure of ammonia + organic nitrogen.

Total phosphorus

Total phosphorus includes dissolved forms, phosphorus absorbed to particles and phosphorus in algal cells. Total phosphorus can be used to define the trophic state of lakes.

Trophic state

Trophic state describes the productivity of lakes. It may be determined using single measures of water quality (e.g. algal biomass, clarity and nutrients) or a combination of measures.

Chapter 1: Introduction

1.1 Purpose

The purpose of this report is to summarise information on the Rotorua Lakes to provide input into the development of the Rotorua Lakes Strategy. The report is organised by lake with general information and summaries of water quality, land cover and consented activities in each catchment. From this information trends in water quality are described and a ranking of restoration priority has been developed. The report concludes with a discussion of water quality management options for the lakes.

1.2 Coverage

This report considers the major lakes which fall within both the Rotorua District Council and Environment B·O·P boundaries. Information is presented for the following twelve lakes;

Lake Rotorua
Lake Tarawera
Lake Rotoiti
Lake Rotoma
Lake Okataina
Lake Rotoehu
Lake Rotomahana
Lake Rerewhakaaitu
Lake Rotokakahi
Lake Okareka
Lake Tikitapu
Lake Okaro

The locations of the lakes are indicated in Figure 1.1.

1.3 Data sources

General information on the origins and morphology of the lakes has been summarised from the Lakes Overview Report (Donald *et al.* 1991). The Lakes Overview provides information and references to a number of topic areas and should be consulted along with the Inventory of New Zealand Lakes (Livingston *et al.* 1986) for more detailed information.

1.3.1 Land cover

Land cover data has been obtained for each of the lake catchments using SPOT satellite images collected over the Bay of Plenty region in February/March 1996. Landcare were contracted to analyse the images using a combination of image analysis software and on-screen digitising. Land cover has been categorised using 16 classes of land of which 11 apply to the lake catchments. To allow an assessment of changes in land cover the data has been compared with information collected in the 1970's for the NZ Land Resource Inventory, or NZLRI (see Livingston *et al.* 1986).

1.3.2 Resource consents

Summaries of the resource consents administered by Environment B·O·P have been produced for each of the lake catchments. The catchment boundaries were identical to those used for the land cover data. Note that the summaries do not include consents administered by the Rotorua District Council.

1.3.3 Water quality

Water quality data for each of the lakes has been summarised from a number of sources including Deely (1995), Donald (1996) and Burns *et al.* (1997). Water clarity data collected in 1955/56 (Jolly 1968) is also presented to give a comparison with the present day situation. Commonly used terms that are related to water quality are defined in the glossary given at the front of this report.

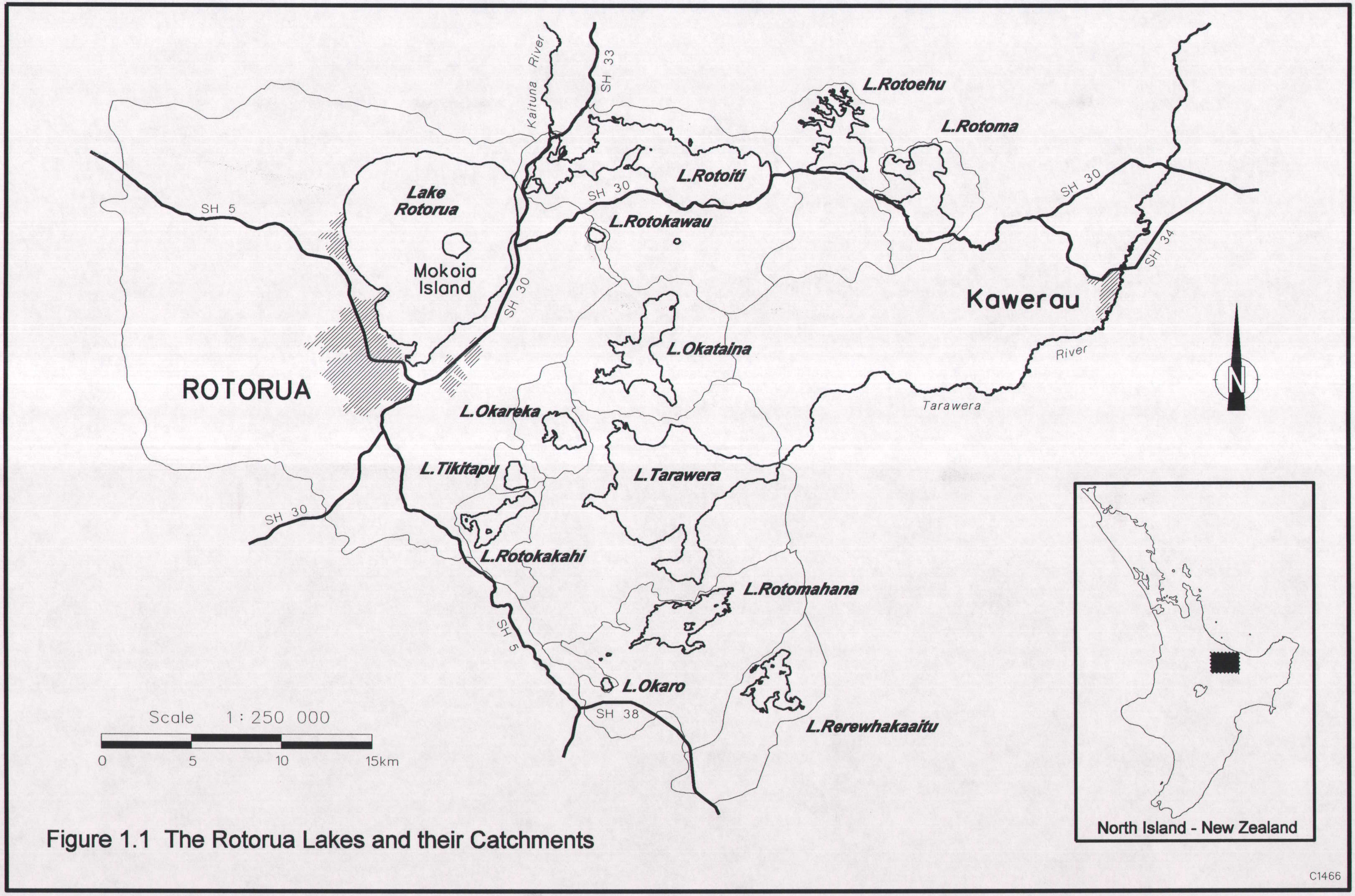

Figure 1.1 The Rotorua Lakes and their Catchments

Chapter 2: Lake summaries

2.1 Lake Rotorua

2.1.1 Introduction

Lake Rotorua was formed 140,000 years ago following the eruption of the Mamaku Ignimbrite. The resultant collapse of the Rotorua Volcanic Centre formed a caldera in which the lake developed. The lake level fluctuated considerably because of volcanic activity within the Okataina Volcanic Centre. This activity blocked the drainage away to the north via the Kaituna River and to the east through the same valley now occupied by the Tarawera River. The maximum levels that were attained for any length of time are still marked by benches at 90 m above the present lake level. The lake has been near its present level for at least the last 13,000 years (Healy 1975).

Lake Rotorua is relatively shallow (Table 2.1), shelving to a depth of 26 m west of Mokoia Island. Geothermal inputs occur directly from hot springs emerging along the southern shore and from water which has flowed via the Puarenga Stream from the Whakarewarewa and Pukeroa Hill geothermal areas. A 45 m deep crater located 1 km north of Sulphur Point was probably formed by a hydrothermal explosion.

Table 2.1: Important statistics for Lake Rotorua.

General		**Land cover (%)**	**1977-1978**	**1996**
Catchment area (ha)	50,777	Indigenous forest/scrub	30.6	25.1
Lake area (ha)	8,079	Exotic forest	8.3	14.3
Maximum depth (m)	44.8	Pasture	52.9	51.8
Mean depth (m)	11	Wetlands	0.2	0.2
Long axis (km)	12.1	Urban	8.1	8.1
Altitude (m)	280			
Age (x 1000 years)	140			

Pastoral farming remains the dominant land cover in the Rotorua catchment (Table 2.1). Generally land cover has remained relatively stable since 1978 with the exception of a 6% increase in exotic forestry reflecting the conversion of pasture (1%) and indigenous forest/scrub (5.5%).

2.1.2 Resource consents

Two-thirds (215) of the current consents held for the Rotorua Lakes exist in the catchment of Lake Rotorua (Appendix 1). There are 49 consented discharges to water of which 20 are storm water, 15 are geothermal waste water and the remainder include 1 dairy shed discharge and a number of miscellaneous wash water, river control and construction consents. Discharges to land include those from 22 dairy sheds, 6 septic tank and sewage discharges and a single piggery. The most significant single consent for discharge to land is held for the discharge of the Rotorua City sewage to the Whakarewarewa Forest.

2.1.3 Water quality

Lake Rotorua is eutrophic and experienced the greatest decline in water quality between 1978 and 1983. This was due to increases in the nutrient load from sewage effluent (Rutherford 1984). In 1986, goals were set for the restoration of the water quality of Lake Rotorua. This involved reducing the nitrogen and phosphorus load from sewage effluent with the aim of reducing algal biomass (to less than 10 mg m^{-3} as chlorophyll-*a*) and increasing water clarity (to 2.5-3.0 m).

Sewage was diverted to the Whakarewarewa Forest in 1991. Since that time the lake has met the restoration targets for clarity and is close to meeting the targets for total nitrogen and algal biomass (Hall *et al.* 1995, Burns *et al.* 1997 and Table 2.2). Phosphorus has however increased because the nitrogen limited algal community is unable to take it up. Hall *et al.* (1995) suggested that this was a cause for concern as the nutrient conditions favoured the development of blue-green algae that are able to utilise atmospheric nitrogen. Severe blooms of *Anabaena*, a blue-green algae, occurred in the lake in the summer of 1997 indicating that this concern was well founded.

Table 2.2: Water quality summary for Lake Rotorua.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	3.6	2.5	2.4
Algal biomass (mg m^{-3} Chl-*a*)		6.9	7.9
Dissolved reactive phosphorus (mg m^{-3})		8	34
Total phosphorus (mg m^{-3})		43	63
Ammonia (mg m^{-3})		18	31
Nitrate (mg m^{-3})		68	4
Total Kjeldahl nitrogen (mg m^{-3})		442	402

2.1.4 Summary/assessment

The restoration and maintenance of the water quality of Lake Rotorua remains a high priority. The rate of further recovery of the lake will depend somewhat on the frequency of nutrient release from the bottom sediments, which occurs during calm summer conditions. Recovery can be sustained by ensuring the long-term success of the forest irrigation scheme and minimising additional nutrient inputs to the lake. Sources of nutrients that could be reduced include those from areas of urban development (septic tanks and storm water) and pastoral farming.

2.2 Lake Tarawera

2.2.1 Introduction

Tarawera is a large deep lake (Table 2.3) located within the southwestern section of the Haroharo Caldera, where it was formed and held back by lava flows from the Haroharo and Tarawera volcanoes. The lake level was raised approximately 10 metres following the Mount Tarawera eruption in 1886 which blocked the outflow to the Tarawera River. On the western shore the wall of the caldera is irregular and eroded while to the north a relatively young rhyolite lava dome separates the lake from Lake Okataina. Geothermal springs exist on the southern and northern shores.

Indirectly the catchment includes five other lakes within the Lake Tarawera 'system'. Lake Rotokakahi drains into Tarawera via the Te Wairoa Stream and Lake Okareka does so via the Waitangi Spring. Lake Rotomahana has an artificial overflow to Lake Tarawera that operates only during high lake levels. There are no surface outlets from Lakes Tikitapu or Okataina, but these are believed to drain by sub-surface flow to Lake Tarawera along with Lake Rotomahana (BOPCC 1985). The annual drainage of Lake Tarawera is about 10% of the lake volume and the lake level fluctuates up to 0.4 metres (Livingston et al 1986).

Table 2.3: Important statistics for Lake Tarawera.

General		Land cover (%)	1967	1996
Catchment area (ha)	14,494	Indigenous forest/scrub	70.8	60.1
Lake area (ha)	4,165	Exotic forest	12.1	15.4
Maximum depth (m)	87.5	Pasture	16.7	21.1
Mean depth (m)	50	Wetlands	0.0	0.0
Long axis (km)	11.4	Urban	0.0	0.7
Altitude (m)	299			
Age (x 1000 years)	5			

Indigenous forest and scrub form the dominant land cover but these have declined by 10% since 1967 (Table 2.3). This appears to have been due to the conversion of land to exotic forestry, pasture and urban areas.

2.2.2 Resource consents

A total of ten consents are currently held in the Tarawera catchment (Appendix 1). Discharges to water include that from the Lake Rotomahana overflow, held by Environment B·O·P, a single primary treated sewage discharge. Discharges to land include a dairy shed, septic tank effluent and waste from a timber mill.

2.2.3 Water quality

Lake Tarawera is oligotrophic. While there has been a decline in water clarity since 1955/1956 the situation has stabilised (Table 2.4) and Tarawera is among the clearest of the Rotorua lakes.

Table 2.4: Water quality summary for Lake Tarawera.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	9.7	7.1	8.5
Algal biomass (mg m^{-3} Chl-*a*)		2.1	2
Dissolved reactive phosphorus (mg m^{-3})		4	2
Total phosphorus (mg m^{-3})		12	12
Ammonia (mg m^{-3})		7	3
Nitrate (mg m^{-3})		22	13
Total Kjeldahl nitrogen (mg m^{-3})		104	106

2.2.4 Summary/assessment

There are no immediate concerns with the water quality of Lake Tarawera. Provided any further development in the catchment is carefully controlled, the water quality is likely to remain high. There is increasing pressure for development in this area because of the proximity of the lake to Rotorua, a major urban centre, and the largely undeveloped nature of the catchment. In managing the lake consideration should also be given to any development in adjacent catchments as many of the surrounding lakes feed into Tarawera by subsurface and/or surface flow.

2.3 Lake Rotoiti

2.3.1 Introduction

Lake Rotoiti is a moderately large and deep lake (Table 2.5) located in part in the Haroharo Caldera. The eastern basin occupies the caldera and is deeper and limnologically distinct from the shallow western basin. Geothermal inputs to the lake are present on the shore and the bed of the lake.

Annual drainage is about 13% of the lake volume. The western basin receives water from Lake Rotorua through the Ohau Channel (average 18 $m^3 s^{-1}$). The Kaituna River is the only outflow from the lake at an average rate of 24.5 $m^3 s^{-1}$. The mean hydraulic residence time for the lake, approximated from the total volume ($1.13 \times 10^9 m^3$) and the outflow, is 1.5 years.

Table 2.5: Important statistics for Lake Rotoiti.

General		Land cover (%)	1977-1978	1996
Catchment area (ha)	11,861	Indigenous forest/scrub	45.8	42.9
Lake area (ha)	3,457	Exotic forest	7.1	30.4
Maximum depth (m)	93.5	Pasture	44.6	23.9
Mean depth (m)	31.5	Wetlands	0.0	0.2
Long axis (km)	15	Urban	0.0	1.1
Altitude (m)	279			
Age (x 1000 years)	8.5			

Indigenous forest and scrub form the dominant land cover but these have declined slightly since 1978 (Table 2.5). In contrast exotic forestry has increased by 23% reflecting the conversion of pastoral land.

2.3.2 Resource consents

Twenty six consents are current in the catchment of Lake Rotoiti (Appendix 1). Significant consents include those held by Environment B·O·P for the operation of the Ohau Channel control structure which regulates the level of Lake Rotorua. The single consent to discharge to surface water is held by the Minister of Conservation for the application of herbicide to control nuisance aquatic weeds in the lake. The five consents to discharge to land include three for septic tank effluent and two for geothermal wastewater.

2.3.3 Water quality

Lake Rotoiti is mesotrophic and is influenced by Lake Rotorua. For example, Vincent *et al.* (1986) found that over a year approximately 60% of the water flowing through the Ohau Channel flows into the main body of Lake Rotoiti. This underflow has the beneficial effect of adding oxygen to the bottom waters but also contributes nutrients and algae. Geothermal inflows add nitrogen to the lake and algal proliferations can occur adjacent to these inflows. The water quality of Lake Rotoiti is considered to have improved reflecting the improvement in Lake Rotorua. For example, Burns *et al.* (1997) found that Rotoiti is now in a less eutrophic state with lower nutrients, dissolved oxygen depletion, algal biomass and fewer eutrophic algal species compared to the 1980's.

Table 2.6: Water quality summary for Lake Rotoiti.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	6.6	5.1	5
Algal biomass (mg m^{-3} Chl-*a*)		3.7	5.8
Dissolved reactive phosphorus (mg m^{-3})		15	9
Total phosphorus (mg m^{-3})		31	29.5
Ammonia (mg m^{-3})		47	12.5
Nitrate (mg m^{-3})		40	26
Total Kjeldahl nitrogen (mg m^{-3})		277	234

2.3.4 Summary/assessment

The water quality of Lake Rotoiti has improved in line with the improvements that have occurred in Lake Rotorua. Further improvements are likely as the effects of a reduction of pastoral land are felt. In managing the lake, it must be recognised that the eastern and western basins are distinct. The western basin is relatively shallow, usually well mixed and partially nutrient enriched. The eastern basin is deeper, exhibits stable temperature stratification in summer and is not as heavily influenced by water from the Ohau Channel.

Options for reducing the nutrient load to the lake include dealing with urban runoff and septic tank inputs. While these inputs are likely to be a small part of the total load, they have the potential to produce localised enrichment particularly in enclosed areas like Okawa and Te Weta Bays.

2.4 Lake Rotoma

2.4.1 Introduction

Lake Rotoma is the easternmost of the Rotorua lakes located within the Okataina Volcanic Centre. The lake was formed by the Rotoma eruption. This created a caldera consisting of two basins, the southern one of which contains a central submerged peak that may be a small rhyolite dome. In pre-European times the peak was exposed and there is evidence of Maori settlement. The northern basin has a maximum depth of 83 m and the southern basin 73.5 m (Clayton *et al.* 1981).

There are several relatively large spit-formed lagoons adjoining the lake. Inflows include two minor ephemeral surface streams and springs that emerge around the shore. Outflow is by underground drainage from the Matutu Basin through the porous pumice strata into an adjacent swamp (Clayton et al 1981). Lakes Rotoma and Rotoehu contribute about 1.5 $m^3 s^{-1}$ of water to Lake Rotoiti by subsurface flows (Pittams 1968). About half the potential runoff from the Lake Rotoma catchment is lost by seepage to Lakes Rotoehu and Rotoiti and annual outflow is equal to 7% of the lake volume. Since records began, the lake level has fluctuated over a range of 4.2 m (Stringfellow and Bowis 1994), mainly as a result of variations in rainfall.

Table 2.7: Important statistics for Lake Rotoma.

General		Land cover (%)	1977	1996
Catchment area (ha)	2,914	Indigenous forest/scrub	39.9	39.8
Lake area (ha)	1,104	Exotic forest	2.2	31.7
Maximum depth (m)	83	Pasture	56.3	22.8
Mean depth (m)	36.9	Wetlands	0.0	0.2
Long axis (km)	5.2	Urban	1.6	1.1
Altitude (m)	313			
Age (x 1000 years)	8.5			

Indigenous forest and scrub have remained the dominant land cover since 1977 (Table 2.7). In contrast, during the same period some 30% of pastoral land in the catchment has been converted to exotic forestry.

2.4.2 Resource consents

Just six consents are held in the catchment of Lake Rotoma (Appendix 1). These include a single consent to discharge septic tank effluent to land and consents for public water supplies. Environment B·O·P holds consent to divert water from Lake Rotoma to Lake Rotoehu. This was issued in 1972 because of concerns with high levels in Lake Rotoma but was never exercised.

2.4.3 Water quality

Lake Rotoma is oligotrophic and generally has the highest water clarity of the Rotorua lakes. Nutrient concentrations are low and there has been no decline in water quality since records began (Burns *et al.* 1997 and Table 2.8).

Table 2.8: Water quality summary for Lake Rotoma.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	10.4	9.5	10.6
Algal biomass (mg m^{-3} Chl-*a*)		1.2	2.1
Dissolved reactive phosphorus (mg m^{-3})		2	<1
Total phosphorus (mg m^{-3})		7	3
Ammonia (mg m^{-3})		5	3
Nitrate (mg m^{-3})		15	6
Total Kjeldahl nitrogen (mg m^{-3})		154	137

2.4.4 Summary/assessment

While a third of the catchment of Lake Rotoma has been converted to exotic forestry since 1977 this has had no apparent effect on water quality. In this case the conversion of pastoral land to forestry must be seen as a benefit to the lake as it is likely to have decreased nutrient inputs. Rotoma can be expected to remain oligotrophic because of a combination of minimal inflows from hot springs and surface streams, the relatively small area of catchment modification and the existence of uniformly deep basins (McColl 1974).

2.5 Lake Okataina

2.5.1 Introduction

Lake Okataina is located on the western margin of the Haroharo Caldera. The lake was formed about 7,000 years ago after lava flows of the Mamaku eruptive episode dammed the valley. There may have been one or two small lakes present prior to the formation of the larger Lake Okataina (Lowe and Green 1987). The eroded walls of the Haroharo Caldera form the western margin while rhyolite lava flows form the eastern margin. The lake has two main basins, the southern end is deepest at 78.5 m (Table 2.9) with a ridge rising to 50 m before deepening in the northern basin down to 65 m.

There are no surface outflows from the lake and the catchment area is relatively large with a number of small streams entering the lake. Geothermal springs occur on the eastern shore.

Table 2.9: Important statistics for Lake Okataina.

General		Land cover (%)	1977-1978	1996
Catchment area (ha)	5,676	Indigenous forest/scrub	85.8	84.6
Lake area (ha)	1,104	Exotic forest	3.6	5.7
Maximum depth (m)	78.5	Pasture	10.7	9.6
Mean depth (m)	39.4	Wetlands	0.0	0.0
Long axis (km)	6.2	Urban	0.0	0.0
Altitude (m)	311			
Age (x 1000 years)	7			

Indigenous forest and scrub have remained the dominant land cover since 1978 (Table 2.9). Only a small proportion of the catchment is modified with 11% in pasture and 6% as exotic forest.

2.5.2 Resource consents

Five consents are held in the catchment of Lake Okataina (Appendix 1). Of these two are for the discharge of domestic wastewater and septic tank effluent. The single consent to discharge to surface water is held by the Minister of Conservation for the application of herbicide to control nuisance aquatic weeds in the lake.

2.5.3 Water quality

Lake Okataina is oligotrophic. While water clarity has fluctuated (Table 2.10) Burns *et al.* (1997) concluded that the trophic state of the lake has not changed since 1970/71. The deterioration in water clarity in the early 1990's is thought to be due to a rapid rise in water level at this time. This released a flush of accumulated nutrients and humic matter from the shore of the lake.

Table 2.10: Water quality summary for Lake Okataina.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	7	5.9	8.9
Algal biomass (mg m^{-3} Chl-*a*)		6.1	2.3
Dissolved reactive phosphorus (mg m^{-3})		6	4
Total phosphorus (mg m^{-3})		16	5
Ammonia (mg m^{-3})		9	4
Nitrate (mg m^{-3})		3	<1
Total Kjeldahl nitrogen (mg m^{-3})		170	114

2.5.4 Summary/assessment

The catchment of Lake Okataina remains largely undeveloped and for this reason the water quality of the lake is likely to remain high. Cyclical changes in climate can be expected to occasionally give rise to rapidly changing lake levels resulting in short-term reductions in water clarity.

2.6 Lake Rotoehu

2.6.1 Introduction

Lake Rotoehu was formed at the same time as Lake Rotoiti. Rotoehu occupies a drowned river valley etched back from the caldera ring and dammed by lava associated with the Rotoma eruptive episode. The valley was cut during the period when drainage flowed south through the Haroharo Caldera (Healy 1975). The valley was formerly cut much deeper than the present depth indicates, and appears to have been filled by pumice from eruptions of the Haroharo complex.

The northern arms of Lake Rotoehu are extremely digitate (finger-like) and do not exceed 13.5 m in depth (Table 2.11). The lake has no surface outlet, but water disappears into a hole alongside the shore in one of the northern arms (Healy 1975). Geothermal springs (Waitangi Soda Spring) emerge on the southeastern shore and some direct geothermal input may occur in the southwestern region.

Table 2.11: Important statistics for Lake Rotoehu.

General		Land cover (%)	1977	1996
Catchment area (ha)	5,673	Indigenous forest/scrub	39.3	29.1
Lake area (ha)	795	Exotic forest	9.5	29.7
Maximum depth (m)	13.5	Pasture	51.1	39.9
Mean depth (m)	8.16	Wetlands	0.0	0.4
Long axis (km)	4.6	Urban	0.0	0.0
Altitude (m)	295			
Age (x 1000 years)	8.5			

Pasture is the dominant land cover in the catchment but has declined by 11% since 1977 (Table 2.11). This decline, along with a similar decline in the cover of indigenous vegetation, reflects a 20% increase in the cover of exotic forestry in the catchment.

2.6.2 Resource consents

Seven consents are held in the catchment of Lake Rotoehu (Appendix 1). Discharge consents are held for the diversion of water from Lake Rotoma (see 2.4.2), and discharges to land from a dairy shed and geothermal pool water.

2.6.3 Water quality

Lake Rotoehu is eutrophic and has experienced severe blooms of blue green algae (*Anabaena spiroides*) since 1993 (Donald 1996). While this species of algae is potentially toxic, preliminary tests have not revealed any toxicity. The major change has been reductions in water clarity due to the higher algal biomass (Table 2.12).

Table 2.12: Water quality summary for Lake Rotoehu.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	4.7	4.1	2.5
Algal biomass (mg m^{-3} Chl-*a*)		2.2	17.1
Dissolved reactive phosphorus (mg m^{-3})		5	8
Total phosphorus (mg m^{-3})		27	44
Ammonia (mg m^{-3})		6	46
Nitrate (mg m^{-3})		101	68
Total Kjeldahl nitrogen (mg m^{-3})		263	494

2.6.4 Summary/assessment

Lake Rotoehu has undergone an accelerated rate of eutrophication since the early 1990's. This has lead to the issuing of health warnings in summer because of concerns regarding blooms of potentially toxic algae. Initial measures to restore the lake have included the retirement of the pastoral margins on the eastern side of the lake. The loss of pastoral land to exotic forestry is likely to reduce nutrient loading further but concerns remain regarding dairy farming in the catchment.

2.7 Lake Rotomahana

2.7.1 Introduction

Lake Rotomahana was extensively modified and enlarged during the 1886 eruption of Mount Tarawera. A series of hydrothermal explosions created deep craters that formed an extension of the 'Tarawera Rift' to the south-west of the mountain. The craters subsequently filled to form a single lake reaching its highest level at 341.2 m above sea level in March 1972. The lake occupies the site of two former lakes, one of these was a very active geothermal centre which still contributes significant inputs to the lake in this area.

Three hot springs on the bed of the lake are located to the west of Patiti Island. The surface outflow from the lake is artificial as the previous drainage stream from the valley (Kaiwaka Stream) was deeply buried forming a ridge between Rotomahana and Lake Tarawera. Lake Rotomahana has the greatest mean and maximum depths of the Rotorua lakes (Table 2.13).

Table 2.13: Important statistics for Lake Rotomahana.

General		Land cover (%)	1978	1996
Catchment area (ha)	7,994	Indigenous forest/scrub	47.2	42.7
Lake area (ha)	897	Exotic forest	4.1	14.1
Maximum depth (m)	125	Pasture	46.2	41.4
Mean depth (m)	60	Wetlands	2.1	0.0
Long axis (km)	6.2	Urban	0.0	0.0
Altitude (m)	335			
Age (years)	111			

Pasture and indigenous vegetation dominate the catchment of Lake Rotomahana (Table 2.13). Both have declined since 1978 as the area of exotic forest has increased. The land cover data suggests that the area of wetlands in the catchment has declined since 1978. At least part of this change may be due to the loss of shallow littoral areas as the level of the lake has declined.

2.7.2 Resource consents

Of the 22 consents current in the catchment of Lake Rotomahana 13 are for the discharge of dairy shed effluent to land (Appendix 1). Other consents authorise the discharge of wood processing waste to land, a single stormwater discharge and a consent for the control of the lake overflow structure which is held by Environment B·O·P.

2.7.3 Water quality

Lake Rotomahana is mesotrophic. Since 1955/56 there has been no obvious change in water clarity suggesting that the water quality of the lake has not significantly declined (Table 2.14).

Table 2.14: Water quality summary for Lake Rotomahana.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	3.8	3.6	4.2
Algal biomass (mg m^{-3} Chl-*a*)		6	4.1
Dissolved reactive phosphorus (mg m^{-3})		21	16
Total phosphorus (mg m^{-3})		65	34
Ammonia (mg m^{-3})		8	19
Nitrate (mg m^{-3})		43	47
Total Kjeldahl nitrogen (mg m^{-3})		167	183

2.7.4 Summary/assessment

The water quality of Lake Rotomahana is heavily influenced by geothermal activity. While this activity contributes nutrients to the water it is unclear what the relative contribution of geothermal inputs and catchment runoff are. Rotomahana is probably a naturally mesotrophic lake as is indicated by the water clarity which does not appear to have changed since 1956. Regardless of this, because of the predominantly pastoral land cover and the geothermal inputs the lake should be considered vulnerable to further eutrophication.

2.8 Lake Rerewhakaaitu

2.8.1 Introduction

Lake Rerewhakaaitu lies at the base of the southern slopes of Mount Tarawera. The lake occupies a shallow basin overlying ignimbrite that extends from the Kaingaroa Plateau. The main body of the lake reaches only 15.8 m in depth, but a small arm extends into a low ignimbrite ridge formerly connected with an explosion crater named Awaatua, 31 m deep. The main body of the lake was formed by pyroclastic ignimbrite that created a dam during the Kaharoa eruption about 700 years ago. Awaatua is a hydrothermal explosion crater and was formed about 12,000 years ago

There is normally no surface outflow from Rerewhakaaitu. Water is known to seep from the Awaatua basin to emerge as springs in the tributary of a stream flowing into Lake Rotomahana. During periods of high lake level, a drain takes the overflow to the Mangaharakeke Stream, a tributary of the Rangitaiki River (Healy 1975).

Table 2.15: Important statistics for Lake Rerewhakaaitu.

General		Land cover (%)	1978	1996
Catchment area (ha)	3,816	Indigenous forest/scrub	0.0	6.2
Lake area (ha)	579	Exotic forest	0.0	14.7
Maximum depth (m)	15.8	Pasture	100.0	76.7
Mean depth (m)	7	Wetlands	0.0	2.4
Long axis (km)	3.8	Urban	0.0	0.0
Altitude (m)	438			
Age (x 1000 years)	0.7			

Pasture is the dominant land cover in the catchment but has declined since 1978 (Table 2.15). While part of this decline is due to a 15% increase in exotic forestry development there has also been a 6% increase in the proportion of native vegetation. This is thought to be due to riparian protection work that was carried out around the lake and stream margin in the 1970's.

2.8.2 Resource consents

Of the 27 consents current in the catchment of Lake Rerewhakaaitu 22 are for the discharge of dairy shed effluent to land (Appendix 1). Other consents include those held by the Rotorua District Council for the control of the lake level (authorisations to dam and divert).

2.8.3 Water quality

Lake Rerewhakaaitu is mesotrophic. Recent data suggest that the water quality of the lake is improving with lower algal biomass and a resulting increase in water clarity (Table 2.16). Lake Rerewhakaaitu is rare amoung the Rotorua lakes in being phosphorus limited (White & Payne 1980).

Table 2.16: Water quality summary for Lake Rerewhakaaitu.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	No data	5	5.9
Algal biomass (mg m^{-3} Chl-*a*)		3.4	2.7
Dissolved reactive phosphorus (mg m^{-3})		1	1
Total phosphorus (mg m^{-3})		10	7
Ammonia (mg m^{-3})		5	6
Nitrate (mg m^{-3})		62	37
Total Kjeldahl nitrogen (mg m^{-3})		319	325

2.8.4 Summary/assessment

While a large proportion of the catchment of Lake Rerewhakaaitu is pastoral there is no indication that the lake has deteriorated in recent times. The conversion of parts of the catchment into forestry and riparian protection works has probably helped to arrest any further eutrophication. The lake should be considered vulnerable to eutrophication because of its shallow nature and the predominantly pastoral land cover.

2.9 Lake Rotokakahi

2.9.1 Introduction

Lake Rotokakahi (Green Lake) is located within the Okataina Volcanic Centre. It occupies a valley that formerly drained to Lake Tarawera. This valley was blocked at the north-east end by a rhyolite lava dome formed during the Rotorua Ash eruptive episode. Surface outflow is still to Lake Tarawera via the Te Wairoa Stream. The deepest area of the lake is at the western end with a maximum depth of 32 m while the eastern end is around 20-25 m in depth.

Table 2.17: Important statistics for Lake Rotokakahi.

General		Land cover (%)	1977-1978	1996
Catchment area (ha)	1,872	Indigenous forest/scrub	28.6	25.7
Lake area (ha)	452	Exotic forest	56.4	46.5
Maximum depth (m)	32	Pasture	15.1	27.8
Mean depth (m)	17.5	Wetlands	0.0	0.0
Long axis (km)	4.3	Urban	0.0	0.0
Altitude (m)	394			
Age (x 1000 years)	13.3			

Exotic forestry remains the dominant land cover but this has declined slightly in importance since 1978 (Table 2.17). This decline appears to be due to a 200 ha increase in the extent of pasture. A large part of this discrepancy may be due to differences in defining the catchment boundaries as the total catchment area defined in this study is approximately 130 ha greater than the NZRLI data.

2.9.2 Resource consents

There are no current consents administered by Environment B·O·P in the catchment of Lake Rotokakahi (Appendix 1).

2.9.3 Water quality

Lake Rotokakahi is mesotrophic. Although the water clarity is lower than that recorded in the 1950's (Table 2.18) Burns *et al.* (1997) concluded that there has been no discernible change since 1970/71.

Table 2.18: Water quality summary for Lake Rotokakahi.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	8	5.8	6.8
Algal biomass (mg m^{-3} Chl-*a*)		1.7	3.9
Dissolved reactive phosphorus (mg m^{-3})		3	2
Total phosphorus (mg m^{-3})		15	8
Ammonia (mg m^{-3})		8	4
Nitrate (mg m^{-3})		19	4
Total Kjeldahl nitrogen (mg m^{-3})		187	195

2.9.4 Summary/assessment

While the water quality of Lake Rotokakahi has probably declined since the 1950's there are no immediate concerns that the quality is declining further.

2.10 Lake Okareka

2.10.1 Introduction

Lake Okareka occupies a valley eroded back into the ignimbrite plateau on the western margin of the Haroharo Caldera. This valley formerly drained to Lake Tarawera but filled after being cut off by lava associated with the Te Rere eruptive episode. The outflow is now controlled to regulate the lake level with discharge to Lake Tarawera via the Waitangi Spring. Of the Rotorua lakes Okareka has the second highest density of human habitation with the population increasing during summer.

Table 2.19: Important statistics for Lake Okareka.

General		Land cover (%)	1977-1978	1996
Catchment area (ha)	1,865	Indigenous forest/scrub	44.4	38.1
Lake area (ha)	334	Exotic forest	0.0	2.6
Maximum depth (m)	33.5	Pasture	55.6	55.8
Mean depth (m)	20	Wetlands	0.0	0.0
Long axis (km)	2.8	Urban	0.0	2.9
Altitude (m)	355			
Age (x 1000 years)	19			

Pasture is the dominant land cover and has changed little in extent since 1978 (Table 2.19). The area of indigenous vegetation has been reduced by 6% due to increases in urban and exotic forestry development.

2.10.2 Resource consents

Five consents are held in the catchment of Lake Okareka (Appendix 1). Of these, two are for air discharges, one is for a private weir structure while the remaining consent relates to a quarry operation. A resource consent is also held by the Minister of Conservation for the control of aquatic weeds in the lake.

2.10.3 Water quality

Lake Okareka is mesotrophic. Burns *et al.* (1997) tentatively concluded that the water quality did not change between 1970/71 and 1993/94. The authors suggested that the lake might have actually become more oligotrophic. Recent monitoring has suggested that the water clarity has increased markedly since 1990 (Table 2.20).

Table 2.20: Water quality summary for Lake Okareka.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	6.7	5.7	7.9
Algal biomass (mg m^{-3} Chl-*a*)		4	3
Dissolved reactive phosphorus (mg m^{-3})		3	2
Total phosphorus (mg m^{-3})		13	6
Ammonia (mg m^{-3})		6	5
Nitrate (mg m^{-3})		29	33
Total Kjeldahl nitrogen (mg m^{-3})		196	227

2.10.4 Summary/assessment

While there are no immediate concerns with the water quality of Lake Okareka it is vulnerable to eutrophication because of the large area of catchment which is used for pastoral farming. Burns et al. (1997) suggest that recent improvements in water quality may be a result of soil conservation works which were carried out in the catchment in the late 1970's (Hall and Hayward 1976).

2.11 Lake Tikitapu

2.11.1 Introduction

Lake Tikitapu (Blue Lake) is located adjacent and to the north of Lake Rotokakahi on the western margin of the Haroharo Caldera. As with Rotokakahi the lake was formed after damming of lava from the Rotorua Ash eruptive episode 13,300 years ago. The lake is circular with a generally flat bed that reaches a maximum depth of 27.5 m. There are no surface outflow from the lake.

Table 2.21: Important statistics for Lake Tikitapu.

General		Land cover (%)	1977-1978	1996
Catchment area (ha)	567	Indigenous forest/scrub	80.9	79.2
Lake area (ha)	146	Exotic forest	11.4	17.3
Maximum depth (m)	27.5	Pasture	7.7	3.5
Mean depth (m)	18	Wetlands	0.0	0.0
Long axis (km)	1.6	Urban	0.0	0.0
Altitude (m)	417.8			
Age (x 1000 years)	13.3			

Indigenous vegetation remains the dominant land cover and this has changed little in area since 1978 (Table 2.21). The area of pastoral land has declined reflecting an increase in the extent of exotic forestry.

2.11.2 Resource consents

A single consent is held in the catchment of Lake Tikitapu (Appendix 1). This relates to the taking of groundwater for community water supply.

2.11.3 Water quality

Tikitapu is oligotrophic. The lake water is unusual in that it has a very low ionic concentration due to the small size of the catchment. Burns *et al.* (1997) noted that the proportion of green algae in the lake has increased in recent years. Despite this, there was no clear indication that the lake is undergoing a change in water quality.

Table 2.22: Water quality summary for Lake Tikitapu.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	7.5	7.3	6.4
Algal biomass (mg m^{-3} Chl-*a*)		2.3	2.6
Dissolved reactive phosphorus (mg m^{-3})		3	1
Total phosphorus (mg m^{-3})		14	4
Ammonia (mg m^{-3})		6	3
Nitrate (mg m^{-3})		21	35
Total Kjeldahl nitrogen (mg m^{-3})		193	196

2.11.4 Summary/assessment

Tikitapu is an oligotrophic lake possessing a unique water chemistry. This latter property is reflected in the biota with a general lack of diatoms and molluscs and a restriction of the growth potential of aquatic weeds. This general high water quality is likely to be maintained providing the catchment is not significantly modified.

2.12 Lake Okaro

2.12.1 Introduction

Lake Okaro is a small crater formed by a hydrothermal explosion which may have been associated with the Kaharoa eruptive episode. The lake is located in the Waiotapu thermal area about two kilometres north of the dacite volcano Maungakakaramea (Rainbow Mountain).

The water quality has been directly affected by agricultural runoff. A small stream enters the north-west margin of the lake and the Haumi Stream drains the lake from the south-east to join the Waimangu Thermal Valley stream which enters Lake Rotomahana.

The entire catchment of Lake Okaro was converted to pasture by the 1950's. An intensive study was undertaken by the Taupo Research Laboratory (DSIR) over the period 1979-1986 to help understand the structure and dynamics of a eutrophic lake ecosystem.

Table 2.23: Important statistics for Lake Okaro.

General		Land cover (%)	1978	1996
Catchment area (ha)	407	Indigenous forest/scrub	0.0	3.6
Lake area (ha)	32	Exotic forest	0.0	0.7
Maximum depth (m)	18	Pasture	100.0	95.7
Mean depth (m)	12.1	Wetlands	0.0	0.0
Long axis (km)	0.7	Urban	0.0	0.0
Altitude (m)	423			
Age (x 1000 years)	0.8			

Since 1978, there has been a small decline in the area of pasture (Table 2.23). The land cover data suggest that this has been replaced by indigenous vegetation and exotic forest.

2.12.2 Resource consents

A single consent is held in the catchment of Lake Okaro (Appendix 1). This relates to the discharge of dairy shed effluent to land.

2.12.3 Water quality

Lake Okaro is eutrophic and may be better described as hypertrophic. Water clarity is the lowest of the Rotorua lakes reflecting the very high algal biomass (Table 2.24). Blue green algae, including potentially toxic species, alternate in dominance with green algae.

Table 2.24: Water quality summary for Lake Okaro.

Parameter	1955/1956	1990/1991	1992/1994
Clarity (m)	No data	1.2	1.5
Algal biomass (mg m^{-3} Chl-*a*)		25.9	14.9
Dissolved reactive phosphorus (mg m^{-3})		108	68
Total phosphorus (mg m^{-3})		179	114
Ammonia (mg m^{-3})		783	408
Nitrate (mg m^{-3})		178	133
Total Kjeldahl nitrogen (mg m^{-3})		1,333	1,009

2.12.4 Summary/assessment

Lake Okaro is relatively well studied and is certainly the most eutrophic of the Rotorua lakes. Since the catchment was converted from native vegetation to pasture, water quality has progressively deteriorated. The algal community has shifted towards blue-green species and these frequently form blooms. The resultant loss of water clarity has apparently caused a contraction of the range of submerged macrophytes and the loss of koura (crayfish) from the lake. Frequent fish kills during the 1970's and 1980's were due to dissolved oxygen depletion.

The restoration of Lake Okaro is a priority but will only be achieved if the proportion of pasture in the catchment is reduced. Initial water quality improvements could be achieved by retiring the lake margins. In the long-term encouragement could be given to develop forestry in the catchment. Restoration measures such as the use of hypolimnetic aeration and alum treatment have been suggested in the past. These are likely to provide an expensive short-term solution but will not prevent additional nutrients from entering the lake.

Chapter 3: Discussion

3.1 General summary

3.1.1 Introduction

The Rotorua Lakes share a volcanic origin but each has its own special characteristics. For example, in terms of water quality the lakes span the entire range from oligotrophic (Lakes Rotoma and Okataina) to highly eutrophic (Lake Okaro). The physical characteristics of the lakes also vary widely from uniformly shallow lakes (Lakes Rotorua, Rotoehu and Rerewhakaaitu) to deep lakes (Lakes Tarawera, Rotomahana and Okataina).

The information given in this report is summarised further in this chapter to assist in defining those issues that are of importance to the water quality of the lakes. This is followed by a consideration of how the management of water quality should be approached.

3.1.2 Land cover

With the exception of Lake Okataina, all of the lakes have experienced significant catchment modification within this century. While the initial modification was for pastoral development, there has been an overall increase in exotic forest of 8.9% (7,723 ha) since the 1970's (Table 3.1, Appendix 2). This has been at the expense of indigenous vegetation (6.3% decline, 5,467 ha) and pasture (3.7% decline, 3,211 ha).

Table 3.1: Land cover summary for the catchments of the Rotorua Lakes.

General		Land cover (%)	1970's	1996	Change (%)
Catchment area (ha)	107,916	Indigenous forest/scrub	42.1	35.8	-6.3
Lake area (ha)	21,144	Exotic forest	8.1	17.1	8.9
Land area (ha)	86,771	Pasture	45.4	41.6	-3.7
		Wetlands	0.3	0.2	-0.1
		Urban	3.8	4.2	0.4

In some of the lake catchments the extent of exotic forest development has been dramatic. For example, since 1977 the area of exotic forestry in the catchment of Lake Rotoma has increased by 30% due to the conversion of pastoral land. In others the extent of pastoral land has remained stable (e.g. Lakes Rotorua, Okataina and Okareka). As might be expected, there is some relationship between the water quality of each lake and the pattern of land cover in the catchment. For example, Lake Okataina has very high water quality (oligotrophic) and a catchment composed almost entirely of indigenous forest. In comparison, the catchment of eutrophic Lake Okaro is almost entirely pastoral.

3.1.3 Resource consents

The resource consent summaries give a useful indication of activities in the lake catchments. Of the 325 consents identified, 215 (66%) are held in the catchment of Lake Rotorua (Appendix 1). This is largely a reflection of the large area of the Rotorua catchment (49% of the total Rotorua Lakes land catchment). Lake Rerewhakaaitu has the highest density of consents in the catchment (8.3 consents/1,000 ha of land) followed by Rotorua (5 consents/1,000 ha) and a group of lakes at around 3 consents/1,000 ha (Appendix 1).

3.1.4 Water quality trends

A summary of the recent water quality trends in the Rotorua Lakes is given in Table 3.2. Only the water quality of Lake Rotoehu has obviously declined in the last ten years. Lake Rotorua is the only lake for which water quality restoration goals have been set and these measures have been effective. Of the other lakes in this group, Rotoiti has improved because of the influence of Rotorua while Rerewhakaaitu and Okareka have probably improved because of catchment works carried out in the 1970's.

Table 3.2: Summary of water quality trends in the Rotorua Lakes.

Water quality trend		
Improving	**Stable**	**Declining**
Okareka	Okataina	Rotoehu
Rerewhakaaitu	Okaro	
Rotoiti	Rotokakahi	
Rotorua	Rotoma	
	Rotomahana	
	Tarawera	
	Tikitapu	

Note that the stable lakes include the most eutrophic (Lake Okaro) and the most oligotrophic (Okataina, Rotoma, Tarawera). Lake Okaro is now probably in equilibrium with its catchment and is unlikely to deteriorate further unless there is a change in land cover which increases the input of nutrients to the lake.

3.2 Water quality management

3.2.1 Introduction

The management of the water quality of the Rotorua Lakes is a central issue that will be addressed by the Lakes Strategy. The following sections prioritise the lakes in terms of the need for water quality restoration and give a discussion in broad terms of how the water quality of the lakes might be managed. The final section concludes with a discussion of options for classifying the lakes under the Resource Management Act.

3.2.2 Restoration priorities

The following table gives a ranking of restoration priority for each of the lakes based on water quality (trophic status) alone. Note that the eutrophic lakes, those with the lowest water quality, have been given the highest priority. While the high quality oligotrophic lakes are given a low priority, management action will still be required to ensure that the water quality of these lakes is maintained.

Table 3.3: Preliminary restoration priorities based on water quality.

Restoration priority		
Low	**Medium**	**High**
Okataina	Okareka	Okaro
Rotoma	Rerewhakaaitu	Rotoehu
Tarawera	Rotoiti	Rotorua
Tikitapu	Rotokakahi	
	Rotomahana	
Oligotrophic	**Mesotrophic**	**Eutrophic**
Trophic status		

This prioritisation is preliminary and is intended as a starting point for discussion on how each of the lakes should be managed. Although water quality issues must be given high weighting, the final prioritisation will be determined by a consideration of the major issues for each of the lakes.

3.2.3 Options for achieving restoration

The restoration and maintenance of the water quality of the Rotorua Lakes can be achieved by controlling the diffuse release of contaminants from land based activities. Since the Rotorua City sewage was diverted to land treatment there are few significant point source discharges to the lakes. Stormwater discharges are a potential concern and more information is needed to quantify the contaminant loads, particularly into Lake Rotorua.

The following are practical measures which should be adopted to reduce the release of contaminants into the lakes from land based activities.

a) Stream and lake margin protection works

Riparian protection has been clearly identified as an effective means of reducing diffuse inputs of contaminants into New Zealand waterways (Collier 1995). These techniques have been applied to a number of the Rotorua lake catchments. The Upper Kaituna Catchment Control Scheme was initiated in the 1970's and involved fencing and planting of the margins of streams entering Lakes Rotorua and Rotoiti (BOPCC 1975). Experience with similar soil conservation works, carried out in the catchments of Lakes Okareka and Rerewhakaaitu, suggest that it may take up to twenty years before any improvements in water quality become apparent.

Attention has recently been focused on protecting the margins of the lakes, particularly in pastoral areas where stock have direct access to the water. The lake margin protection work carried out on Lake Rotoehu was a response to the rapid decline in water quality that began in the early 1990's. Works of this nature should be extended to the margins of all the lakes to maintain and/or enhance water quality.

b) Protection of lake margin wetlands

A recent report concluded that wetlands located around the margins of the lakes play an important role in reducing nutrient inputs (Gibbs and Lusby 1996). In established wetlands a substantial amount (up to 98%) of the dissolved inorganic nitrogen was found to be removed from the groundwater as it passed through the wetland. In wetlands that had been damaged by development there was little or no nitrogen removal. It was also concluded that lake margin wetlands are able to remove faecal bacteria and phosphorus from groundwater contaminated with septic tank effluent. These wetlands should be protected particularly where they form a buffer between the lake and areas of urban or pastoral development. In certain areas wetlands may develop naturally as a result of riparian protection works.

c) Off site treatment of domestic effluent

The use of septic tanks to treat and dispose of domestic effluent is common around the margins of the lakes. This form of disposal has the potential to degrade water quality, particularly where there is a high density of dwellings in enclosed bays (McIntosh 1992). Recent initiatives by the Rotorua District Council have sought to gauge the level of community support for the reticulation and off site treatment of domestic effluent.

d) Land-use controls

As indicated in Table 3.1 the major land cover in the Rotorua Lakes catchment is pastoral, followed by indigenous vegetation and exotic forestry. Intensive pastoral use, particularly dairy farming, has the greatest potential to degrade water quality. Of 61 consents authorising the disposal of dairy shed effluent, 60 are to land by irrigation or soakage and one is for disposal to surface water. Although exotic forestry has increased markedly in the catchments of some of the lakes, there are no indications that this has degraded water quality. For example, while Lakes Rotoma and Rotokakahi have the highest percentage of exotic forest of the Rotorua Lakes the water quality has remained stable.

Having regard to the above it might seem appropriate to encourage the current trend of converting pastoral land to forestry. A potential concern with exotic forestry is the decline in water yields from the catchment compared to other types of land cover. There are also issues relating to the effects on aesthetic or landscape values. In reality the preferable situation for the Rotorua Lakes is likely to be a mosaic of different land cover, including indigenous forest, pasture and exotic forest.

Under the Resource Management Act regional councils are responsible for controlling the use of land for the purpose of maintaining and enhancing water quality. While in theory regional councils could prohibit certain land uses in sensitive catchments, experience has shown that the most effective way to control the effects of land use activities is through a combination of education and environmental guidelines. Specific guidelines should be developed for the Rotorua Lakes catchment with the objective of reducing the input of contaminants from land based activities.

3.2.4 Lake classification

Under the Resource Management Act (RMA) regional councils may classify waters for specific purposes (Section 69). The Third Schedule of the RMA gives a range of classes with associated water quality standards. These are intended to set the background for considering applications for resource consents by setting minimum standards. Regional councils may adopt these classes and standards in a plan or specify new ones if these are not adequate or appropriate.

Seven of the Rotorua lakes have been classified in the Proposed Regional Plan for the Tarawera River Catchment (see Appendix 3). Lakes Tarawera, Rotokakahi, Tikitapu, Okareka, Rotomahana and Okataina are classified to be managed in their "natural state" (NS). Natural state is defined as the water quality of the lakes as at 1994. Lake Okaro has been classified to meet contact recreation standards (CR), with water quality standards that are lower than the NS classification.

The classification of the Rotorua Lakes will need to be considered during the development of the Rotorua Lakes Strategy. The following options are suggested;

1) Retain the status quo
2) Retain the existing classifications and extend these to the remaining lakes as appropriate
3) Classify each of the lakes using a new classification scheme. A result of this could be that the Tarawera catchment lake classifications are altered.

Of the twelve Rotorua lakes, five do not have any form of water quality classification. As with the determination of priority lakes the purpose and structure of any classifications will depend on community aspirations for the lakes. This will be determined during the Rotorua Lakes Strategy consultation process.

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Appendix 1: Summary of consents administered by Environment BOP as at July 1997.

Consent type	Current consents by lake catchment											
	Rotorua	Tarawera	Rotoiti	Rotoma	Okataina	Rotoehu	Rotomahana	Rerewhakaaitu	Rotokakahi	Okareka	Tikitapu	Okaro	**Grand total**
Air	12						1			2			15
Dam	2		2				1	1					6
Discharge to water	50	3	1	1	1	2	2	2		1			63
Discharge to land	42	3	5	1	2	2	15	22				1	93
Divert	12	1	1	1									15
Geothermal	43		1										44
Land-use	22	2	4	1	1	2	1	1		2			36
Surface take	13		5	1	1		1						21
Under take	19	1	5	1		1	1	1			1		30
Use			2										2
Total	215	10	26	6	5	7	22	27	0	5	1	1	325

Land area	42,698	10,329	8,404	1,810	4,572	4,878	7,097	3,237	1,420	1,531	421	376	86,771
Consents/1,000 ha	5.0	1.0	3.1	3.3	1.1	1.4	3.1	8.3	0.0	3.3	2.4	2.7	3.7

Appendix 2: Land use data summary for the Rotorua Lake Catchments as at February/March 1996

Land cover	Catchment area (ha)												
	Rotorua	Tarawera	Rotoiti	Rotoma	Okataina	Rotoehu	Rotomahana	Rerewhakaaitu	Rotokakahi	Okareka	Tikitapu	Okaro	**Total**
Bare ground	229	274	71	81	3	43	124			8			**834**
Coastal sand													
Forest - indigenous	9,111	5,168	3,225	714	3,613	1,402	2,346	94	324	461	315	3	**26,775**
Forest - production	6,118	1,592	2,554	573	261	1,447	1,003	475	661	39	73	3	**14,799**
Horticulture	4												**4**
Land- cropping													
Pasture - exotic	22,106	2,179	2,009	412	439	1,947	2,937	2,484	394	855	15	359	**36,136**
Grassland - tussock													
Scrub - mixed	1,604	1,039	380	6	256	19	685	107	42	123	18	11	**4,288**
Scrub - exotic			51										**51**
Urban	2,813	72	46	20						45			**2,996**
Urban - open space	633		46										**679**
Wetlands - coastal													
Water	8,079	4,165	3,457	1,104	1,104	795	897	579	452	334	146	32	**21,144**
Wetland - inland	81	5	21	4		21	1	77					**210**
Total area (ha)	50,777	14,494	11,861	2,914	5,676	5,673	7,994	3,816	1,872	1,865	567	407	**107,916**

Land use	Percent of catchment excluding lake surface												
	Rotorua	Tarawera	Rotoiti	Rotoma	Okataina	Rotoehu	Rotomahana	Rerewhakaaitu	Rotokakahi	Okareka	Tikitapu	Okaro	**Total**
Bare ground	0.5	2.7	0.8	4.5	0.1	0.9	1.8			0.5			**1.0**
Coastal sand													
Forest - indigenous	21.3	50.0	38.4	39.4	79.0	28.7	33.1	2.9	22.8	30.1	75.0	0.8	**30.9**
Forest - production	14.3	15.4	30.4	31.7	5.7	29.7	14.1	14.7	46.5	2.6	17.3	0.7	**17.1**
Horticulture	0.0												**0.0**
Land- cropping													
Pasture - exotic	51.8	21.1	23.9	22.8	9.6	39.9	41.4	76.7	27.8	55.8	3.5	95.7	**41.6**
Grassland - tussock													
Scrub - mixed	3.8	10.1	4.5	0.3	5.6	0.4	9.7	3.3	2.9	8.0	4.2	2.8	**4.9**
Scrub - exotic			0.6										**0.1**
Urban	6.6	0.7	0.5	1.1						2.9			**3.5**
Urban - open space	1.5		0.5										**0.8**
Wetlands - coastal													
Wetland - inland	0.2	0.0	0.2	0.2		0.4	0.0	2.4					**0.2**

Appendix 3: Classification and water quality rules for the Rotorua lakes covered by the Regional Plan for the Tarawera River Catchment.

16.8.4 Methods of Implementation - Rules

(a) All water within lakes Tarawera, Rotomahana, Okataina, Okareka, Tikitapu, and Rotokakahi in the Upper Tarawera Lakes catchment, excluding Lake Okaro, is classified to be managed in its Natural State (NS), and any discharge permit granted for the discharge of contaminants into these waters shall be subject to conditions ensuring compliance with the classification standard in Rules 16.8.4(b) and the requirements of Rules 16.8.4(l) and 16.8.4(m).

(b) The standards for **Class NS**, that apply after reasonable mixing of any contaminant or water with the receiving surface water and disregard the effect of any natural perturbation that may affect the water body, are:

(i) The concentration of dissolved oxygen shall exceed 80% of saturation concentration,

(ii) No increase in colour as assessed by measurement on the Munsell Hue scale, and no decrease in visual clarity as assessed by black disc measurement,

(iii) No detectable increase in acute and chronic toxicity between a reference water sample and a sample of the discharge diluted with that water at the specified mixing ratio,

(iv) No increase in temperature,

(v) No change in pH,

(vi) No production of conspicuous oils and grease films, scums or foams, or floatable or suspended materials,

(vii) No conspicuous increase in biological growths.

(viii) Aquatic food resources shall not be rendered unsuitable for human consumption, nor water rendered unsuitable for stock watering,

(ix) No increase in the emission of objectionable odour.

(x) No net increase in nutrient inputs.

In the context of this Rule, Class NS standards shall be measured against 1994 water quality standards in the total water column of a lake.

(c) All surface water within Lake Okaro is classified to be managed for Contact Recreation (CR), and any discharge permit granted for the discharge of contaminants into the water of Lake Okaro shall be subject to conditions ensuring compliance with the classification standards in Rules 16.8.4(d) and the requirements of Rules 16.8.4(l) and 16.8.4(m).

(d) The standards for **Class CR**, that apply after reasonable mixing of any contaminant or water with the receiving surface water and disregard the effect of any natural perturbation that may affect the water body, are:

(i) No decrease in visual clarity below 1.6 metres as measured by the black disc technique,

(ii) No detectable increase in acute and chronic toxicity between a reference water sample and a sample of the discharge diluted with that water at the specified mixing ratio,

(iii) No increase in temperature of more than 3°C, and maximum not to exceed 25°C,

(iv) pH shall remain within the range of 6.0 to 9.0,

(v) No production of conspicuous oils or grease films, scums or foams, or floatable or suspended materials,

(vi) No conspicuous increase in biological growths.

(vii) The median concentration of enterococci of at least 5 samples taken throughout the bathing season[1] shall not exceed 33 enterococci per 100ml, nor shall any single sample exceed 107 enterococci per 100ml,

(viii) No increase in the emission of objectionable odour.

[1]The bathing season is defined as the period from 1 November to Easter inclusive.