

# Lake Okaro Action Plan



ISSN 1175 9372  
Environmental Publication 2006/03



An Environment Bay of Plenty, Rotorua District Council and Te Arawa Maori Trust Board joint project

## Foreword

We are pleased to present the Lake Okaro Action Plan, which aims to improve the water quality of Lake Okaro over the long term.

Lake Okaro is the second of the Rotorua Lakes to have an Action Plan developed for it, the first being Lake Okareka. Although small, Lake Okaro is a popular local water skiing location and is appreciated for its quiet rural situation. The local community's support for the Action Plan, and their pragmatic viewpoints on actions to improve water quality, has greatly assisted the development of this Action Plan.

Lake Okaro has suffered over past decades from large inputs of nitrogen and phosphorus from pastoral land use and development in the catchment. The result has been algae blooms that cause undesirable smells and surface scums, release toxins and prompt health warnings. The lower lake water column loses all its oxygen during the summer and autumn months.

The Action Plan outlines six key actions to improve lake water quality:

- A nutrient-absorbent lakebed cap.
- A constructed wetland.
- Riparian protection.
- Best management practice investigations.
- Monitoring of lake nutrient load and effectiveness of individual actions.
- A Lake Okaro-specific review of section 9.4 rules in the Regional Water and Land Plan.

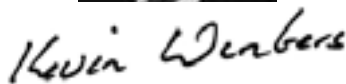
Once these actions are in place, Lake Okaro's water quality should eventually improve to meet its target in the Regional Water and Land Plan, where cyanobacterial blooms become less invasive and recreational use of the lake can continue.

Rotorua District Council, Environment Bay of Plenty and Te Arawa Maori Trust Board look forward to working with the Lake Okaro community to implement the actions in this document.



  
**John C Cronin**  
Chairman  
Environment Bay of Plenty



  
**Kevin Winters**  
Mayor  
Rotorua District Council



  
**Anaru Rangihuea**  
Chairman  
Te Arawa Maori Trust Board



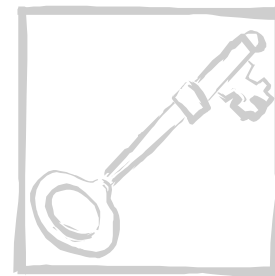
## Contents

<b>Foreword</b> .....	i
<b>Chapter 1: Key Recommendations</b> .....	1
<b>Chapter 2: Summary of Actions</b> .....	3
<b>Chapter 3: Purpose and Setting for the Lake Okaro Action Plan</b> .....	5
3.1 Lake Okaro Action Plan Purpose.....	5
3.2 Facts About Lake Okaro and its Catchment.....	5
3.3 Lake Ownership .....	8
3.4 Existing Regional Water and Land Plan Rules.....	8
3.5 The Degraded Water Quality Problem.....	8
<b>Chapter 4: Nutrient Input Reduction Targets</b> .....	9
4.1 Lake Okaro’s Water Quality Target in the Regional Water and Land Plan .....	9
4.2 Nutrient Reduction Target.....	9
4.3 Main Approach .....	11
<b>Chapter 5: The Sources of Nitrogen and Phosphorus to Lake Okaro</b>	<b>13</b>
5.1 Lake Okaro’s Nutrient Budget.....	13
5.2 Livestock Farming .....	13
5.3 Lakebed Sediment .....	14
5.4 Waterfowl .....	14
5.5 Delayed Nutrient Inflows from Historic Land Use .....	14
<b>Chapter 6: Nutrient Input Reduction Actions</b> .....	<b>17</b>
6.1 Phosphorus-Absorbent Lakebed Cap.....	17
6.1.1 A Medium-term Measure .....	17

6.1.2	<i>Alum Application</i> .....	17
6.1.3	<i>Flocculant Product Comparison</i> .....	18
6.1.4	<i>Lake Bed Flocculant Cap Application</i> .....	19
6.1.5	<i>Costs</i> .....	19
6.1.6	<i>Responsibility</i> .....	19
6.2	<i>Constructed Wetland</i> .....	20
6.2.1	<i>Enhanced Denitrification using a Constructed Wetland</i> .....	20
6.2.2	<i>Nitrogen Removal Rates</i> .....	20
6.2.3	<i>Base Flow and Flood Flows</i> .....	20
6.2.4	<i>Phosphorus Removal Rates</i> .....	21
6.2.5	<i>Ancillary Values of Constructed Wetlands</i> .....	22
6.2.6	<i>Costs and Timeframe</i> .....	22
6.2.7	<i>Maintenance Responsibilities</i> .....	22
6.3	<i>Riparian Protection</i> .....	22
6.3.1	<i>The Goals of Riparian Protection</i> .....	22
6.3.2	<i>Nutrient Reduction Benefits</i> .....	23
6.3.3	<i>Northern stream</i> .....	24
6.3.4	<i>Southern Stream</i> .....	24
6.3.5	<i>Costs and Timeframes</i> .....	24
6.3.6	<i>Maintenance Responsibility</i> .....	25
6.4	<i>Best Management Practices</i> .....	25
6.4.1	<i>Examples of Best Management Practices</i> .....	25
6.4.2	<i>Regional Water and Land Plan Policy</i> .....	26
	<b>Chapter 7: Rules to Protect Gains Made</b> .....	<b>27</b>
7.1	<i>Existing Regional Water and Land Plan Rules</i> .....	27
7.2	<i>Rule Review and Timeframes</i> .....	28
	<b>Chapter 8: Anticipated Effects</b> .....	<b>29</b>

8.1	Environmental Effects .....	29
8.2	Economic Effects .....	29
8.3	Other Effects .....	30
	<b>References</b> .....	<b>31</b>
	<b>Appendices</b> .....	<b>33</b>
	Appendix 1 - Trophic Level Index (TLI) and Other Indicators.....	35
	Appendix 2 - Lake Okaro Action Plan's Working Party, Public Submissions, Adoption and Review Process .....	39
	Appendix 3 - Sediment Nutrient Release .....	41
	Appendix 4 - Lake Okaro Trophic State Targets .....	43
	Appendix 5 - Rotorua District Plan.....	45
	Appendix 6 - Regional Water and Land Plan Methods 35, 35A and 35B (as amended by appeal resolutions).....	47
	Appendix 7 - Environmental Programmes .....	51
	Appendix 8 - Five Lake Phosphorus-Binding Products .....	53





## Chapter 1: Key Recommendations

---

- 1 That Environment Bay of Plenty apply a nutrient-absorbent cap to the lakebed of Lake Okaro to minimise nutrient releases from lakebed sediments over the short term (~7 years).
- 2 That Environment Bay of Plenty construct a wetland on Rotorua District Council reserve land and adjacent private land (Waionehu Farm) to remove nitrogen from the two main streams entering Lake Okaro.
- 3 That Environment Bay of Plenty, in conjunction with landowners, complete riparian fencing and planting of all streams in the Lake Okaro catchment.
- 4 That Environment Bay of Plenty, in conjunction with landowners, investigate the adoption of best management practices to reduce nutrient runoff from pasture, and attenuation of high stream flows to enhance wetland performance.
- 5 That Environment Bay of Plenty monitor and assess the ongoing nutrient load status of Lake Okaro and the effectiveness of individual actions to improve lake water quality.
- 6 That Environment Bay of Plenty, in conjunction with the Lake Okaro working party, initiate a review of the rules in section 9.4 of the Regional Water and Land Plan in January 2006, and publicly notify new rules for the Lake Okaro catchment by 31 December 2007.





## Chapter 2: Summary of Actions

Catchment reduction target: 910 kilograms of nitrogen and 20 kilograms of phosphorus.

Table 1 Summary of actions

Action	Responsibility	Estimated Costs (\$)	Expected Timeframe <sup>1</sup>	Predicted nutrient reduction <sup>2</sup> (kg/yr)	
				Nitrogen	Phosphorus
In-lake phosphorus-absorbent cap (not part of catchment nutrient reduction) <sup>3</sup>	EBOP	225,000	May 2006 – 2008	240 <sup>4</sup>	380
Constructed wetland	EBOP/landowners <sup>5</sup>	520,000	Apr – Dec 2005	348	16
Riparian: fencing, planting, restoration	EBOP/landowners	200,000	2006 - 2011	423	37
Best management practices	EBOP/landowners	varies <sup>6</sup>	ongoing	139 <sup>7</sup>	0
<b>TOTAL</b>		945,000 + BMP		<b>910</b>	<b>53</b>

<sup>1</sup> Timeframes cannot be finalised until each project is approved and funded.

<sup>2</sup> While these actions will reduce nitrogen and phosphorus inputs to Lake Okaro, the expected nutrient quantity reduction from a specific action is a broad estimate.

<sup>3</sup> This action to reduce the internal nutrient load does not contribute to the catchment reduction target in the box above, because the internal lake nutrient releases are subtracted from the overall lake nutrient reduction target.

<sup>4</sup> 240 is a gross estimate of potential N-ammonium removal by the phosphorus-absorbent cap – 1/10 of the average nitrogen load released from the lakebed sediments each year.

<sup>5</sup> The owners of Waionehu Farm Ltd have donated use of 2 hectares of their dairy farm for the constructed wetland site.

<sup>6</sup> This cost will vary depending on the extent and effectiveness of products and practices used.

<sup>7</sup> The 139 kg/year is the remainder from the nitrogen target not achieved by the other catchment-based actions. This may come from best management practices.





## Chapter 3: Purpose and Setting for the Lake Okaro Action Plan

---

### 3.1 Lake Okaro Action Plan Purpose

The purpose of this Action Plan is to:

- Set out the reasons why Lake Okaro's water quality has degraded.
- Outline the development of the Lake Okaro Action Plan.
- Direct Environment Bay of Plenty, Rotorua District Council and catchment landowners' actions in the Okaro catchment to meet Lake Okaro's water quality target.
- Inform people about these actions to improve Lake Okaro's water quality.

### 3.2 Facts About Lake Okaro and its Catchment

- Lake surface area: 3 hectares (smallest of the publicly managed Rotorua Lakes)
- Catchment area: 359 hectares (excluding the lake)
- Lake surface height: 423 metres above sea level
- Average depth: 12.5 metres
- Deepest point: 18 metres
- Trophic state: Supertrophic (very high nutrients and algal productivity)
- 2005 lake ownership: Rotorua District Council (including the lake edge reserve)
- Land cover: Refer to Table 2 and Figure 2

Lake Okaro is located 20 kilometres southeast of Rotorua, and two kilometres north of Maungakakamea/Rainbow Mountain. Geologists believe that a small geothermal explosion created Lake Okaro around 800 years ago as part of the Waiotapu thermal area. A stream feeds the lake from the northwest with a smaller stream below it. The Haumi Stream drains the lake from the southeast, joins the Waimangu Thermal Valley stream and flows to Lake Rotomahana.

Groundwater is believed to be shallow and contained within the surface water catchment. It seeps into the streams and the lake.

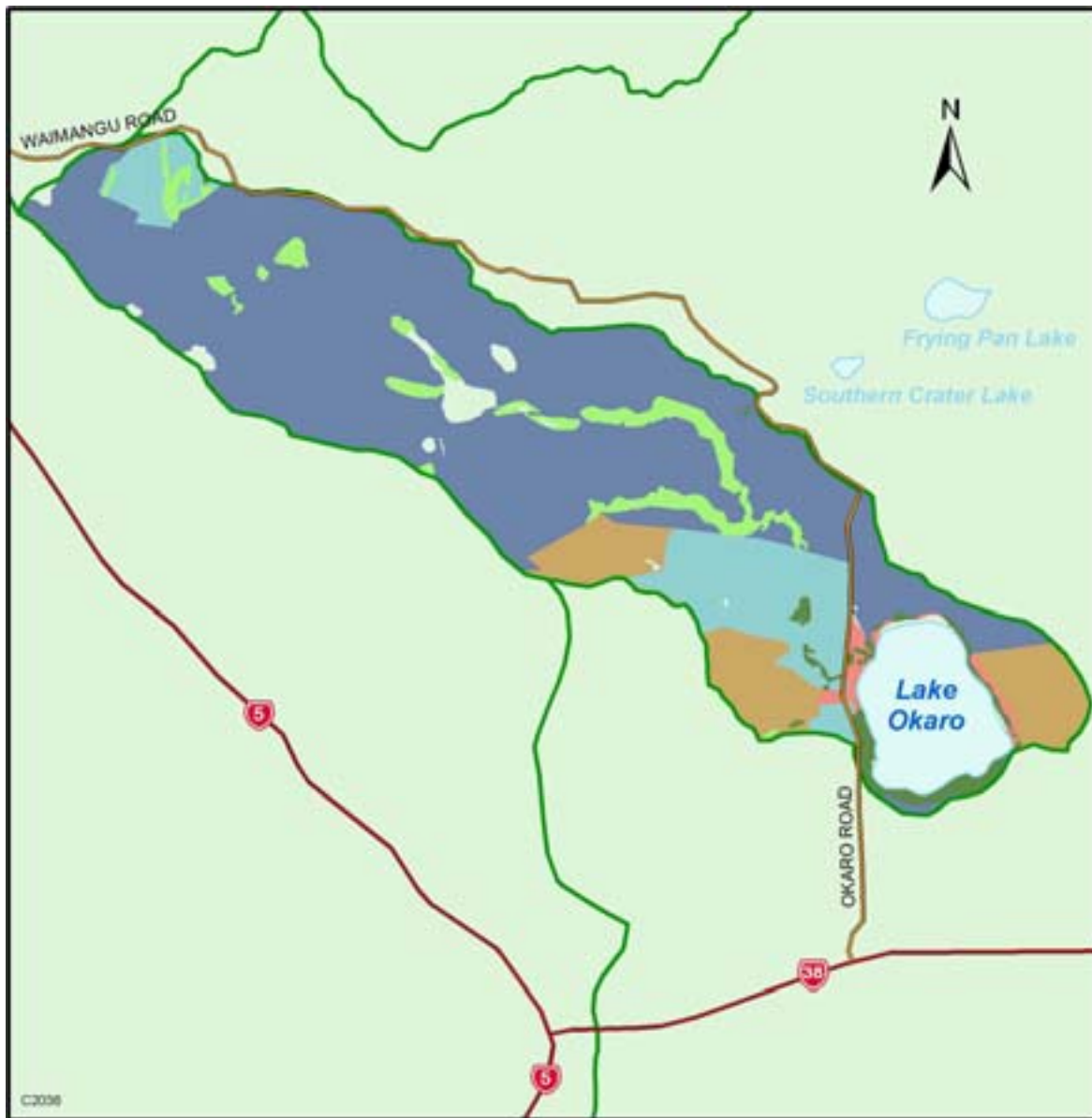
Recreational uses of the lake include boating, water skiing and fishing. The Medical Officer of Health warns against contact recreation when cyanobacterial blooms are on the lake. Lake water with cyanobacterial blooms may contain toxins. Drinking these toxins can harm the liver, the nervous system or the gastrointestinal tract. The toxins can affect humans, livestock, birds, and fish to a lesser extent. Skin contact with the toxins may trigger allergic reactions or asthma.



Figure 1 Lake Okaro and surrounding area

Table 2 Catchment land cover

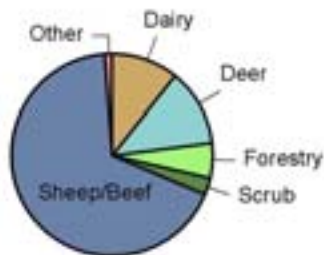
Land Cover	Area	
	ha	%
Native bush	13.5	3.6
Exotic trees	2.5	0.7
Exotic pasture	359	95.7
<b>TOTAL</b>	<b>375</b>	<b>100</b>



**LEGEND**

	Dairy	38,314 ha
	Deer	42,831 ha
	Sheep/beef	237,492 ha
	Forestry	19,901 ha
	Scrub	9,004 ha
	Other	4,287 ha
<b>TOTAL</b>		<b>351,829 ha</b>

**% LANDUSE**



**LOCALITY**



© Environment Bay of Plenty (the Bay of Plenty Regional Council).

Figure 2 Land use (2003) map of the Lake Okaro catchment

### 3.3 Lake Ownership

The Crown is negotiating ownership transfer of the Rotorua Lakes' beds to the Te Arawa people, resulting from a grievance claim to the Waitangi Tribunal. The lakes' water column would remain in Crown ownership. Lake Okaro is excluded from this handover because it is not Crown land; it is owned and administered by Rotorua District Council.

Te Arawa have indicated that they wish to pursue the matter of Lake Okaro with Rotorua District Council outside the Treaty of Waitangi claim settlement process. The Minister in Charge of Treaty of Waitangi Negotiations has encouraged Rotorua District Council to come to an agreement with Te Arawa on the management and ownership of the Lake Okaro Recreation Reserve that is acceptable to both parties.

The Te Arawa lakes settlement or possible ownership/management negotiations between Te Arawa and Rotorua District Council are unlikely to affect the implementation of the Lake Okaro Action Plan. Some in-lake restoration works may be recorded on the property title. In any case Te Arawa will adopt the Action Plan's recommendations through the Rotorua Lakes Strategy Joint Committee.

### 3.4 Existing Regional Water and Land Plan Rules

Section 9.4 of the Regional Water and Land Plan contains rules controlling nitrogen and phosphorus export from catchment land uses. The rules aim to ensure that total nutrient inputs to the lake from the catchment do not increase beyond their existing level. Environment Bay of Plenty, Rotorua District Council and landowners are investing resources into restoring lake water quality. Increases in nitrogen and phosphorus leaching and runoff from land use could undermine these water quality improvements.

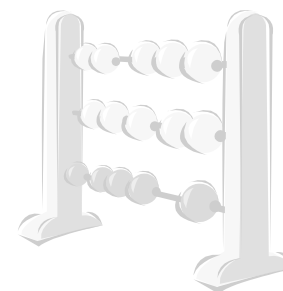
The existing section 9.4 rules apply within Lakes Okaro, Rotorua, Rotoiti, Rotoehu and Okareka catchments. Environment Bay of Plenty will begin a review of these rules in January 2006 (excluding Lake Okareka's catchment, which already has a review underway) to tailor them so they are more appropriate and specific to the individual lake catchments. This Action Plan presumes that regardless of rule reviews and changes, the rules' overall goal (to halt increases in diffuse nutrient export to the lake) will remain the same and the actions contained in this Action Plan can therefore induce water quality improvements over the long-term.

For more information about the section 9.4 rules, see Chapter 7.

### 3.5 The Degraded Water Quality Problem

Anecdotal reports indicate that Lake Okaro's water quality began to degrade significantly in the late 1970's. A long dry period may have triggered the collapse in water quality. Large amounts of nitrogen and phosphorus, which are essential for plant growth, entered the lake and fed algae and cyanobacteria blooms. Nitrogen and phosphorus built up from livestock farming in the catchment without modern best environmental practices like fenced streams, stock effluent treatment and nutrient leaching mitigation.

Lake water quality was lowest in the late 1990's and since then has shown minor improvement. However lake water quality is still degraded. Large amounts of nitrogen and phosphorus are still entering the lake, both from the catchment and re-cycling from the lakebed sediments. Algae and cyanobacteria species bloom regularly throughout the year. These blooms hinder recreational use and aesthetic enjoyment of the lake, and have adverse effects on plant and animal species living in the lake.



## Chapter 4: Nutrient Input Reduction Targets

### 4.1 Lake Okaro's Water Quality Target in the Regional Water and Land Plan

The overall opinion of communities around the Rotorua Lakes is that lake water quality should not deteriorate further, and some degraded lakes should be improved. The Regional Water & Land Plan<sup>8</sup> sets water quality targets for the Rotorua Lakes as Trophic Level Indexes TLI's, based on this community input.

The Trophic Level Index (TLI)<sup>9</sup> is a measurement of lake water quality. The higher a lake's TLI, the lower the water quality of the lake. Lake Okaro's current TLI (3-yearly average to June 2004) is 5.5 – a supertrophic, highly productive lake filled with nutrients. Environment Bay of Plenty set Lake Okaro's TLI target at a level it considered realistically achievable – 5.0.

<b>TLI (to June 2004)</b> <b>5.5</b>
---

<b>Target TLI:</b> <b>5.0</b>
----------------------------------

This Action Plan determines that Lake Okaro's target TLI is realistically achievable, based on the calculations in 4.2 below and the Summary of Actions table in Chapter 2.

### 4.2 Nutrient Reduction Target

Nitrogen and phosphorus concentrations within Lake Okaro are the main drivers of the lake's water quality decline. To improve Lake Okaro's water quality over the long term (15-20 years), nitrogen and phosphorus inputs into the lake from the catchment need to decrease. Lake Okaro also has a substantial "internal load" of nitrogen and phosphorus from lakebed sediments. The internal load enters the water column when the lake's bottom waters run out of oxygen over the summer/autumn period. These nutrient releases need to be targeted if Lake Okaro's water quality is to improve in the medium term (4-15 years).

<sup>8</sup> The Regional Water and Land Plan was "proposed" when staff prepared the Action Plan, because some sections of the Plan were still under appeal at the Environment Court. The Regional Water and Land Plan should become operative by mid-2006.

<sup>9</sup> See Appendix 1 for an explanation of the Trophic Level Index. The Trophic Level Index targets for each of the Rotorua Lakes are listed in Objective 10 of the Regional Water and Land Plan.



By decreasing nitrogen and phosphorus inflows, the algae growth – death – decomposition cycle will slow down and lake quality will begin to improve towards its target TLI.

Some fencing and planting on Lake Okaro's lake edges and stream banks has helped buffer stream nutrient loads, but major reductions must be achieved elsewhere for the lake to begin recovery.

Table 3 summarises the calculation of the nitrogen and phosphorus reduction target needed for Lake Okaro to attain its target TLI.

*Table 3 Nutrient target calculations*

Symbol	Description	Nitrogen kg/year	Phosphorus kg/year	Notes
C1	Current nutrient inputs, using export coefficients based on stream nutrient concentrations	5,000	780	Taken from Table 4's nutrient budget in 5.1, and includes sediment nutrient release averages (Appendix 3)
C2	Current nutrient inputs, measured from in-lake nutrient concentrations	7,710	730	A more reliable measurement that includes all sediment nutrient release (Appendix 3)
T	Estimated Target nutrient inputs into Lake Okaro	4,390	330	This nutrient input level, over time, should lower Lake Okaro's TLI to 5.0
<b>R = C2 - T</b>	Estimated total nutrient Reduction needed	3,320	400	Current nutrient inputs minus target nutrient inputs
I	Internal load (average from Appendix 3)	2,410	380	The catchment nutrient load is separated from the internal lakebed load
<b>E = R - I</b>	New estimated External nutrient load reduction from lake catchment	910	20	Nutrient reduction estimate minus averaged internal nutrient load

**N = 910 kg/yr**

**P = 20 kg/yr**

The first two rows in Table 3 compare the results of calculating a lake's nutrient budget from the lake and calculating it from the catchment. Phosphorus input results are similar, but the two nitrogen results vary significantly. The Action Plan uses the lake-sourced method because:

- It is prudent to overestimate rather than underestimate nitrogen inputs to improve lake quality.
- Lake-sourced calculations are based on the actual measured levels of nutrients in the lake. An unaccounted factor in the catchment-sourced calculation could have affected the results.

### 4.3 **Main Approach**

The operating method to achieve the N & P targets is:

- (a) Absorb the release of phosphorus (and some nitrogen) from the Okaro lakebed sediments to peg back the lake-algae-anoxia-nutrient release cycle.
- (b) (b)“Turn down the taps” – reduce the long-term inflows of nitrogen and phosphorus entering Lake Okaro.





## Chapter 5: The Sources of Nitrogen and Phosphorus to Lake Okaro

### 5.1 Lake Okaro's Nutrient Budget

As mentioned in the previous chapter, nitrogen and phosphorus concentrations in the lake are the key drivers of water quality decline and phytoplankton growth in Lake Okaro. Most nitrogen and phosphorus inputs to Lake Okaro come from land use in the catchment. Comparative land use nutrient export follows the order: native bush/exotic trees < sheep/beef/deer farming < dairy farming.

Table 4 Lake Okaro's catchment nutrient budget

Land Cover	Area ha	Export Coefficient		Nutrient Load			
		nitrogen kg/ha/year	phosphorus kg/ha/year	nitrogen kg/year	%	phosphorus kg/year	%
Scrub	13.2	2.5	0.04	33	1.3	0.5	0.1
Forestry	19.9	2.5	0.04	49	1.9	0.8	0.2
Sheep/beef	237.5	7.0	1.10	1,663	64.3	261.3	66.0
Deer	42.8	6.0	1.50	257	9.9	64.2	16.2
Dairy	38.3	15.0	1.80	575	22.2	68.9	17.4
Other	4.3	2.5	0.04	11	0.4	0.2	0.1
Wetland	1.4						
Catchment total	357.4			2588	100	395.9	100
Internal				2,400		380.0	
Total:				4,988		775.9	
<b>Total (tonnes)</b>				<b>5</b>		<b>0.78</b>	

### 5.2 Livestock Farming

Pastoral land use (sheep, cattle, deer, dairy farming) is the main contributor of nitrogen to Lake Okaro. Fertilisers, and nitrogen-fixing plants like clover, bind nitrogen to soils. Some of this can be washed or leached away. Grazing animals return some nitrogen to the soil in dung and in urine spots. The latter is a major source of nitrogen leached from pasture, particularly in winter and spring when soils are saturated and grass growth is slow. Generally the higher the intensity of pasture-grazing the higher the nitrogen export.

Allophane clay particles in Lake Okaro's Rotomahana-mud-based soil help absorb phosphorus. Yet phosphorus still enters waterways through farm runoff and erosion.

Phosphorus export is also related to land use type and extent, land gradient, climate, stocking rates, management practices and other variables.

### 5.3 Lakebed Sediment

Around half of the phosphorus inputs and a third of the nitrogen inputs to Lake Okaro are from the lakebed. How this occurs is explained below.

In the winter, Lake Okaro's water temperature ranges around 10°C from top to bottom. Oxygen from the atmosphere mixes throughout the water. From September, the surface waters start to warm. As warm water is less dense than colder water, the top and bottom waters (epilimnion and hypolimnion) stratify and water mixing only occurs within each of the layers – not between them. It can only take half a degree of temperature difference for this to happen. As dead algae sink and decompose, the decomposition process uses up oxygen from the bottom waters. Lake Okaro has the greatest concentration of algae out of all the Rotorua lakes; so once this process begins the bottom waters run out of oxygen and are completely devoid of oxygen before the end of December. Any oxygen transfer to these waters is minimal and quickly used up by bacteria.

In these anoxic conditions, the lake sediments begin to release nitrogen and phosphorus into the bottom water. When winter arrives the water temperature becomes constant again and the lake remixes, dispersing nutrients through the water column. These nutrients promote algal blooms. Eventually the algae growth uses up the nutrients and the dissolved nutrient concentration in the water decreases. A surplus of dissolved phosphorus remains. In spring, the cycle begins again as the waters stratify and algae decomposition causes the bottom waters to lose their oxygen.

Nutrients released from lakebed sediments have a low nitrogen: phosphorus ratio (low levels of nitrogen to a unit of phosphorus). This ratio tends to favour the cyanobacteria species over "good" algae, because cyanobacteria can transfer nitrogen from the air into their cells if there is a limited amount of nitrogen in the water.

### 5.4 Waterfowl

Waterfowl recycle nutrients within a lake by grazing on aquatic plants and returning nutrients to the water as uric acid. Nutrients in uric acid deposited by birds eating grass in nearby paddocks may end up in the lake. Nonetheless, the percentage of nutrient inputs to the lake from waterfowl into Lake Okaro is very small – estimated at 0.6% of nitrogen inputs and 1.3% of phosphorus inputs from the catchment (Bioresearches, 2002). Even so they can increase the levels of soluble nutrients in the water, which are then available for algal growth. When they roost on the lake in large numbers there are also bacterial contamination risks.

### 5.5 Delayed Nutrient Inflows from Historic Land Use

Unlike some of the other lakes in the Rotorua district, scientists believe that there is rapid rainfall runoff in the catchment of Lake Okaro and less infiltration to groundwater. Lake Okaro is the second-highest lake in the Rotorua district, so it has a small, elevated groundwater catchment. Groundwater outside the catchment drains to lower streams and lakes. Rotomahana mud from the Mt Tarawera eruption is less permeable than the pumice layers around other lakes. Because of this, groundwater flows within the catchment remain shallow and either seep into streams or enter the lake directly.

The young groundwater age means that Lake Okaro's water quality reflects the degree of pastoral land use in its catchment. A long lag period between any land use changes and their effects on lake water quality, like 50-100 year lag period for Lake Rotorua, is unlikely.

Anecdotal evidence indicates that much of the lake catchment was cleared for agriculture in the 1950's, but it took another 15-20 years for the lake to stabilise at a highly eutrophic state. Therefore, the effects of nutrient reductions within the catchment should be fully evident in the lake within 15-20 years. In-lake actions like lakebed capping should speed up this water quality restoration process.





## Chapter 6: Nutrient Input Reduction Actions

---

The proposed nitrogen and phosphorus-reducing actions to meet Lake Okaro's TLI target are:

- A phosphorus-absorbent lakebed cap (that may also absorb some forms of nitrogen).
- A constructed wetland to remove nitrogen from stream flows.
- Protection of all riparian margins in the catchment.
- Best management practices to reduce nitrogen leaching from land use over time.

### 6.1 Phosphorus-Absorbent Lakebed Cap

#### 6.1.1 A Medium-term Measure

Almost half of phosphorus entering Lake Okaro is released during anoxic conditions from the lakebed sediment. A mineral layer to absorb phosphorus releases from sediments could decrease algal biomass and improve lake water quality. The "lakebed cap" could last for around seven years.

#### 6.1.2 Alum Application

The first attempt at removing dissolved phosphorus in-lake was application of a chemical called alum<sup>10</sup>. Alum binds to phosphorus in the water column, forms microscopic flocs and settles on the lakebed.

On 16 December 2003, 13 m<sup>3</sup> of commercial grade alum was applied to Lake Okaro by a boat with a spray boom (see Figure 3). The application took two days.

---

<sup>10</sup> Alum is the trade name for Aluminium sulphate  $AlK(SO_4)_2$ .





*Figure 3 Lake Okaro alum application*

The alum sank into the lake on application without affecting the lake's pH. The next day the alum was only partially located but on the following day it was distributed throughout the surface waters. It was surmised that the alum had plunged to the thermocline (the temperature drop between upper and lower waters) and temporarily accumulated there until the surface water currents gradually mixed it. After five days the alum was thoroughly mixed throughout the surface waters.

The alum lowered phosphorus concentrations by 20% compared to past July levels, as measured in July 2004 after an annual lake cycle.

### 6.1.3 Flocculant Product Comparison

Since the 2003 alum application, various companies have investigated and marketed other phosphorus-flocculant products in New Zealand. The products include Zeolite, modified forms of Zeolite, Phoslock, cleaned melter slag<sup>11</sup>, allophane, and others. Different Zeolite-based products also have the potential to remove some nitrate-N and ammonium-N.

Researchers are testing these products in the laboratory and in restricted field trials. For example, Environment Bay of Plenty commissioned fifteen "limnocorral mesocosms" to be placed at the northern end of Lake Okaro. The mesocosms are 2 m diameter plastic cylinders that extend from the lake surface to the lakebed, encompassing a complete column of lake water. Scientists will use these mesocosms to compare the effectiveness of four flocculants. The mesocosm results will help make decisions about the best flocculant product to use in Lake Okaro and maybe other small lakes and enclosed bays as well.

The flocculants that will be tested in the mesocosms are contrasted in Appendix 8.

<sup>11</sup> Melter slag is the waste by-product from the steel-making process.

### 6.1.4 Lake Bed Flocculant Cap Application

Environment Bay of Plenty intends to use the results of the mesocosm and laboratory studies to design a proposal for a whole lake treatment. The treatment should ideally create a sediment “cap” that will absorb phosphorus (and potentially some nitrate and/or ammonium<sup>12</sup>) ions released from lakebed sediments. The chosen flocculant product will be applied to the 20 ha of lakebed that is deep enough to turn anoxic during the warmer months. Environment Bay of Plenty will apply the flocculant annually for three years to spread the cost over three financial years.

Environment Bay of Plenty scientists estimate that a nutrient-absorbing flocculant cap applied to Lake Okaro should last for around 7 years. During this period Environment Bay of Plenty will monitor the lake’s nutrient status, rate of hypolimnion deoxygenation and lakebed nutrient release. This monitoring will help determine the success of the flocculant cap, and whether Lake Okaro’s water quality could benefit from a different in-lake engineering or treatment option.

### 6.1.5 Costs

This section does not include the costs of flocculant tests and trials, because they do not directly improve lake water quality and the test results will be useful for other lakes as well as Lake Okaro.

An effective capping layer needs around 5 tonnes of flocculant per hectare of lakebed. Twenty hectares of Lake Okaro’s lakebed turns anoxic during the year. The other 12 ha is shallow and infrequently turns anoxic.

Phoslock, the most expensive product tested, costs \$2,500 per tonne. Suppliers have estimated market value of locally-sourced products like modified Zeolite or NZ melter slag at less than half the Phoslock price.

$$\frac{\$2,500}{2} = \$1,250 \times 5 \text{ tonnes} \times 20 \text{ hectares} = \$125,000$$

Added to this is the application cost estimated at \$10,000 per day. Applying 100 tonnes of flocculant should take approximately 10 days.

\$125,000 (flocculant cost) + \$10,000 x 10 (application cost) = \$225,000 total.

As Environment Bay of Plenty intends to spread the flocculant load over three years, the estimated annual cost is \$75,000. The actual cost may be less than this estimate, depending on the product chosen and the recommended application rate.

### 6.1.6 Responsibility

Environment Bay of Plenty’s Environmental Investigations section is expected to be the consent holder for the phosphorus-absorbent cap. The section will be responsible for the cap application (via contractors) and monitoring of environmental effects.

<sup>12</sup> Ammonium (NH<sub>4</sub>) is a “reduced” form of nitrogen released from sediments when the lake-ground interface loses its oxygen. Nitrate is an oxidised form of nitrogen found in oxygenated lake water.

## 6.2 Constructed Wetland

### 6.2.1 Enhanced Denitrification using a Constructed Wetland

A constructed wetland in this context is a wetland area created primarily to remove a substantial amount of dissolved nitrogen from water flows. The process relies on the build-up of organic rich sediments and abundant denitrifying bacteria. Bacteria living around wetland plant roots in rich, damp organic soil use adjacent oxygenated and deoxygenated areas to bring about coupled nitrification-denitrification reactions. In other words they change ammonium to nitrate and nitrite, and then to nitrogen gas which wetland plants vent to the air. Plant material also takes up a small amount of nitrogen and phosphorus.

Intact wetland vegetation along lake margins or streams can form zones where a similar process happens. How much nitrogen is removed depends on how much water entering the stream seeps in through organic-rich zones, which are home to denitrifying bacteria. A high rate of surface flow through a small wetland area does not remove much nitrogen as the water only has a short contact period with organic-rich soil.

### 6.2.2 Nitrogen Removal Rates

A 2.3 ha constructed wetland to treat the northern and southern Okaro streams' base flows could remove ~193 kg/year nitrogen and a minor amount of phosphorus.

Table 5 Nitrogen removal expected from Lake Okaro Stream's base flow

Season	Mean stream base flow (L/s)	Wetland inflow (m <sup>3</sup> /day)	Mean influent nitrate-N concentration (g/m <sup>3</sup> )	Mean outlet nitrate-N concentration (g/m <sup>3</sup> )	Estimated seasonal percentage reductions	Annual wetland nitrate-N mass loading (kg/yr)	Annual wetland nitrate-N mass removal (kg/yr)	Annual % removal of loading
Summer-optimised	34.5	2981	0.39	0.19 (0.17-0.22)	58% (52-63)	429	193 (165-210)	45% (39-50)
Winter-optimised	34.5	2981	0.39	0.24 (0.22-0.26)	46% (40-50)			

Environment Bay of Plenty has added an extra carbon source to boost bacterial activity and optimise wetland de-nitrification. The nearby Rainbow Mountain timber mill has offered sawdust to add to the wetland as a carbon source.

### 6.2.3 Base Flow and Flood Flows

The theoretical average catchment water output into the lake is 90 L/s, but Table 5's base flow samples show only 34.5 L/s. This indicates that the base flow samples are not generally taken during high flow periods like storms. Nitrate concentrations in high flows are similar to concentrations in low flows. This is different to ammonium and phosphorus concentrations that are higher in storm flows because of surface runoff. Therefore the Action Plan assumes that nitrate concentrations in the surplus flow are the same as in the base flows.

- Average base flow (sampled): 34.5 L/s
- Expected average stream flow over one year: 90 L/s

- Surplus flow (not sampled) averaging peak/flood flows over one year: 55.5 L/s

The constructed wetland could remove some nitrogen from flood flows if some form of upstream detention ponds lowered the flow peaks. Nevertheless even with flow detention, a wetland will remove less nitrogen from high stream flows than “base” stream flows. This is because high stream flows will either bypass the wetland entirely, or at least will move through the wetland more quickly.

Presuming that some high flows can be detained in detention dams and upper catchment ponds, the de-nitrification rate of all flows above base flow is assumed to be one half of the base flow rates.

*Table 6 Nitrogen removal expected from Lake Okaro streams' annual flow*

	Average Base Flow	Average Surplus Flow
Flow rate (L/s)	34.5	55.5
Influent nitrate-N concentration (g/m <sup>3</sup> )	0.39	0.39
Annual wetland nitrate-N mass loading (kg/yr)	429	690
Annual removal of loading (%)	45%	22.5%
Annual wetland nitrate-N mass removal (kg/yr)	193	155
<b>Total average nitrogen removal predicted (kg/year)</b>	<b>348</b>	

Other sites may also exist along the streams and around the lake where new wetlands may enhance nutrient reduction rates.

#### 6.2.4 Phosphorus Removal Rates

Constructed wetlands can remove some phosphorus from streams by plant uptake, soil storage and settling out sediment. For example, five Waikato wetlands receiving treated effluent are assimilating between 2% - 14% of total phosphorus from the effluent (Sukias, Tanner 2004). However because phosphorus is not removed from the wetland, eventually these compartments fill up with phosphorus. Phosphorus removal decreases over time and the wetland may end up as a source for phosphorus release.

The weir that will divert water into the constructed wetland and any detention dams upstream will also remove some particulate phosphorus as it settles out of the water flow.

Because there will be some long-term phosphorus absorption and particulate deposition in the wetland and ponds, the Action Plan conservatively estimates the constructed wetland could remove a long-term average of 16 kilograms of phosphorus per year (4% of total phosphorus in the stream). If phosphorus removal by the Lake Okaro wetland drops below this removal rate over time, maintenance excavation of the wetland should be investigated to remove stored phosphorus.

To improve phosphorus removal, Environment Bay of Plenty will investigate the use of phosphorus-absorbent substances held in socks or gabions. These could be placed at the constructed wetland's entrance or exit points to absorb more dissolved phosphorus out of the water flow.

### 6.2.5 Ancillary Values of Constructed Wetlands

Constructed wetlands have other values too, like:

- Habitat for rare native plants and animals
- Game bird hunting opportunities
- Educational areas
- Land's aesthetic appearance and enjoyment

### 6.2.6 Costs and Timeframe

Table 7 Lake Okaro constructed wetland's costs and timeframes

	Costs	Timeframes
Earthworks	\$420,000	April – July 2005
Wetland planting	\$100,000	August – November 2005
Official public opening	~	2 February 2005 (World Wetland Day)

### 6.2.7 Maintenance Responsibilities

Waionehu Farm landowner: Wetland's perimeter fence within Waionehu Farm to ensure no livestock access.

Rotorua District Council: Wetland's perimeter fence (where present) on the Okaro Road reserve and Lake Okaro reserve.

Boardwalks, decks and walkways in the constructed wetland area.

Environment Bay of Plenty: Overall wetland management. Signs, pest plant and pest animal control, wetland operation, plant establishment, wetland performance monitoring, water flows and detention dams. Operation and maintenance of the inlet and outlet structures<sup>13</sup>.

## 6.3 Riparian Protection

### 6.3.1 The Goals of Riparian Protection

Riparian protection is the planting and stock-exclusion fencing of land alongside stream or lake margins. Riparian protection strips at least 10 m wide are recommended for sustainable native vegetation canopies. Strips narrower than this are generally dominated by exotic brushweeds and require more management. The goal with fencing is the complete exclusion of all livestock from waterways, as well as making sure the fence can stand up to floods and livestock movements. This benefits the stream (e.g. no trampling or urinating in the stream) and the farmer (e.g. control of stock movement and healthier animals). Planting dense grass, reed and bush vegetation help steady the stream channel, reduce erosion, trap sediment, and cut back nitrogen and phosphorus inputs to waterways.

The importance of riparian protection is reflected in Objective 16(b) of the Regional Water and Land Plan.

Objective 16: Achieve the retirement of riparian margins in the following priority catchments:

- (b) Rotorua lakes.
  - (i) All lake margins – 100% by 2007.
  - (ii) Rivers and streams in all lake catchments – 100% by 2020.
  - (iii) Rivers and streams in the catchment of Lake Rotorua – 90% by 2010.

Therefore the goal in the Lake Okaro catchment is complete riparian protection of all streams and lake margins.

### 6.3.2 Nutrient Reduction Benefits

Two unnamed streams (called here “northern” and “southern”) flow into the northwestern side of Lake Okaro (see Figure 4). Some riparian edges are already protected, but one section of lake margin and some stream sections still have varying levels of stock access.

The nutrient reduction benefits from complete riparian fencing and replanting of Lake Okaro’s stream and lake edge buffers with appropriate plants were estimated using NPLAS<sup>14</sup>. NPLAS estimated reductions in the order of: N = 423 kg/year, P = 37 kg/year. This is a very broad estimate. Actual nutrient reductions achieved will depend on eliminating stock access to waterways and appropriate dense river edge vegetation.



Figure 4 Lake Okaro catchment stream riparian protection status

<sup>13</sup> Environment Bay of Plenty may delegate this responsibility to Rotorua District Council through a separate agreement, if both councils approve.

<sup>14</sup> NPLAS: Nitrogen & Phosphorus Load Assessment System. NPLAS is a computer model that estimates a property’s annual nitrogen and phosphorus export.

### 6.3.3 Northern stream

The northern stream is the larger of the two streams, with a total length of 3,920 m (including tributaries). Approximately 3,390 m of stream channel is located within Rotomahana Station (Landcorp Farming Ltd), 310 m within Waionehu Farms Limited and 220 m within the Lake Okaro Recreation Reserve (Rotorua District Council).

Three ponds/mini-craters ranging from 0.8 ha to 2.8 ha are also located on Rotomahana Station. The stream channel includes the largest pond. Part of this pond/crater has been fenced and planted in native vegetation by the Department of Conservation.

Livestock cannot access the northern stream section within the Lake Okaro Recreation Reserve and Waionehu Farm Ltd property.

Within Rotomahana Station (until recently) all stream channels had poplars and willows planted along the riparian margins, with stock excluded for most of the stream length. But these poplars were old and regularly fell over the fences, allowing stock access to streams. Most of the poplars are now removed but some poplar & willow brush, scrub and blackberry remains.

Environment Bay of Plenty will work with the Rotomahana Station managers on an Environmental Programme. The programme is likely to involve:

- Fencing of all streams margins by 2009.
- Wood removal and weed control from 2005 to 2010 to allow the old roots and stumps to break down in the soil.
- Planting of the stream banks with native plant species that take up nutrients.

### 6.3.4 Southern Stream

The southern stream is 1070 m long, with 120 m within the Lake Okaro Recreation Reserve and the remainder on the Waionehu Farm Ltd property.

There is no stock access to the lower 470 m of this stream.

An Environmental Programme is underway for Waionehu Farm Ltd, including fencing and revegetation of the remainder of the southern stream.

### 6.3.5 Costs and Timeframes

The ballpark total cost for complete fencing and planting of all riparian margins in the Lake Okaro catchment is \$200,000. Environment Bay of Plenty, Rotorua District Council (for the lake reserve) and landowners should aim to complete all riparian protection works by the end of 2012. However, this depends on negotiations, Environmental Programmes, work prioritisation and other factors. Note that this ballpark cost is only for works undertaken in the Lake Okaro catchment. Costs listed in Environmental Programmes are given on a per-property basis.

### 6.3.6 Maintenance Responsibility

Once fencing, riparian planting and other establishment works are in place, landowners will be responsible for maintenance as set out in the Environmental Programme standard. The first two years of plant tending are part of the Environmental Programme establishment works. Environmental Programmes are registered against the property title.

If any works relating to riparian areas (such as detention dams) are separate from an Environmental Programme, Environment Bay of Plenty and landowners will be jointly responsible to negotiate a maintenance regime.

## 6.4 Best Management Practices

The actions covered so far do not (with current estimates) quite reach the nitrogen reduction target. 149 kg/yr still needs to be trimmed back. To meet this target and maybe even get beyond it, landowners should consider best management practices to reduce nutrient loads flowing into Lake Okaro.

### 6.4.1 Examples of Best Management Practices

Examples of some best management practices<sup>15</sup> trialled, promoted or suggested by agricultural scientists are:

- Nutrient budgeting to minimise unnecessary nutrient application when spreading fertiliser or effluent.
- Protecting riparian areas (covered in 6.4).
- Wintering off dairy cows outside the catchment.
- Using a covered winter feed pad with collection and treatment of feed pad runoff.
- Avoiding bare soil on slopes where runoff and erosion could occur.
- Applying nitrification inhibitors. These inhibit conversion of ammonium-N (binds with soil for plants to use) to nitrite-N and nitrate-N (which leach more easily to waterways).
- Planting woodlots on less economic pasture land.
- Not bringing in supplementary feed from outside the catchment.
- Using deep-rooted grasses.
- Implementing stocking and grazing management policies.
- Changing feedstock types.

---

<sup>15</sup> Best management practices are also called land management techniques, best environmental practices, or best practice options



- Changing animal behaviour (e.g. deer prancing up and down a fence line, disturbing soil).
- Varying gut microbial species to reduce the amount of nitrogen leaving the animal in urine patches.

Some of these practices have not yet been fully researched. The costs, nutrient reduction benefits and productivity benefits are unknown. Over time as research and trials continue it is expected that more best management practices will become viable for landowners to use. Environment Bay of Plenty will keep in contact with local landowners over time to assess whether best management practices could benefit Lake Okaro's water quality and landowners as well.

#### 6.4.2 **Regional Water and Land Plan Policy**

The Regional Water and Land Plan also encourages use of best management practices within the Rotorua Lakes catchments.

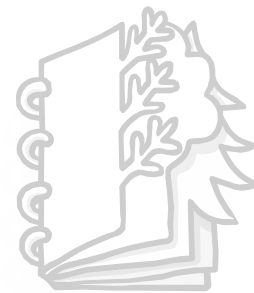
Policy 29D states:

“To promote and support land use change and/or land management practices in the catchments of the Rotorua Lakes that will achieve lake water quality improvement.”

Method 35B (c) & (d) states:

“Environment Bay of Plenty will support land use changes, and changes to land use rules, that:

- (a) Recognise that land use change and land management practices are an important part of lake management.
- (b) Actively promote & support low nutrient loss land uses and land management practices in the catchments of the Rotorua Lakes.”



## Chapter 7: Rules to Protect Gains Made

---

### 7.1 Existing Regional Water and Land Plan Rules

Method 35 of the Regional Water and Land Plan (see Appendix 6) states that the Action Plan should:

*“Determine if regulatory measures are necessary to control the discharge of nitrogen or phosphorus, or both, from land use activities in the lake catchment (Refer to Method 35A [– review of section 9.4 rules]).”*

Landowners farming within the Lake Okaro catchment have developed their land in good faith, with implicit encouragement from central government policies in the past. Because of this, at this stage Environment Bay of Plenty will fund most of the nutrient reduction within the Lake Okaro catchment as part of the Rotorua Lakes Action Programme funding. Environment Bay of Plenty will encourage landowners to implement best management practices (as discussed in 6.5) to achieve the remainder of the nitrogen reduction in Chapter 4.

However, regulatory measures are needed to protect Lake Okaro from increasing diffuse nitrogen and phosphorus export. Increased nitrogen and phosphorus exports from intensified land use would start to nullify benefits from actions in this Action Plan. It would undermine the community, district and region’s investment into lake quality.

Environment Bay of Plenty introduced rules in section 9.4 of the Regional Water and Land Plan to limit nitrogen and phosphorus export from a property beyond its benchmark level. A nutrient budget model called NPLAS creates the benchmark using data from July 2001 to June 2004 to estimate average nitrogen and phosphorus export from a property per year. NPLAS considers:

- Climate and soil type
- Fertiliser application
- Stock numbers and ratios
- Mitigating factors, e.g. riparian vegetation, wetlands, etc.

The rules' implications are:

- Environment Bay of Plenty must receive the information needed to calculate the NPLAS benchmark from landowners before 31 December 2005 or when the property is sold, whichever is sooner (Environment Bay of Plenty will help landowners with this requirement).
- All land uses in the Lake Okaro catchment are permitted (subject to all other relevant regional and district rules) as long as they do not exceed their property's overall nutrient export benchmark.
- Any land use change or land management change that potentially increases the nutrient export, but can be fully offset on the property, is a permitted activity.
- Any land use change or land management change that exceeds the property's nutrient export limit but is off-set elsewhere in the catchment is a controlled activity and will need resource consent. A consent application must be lodged with Environment Bay of Plenty.
- Any land use change or land management change that exceeds the property's nutrient export limit and is not off-set elsewhere in the catchment is a discretionary (restricted) activity. A consent application must be lodged with Environment Bay of Plenty.

## 7.2 Rule Review and Timeframes

There is still the question whether these section 9.4 rules to restrict increases in nitrogen and phosphorus export are a fair and equitable way to protect lake water quality. Method 35 states that the Action Plan should:

*"Include fair and equitable provisions to address effects on existing land uses where it is necessary to restrict land use to maintain or improve water quality. Such provisions include, but are not limited to, criteria for possible financial compensation and land acquisition."*

Rather than considering these provisions in the Action Plan, they will be considered as part of the section 9.4 review required by Method 35A of the Regional Water and Land Plan (see Appendix 6).

Method 35A states that Environment Bay of Plenty, in conjunction with the Lake Okaro Action Plan working party, must undertake a Lake Okaro-specific review of the necessity and application of section 9.4's rules. The review must be initiated in January 2006, with a change to the Regional Water and Land Plan publicly notified by 31 December 2007.



## Chapter 8: Anticipated Effects

---

### 8.1 Environmental Effects

Once the actions in this Action Plan take place: nutrient-absorbent flocculant cap, constructed wetland, riparian protection and best management practices, the long-term environmental effects anticipated are:

- Lake Okaro's trophic level index drops from 5.5 to at most 5.0 (similar to Lake Rotorua's water quality in 2004-05).
- A predominance of non-toxic algal species replaces cyanobacterial bloom dominance.
- Complete lake anoxia occurs less often, with less fish deaths and waterfowl botulism.
- Lake weed (aquatic macrophyte) populations may increase in area and volume as algae and cyanobacterial blooms diminish.

### 8.2 Economic Effects

- A loss of two hectares of pasture for the constructed wetland may cause a small decrease in income for the owners of Lot 2 DPS 89377. Some earth from wetland construction was used to smooth out an area of nearby pasture. This may partly offset the economic loss of pastoral land conversion to wetland.
- Some limitations on future increased farm production because of the rules in section 9.4 of the Regional Water and Land Plan (discussed in Chapter 7). The economic effects of the rules may be partly mitigated through new farming technology and research into land-water interactions, or through the rule review process in 2006/07. The Nimmo-Bell (2004) report gives some examples of section 9.4's macro-economic implications, based on land use in the Lake Rotorua and Lake Rotoiti catchments.
- Improved fishing opportunities and the potential for Lake Okaro to host increased waterskiing activity because of improved lake water quality may have minor economic spin-offs for the wider Rerewhakaaitu area and the Rotorua district.

### 8.3 **Other Effects**

- Lake recreational opportunities improve as cyanobacterial bloom incidences decrease.
- A large wetland habitat is created for some threatened bird and plant species.
- Intrinsic lake values are protected, and the amenity value of the lake to the wider Rerewhakaaitu and Rotorua communities is enhanced.

## References

---

- Bell B (2004): An Economic Evaluation of Water Quality Induced Changes in Rotorua and Rotoiti Catchments: Part A) Land Use Change Scenarios, Part B) Macro-Economic Implications. Nimmo-Bell & Company Ltd report to Environment Bay of Plenty, June 2004.
- Bioresearches (1991): Report on rural land use practices in the Rotorua District. Sigma Consultants' report to Rotorua District Council, June 1993.
- Bioresearches (2002): First order estimation of the nutrient and bacterial input from aquatic birds to twelve Rotorua lakes. Prepared for Environment Bay of Plenty by G L Don and W F Donovan.
- Bioresearches (2003a): Estimate of geothermal input to twelve Rotorua lakes. Prepared for Environment Bay of Plenty by C L Donovan and W F Donovan.
- Burns N M; J C Rutherford and J S Clayton (1999): A monitoring and classification system for New Zealand lakes and reservoirs. *Journal of Lake and Reservoir Management* 15 (4):255 – 271, 1999.
- Cooper A B and C E Thomsen (1987): Nitrogen and phosphorus in stream waters from adjacent pasture, pine and native forest catchments. *NZ Journal of Marine and Freshwater Research* 1988 Vol 22:279 - 291.
- Donald R (1997): Rotorua Lakes Summary Report. Environment Bay of Plenty Environmental Report 97/21.
- Edmeades D C (2004): Nitrification and Urease Inhibitors. Environment Bay of Plenty Environmental Publication 2004/11. Prepared by agKnowledge, Hamilton.
- Ellery G (2004): Lake Level and Volume Summary of the Rotorua Lakes. Environment Bay of Plenty Internal Report 2004/08.
- Gibbs M M and F E Lusby (1996): Lake edge wetlands: Their environmental significance to the Rotorua Lakes. NIWA consultancy report # BPR005/2 to Environment Bay of Plenty.
- Hoare R A (1980): The sensitivity to phosphorus and nitrogen loads, of Lake Rotorua, New Zealand. *Prog Water Tech* Vol 12 Toronto pp 897 – 904.
- Hoare R A (1987): Nitrogen and phosphorus in the catchment of Lake Rotorua. Publication No 11, Water Quality Centre, Ministry of Works and Development, Hamilton. June 1987.
- Macaskill J B; A B Cooper and E J Bowman (1997): Nitrogen and phosphorus in streams draining catchments of different land use in the Rotorua Lakes district. NIWA client report for Environment Bay of Plenty BPR 223.

- Matheson F and J S Clayton (2002): Aquatic plant harvesting in lakes for nutrient renovation. NIWA client report for Environment Bay of Plenty. HAM2002-010 BOP03205, August 2002.
- McIntosh J J *et. al.* (2001): Lake Rerewhakaaitu Project. Environment Bay of Plenty Environmental Report 2001/15.
- Menner J C; S F Ledgard and A G Gillingham (2004): Land Use Impacts on Nitrogen and Phosphorus Loss and Management Options for Intervention. AgResearch client report for Environment Bay of Plenty, June 2004.
- Pridmore R D (1987): Phytoplankton response to changed nutrient concentrations. Chapter 18. In: W N Vant (Ed). *Lake Manager's Handbook*. Water & Soil Miscellaneous Publication No. 103, NWSCO, Wellington.
- Ray D; M Gibbs and G Timpany (2002a): Septic Tank Leachate study for Rotorua Lakes – Stage 2. RDC00208/1 prepared for Rotorua District Council by NIWA, April 2002.
- Ray D and G Timpany (2002b): Measurement of nitrogen inputs to Lake Okareka. Prepared for Environment Bay of Plenty BOP01202/1 by NIWA, Hamilton.
- Russelle M (1996): Pasture Nitrogen Flow. In 'US Dairy Forage Research Center, 1996 Informational Conference with Dairy and Forage Industries.'
- Rutherford J C (1987): Internal nitrogen and phosphorus loads in Lake Rotorua, New Zealand. Paper presented at XXIII SIL Congress, Hamilton Feb 9 – 14 1987.
- Rutherford J C and A B Cooper (2002): Lake Okareka Trophic State Targets. Prepared for Environment Bay of Plenty by NIWA, Hamilton.
- Scholes P (2004): Rotorua Lakes Water Quality 2004 Report. Environment Bay of Plenty Environmental Publication 2004/17.
- Strategy for the Lakes of the Rotorua district. Te Arawa Maori Trust Board, Environment Bay of Plenty, Rotorua District Council joint document. August 2000.
- Sukias J and C. Tanner (2004): Evaluation of the Performance of Constructed Wetlands Treating Domestic Wastewater in the Waikato Region. NIWA Client Report HAM2004-013, for Environment Waikato. March 2004.
- Timperley M H (1983): Phosphorus in spring waters of the Taupo Volcanic Zone, North Island, New Zealand. *Chemical Geology* 38(1983) 287-306.
- Vincent W F (1980): Biological transformations of nitrogen in New Zealand freshwaters. In 'Nitrogen Balances in NZ Ecosystems.' Gandar P W (ed), DSIR Palmerston North.
- Wilding T K (2000): Rotorua Lakes Algae Report. Environment Bay of Plenty Environmental Report2000/06.
- Williamson R B; C M Smith and A B Cooper (1996): Watershed riparian management and its benefits to an eutrophic lake. *Journal of Water Resources Planning and Management*. Jan/Feb 1996, pp 24 – 32.

## Appendices

---

*Appendix I Trophic Level Index (TLI) and Other Indicators*

*Appendix II ..... Lake Okaro Action Plan's Working Party,  
Public Submissions, Adoption and Implementation Process*

*Appendix III ..... Sediment Nutrient Release*

*Appendix IV ..... Lake Okaro Trophic State Targets*

*Appendix V ..... Rotorua District Plan*

*Appendix VI ..... Regional Water and Land Plan Methods 35, 35A & 35B*

*Appendix VII ..... Environmental Programmes*

*Appendix VIII ..... Five Lake Phosphorus-binding Products*





## Appendix 1 - Trophic Level Index (TLI) and Other Indicators

### 1.1 Trophic Level Index

The Trophic Level Index (TLI) is an indicator of lake water quality. Burns, Rutherford and Clayton (1999) developed this index for New Zealand conditions because other international indices were not adequate to deal with New Zealand lakes. The Ministry for the Environment has adopted the TLI as a national indicator for New Zealand state of the environment reporting, and a TLI goal has been set for each of the Rotorua Lakes in the Regional Water and Land Plan.

Four parameters combine to construct the TLI: total nitrogen, total phosphorus, clarity and chlorophyll *a*. The parameters reflect the dynamics of the annual lake cycle.

Nitrogen and phosphorus are essential plant nutrients. In large quantities they can encourage the rapid growth of nuisance aquatic plants such as algae. High levels of water-bound nitrogen and phosphorus most often come from agricultural and urban land use, but can also come from geothermal inputs and deep springs that leach phosphorus from the rock geology.

Clarity is measured using a Secchi disc attached to a rope. The rope records the depth at which the disc disappears from sight.

Chlorophyll *a* is the green pigment in plants used for photosynthesis. It is a good indicator of the total quantity of algae in a lake. Algae are a natural part of any lake system, but large amounts of algae decrease water clarity, make the water look green, can form surface scums, reduce dissolved oxygen levels, can alter pH levels, and can produce unpleasant tastes and smells.

Calculations for the TLI:

- $TL_n = -3.61 + 3.01 \log(TN)$
- $TL_p = 0.218 + 2.92 \log(TP)$
- $TL_s = 5.10 + 2.27 \log(1/SD - 1/40)$
- $TL_c = 2.22 + 2.54 \log(Chl_a)$
- $TLI = \Sigma (TL_n + TL_p + TL_s + TL_c) / 4$

### 1.2 Trophic States

The higher the TLI, the lower the water quality, and the greater risk of environmental 'problems' like algal blooms and unusual foams. It can also deoxygenate the bottom water which releases nutrients from the sediment. Trophic level bands are grouped into trophic states for qualitative description as shown below.

Table 8 Trophic States

Trophic state	Nutrient enrichment category	Trophic level	Chla (mg/m <sup>3</sup> )	Secchi depth (m)	TP (mg/m <sup>3</sup> )	TN (mg/m <sup>3</sup> )
Ultra-microtrophic	Extremely Low	0.0 to 1.0	< 0.33	> 25	< 1.8	< 34
Microtrophic	Very Low	1.0 to 2.0	0.33 – 0.82	25 – 15	1.8 – 4.1	34 – 73
Oligotrophic	Low	2.0 to 3.0	0.82 – 2.0	15 – 7.0	4.1 – 9.0	73 – 157
Mesotrophic	Medium	3.0 to 4.0	2 – 5	7.0 – 2.8	9 – 20	157 – 337
Eutrophic	High	4.0 to 5.0	5 – 12	2.8 – 1.1	20 – 43	337 – 725
Supertrophic	Very high	5.0 to 6.0	12 – 31	1.1 – 0.4	43 – 96	725 – 1558
Hypertrophic	Extremely high	6.0 to 7.0	> 31	< 0.4	> 96	> 1558

**Microtrophic** lakes are very clean, and often have snow or glacial sources. Lake Sumner in North Canterbury is a microtrophic lake.

**Oligotrophic** lakes are clear and blue, with low levels of nutrients and algae. Lake Rotoma is an oligotrophic lake.

**Mesotrophic** lakes have moderate levels of nutrients and algae. Lake Rerewhakaaitu is a mesotrophic lake.

**Eutrophic lakes** are green and murky, with higher amounts of nutrients and algae. Lakes Rotorua and Rotoiti are now both eutrophic lakes.

**Supertrophic lakes** are fertile and saturated in phosphorus and nitrogen, and have very high algae growth and blooms during calm sunny periods. Lake Okaro is a supertrophic lake.

**Hypertrophic lakes** are highly fertile and supersaturated in phosphorus and nitrogen. They are rarely suitable for recreation and habitat for desirable aquatic species is limited. Lakes Hakanoa, Ngaroto, Mangahia, Waahi and Waikare in the Waikato are hypertrophic lakes.

### 1.3 Cyanobacteria

Cyanobacteria (blue-green algae) blooms often occur more frequently and more extensively in lower quality water. The worst quality lake waters commonly experience cyanobacteria blooms e.g. Okawa Bay (TLI 5.3), Lake Okaro (TLI 5.7). Lake Rotoehu started experiencing sustained algal blooms from 1994 as the quality of the lake deteriorated and the TLI increased from 3.7 to 4.8.

Cyanobacteria blooms can form in lakes with good water quality, like Lake Tarawera. Here a large inflow of water with a low nitrogen to phosphorus ratio enters the lake along the shoreline adjacent to Rotomahana. This favours cyanobacteria and when conditions are calm they can assume bloom proportions.

#### 1.4 **Dissolved Oxygen**

Dissolved oxygen is important for fish and other aquatic life to live. Water should ideally be more than 80 percent saturated with dissolved oxygen for most aquatic species to live in it.

In lakes where the waters do not mix for several months over the summer, reduced dissolved oxygen levels in the bottom waters is of concern, especially for fish and other aquatic animals. Bacteria feeding on decaying algal material use up dissolved oxygen in the bottom waters. When this happens, nitrogen and phosphorus are released from the lakebed sediments. When the lake waters re-mix in winter these nutrients are available for plants and algae in the surface waters.

#### 1.5 **E-coli (faecal coliforms)**

*Escherichia coli* (*E. coli*) is a freshwater indicator organism for some disease-causing agents in the water. E-coli comes from human and animal faeces, so if they are present in water there are likely to be other bacteria as well that make the water unsafe for drinking or swimming. Drinking water should have no detectable E-coli bacteria in it at all. Water used for recreation should ideally have less than 126 E-coli colonies per 100 ml of water, though this standard does vary.



## **Appendix 2 - Lake Okaro Action Plan's Working Party, Public Submissions, Adoption and Review Process**

Environment Bay of Plenty prepared draft working papers in October 2003 to summarise Lake Okaro's water quality problem and information on options to improve the water quality.

A working party was formed on 18 December 2003 to discuss options to reduce the nutrient load on Lake Okaro. The working party is made up of the local landowners, sector group representatives and staff from Rotorua District Council and Environment Bay of Plenty. The working party met on the following dates:

- Tuesday 6 April 2004
- Thursday 30 September 2004
- Tuesday 12 April 2005
- Tuesday 26 July 2005

Topics discussed at the meetings include the alum trial, the constructed wetland, riparian protection and fencing, water supply, nutrient management, conservation values, and others.

Environment Bay of Plenty and Rotorua District Council formulated a proposed Lake Okaro Action Plan based on the working party discussions and other investigations. This was approved and released for submissions by:

- Environment Bay of Plenty's Regulation and Monitoring Committee on 11 October 2005, after requesting an additional funding report presented on 3 November 2005.
- Rotorua District Council's Planning & Bylaws Committee on 11 October 2005.
- Rotorua Lakes Strategy Joint Committee on 17 November 2005.

The proposed Lake Okaro Action Plan was open for submissions from 23 November 2005 to 23 January 2006. No submissions were received.

The Rotorua Lakes Strategy Joint Committee formally adopted the Lake Okaro Action Plan on 29 March 2006.

A review of the Lake Okaro Action Plan, assessing its implementation and effectiveness against Lake Okaro's long-term water quality target should begin by 2017. This 10-year period is a "medium-term" timeframe for Lake Okaro. Some progress towards the anticipated effects listed in Chapter 8 should be noticeable by 2017, once the Lake Okaro Action Plan's actions are implemented (see section 4.2).



## Appendix 3 - Sediment Nutrient Release

Table 9 calculates the sediment nutrient release from the concentration of dissolved nutrients in the water column after mixing has taken place. The volume is calculated from the surface area of 320,000 m<sup>2</sup> by the mean depth of 12.1 m.

Table 9 Sediment nutrient releases recorded August 1992 – June 2001

Date	Time	DRP g/m <sup>3</sup>	NH <sub>4</sub> N g/m <sup>3</sup>	DRP g/m <sup>3</sup> average	NH <sub>4</sub> N g/m <sup>3</sup>	P tonnes	N tonnes
<b>BOP130017 18m Basin</b>							
06/08/92	11:40:00	0.063	0.296				
06/08/92	11:40:00	0.063	0.319				
06/08/92	11:40:00	0.064	0.318				
06/08/92	11:40:00			0.063	0.311	0.25	1.20
17/08/93	10:53:00	0.111	0.676				
17/08/93	10:53:00	0.111	0.671				
17/08/93	10:53:00	0.113	0.696				
17/08/93	10:53:00			0.112	0.681	0.43	2.64
08/08/94	10:30:00	0.114	0.830				
08/08/94	10:30:00	0.114	0.785				
08/08/94	10:30:00	0.120	0.764				
08/08/94	10:30:00			0.116	0.793	0.45	3.07
24/06/97	12:00:00	0.123	0.565				
24/06/97	12:00:00	0.124	0.566				
24/06/97	12:00:00			0.124	0.565	0.48	2.19
13/07/00	11:40:00	0.034	0.453				
13/07/00	11:40:00	0.034	0.459				
13/07/00	11:40:00			0.034	0.456	0.13	1.77
19/06/01	12:56:00	0.079	0.684				
19/06/01	13:00:00	0.082	0.727				
19/06/01	13:03:00	0.090	1.260				
19/06/01	13:00:00			0.084	0.890	0.32	3.45
<b>Average</b>						<b>0.38</b>	<b>2.41</b>





## Appendix 4 - Lake Okaro Trophic State Targets

Rutherford and Cooper (2002) reviewed Environment Bay of Plenty's Lake Okareka Draft Action Plan Working Paper. The process followed in that review is also followed here. The ratio of total nitrogen divided by total phosphorus (TN/TP) in Lake Okaro has ranged from 8 – 14 since 1990. Pridmore (1987) states that a TN/TP ratio of 10 – 17 should produce balanced phytoplankton growth. Therefore, the nutrient content of Lake Okaro is balanced with a tendency for nitrogen limitation.

Using the method of Rutherford & Cooper (2002) an even reduction was applied across the four TLI parameters in order to calculate the required nitrogen and phosphorus reduction. At Lake Okaro this results in a reduction of 0.72 to each of the four component TLx values. Thus it was estimated that an average lake concentration of 68 mgP/m<sup>3</sup> and 730 mgN/m<sup>3</sup> would give an average TLI of 5.0. Current lake concentrations are 123 mgP/m<sup>3</sup> and 1282 mgN/m<sup>3</sup>, which implies that a reduction of 44% is required.

Table 10 Current and target lake quality and trophic level indices

	Chla mg/m <sup>3</sup>	SD m	TP mg/m <sup>3</sup>	TN mg/m <sup>3</sup>
Current lake quality	33.00	1.61	123.34	1281.84
Current TLx	TLc 5.86	TLs 4.99	TLp 6.30	TLn 5.73
Required reduction	0.72	0.72	0.72	0.72
Target TLx	5.14	4.27	5.58	5.01
Target lake quality	14.1	2.2	68.0	730.0

Gibbons-Davies 2003 (average 1990-2001)

Average = 5.72	Target = 5.00	Reduction = 0.72
----------------	---------------	------------------

The target lake quality is higher than the quality of Lake Okaro has been at any time over the last ten years, although the secchi disc depth averaged 2.25 metres in the 2000/2001 sampling year. Table 11 illustrates the Rutherford and Cooper (2002) method to calculate the catchment load reduction.

Table 11 Current nutrient load estimate based on average lake concentrations (1994-2001), and target nutrient loads to reach proposed target lake concentrations

	chl <sub>a</sub> mg/m <sup>3</sup>	SD m	TP mg/m <sup>3</sup>	TN mg/m <sup>3</sup>	
Average 1990-2001	33.00	1.61	123.34	1,281.84	Gibbons-Davies (2004)
Target lake quality reduction	14.10	2.20	68.00 45%	730.00 43%	
Concentration reduction sought			55.34	551.84	
Lake area A m <sup>2</sup>	320,000				Donald (1997)
Lake volume m <sup>3</sup>	3,872,000				Mean depth 12.1 m
Catchment runoff Q1 m <sup>3</sup> /yr	2,400,000				375 ha, 640mm
Rainfall on lake Q2 m <sup>3</sup> /yr	187,200				32 ha, 585 mm
Total inflow Q = Q1 + Q2	2,587,200				
Hydraulic loading Q/A m/yr	8.1				
Predicted retention coefficient R	0.57				
			TP (t/yr)	TN (t/yr)	
Estimated current load			0.73	7.71	M = CQ/(1-R)
Estimated target load			0.33	4.39	
Estimated reduction			0.40	3.32	

## **Appendix 5 - Rotorua District Plan**

The Lake Okaro catchment is zoned Lakes A in the Rotorua District Plan. This zone manages land use based on two primary policy levels, termed the Sensitive Policy Area and Less Sensitive Policy Area, through a series of environmental performance standards. The Okaro landscape policy area is part of the Less Sensitive Policy Area.

The Lakes A Zone rules use a sub-level approach of management areas for each of the identified policy areas within the zone. In the plan the entire policy area of Lake Okaro is classed as management area Less Sensitive Rural.

The Action Plan is consistent in its approach with the specific Lakes A Zone landscape policies and wider objectives and policies for this area. The landscape policies promote:

- Planting of Lake Okaro's riparian margins.
- Maintenance of expansive areas of vegetation including indigenous vegetation.
- Development of land in ways that revegetate erosion-prone land and enhance water quality.
- Buffers to protect waterbodies and the integrity of the indigenous ecology.

The wider objectives and policies of the Lakes A Zone seek to (among others) maintain, enhance and promote:

- Indigenous biodiversity and natural character.
- Water quality, healthy functioning aquatic ecosystems, wetlands and riparian areas.
- Land management that avoids adverse effects on water quality.
- Existing amenity values and public lake access.
- Integrated and co-ordinated management of the lakes through partnerships and working relationships with community groups and iwi.



## Appendix 6 - Regional Water and Land Plan Methods 35, 35A and 35B (as amended by appeal resolutions)

The following methods provide the legal impetus behind the formation of working parties and action plans for the Rotorua Lakes.

Method 35            Develop and implement Action Plans to maintain or improve lake water quality to meet the Trophic Level Index set in Objective 10. Action Plans will be developed according to the following process.

### Action Plan Stages

- 1     Stage 1 – Risk Assessment and Problem Evaluation
  - (a)   Identify lakes that exceed the Trophic Level Index (TLI) set in Objective 10, and initiate Stage 3. As at August 2003, the lakes that exceed the TLI are Lakes Okareka, Rotoehu, Okaro, Rotorua and Rotoiti. The timeline to initiate Stage 3 is:
    - (i)    Lake Okareka – early 2003.
    - (ii)   Lake Rotoehu, Lake Okaro – mid 2003
    - (iv)   Lakes Rotorua & Rotoiti – mid 2003
  - (b)   For all other Rotorua Lakes not specified in (a):
    - (i)    Evaluate the risk of the lake exceeding the TLI set in Objective 10, and initiate Stage 2. The timeline to initiate the risk assessment is: Lakes Rerewhakaaitu, Tarawera, Rotoma, Okataina, Tikitapu, Rotokakahi, Rotomahana – 2005. The risk of the lake exceeding the TLI will be assessed using all lake water quality monitoring data, including, but not limited to, dissolved oxygen (Hypolimnetic Volumetric Oxygen Depletion Rate, HVOD), water temperature, nitrogen and phosphorus levels, Chlorophyll a, algal species, Secchi disc depth, Trophic Level Index, and Percent Annual Change (PAC). The evaluation will take into account the age of groundwater, spring water and inflowing stream water in the catchment, and the lag time between land use activities and effects on water quality.
    - (ii)   Where state of the environment monitoring identifies that a lake exceeds its TLI specified in Objective 10, where the 3-year moving average TLI for the lake exceeds its designated TLI specified in Objective 10 by 0.2 for 2 consecutive years, initiate Stage 3.
- 2     Stage 2 – Project Prioritisation
  - (a)   Evaluate the results from Stage 1(b)(i) to determine if Stage 3 and 4 of the Action Plans are necessary to maintain or improve lake water quality.
  - (b)   Prioritise the development of Stage 3 and 4 of the Action Plans for lakes where such action is necessary. Prioritisation will be determined in-conjunction with the co-management partners of the Strategy for the Lakes of the Rotorua District.
- 3     Stage 3 – Development of Action Plan for Lake Catchment
  - (a)   Where lake water quality exceeds the TLI:
    - (i)    Identify and quantify the lake water quality problem and any necessary research.

- (ii) Identify and quantify the reduction of nitrogen and phosphorus required in the catchment to achieve the TLI in Objective 10.
- (iii) Estimate the contributing sources of nitrogen and phosphorus in the catchment, and the effects of existing land uses and activities in the catchment on the lake's nutrient load.
- (iv) Estimate the lag between actual land use change and lake water quality effects.
- (v) Establish a timeline for developing an Action Plan for the lake catchment.
- (b) Disseminate information and research findings to the community.
- (c) Develop and implement Stage 3 and 4 of the Action Plan in conjunction with an Action Plan Working Group comprising appropriate parties from the individual catchment. The Action Plan Working Group will include, but is not limited to, Rotorua District Council, iwi, community groups, landowners, and relevant resource management agencies and industry representative groups. The main aims of Stage 3 of the Action Plan are:
  - (i) Identify factors that affect lake water quality and any necessary research.
  - (ii) Include fair and equitable provisions to address effects on existing land uses where it is necessary to restrict land use to maintain or improve water quality. Such provisions include, but are not limited to, criteria for possible financial compensation and land acquisition.
  - (iii) Identify efficient, cost-effective and equitable measures and options to reduce inputs of nitrogen and phosphorus from the lake catchment to maintain or improve lake water quality.
  - (iv) Determine if the TLI in Objective 10 can be realistically achieved, and a practicable timeline for achieving the target TLI.
- (d) Identify the costs and benefits of different nutrient management and reduction methods. Such methods include, but are not limited to:
  - (i) Education on nutrient management;
  - (ii) Riparian retirement;
  - (iii) Constructed wetlands;
  - (iv) Sewage reticulation;
  - (v) Review of existing discharge consents in the catchment;
  - (vi) Land use changes;
  - (vii) Land purchase or lease;
  - (viii) Engineering works;
  - (ix) Nutrient trading systems.
- (e) Take into account the macro-economic and micro-economic effects of lake water quality maintenance or improvement measures, including the value of land use and lake water quality to the catchment, district, region and wider community.
- (f) Apply existing funding policies and other funding options for lake water quality maintenance or improvement works, including, but not limited to:
  - (i) Differential rating as a means of paying for works within the catchment;
  - (ii) Central government funding.
  - (iii) User charges.
  - (iv) Environmental Programmes.
- (g) Determine if regulatory measures are necessary to control the discharge of nitrogen or phosphorus, or both, from land use activities in the lake catchment. (Refer to Method 35A.)
- (h) Document a timetable for implementing nutrient management and reduction options.

#### 4 Stage 4 – Implementation and Monitoring of Action Plans

- (a) Implement the lake water quality improvement measures identified and agreed to in Stage 3.
- (b) Evaluate and report progress towards achieving the TLI in Objective 10 to all parties, and the community.

#### Method 35A

In conjunction with the Action Plan Working Party (refer to Method 35), review the necessity and application of the Rules in section 9.4 of this regional plan to individual lake catchments.

- 1 The review will:
  - (a) Consider matters from the Action Plans developed in accordance with Method 35.
  - (b) Consider how to achieve the long-term sustainable management of nitrogen and phosphorus use and discharges in the individual lake catchment.
  - (c) Recognise that it may be efficient, effective, and appropriate to develop and implement specific rule(s) for each of the lake catchments.
  - (d) Recognise that the Action Plan Working Group may recommend to Environment Bay of Plenty any changes to the rules in section 9.4, but Environment Bay of Plenty retains control over the plan change process. Members of the Action Plan Working Party, and individuals retain the right of submission and appeal.
  - (e) Include any changes to the rules in section 9.4 through a plan change process in accordance with the requirements of the First Schedule to the Resource Management Act 1991.
- 2 The review will be discussed during the development of the Action Plans, and plan change(s) initiated for:
  - (a) Lake Okareka – January 2005.
  - (b) Lake Rotoehu – January 2006.
  - (c) Lake Okaro – January 2006.
  - (d) Lake Rotorua and Rotoiti – January 2006.

Method 35B Support land use changes, and changes to land use rules, that:

- (a) Achieve lake management objectives identified in lake Action Plans developed in accordance with Method 35.
- (b) Integrate land use planning and rules in Environment Bay of Plenty's resource management plans and Rotorua District Council's District Plan for lake catchments.
- (c) Recognise that land use change and land management practices are an important part of lake management.
- (d) Actively promote and support low nutrient loss land uses and land management practices in the catchments of the Rotorua Lakes.





## **Appendix 7 - Environmental Programmes**

Environmental programmes are contractual agreements between rural landowners and Environment Bay of Plenty. They assist rural landowners to implement various best practice options on their farm. They often involve funding from Environment Bay of Plenty and/or Rotorua District Council in recognition of the benefits these actions have for the district and the region (such as improved lake water quality).

Council staff develop the environmental programme through negotiations with landowners. Environmental programmes detail specifications of works or management changes, and allocate responsibility and cost share for initial works and subsequent maintenance.



## Appendix 8 - Five Lake Phosphorus-Binding Products

Table 12: Comparison of lake phosphorus-binding products

Name	Description	Advantages	Disadvantages
Phoslock	A clay infused with lanthanum.	<ul style="list-style-type: none"> <li>• Inert, not toxic.</li> <li>• Proven effective.</li> <li>• Caps P release from sediments.</li> </ul>	<ul style="list-style-type: none"> <li>• Comparatively expensive.</li> <li>• Manufactured overseas.</li> <li>• Not as effective at short-term P-removal in water.</li> </ul>
Alum	Aluminium sulphate $AlK(SO_4)_2$	<ul style="list-style-type: none"> <li>• Comparatively cheap.</li> <li>• Proven effective.</li> </ul>	<ul style="list-style-type: none"> <li>• Not effective as a P sediment cap.</li> <li>• May release P again under certain conditions.</li> </ul>
Melter slag	Crystalline mineral oxides	<ul style="list-style-type: none"> <li>• Re-use of waste product.</li> <li>• Comparatively cheap.</li> <li>• May also remove some N-ammonium ions.</li> </ul>	<ul style="list-style-type: none"> <li>• Unproven in the field.</li> <li>• May have toxicity concerns.</li> </ul>
Z2 / modified Zeolite (two + variations)	Porous silicate crystal infused with another chemical (such as alum)	<ul style="list-style-type: none"> <li>• Locally mined and manufactured.</li> <li>• Can remove some N-ammonium as well as P.</li> <li>• Can act as a sediment cap.</li> </ul>	<ul style="list-style-type: none"> <li>• Unproven in the field.</li> </ul>
Allophane	A clay-sized mineral containing aluminium and silicon, found in volcanic soils.	<ul style="list-style-type: none"> <li>• Extensive deposits.</li> <li>• Locally mined.</li> <li>• Comparatively cheap.</li> </ul>	<ul style="list-style-type: none"> <li>• Unproven in the field.</li> </ul>

Table 12 is only an initial comparison based on current knowledge. The limnocorral mesocosm trial will help determine the cost-effectiveness and efficiency of these products, along with any other advantages or disadvantages.