Algae in the Rotorua Lakes

Algal bloom at Okawa Bay, Lake Rotoiti in February 2003

Introduction

Algae are a diverse group of plants that includes seaweeds, bottom-living cells, and phytoplankton that are suspended in the water. Algae are a vital part of lakes as they are the main producers of food and oxygen. Most other organisms therefore depend directly or indirectly on algae to sustain life. All algae contain chlorophyll, which is a green pigment that enables them to build up biomass and obtain energy by capturing light.

Other coloured pigments are sometimes present and may become clearly visible when there are red tide blooms in estuaries or the ocean, or blue/green coloured algal blooms in lakes.

Blue-green algae – *cyanobacteria*

Different species of algae thrive under different environmental conditions. In winter, phytoplankton known as diatoms are generally abundant. This group is well adapted to low light levels and thrives in winter when the water column is fully mixed from top to bottom, enabling the heavy cells to remain suspended in the water. Blue-green algae (cyanobacteria) are a group of bacteria, rather than true algae, that have acquired chlorophyll to capture light and behave like plants.

Photo of Anabaena planktonica, one of the blue-green algae responsible for the bloom in Lake Rotoiti in summer 2002-3 (magnified = 400 times). The clear cell in the middle of the filament is a heterocyst, a specialised cell for nitrogen fixation. Photo: Eloise Ryan.

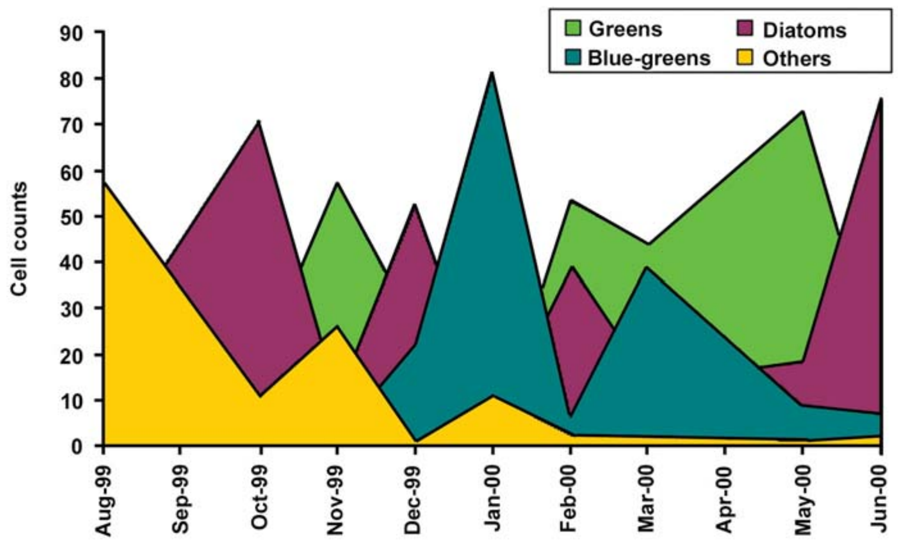
Cyanobacteria are present naturally in lakes but they may congregate into surface blooms under specific environmental conditions, though not all algal blooms are due to cyanobacteria. Many species of cyanobacteria thrive when there are high light and nutrient levels, as well as warm water temperatures. Several species have gas vesicles that enable them to float, and congregate at the water surface to form blooms under calm summer conditions.

In addition, some species of cyanobacteria can ‘fix’ atmospheric nitrogen. This process allows them to take advantage of the limitless supply of nitrogen gas that is dissolved in water, freeing themselves of dependence on nitrogen solutes such as nitrate and ammonia which might otherwise limit their rate of growth.

Nutrients

The key to reducing the frequency of algal blooms is to restrict the nutrient supply of nutrients. With increasing levels of nutrients, more algal growth occurs near the water surface and the proportion of nuisance cyanobacteria increases.

Phosphorus and nitrogen are nutrients that are especially important in the Rotorua lakes because they are present naturally at levels that are less than optimal for growth of algae, compared with other nutrients such as potassium or iron. If you live in one of the catchments of the Rotorua lakes, where the water eventually drains to a lake, then your activities will have a bearing on how much nitrogen and phosphorus reaches that lake and, therefore, on the algal growth and water quality of the lake.



Cell counts in Lake Rotorua, 1999 to 2000 showing the variations between different groups of algae. Note how quickly variations occur between the different groups.

Monitoring and management

Some cyanobacteria produce toxins that may cause skin irritations or problems with the nervous system or liver if swallowed in large quantities (acute toxicity) or with prolonged low-level exposure (chronic toxicity). Environment Bay of Plenty conducts regular monitoring of algae in the Rotorua lakes to ensure that the lakes are safe for swimming and other recreational activities.

Health warnings are occasionally issued for lakes or bays, to alert lake users of the potential health risks from entering water affected by high levels of cyanobacteria.

Environment Bay of Plenty conducts routine monitoring at twelve of the Rotorua lakes to assess levels of nutrients, algae and water clarity. These measurements are combined into a single measure known as the Trophic Level Index, to provide an overall assessment of water quality for each of the 12 lakes.

The Trophic Level index is also used in the Water and Land Plan to assist with decisions on sewage schemes, land retirement and lake management, in consultation with the community.

Environment Bay of Plenty has also funded the Chair in Lakes Management and Restoration at Waikato University to carry out research on the causes of algal blooms. This research is being used to provide a sound scientific basis for management actions that are being proposed for the lakes.

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This fact sheet was prepared by Dr David Hamilton.

This fact sheet was last updated January 2005.

Lake Dynamics

Introduction

Water quality in the Rotorua lakes is governed by complex interactions between physical, chemical and biological processes.

Physical processes determine the transport and mixing of substances in a lake.

Chemical processes determine the availability of solutes, including nutrients, for plant growth.

Biological processes affect the way that different organisms interact and how they respond to the physical and chemical environment.

Lake mixing

The deeper Rotorua lakes such as Tarawera, Rotoiti and Rotoma mix fully from top to bottom in winter, but stratify into two layers during warm, calm periods in summer and autumn. This stratification occurs because surface waters become warmer and buoyant when they are heated by the sun, while bottom waters remain cool and dense. In winter as the surface waters cool, the water column mixes fully again.

In the shallow Rotorua lakes, such as Rotorua, Rotoehu and Rerewhakaaitu, mixing occurs almost continuously, though in warm, calm periods there may be brief periods of stratification.

When temperature stratification occurs, substances are dispersed across a lake many times faster than they are dispersed through the lake depth. This often results in large gradients in the concentration of organisms and chemical substances over the depth of the lake.

Oxygen levels

With the exception of specialised anaerobic organisms, all life depends on the presence of dissolved oxygen. Oxygen in the surface waters of a lake usually remains stable because losses from respiration are replenished by gains from the atmosphere or photosynthesis, the process used by plants and algae to capture light energy and convert inorganic nutrients (e.g. phosphorus and nitrogen) into organic material. When lakes stratify, however, oxygen in the bottom waters is not replenished adequately because atmospheric inputs are cut off and there is insufficient light for photosynthesis in the deeper, dark waters. The rate that oxygen is depleted from the bottom waters when a lake stratifies is determined strongly by the supply of organic matter arising as algae settle out of the water column and die. This supply of organic matter acts as food for bacteria, which use oxygen to break it down.

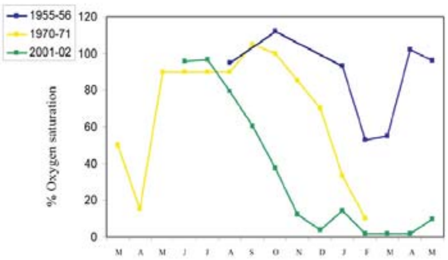
If high levels of nutrients stimulate the growth of algae in the surface layer and result in an oversupply of organic matter, then all of the oxygen in the bottom waters of a lake may be consumed before being restored by winter mixing in deep lakes or wind action in shallower lakes.

Aerial view of Lake Rotoiti

Nutrients from bottom sediments

The loss of oxygen from the bottom waters of a lake leads to a chain of chemical reactions as bacteria ‘scavenge’ material for oxygen. Oxygenated forms of iron and manganese are scavenged by bacteria, which change these compounds from particle-bound forms in the bottom sediments to dissolved forms that diffuse into the water. Nutrients such as phosphorus that were previously bound to the iron and manganese, also dissolve and diffuse into the water.

This complex cycle is dangerous for the health of the lake, since the loss of oxygen from the bottom waters can mobilise large quantities of nutrients such as phosphorus, that were previously locked up in the bottom sediments.

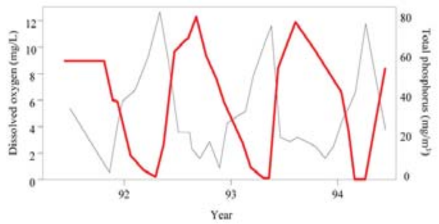


Declining levels of oxygen during the stratefied period in Lake Tikitapu are cause for concern because of nutrients that may be released from the bottom sediments and stimulate algal blooms.

Feedback to growth of algae

Very large quantities of phosphorus are being released from the bottom sediments of Lakes Rotoiti and Okaro when these lakes stratify and oxygen is lost from bottom waters. As the nutrients released from the bottom sediments are mixed through the water column, with each annual cycle they stimulate further algal growth.

This perpetuates a vicious cycle of loss of oxygen, nutrient release and more algal growth, which characterises the dynamics of Lakes Rotoiti and Okaro.



Dissolved oxygen (red line) and phosphorus levels (black line) in the bottom waters of Lake Rotoiti, showing how seasonal loss of oxygen leads to a large increase in phosphorus concentrations through release from the bottom sediments. More than 15 tonnes of phosphorus may be released each year when the oxygen levels are reduced.

Monitoring and research

Environment Bay of Plenty conducts routine monitoring of 12 Rotorua lakes to detect changes in nutrient and phytoplankton levels and water transparency. It has also funded a Chairperson in Lakes Management and Restoration at the University of Waikato, to provide independent scientific support for managing the Rotorua lakes.

Research conducted at the University of Waikato has identified clearly that while oxygen levels have remained stable in the bottom waters of some lakes (e.g. Tarawera and Rotoma), it has declined progressively for a number of years in others (e.g. Lakes Tikitapu and Okareka). In some lakes expensive engineering works may be required to restore oxygen levels to bottom waters, so that people can continue to enjoy the lake the way they have been accustomed to in the past.

Action also needs to be taken to prevent more nutrients getting to the lakes. This will ensure that the Rotorua lakes continue to provide a valuable tourism and recreational resource for years to come.

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Lake Trophic Level

Sunset at Lake Tarawera. The way in which we manage nutrient inputs to this lake and other Rotorua lakes will decide the long-term changes in lake water quality.

Introduction

Lakes such as Tarawera and Rotoma are clear and appear blue because most of the light is absorbed by water; red light is absorbed strongly, while blue light is scattered and reaches the human eye. Lakes such as Rotoiti and Okaro have high levels of suspended algae and appear green because algae absorb blue and red light strongly, but reflect green light.

These and other differences between the lakes can be reflected numerically by measuring physical parameters within a lake. A measure of these physical parameters can then be incorporated into an index defining the life-supporting capacity of the lake. Such an index reflects the trophic level of a lake.

Measuring Trophic Levels

Several measures are used to determine lake trophic level.

Nitrogen and phosphorus are nutrients that affect the concentrations of algae in a lake; the higher the concentration of these nutrients, the more eutrophic (nutrient rich) a lake is.

Water transparency is also used to determine lake trophic status. Water clarity is measured with a Secchi disk: a circular white or black-and-white disk that is lowered through the water to a depth where it disappears from view.

In clear, oligotrophic lakes such as Rotoma, the Secchi disk depth may be greater than 10 metres while in eutrophic lakes with low visibility, the Secchi disk depth may be less than one metre.

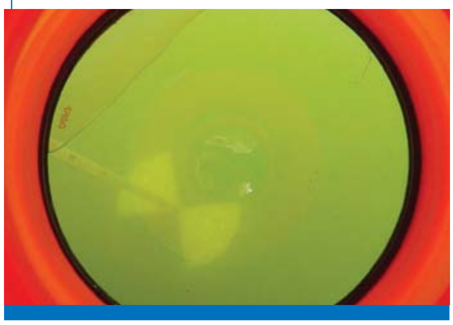
Concentrations of algae are the best measure of lake trophic status though it is difficult to measure algae directly.

Chlorophyll *a* concentration is most often used to give an indirect measure of algal concentrations. Chlorophyll *a* is the pigment present in all algae that makes them appear green and allows them to obtain energy from the sun.

Levels of oxygen provide an indirect measure of lake trophic status. Eutrophic lakes often have little or no oxygen in their bottom waters through summer, and may have no oxygen in their bottom waters for long periods of the year.

Trophic Level Index

Assessing the trophic state of a lake, and whether water quality is improving or declining, is complex



Water transparency measurement In Lake Rotoiti in 2003, showing visibility of the Secchi disk view through a viewing port of the water surface. In this case the low water clarity is due to a bloom of blue-green algae.
Photo: David Burger

and there are many different measurements that may be used. It is convenient, however, to combine measurements such as nutrients, water clarity and chlorophyll *a* in a mathematical equation to produce a single measure that gives a 'snapshot' of lake trophic level at the time that measurements are made.

The Trophic Level Index is formed by measurements of nitrogen, phosphorus, clarity and chlorophyll *a.* The Trophic Level Index has been especially formulated for New Zealand lakes and is rated from zero (ultra-microtrophic) to 7.0 (hypertrophic) to define a range of of lake types. The Trophic Level Index is used by Environment Bay of Plenty in the Regional Water and Land Plan to guide decisions about management of lakes and their catchments. In lakes where the TLI value has increased or where it is already at a level above the target set in the Regional Water and Land Plan, the aim is to reduce it to below the target, to improve water quality and reduce the likelihood of algal blooms.

Action plans are being developed to restore several of the Rotorua lakes. These plans use the Trophic Level Index to assess trends in lake water quality.

Trophic Level	Lake Type	Perceived Lake Quality
0.1–1.0	Ultra-microtrophic	Excellent
1.1–2.0	Microtrophic	↑
2.1–3.0	Oligotrophic	↕
3.1–4.0	Mesotrophic	↕
4.1–5.0	Eutrophic	↕
5.1–6.0	Supertrophic	↓
6.1–7.0	Hypertrophic	Very Poor

Lake Trophic Levels and Lake Types

Lake	3 yearly average TLI 2002 *TLI units*	3 yearly average TLI 2003 *TLI units*	3 yearly average TLI to 2004 *TLI units*	Regional Water & Land Plan *TLI units*	Long Term Trend In terms of TLI units over analysis period	Lake Type based on Trophic Level
Okaro	–	5.5*	5.5*	5.0	Degraded but definite improvement	Supertrophic
Rotorua	4.8	4.9	4.9	4.2	Degraded No change	Eutrophic
Rotoehu	4.7	4.7	4.6	3.9	Degraded No change	Eutrophic
Rotoiti	4.0*	4.3*	4.3	3.5	Definite degradation	Eutrophic
Rotomahana	-	3.6*	3.7	3.9	Possible improvement	Mesotrophic
Rerewhakaaitu	3.4*	3.2	3.3	3.0	No change	Mesotrophic
Tikitapu	3.0*	3.1*	3.2	2.7	Probable degradation	Oligotrophic
Okataina	2.8*	3.0*	3.0	2.6	Possible degradation	Oligotrophic
Tarawera	2.8*	2.9*	2.9	2.6	No change	Oligotrophic
Rotoma	-	2.5*	2.6	2.3	No change	Oligotrophic
Rotokakahi	-	-	-	3.1	-	Mesotrophic

*Lake Trophic Level Index value as a three-year average for the Rotorua lakes, a target value in the Regional Water and Land Plan, and long-term trend. *Two Year average.*

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Nutrient Inputs

Algal growth in the Rotorua lakes is dependent on a variety of essential elements, called nutrients. The two most common nutrients are nitrogen and phosphorus. These nutrients can be dissolved (soluble), solid (insoluble), or found in organic matter.

Nitrogen and phosphorus need to be dissolved in a water body, like a lake or stream, before algae can use them. Most nitrogen and phosphorus in a lake is not dissolved but is found in solid particles and organic matter. As this material begins to break down the nutrients dissolve.

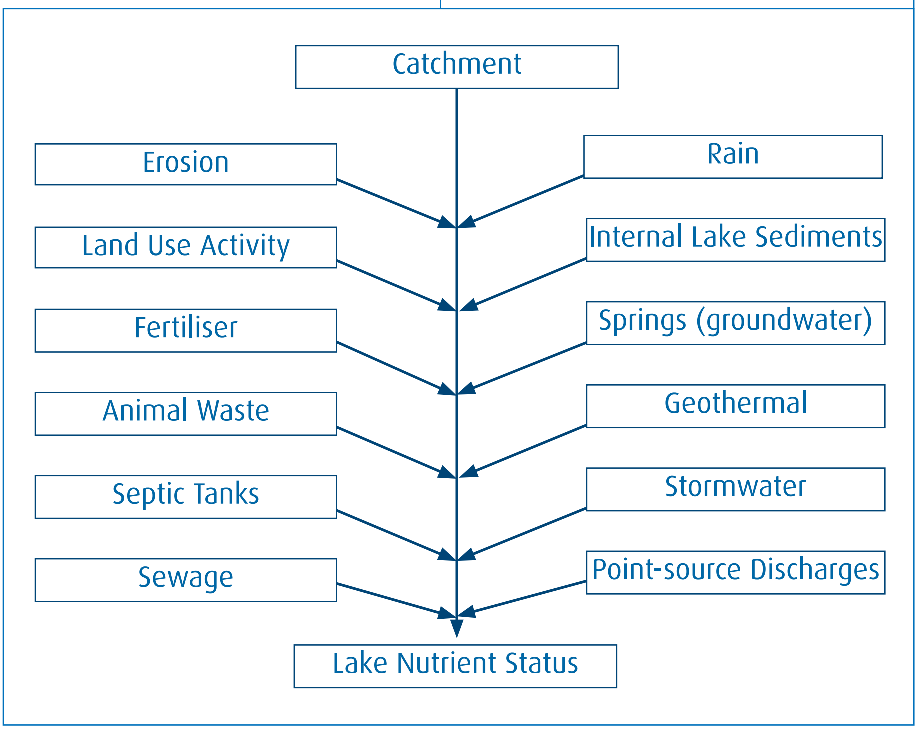
Sometimes algal growth can be slowed down or stopped when a nutrient becomes completely used up. In Lake Rotorua this can happen to both nitrogen and phosphorus at different times.

Nitrogen and phosphorus levels in many of the Rotorua lakes need to decrease to reduce algae numbers and blooms in those lakes.

To do this it is important to know where nitrogen and phosphorus in the Rotorua lakes come from. The diagram below lists the main nutrient sources.

Erosion

Erosion can take many forms, such as slips, stream bank erosion, and runoff from tilled land. Phosphorus is the main nutrient released by erosion, as it is attached to soil particles.



Land use activity

All land use puts nutrients into waterways, even areas of native bush. But native bush and exotic forestry only leach small amounts of nutrients, while intensive farming, horticulture and cropping can export large amounts of phosphorus and nitrogen into waterways and lakes. Nutrient release from a property can be decreased with best management practices.

The Rotorua Lakes Problem

- Many of Rotorua's lakes have too many nutrients, caused by activities such as farming and residential settlement.
- These nutrients (nitrogen and phosphorus) feed algal growth, which degrades water quality.
- The Rotorua Lakes Protection and Restoration Action Programme is initially tackling water quality problems in five lakes in the Rotorua district
- Some long-term solutions focus on land management and include new wetlands, restricting nutrients "outflows" from properties, and changes in land use.
- More urgent solutions include sewerage reticulation, structures to divert flows, and the use of mineral products to lock up nutrients.

Fertiliser

Most fertiliser applied to land stays in the soil, so does not have a major effect on a lake unless it is applied excessively or into a waterway. Storm runoff and over-application of fertiliser can wash or leach excess nutrients into streams and lakes.

Animal waste

Urine from livestock is a major source of nitrogen that easily leaches into groundwater, especially when soils are saturated with water. Dung also has high nitrogen and phosphorus concentrations. When livestock wade in a stream or lake edge they are five times more likely to urinate and defecate in the water than on land. When this happens, large quantities of nutrients are released directly into the water, which algae can use.

Septic tanks

Traditional septic tanks do not remove nitrogen or phosphorus from human effluent, aside from plant uptake and scum and solid settling in the tank. The Rotorua district's volcanic soils generally absorb phosphorus, so nitrogen is the main nutrient leached from septic tanks.

Sewage

Reticulated sewerage treatment plants in the Rotorua district are designed to remove most nitrogen and phosphorus from effluent. However reticulated sewage disposal is still a small source of nutrients to lakes.

Rain

Raindrops collect nitrogen compounds from the air as nitrate and ammonium.

Rainfall on the lake is a direct, though relatively small input of nitrogen.

Internal lake sediments

During summer, many of the Rotorua lakes separate into two layers – a warmer upper layer and a colder bottom layer. These two layers do not mix, so oxygen from the air is not transferred into the bottom layer of water. When algae die, they sink to the bottom of the lake. Oxygen in the bottom layer is used up as they decompose. If there is a large lake algae population, the bottom layer can lose all its oxygen. When this happens, the chemical make-up of lakebed sediments change and nitrogen and phosphorus compounds are released from the sediments. When the lake remixes again in cooler, windier periods these nutrients are distributed throughout the lake.

Springs (groundwater)

Land development in the Rotorua district since the mid-1940s has leached nitrogen into large underground water reservoirs. Some of these groundwater reservoirs store water for a few years, while other areas (like the Mamaku plateau) can hold a unit of water for more than 100 years. Nitrogen (in nitrate form) from land use slowly leaches through the soil to groundwater. Now increasing concentrations of nitrate are showing up in groundwater-fed springs and reflect land use from decades ago. Springs in the Rotorua area can also contain high levels of dissolved phosphorus, leached from volcanic rock underneath the ground.

Geothermal

Nutrients from geothermal flows vary a lot. Some geothermal outputs have high phosphorus concentrations; a few have high ammonium nitrogen concentrations. In some of the Rotorua lakes geothermal inputs are a significant source of nutrients to the lakes.

Stormwater

Stormwater from urban areas can carry heavy metals, hydrocarbons, sediment, and nutrients into waterways from construction sites, deposits of rubbish, roads, industrial areas and other urban sources.

Point source discharges

Point source discharges of nutrients in the Rotorua district are very small, compared to nutrient inflows from the sources above. Examples of a point source discharge: an industrial or food processing plant pipe discharge, or a dairy farm discharge of cowshed runoff to a stream. Major point source discharges of nutrients are controlled by rules in regional plans and conditions in resource consents.

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This fact sheet was last updated April 2005

Riparian Protection – Benefits to the Rotorua lakes

In the Rotorua district, riparian protection buffers are very important to reduce the amount of nutrients (especially phosphorus) entering the lakes from the surrounding land uses.

Riparian protection is the management of the banks of water bodies (like lakes and streams) to protect them from environmental degradation. Livestock are kept out of water bodies by fencing. Plantings between the fence and the water body can be used to filter runoff from land, stabilise land-water margins and help to suppress weeds.

Riparian protection helps remove:

- particulate phosphorus and nitrogen, by trapping the particulates.
- organic nutrients, by breaking down and absorbing the nutrients.
- suspended sediment, by slowing runoff and allowing sediment to settle out.
- faecal material and disease-causing microbes, by bacterial action and settling out.

Riparian protection has limited ability to remove:

- **Dissolved inorganic nitrogen.** Most nitrogen entering water bodies around the Rotorua lakes is in nitrate form. The majority of this comes from livestock urine patches. Nitrate easily leaches from the soil into groundwater, where it can travel under

Protection plantings around Lake Rotoehu

riparian plantings directly into water bodies.

- **Dissolved inorganic phosphorus in surface runoff.** Dissolved inorganic phosphorus is generally not trapped or treated by riparian buffer zones. However there may be some plant uptake and soil absorption.
- **Nutrients and sediments during storm flows.** During heavy rain events most water runoff forms rivulets and small streams, and flows straight over riparian buffer zones.

Riparian vegetation

In general, the wider the riparian buffer zone the more effective it is; yet even narrow riparian buffers have benefits. The type of plants used will depend on the purpose of the riparian protection. For example, a native tree canopy on stream banks will shade the stream, act as an 'ecological corridor' for native birds and fish, and will promote a healthy instream invertebrate community. However, these trees prevent the growth of smaller plants. Streambank erosion may worsen and nutrient-filtering properties will be small. Trees in riparian areas used for nutrient filtering should be planted with enough space between them to let light through, so ground cover plants can survive. Grasses, rushes and small bushes are the best plants to use to prevent nutrients and sediment entering rivers, streams and lakes. Their thick clumps of stems and roots help to slow runoff, trap sediments, and take up nutrients to grow. Around the organic-rich root zones of wetland plants, bacteria transform inorganic nitrogen into nitrogen gas, releasing it to the atmosphere.

The Rotorua Lakes Problem

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Riparian management beside a stream

Riparian protection buffers work best next to small watercourses and temporary streams rather than large streams and rivers, as it is the small channels that catch most of the initial surface runoff from land. Riparian protection upstream will often improve stream and lake water quality downstream.

Effects of riparian protection on the Ngongotaha Stream

The Upper Kaituna Catchment Control Scheme was a large riparian protection programme for Lakes Rotorua and Rotoiti and the streams in the catchment. It began in the 1970s and aimed to reduce the impact of land use around these lakes. More than 4000 hectares of pasture was planted in trees, mostly along stream and lake edges and on poor quality soils. About 540 kilometres of protection fencing was constructed.

In the late 1980s the Ngongotaha Stream was studied for three years to determine the benefits from the Upper Kaituna Catchment Control Scheme programme. Comparison with data collected before the riparian protection found that:

- Actively eroding streambanks had decreased from 30% to 4%.
- Sediment entering the stream had decreased by 85%.
- Particulate nitrogen and phosphorus entering the stream decreased by 33%.
- Total phosphorus inputs decreased by 25%, but total nitrogen inputs stayed constant. The reduction in particulate nitrogen was off-set by an increase in groundwater nitrate levels entering the Ngongotaha Stream.

Overall, the study estimated that the riparian protection works resulted in an 8–9% decline in nitrogen and a 15–20% decline in phosphorus input into Lake Rotorua.

Changes over time

It can take time for the benefits of riparian protection to be seen. In some cases it may take years – longer than changes in the riparian vegetation.

A 1995 study indicated that buffer strips are less effective at phosphorus removal over time. On one site studied 20 years after planting, similar amount of phosphorus were being released as were trapped by the riparian plantings. Future improvements in riparian planting and management may help avoid this.

Riparian protection is not a cure-all solution for the Rotorua lakes. However it is a proven tool to reduce sediment and nutrient inputs to water bodies. Because of this, Environment Bay of Plenty is aiming for retirement of all riparian margins in the Rotorua lakes catchments by 2020.

To help reach this goal, Environment Bay of Plenty offers substantial grants for riparian fencing and planting undertaken as part of an Environmental Programme agreement. Free advice to landowners wanting to protect their riparian areas is also available from Environment Bay of Plenty's land management officers. More information on riparian protection can be found in these ***Sustainable Options*** fact sheets, free on request:

- LM01: Environmental Programmes
- LM02: Riparian Protection
- LM03: Protection Fences
- LM04: Stream Crossings
- LM06: Stock Water Supply
- LM07: Plant Selection for Retirement Areas
- LM08: Management of Environmental Protection Areas
- LM12: Native Plants for Revegetation Projects

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