Phoslock Application - Lake Okareka Final Report

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Executive Summary

The objectives of the Lake Okareka Action Plan are to reduce the load on Lake Okareka by 2.5 tonnes/yr of nitrogen and 0.08 tonnes/year of phosphorus. To achieve these objectives, the stakeholders determined that the following methods were required:

- Reticulate the township for sewage
- Retire land from grazing
- Promote wetland renovation
- Construct a hypolimnetic discharge (pipe bottom water to the outlet)

The hypolimnetic discharge was found to be feasible because the lake discharges from below its surface and there was sufficient head to drive a discharge from 30 m depth. Water would have to be treated to remove the nutrients before discharge to Lake Tarawera. However, it was found that the cost of the hypolimnetic discharge was high especially with the cost of water treatment. It was therefore proposed that the Lake Okareka water could be treated ‘in situ’ and the nutrients retained in the lake, locked into the bottom sediments in the deepest part of the lake.

A meeting of the Lake Okareka working party agreed to the proposal but they felt that the phosphorus target should be increased above the hypolimnetic discharge target of 0.030 tonnes/year. The decision was made to treat the lake to remove 0.1 tonnes/year for three years. This would exceed the total phosphorus annual target for those years. In the meantime sewage reticulation would be proceeding and become effective in reducing the nutrient load on the lake in about three years time. Therefore the proposal provided a benefit to residents with a short payback time and bridged the gap waiting for construction of the sewage reticulation scheme.

Consequently, it was suggested to the lake’s community that Phoslock be applied to the lake to attain the target phosphorus reduction. Phoslock is a product produced by an Australian company at a factory in China. The active ingredient is a ‘rare earth element’ Lanthanum which is held in a matrix of bentonite clay.

Environment Bay of Plenty has applied Phoslock to the surface of Lake Okareka on three occasions:

- 15-17 August 2005
- 27-29 June 2006
- 20-21 March 2007

Phoslock took several months for the finest particles to completely sink to the lake bottom. After the phoslock addition the release of phosphorus from the bottom sediments was reduced by about 100 kg/year.

Another indicator of lake improvement was the deoxygenation of the bottom waters. The date at which the bottom water completely loses all oxygen (become anoxic) is an indicator of lake quality. After the phoslock application this date has been delayed by over a month.

The initial indications are that the application of phoslock to Lake Okareka has been very successful. The target reduction in phosphorus has been achieved. Surprisingly, the rate of de-oxygenation of the bottom waters appears to have been decreased. This is an expected outcome but an improvement was not expected so quickly.

As with most lake treatments the measure of success is determined in the long term rather than the short term monitoring. The major lake remediation method of sewage reticulation will have to be carried out for a lasting improvement to become effective for Lake Okareka.

No adverse effects of the treatment were noted in the lake chemistry or fish and koura health.

Chapter 1: Introduction

An action plan for the remediation of Lake Okareka has been drawn up by Environment Bay of Plenty, the Rotorua District Council and the Te Arawa Lakes Trust in conjunction with the lake's community. The action plan was subject to a public process and submissions were heard by regional, district councillors and board members of the Te Arawa Lakes Trust.

The objectives of the plan are to reduce the load on Lake Okareka by 2.5 tonnes/yr of nitrogen and 0.08 tonnes/year of phosphorus.

To achieve these objectives, the stakeholders determined that the following methods are required:

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A meeting of the Lake Okareka working party agreed to the proposal but they felt that the phosphorus target should be increased above the hypolimnetic discharge target of 0.030 tonnes/year. The decision was made to treat the lake to remove 0.1 tonnes (100 kg)/year for three years. This would exceed the total phosphorus annual target for those years. In the meantime sewage reticulation would be proceeding and become effective in reducing the nutrient load on the lake in about three years time. Therefore the proposal provided a benefit to residents with a short payback time and bridged the gap waiting for construction of the sewage reticulation scheme.

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Lake Okareka is monitored monthly as part of the normal regional monitoring programme for the Rotorua lakes. Over the stratification period of 2004/05 the rate of release of nutrients from the hypolimnion was measured at fortnightly intervals and the mass of phosphorus released calculated at 0.130 tonnes (130 kg) for the whole lake.

The table below summarises a calculation of the annual phosphorus load on the lake.

Source	Phosphorus - tonnes/year
Septic tanks	0.020
External other	0.258
Internal	0.130
Total	**0.408**

Chapter 2: Description of the Proposal

Phoslock is a modified clay product (lanthanum amended bentonite clay), which is capable of efficiently removing phosphorus from natural and industrial waterways, process waters and waste water streams. It was developed in Australia where it has been used to control algal blooms in waterways e.g. the Canning River, Perth.

Phoslock works by absorbing phosphorus from the water column as it settles to the bottom of the lake where it forms a cap (less than 1 millimetre thick). Once it has passed through the water column, Phoslock forms a stable sediment on the bed of the water body which effectively traps the phosphorus that has already been absorbed as well as that released from underlying sediments during period of bottom water anoxia.

Environment Bay of Plenty has applied Phoslock to the surface of Lake Okareka on three occasions:

- 15 – 17 August 2005
- 27 – 29 June 2006
- 20 – 21 March 2007

One tonne of Phoslock removes 11 kg phosphorus, so the 60 tonnes applied would remove 660 kg of phosphorus. We estimated that the annual load released from the Okareka sediments was 130 kg phosphorus/year. The Phoslock applied to Lake Okareka would theoretically be effective for another three years approximately. During this time sewage reticulation should be implemented to ensure that the gains are maintained.

The treated area within Lake Okareka covered approx 170 hectares of the 330 hectare total area, encompassing the deeper basin approximately within the 20 m contour. Phoslock was in the form of small pellets and was applied at a rate of 118 kg's per hectare with a total of 20 tonnes applied with each annual treatment.

A barge, operated by Aqua Ag Air Boat Services, applied the Phoslock to the target area by means of a rotary spreader mounted on the stern. Rotary spreaders are commonly used in agriculture for applying fertiliser.

The barge travelled at a speed of 10 knots per hour with a swath width of 18 metres. To ensure accuracy of application, the barge was fitted with a GPS unit. The application took place over three days for the first two applications and two days for the third.

Chapter 3: Monitoring

Intensive monitoring was undertaken over the period after each application of phoslock to Lake Okareka lessening to monthly monitoring.

3.1 Dissolved oxygen

Phoslock appears to have some effect on levels of dissolved oxygen (Figure 1). It was expected that, in the long term, the rate of de-oxygenation of the bottom water would decrease but that it would take a period of years. The data plotted in Figure 1 shows dissolved oxygen levels plotted at 2 m intervals through the water column of Lake Okareka. When plotted they separate out into 'top' and 'bottom' water. The 'top' water (called epilimnion) is in contact with the atmosphere and remains fully oxygenated. The 'bottom' water (hypolimnion) is isolated from the atmosphere from about October to early June.

As the algae growing in the lake die and drop to the lake bottom in the period after the lake stratifies in October each year, oxygen is used up in decomposition of their organic material. In Okareka all the oxygen in the bottom water is used up before the lake fully mixes in June. This creates the circumstances where phosphorus and nitrogen can be released from the sediments and mixed throughout the lake with the June mixing event.

Figure 1 shows that the date the bottom water completely loses all oxygen has been getting later. In the four years of data that date has moved out almost two months (5/4/2004, 23/3/2005, 19/4/2006, 24/4/2007).

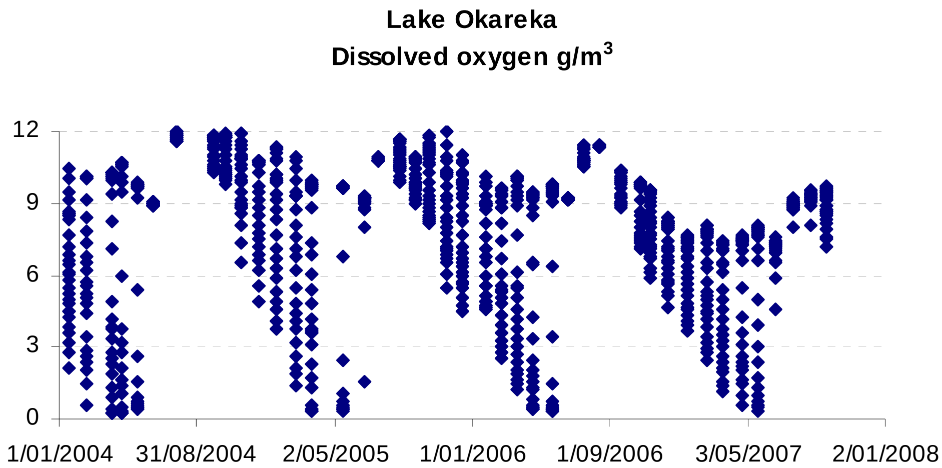


Figure 1 Dissolved oxygen in Lake Okareka at 2 metre intervals.

In January 2006, a high wind event resulted in the lake mixing and oxygen was injected into the bottom waters. The bottom waters were re-oxygenated slightly and this delayed the date that the bottom water completely ran out of oxygen. However, in 2007 there was a definite decrease in the de-oxygenation rate which may well be due to the phoslock application.

Figure 2 shows the corresponding temperature data. The surface water warms to between 22°C and 23°C at the height of summer. The bottom waters are insulated from atmospheric temperature and only warm up by a degree over the year. The warming of the bottom water may be assisted by some geothermal inflow. The surface waters were at normal temperature for Okareka throughout the whole period.

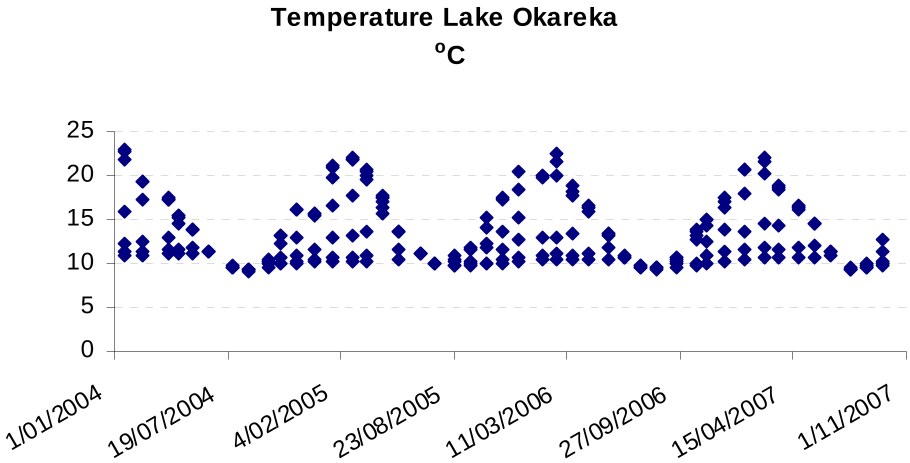


Figure 2 Temperature in Lake Okareka at 7 depths (0,1,5,10,15,20,28 m).

3.2 Lanthanum

Lanthanum is the active ingredient in phoslock and has been used as a marker of the product in the water column.

After each application the highest concentration of lanthanum was detected just after the barge had distributed the product in the lake. This is shown in Figure 3. Subsequent data is shown in Figure 4 on a lower scale which omits the high value but better shows the distribution of lanthanum (phoslock) in the lake water column over time.

Figure 4 shows that the product quickly became fully mixed throughout the water column and settled out slowly. After 2-3 months most of the product had settled to the lake bottom and after five months levels of lanthanum in the water column had returned to pre-application levels.

Data in the plots comes from all depths that were sampled. The higher values were recorded higher in the lake water column. Larger particles would have settled relatively quickly compared to the finer particles, which are represented in the tail of the plots.

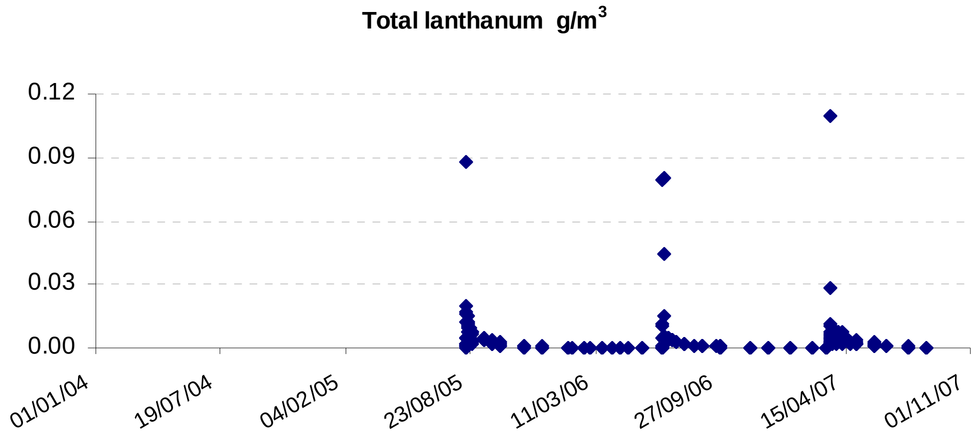


Figure 3 *Lanthanum concentration in Lake Okareka water after the three phoslock applications (full scale plot).*

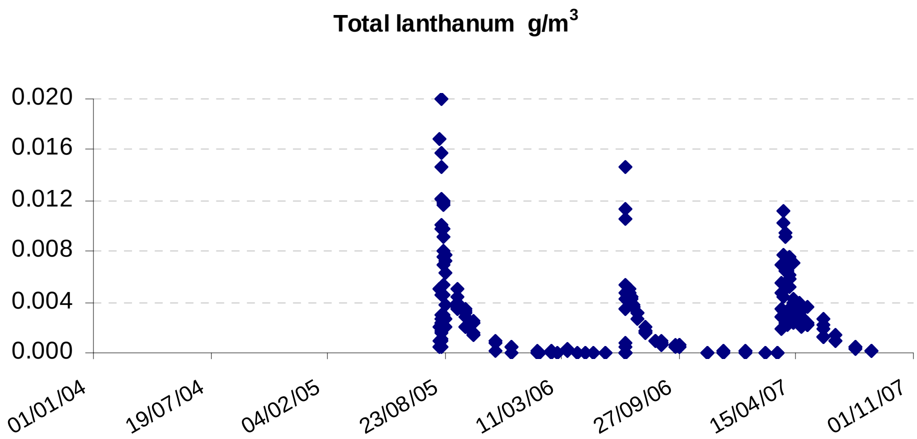


Figure 4 *Lanthanum concentration in Lake Okareka water after the three phoslock applications (downscaled plot).*

3.3 Phosphorus

Figure 5 plots dissolved reactive phosphorus (DRP) levels in the lake after the phoslock application. The higher values are from the lower depths of the lake and show phosphorus accumulating after being released from the sediments once the water has become anoxic.

In the pre-phoslock application years the concentration of DRP reached a maximum of 0.06-0.08 g/m^3 in the hypolimnion (bottom water). This occurred in May - the last month of stratification. After phoslock application the maximum DRP level was recorded as 0.02 g/m^3.

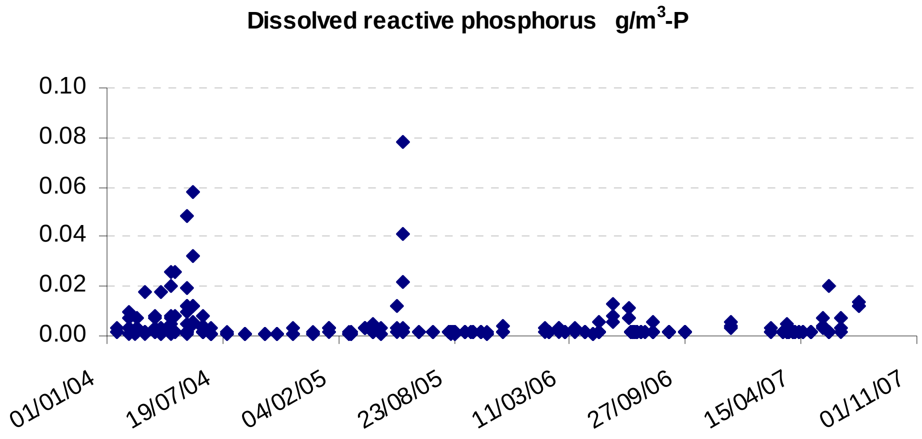


Figure 5 *Dissolved reactive phosphorus (DRP) concentration in Lake Okareka water before the phoslock application and over the period of applications.*

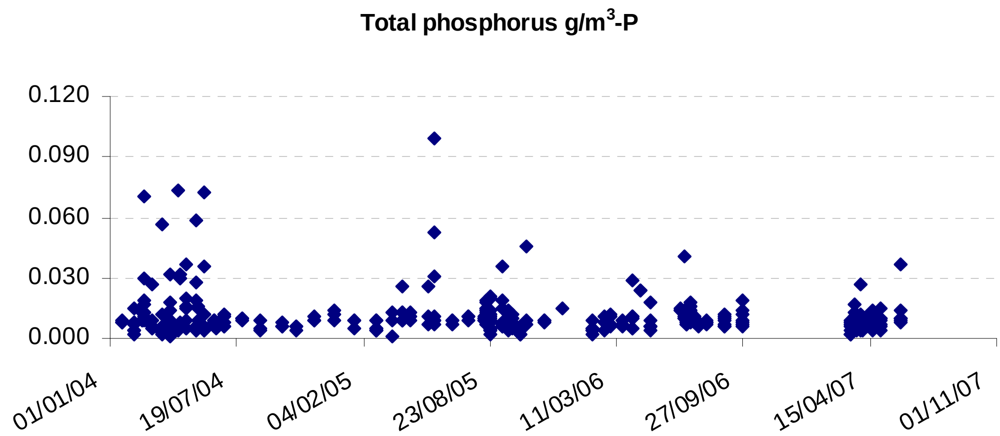


Figure 6 *Total phosphorus (TP) concentration in Lake Okareka water before the phoslock application and over the period of the applications.*

The plot (Figure 6) shows the build-up of phosphorus in the bottom of the lake in the months prior to mixing. The data does not show a reduction in phosphorus levels in the water column. Phosphorus is relatively low in Lake Okareka and periodic high inflows introduce variation to the lake phosphorus levels. In September and October 2005 a slight elevation of total phosphorus was recorded thought to be a result of rainfall generated inputs. This is discussed later.

3.4 Nitrogen

Figure 7 plots nitrate nitrogen levels in the lake for all the depths that were sampled. The higher values reflect levels of nitrogen in the bottom water of the lake generally accumulating once the lake is stratified.

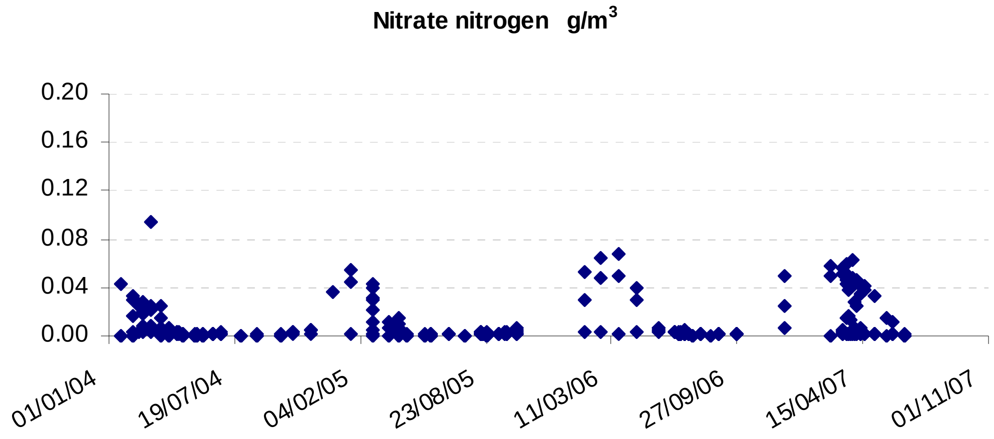


Figure 7 *Nitrate nitrogen concentration in Lake Okareka water before the phoslock application and over the period of the applications.*

Nitrate levels tend to build up in the bottom waters after the lake has stratified and oxygen levels start to run down. Once the bottom waters become devoid of oxygen (anoxic) the nitrate levels become depleted and ammonium nitrogen builds up (Figure 8). After the phoslock application the ammonium nitrogen release from the sediment appears to have been reduced to some extent.

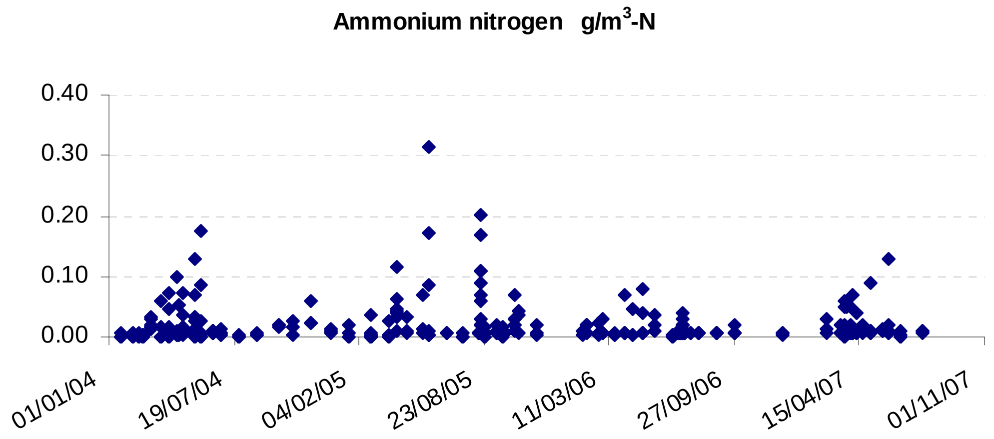


Figure 8 *Ammonium nitrogen concentration in Lake Okareka water before the phoslock application and over the period of the applications.*

Nitrate build-up in the bottom waters from January to April has been described by Hamilton *et al* (2005) in Lake Rotoiti. In Rotoiti the nitrate accumulated from nitrification of material deposited into the bottom water from the breakdown of the winter algal bloom. This occurred while the bottom water was still oxygenated. Once oxygen ran out the nitrate was de-nitrified to nitrogen gas. At the same time ammonium nitrogen started to accumulate being released from the bottom sediments.

3.5 Secchi disc clarity, chlorophyll a, pH

In early 2005, before the phoslock application there was a period of high clarity (Figure 9). Since the phoslock applications there has been an initial decrease in clarity but over the last 12 months some improvement can be noted. The values are all within the usual range for the last decade and could reflect normal variability.

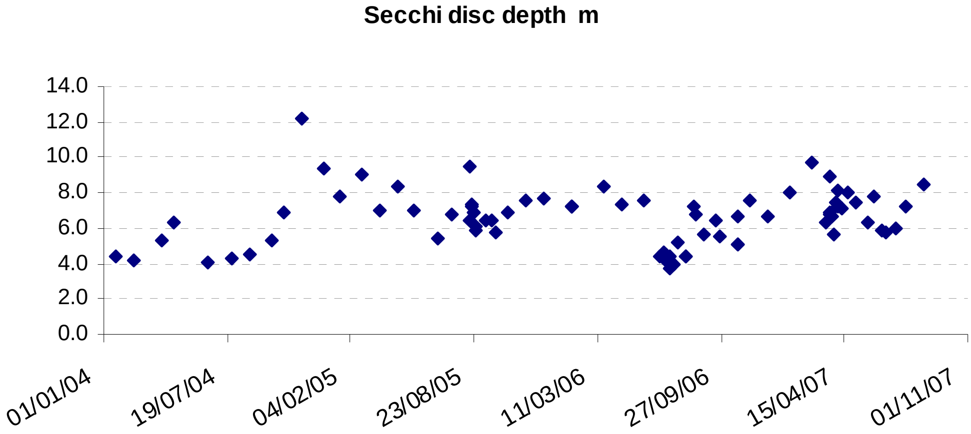


Figure 9 Secchi disc clarity in Lake Okareka water before phoslock was applied and over the period of the applications.

The chlorophyll *a* levels in Figure 10 show a seasonal winter peak of algae. This period of productive growth is a result of the nutrients in the bottom waters becoming available throughout the water column with the June mixing event. Over the last 12 months there appears to be a decrease in chlorophyll *a* coinciding with the secchi disc clarity increase.

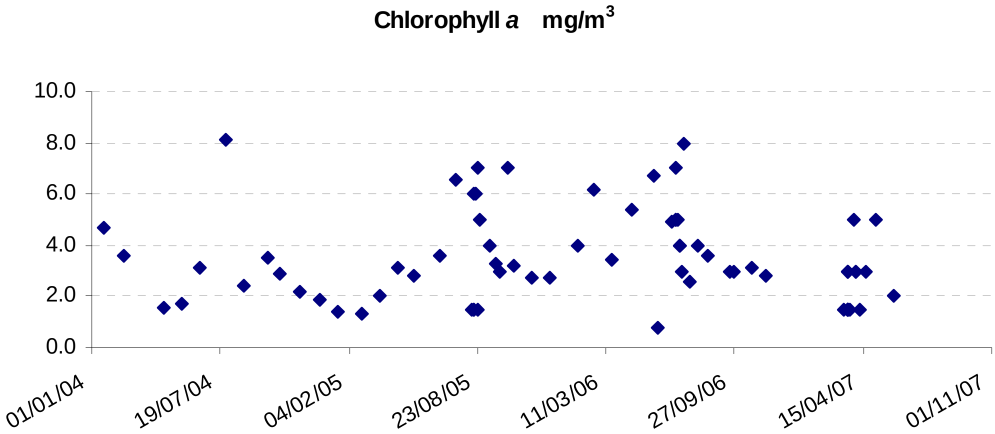


Figure 10 Chlorophyll a in Lake Okareka water before phoslock was applied and over the period of the applications.

Phoslock had no effect on the pH of the lake waters. Figure 11 shows the pH differences in top and bottom waters with lake stratification. Shifts in pH in natural waters are associated with the carbon chemistry. Carbon dioxide is the main cause of day/night (diurnal) variation in pH. Algae utilise carbon dioxide during photosynthesis in the daytime producing oxygen. At night time the opposite occurs as algae respire. Carbon dioxide has a slightly acidic effect on waters so pH rises as carbon dioxide is utilised and falls during respiration. Carbon dioxide and temperature combine to produce annual pH variation. Characteristically, lake surface waters peak in pH in the summer with a minimum value in spring. Lake Okareka experiences minor variation in pH compared to eutrophic lakes like Lake Okaro which displays major seasonal swings.

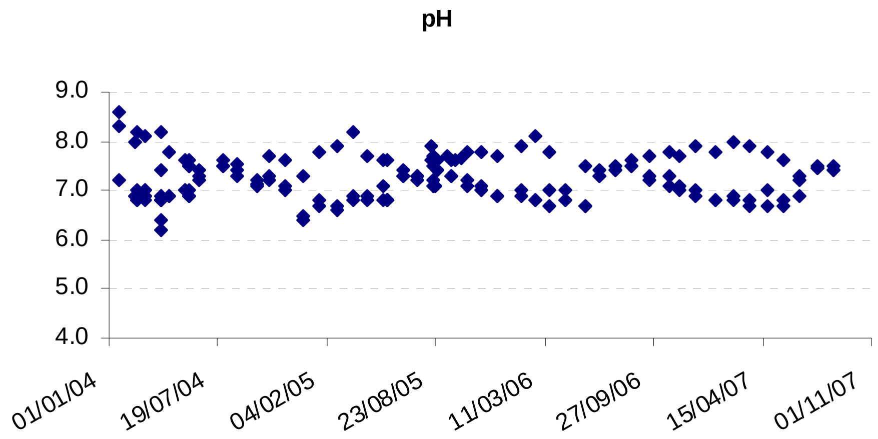


Figure 11 pH of top and bottom water in Lake Okareka.

Chapter 4: Acacia Bay

While monitoring the first application in August 2005 it was found that phosphorus levels increased markedly after rainfall events. The spikes represented a large input to the lake and would be significant to the annual lake nutrient budget. In 2007 monitoring was carried out Acacia Bay to see if these phosphorus flushes occurred in the bay. If that was the case it would indicate that septic tanks were implicated as a source.

Samples were collected from the top and bottom water of the bay from 1 and 10 metre depths. The values are plotted in Figure 12. On three occasions elevated total phosphorus levels were detected. On each occasion significant rainfall was recorded a week to two weeks previously.

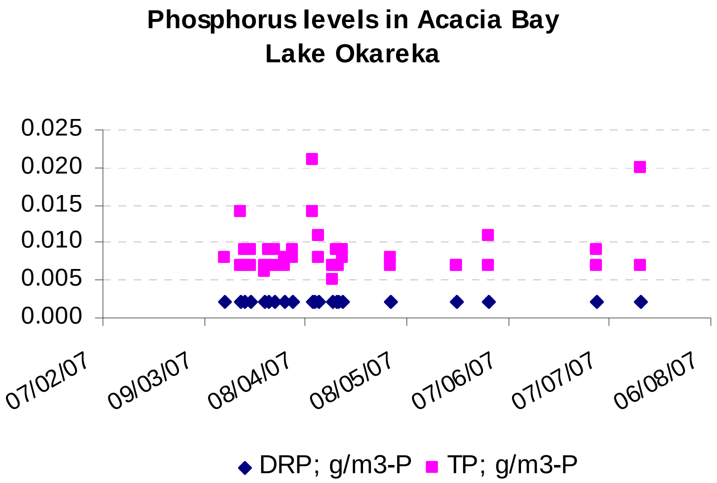


Figure 12 Dissolved and total phosphorus levels in Acacia Bay, Lake Okareka.

From 11-14/3/07 43 mm of rain fell. On 15/3/07 only the surface water was sampled which was at about baseline but on 20/3/07 the bottom water displayed elevated total phosphorus.

From 28-30/3/07 95 mm of rain fell. On 4/4/07 baseline phosphorus levels were recorded in the bay but on 10/4/07 both top and bottom water had elevated total phosphorus levels.

From 2-10/7/07 60 mm of rain fell. On 3/7/07 phosphorus levels were at baseline and on 16/7/07 the top sample was elevated in total phosphorus.

It appears that there is a source of phosphorus that enters Acacia Bay 1-2 weeks after rainfall events. It is picked up in the total phosphorus portion rather than the dissolved reactive phosphorus portion. This could well be the polyphosphate component of septic tank effluent. Polyphosphates are bio-available.

During the periods when these pulses enter the lake, no concurrent pulse of nitrogen was noted.

The survey has confirmed that pulses of phosphorus do enter the lake after rainfall events. The rainwater apparently soaks into the ground and flows to the lake over a period of a week or two. A large quantity of phosphorus is involved in these pulses to double or triple the in-lake phosphorus levels in Acacia Bay. The pulses were initially detected in the centre of the lake in 2005 so the effect is widespread.

More work will be done to obtain better information on this phenomenon.

This has implications for our action plan assessment of the nutrient budget for Lake Okareka and other lakes where the same factor has been used. It was considered that the phosphorus component of septic tank effluent was largely absorbed in the soil. However, we may have underestimated phosphorus transport during storm events.

There are two important outcomes if this is true. Firstly, it puts more importance on hastening sewage reticulation of the community. Secondly, if the phosphorus source is polyphosphate from laundry detergents, it means that substituting for low phosphorus detergents would be beneficial. More investigation will take place.

Chapter 5: Discussion

The Phoslock application to Lake Okareka is intended to be part of a package of remediation methods to remove a fixed quantity of nitrogen and phosphorus from the lake. The main method to remove nutrients is to be sewage reticulation supplemented by some land use change. Each of the three phoslock applications in itself was calculated to remove at least one year of the phosphorus target from the lake. Product specifications states that 1 tonne of phoslock will lock up 11 kg of phosphorus and sequester that in the deep lake sediments.

The results indicate that there has been a reduction of about 100 kg of phosphorus/year in the annual sediment release to the lake water for the past two seasons. Phosphorus absorbing capacity is expected to still remain with the product on the lake bottom. This could restrict phosphorus release for another three or four years. The application can be said to be successful in that respect.

Changes in the dissolved oxygen depletion rate are remarkably good but another season of data is needed to confirm a permanent change.

Landman (2007) has reported on the fish health comparison study between Lakes Okareka and Tikitapu. Lanthanum accumulated in the liver of the trout and hepatopancreas of koura after each application but not in the flesh. This lanthanum was purged from the fish systems by the time the pre sampling for the next application was undertaken.

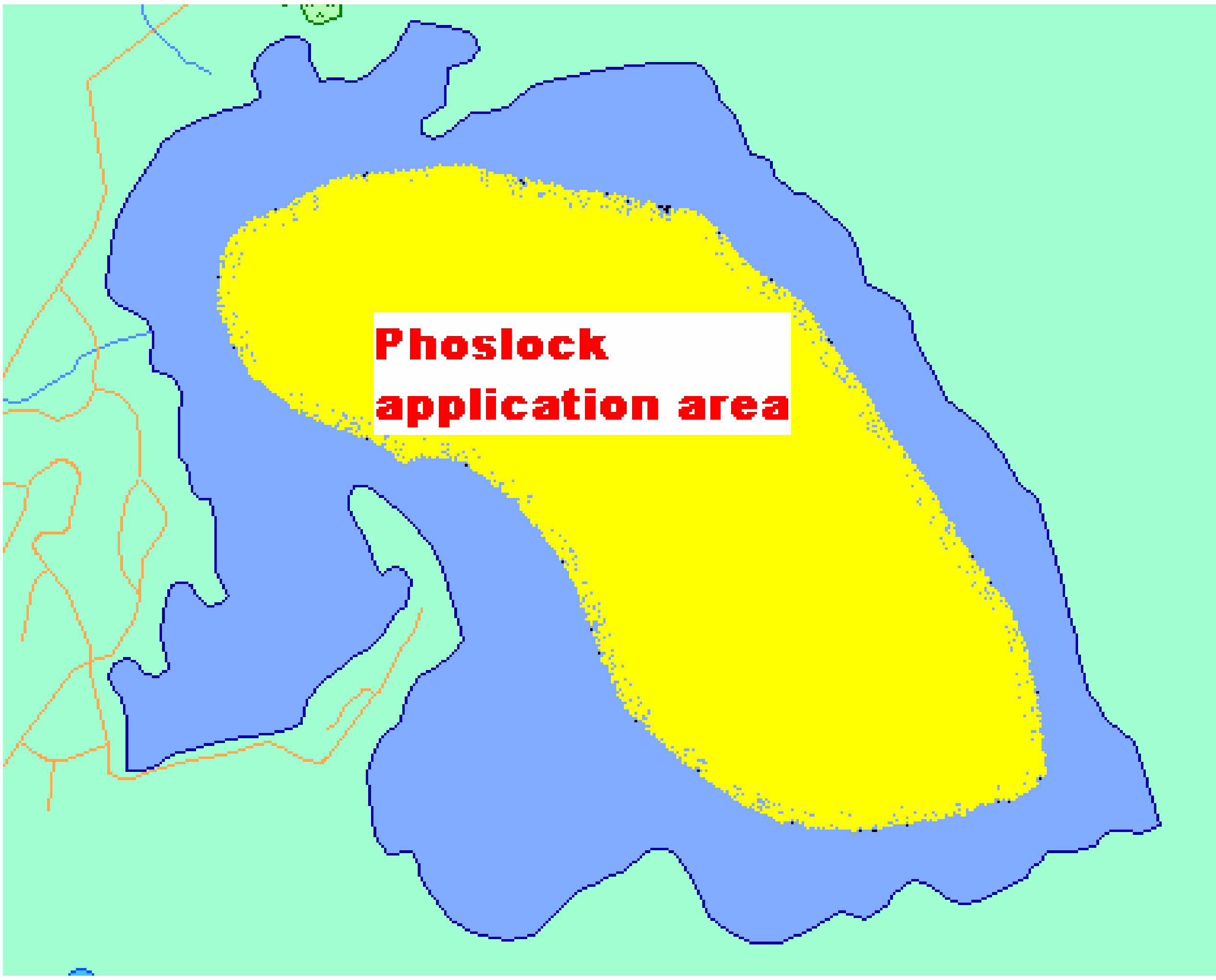
Chapter 6: References

Landman M, Jeroen Brijs, Glover C and Ling N (2007): Lake Okareka and Tikitapu Fish Health Monitoring 2007, 30 October 2007, SCION, Private Bag 3020, Rotorua. Contract report for Environment Bay of Plenty.

Environment Bay of Plenty web page with Lake Okareka action plan details and progress reports on previous Phoslock applications (bottom of page) http://www.envbop.govt.nz/Water/Lakes/Lake-Okareka.asp

Chapter 7: Appendices

Appendix 1 – Map of Phoslock Application Area and Photos



Appendix 2 – Background Information

What is Phoslock?

Phoslock is an activated bentonite clay that locks in phosphorus, then settles to the lake bed as an inert silt. By removing or reducing phosphorus in water, algae are deprived of nutrients and thus growth is reduced.

Lanthanum modified clay (Phoslock) was developed in research undertaken by scientists at the CSIRO Land and Water and funded jointly by the Western Australian State Government's Water and Rivers Commission and the Swan River Trust. The research was initiated in late 1994 to investigate the potential remediation technologies that could be used. An Australian company, IMT Holdings, was awarded an exclusive worldwide licence to manufacture and distribute Phoslock in 2001. IMT is now producing phoslock in commercial quantities at its factory in Kunming, China. Originally formulated and applied to water bodies in slurry form, a granular form of Phoslock has recently been developed, resulting in ease of transportation and better economics. Primaxa is the New Zealand agent for Phoslock.

The product can be used to cap lake sediments and prevent release of phosphorus.

Refer to www.phoslock.com.au.

Haghseresht F 2004: The use of Phoslock™ in reducing filterable reactive phosphorus level in water bodies: An overview of the properties of Phoslock™ and its performance in improving water quality. March 2004 report of IMT Holdings Ltd. http://www.phoslock.com.au/Overview%20of%20the%20Properties%20of%20Phoslock%20(Haghseresht,%20March%2004).pdf

Martin M L Hickey C W 2004: Determination of HSNO ecotoxic thresholds fro granular Phoslock™ (Eureka 1 formulation) Phase 1: Acute toxicity. NIWA Client report: HAM2004-137, NIWA, PO Box 11115, Hamilton, New Zealand. http://www.phoslock.com.au/NIWA%20NZ%20Phoslock%20report%20final.pdf