PHOSLOCK

Phoslock® field trial at K'shani Lake Lodge, Hartbeespoort Dam

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Summary of Results

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Introduction

Hartbeespoort Dam is located 37km west of Pretoria on the Crocodile River (NIWR, 1985). It is classified as hypertrophic due to the runoff from fertilized fields and the inflow of sewage plant effluents from the Northern suburbs of Johannesburg that contain high amounts of salts, phosphates and nitrates. On reaching the dam, these effluents stimulate cyanobacterial growth, which further accelerates eutrophication. For most of the year, Hartbeespoort Dam is dominated by dense populations of the cyanobacterium *Microcystis aeruginosa* (Robarts & Zohary, 1986), usually representing more than 90% of the total algal biomass (NIWR, 1985). During calm weather the buoyant *M. aeruginosa* accumulate to form thick, crusted, floating mats called hyperscums, which usually form in winter in the shelter of the dam wall (Robarts & Zohary, 1985).

Extensive cyanobacterial growth poses several severe implications on the general water quality as well as the maintenance of water treatment standards set for potable water. Massive blooms such as those found in the Hartbeespoort Dam can deplete the dissolved oxygen content resulting in fish kills and discolouration of the water by pigments released from the cells (Rae *et al.*, 1999). Because of their relatively small cell size, cyanobacteria easily penetrate and clog the fine sand filters and the primary coarse fast filters that are fundamental stages in drinking water purification (Botha-Oberholster, 2004). Biodegradation of cyanobacterial blooms contributes to the organic load of the water resulting in increased treatment costs. Non-toxic nuisance compounds such as geosmin and 2-methylisoborneol (2-MIB) that cause taste and odour problems in both dam and purified waters have been associated with cyanobacteria (Rae *et al.,* 1999). Of greater importance is the fact that certain cyanobacteria produce toxic compounds, the consumption of which present severe health risks (Botha-Oberholster, 2004).

High phosphorous levels remain the greatest factor influencing the development of algal blooms. It is accepted that phosphorus control is more achievable than that of nitrogen, because, unlike nitrogen, there is no atmospheric source of phosphorus that is bio-available. In addition, the general equation for photosynthesis (Equation 1) (Hereve, 2000) shows only one gram of phosphorus is required for every seven grams of nitrogen for the formation of the organic matter created in the process.

$$HPO_4^{2-} + 16NO_3^- + 106CO_2 + 122H_2O + 18H^+ \rightarrow (CH_2O_6)106(NH_3)16H_3PO_4 + 138O_2 \quad \ldots(1)$$

This indicates that a small degree of phosphorus reduction can achieve a much greater degree of growth reduction of cyanobacteria than a reduction of a similar magnitude in the nitrogen level. This fact, together with the availability of gaseous nitrogen to N-fixing organisms, makes phosphorus reduction strategies a far more effective alternative in eutrophication management.

Phoslock®, a modified clay which is a mixture of lanthanum and bentonite, is able to bind phosphorous from the water body and form a cap on the sediment to prevent phosphate re-release. Previous Phoslock® applications have involved treating eutrophic waterways prior to the development of an algal bloom. However, laboratory tests have shown that Phoslock® is capable of flocculating algal cells from water, and can bind phosphorus under these bloom conditions. The aims of the field trial on Hartbeespoort Dam are therefore:

- To evaluate the ability of Phoslock to reduce the phosphorus concentration of the water
- To determine the effect of this phosphorus reduction on the algal bloom
- To assess the efficiency of algal flocculation following Phoslock application

The site

The site used for the field trial was a man-made bay at K'shani Lake Lodge, a housing development on Hartbeespoort Dam. The site was approximately 2.5 hectares in size, had an average depth of 3m, and had an opening into the main dam, about 8m wide. This was blocked off with floating logs, to which a tarpaulin curtain was attached to form a moveable boom. The bottom of the tarpaulin was weighed down with chains. A further area was blocked off in a similar manner within the test site to serve as an untreated control area. The site was in a state of algal bloom at the time of treatment in January 2006.

Calculation of Phoslock® quantity needed for treatment

The site was monitored throughout December 2005. The FRP (filterable reactive phosphorus) levels of the water body were between 0.2 and 0.8mg.l^{-1}, and sediment FRP values ranged from 0.6 to 3.84 mg.l^{-1}. The water pH was, on average, 9.2, whereas that of the sediment was 7.5.

Samples were taken three days prior to treatment (**Table 1**). The phosphorus levels had decreased from those seen in December, to 0.09mg.l^{-1}. The pH had increased to 9.8. However, because it was presumed that the phosphorus levels of the sediment were still high, an FRP value of 0.2mg.l^{-1} was used to calculate the amount of Phoslock® necessary to treat the site. At neutral pH, a ratio of 230:1 Phoslock® to phosphorus is recommended, but the high pH of the Hartbeespoort Dam water required a higher dosage. This is due to the fact that the phosphorus adsorption capacity of Phoslock becomes less as the pH is increased, especially above pH 9.

For large water bodies, the manufacturers recommend a Phoslock® dosage of 250g.m^{-2} in order to achieve a 1mm sediment capping. As the water body was approximately 2.5ha in size (25 000m^2 surface area), 6000kg of Phoslock® was used. At a 0.2mg.l^{-1} phosphorus concentration, this will result in a Phoslock® to phosphorus ratio of 400:1, and an 800:1 ratio for a 0.1mg.l^{-1} concentration of phosphorus. This dose was enough to overcome the negative effects of the high pH.

Product application

The product was first mixed into a slurry prior to application; 125kg of Phoslock® was added to 1000L of water. This was mixed well in a large tank upon a barge, and the slurry was sprayed onto the water surface using a pump and hose.

Sampling strategy

Samples were taken three days prior to application, on the day of application immediately prior to treatment, and daily for six days following application. Further samples were taken weekly for five weeks, and then once every two weeks, for a period of one year.

In terms of the samples taken daily prior to application, as well as for six days following application, ten samples were taken each day, including a control sample. The sample sites were chosen so as to best represent the conditions of the site as a whole. Results for the parameters tested (**Table 1**) are averages of these ten samples. Only 5 samples and a control sample were taken in the following weeks of monitoring.

Results

The concentration of FRP decreased by more than 50% in the first 24h after treatment from 0.09mg.l^{-1} to 0.043mg.l^{-1}. The FRP of the control area remained constant. After 48h, the FRP concentration in the treated area had decreased to 0.017mg.l^{-1}, and then stabilised at approximately 0.02mg.l^{-1} for the reminder of the first week of testing. The FRP concentration of the control area remained high (**Table 1**; **Figure 1**). A decrease in the amount of surface algae was observed following application, and after 6 days the algae had not yet returned to its former state.

Unusually high rainfall during the second week of the trial resulted in partial flooding of the test site. The subsequent rise in the level of the dam also resulted in water and algae being washed into the test site from the main dam over the top of the floating logs. This inflow of water and algae was most likely responsible for the increase in FRP concentration in both the treated and control areas to 0.29mg.l^{-1} and 0.22mg.l^{-1} respectively (**Figure 2**). By the third week, the FRP concentration of the control area had once again increased, whereas that of the treated area had decreased to approximately 0.1mg.l^{-1}. During the weeks that followed, the FRP concentration of the control area fluctuated, but remained above 0.2mg.l^{-1}. The treated area continued to show an improvement and decreased to 0.015mg.l^{-1} by the seventh week after treatment. The FRP concentration of the treated area remained below 0.02mg.l^{-1} throughout the winter months, despite the fact that the algae started to die off when the water temperature dropped below 15ºC, in mid May. There was a decrease in the FRP concentration in the control area, from 0.72mg.l^{-1} in week 3 (February), to 0.04 mg.l^{-1} in week 26 (August). However, after week 26, the FRP concentration increased steadily in the control area, but remained low at 0.015mg.l^{-1} in the treated area until November (week 43), by which time the control area had increased to 0.32mg.l^{-1}. The temperature of the water increased from 12ºC to 25ºC from August to November (**Figure 6**).

The amount of algae present in the test site varied throughout the initial 7 weeks of testing. Immediately after application there was a visible decrease in the quantity of surface algae, as the Phoslock has a flocculating effect. There was a large amount of algae present after the heavy rains in week 2, due to algae being washed in from the main dam. Despite the boom, small amounts of algae were still able to flow into the test area from the main dam. The algae remained present in the treated area throughout the period of testing, although the amount decreased once the water temperature decreased to below 15mg.l^{-1}. There appeared to be a

smaller amount of algae in the treated area when compared with the control area. Both the treated and control areas were free of algae through the winter months, but the algal growth began in September (week 33) when the FRP concentration reached 0.2mg.l^{-1} and the water temperature 14.9ºC. At this stage the FRP concentration of the treated area was 0.02mg.l^{-1} and there was no algal growth. The water level in the main dam as well as the trial site decreased throughout winter, and by September the level had dropped by approximately 1m. The summer rains began in October, and there was a rapid rise in the water level. By early November the water had risen back to its original level, with water containing phosphates and algae flowing in from the main dam. Up to that point no algal growth was visible in the treated site.

The pH values of the control and treated areas remained very similar throughout the trial. Following Phoslock application, the treated area showed a decrease in pH when compared to the control (**Figure 3**). However, by the second week after treatment, both the control and treated areas were once again of similar pH, and followed a similar trend thereafter (**Figure 4**). The pH of both sites decreased with time to below 9 by the end of August. However, as the water temperature increased and algal growth occurred, the pH of both areas increased.

The nitrate concentration varied in both the treated and control areas throughout the duration of the trial, although both areas showed a similar trend (**Figure 5**). There was an increase in nitrates in both areas in the second week, which can once again be contributed to the heavy rain and inflow of water into the test site from the main dam, and runoff from the land into the test site. In the following weeks, the nitrate concentration decreased and stabilised, ranging from 1 to 4mg.l^{-1} in both the control and the treated areas. From week 9 (April), both sites showed an increasing trend, but the nitrate concentration was greater in the control area (23.3 mg.l^{-1}) than the treated area (9.6mg.l^{-1}) by week 26 (August). From August to November the nitrate concentration decreased in the control and treated areas from 8.1mg.l^{-1} to 0.6mg.l^{-1}, and 5.35mg.l^{-1} to 2.125mg.l^{-1} respectively.

Table 1: Results of tested parameters before and after treatment with Phoslock®

	Treated												
Parameter	**Day -2**	**Day -1**	**Day 0**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Week 2**	**Week 3**	**Week 4**	**Week 5**
FRP ($mg.l^{-1}$)	0.08	0.06	0.09	0.043	0.017	0.02	0.021	0.025	0.024	0.2925	0.0925	0.1225	0.055
Nitrate ($mg.l^{-1}$)	2.5	4.15	3.75	4.53	2.9	6.4	7.5	5	6.2	3.4	4.2	2.575	3.425
pH	9.824	9.63	9.791	9.16	9.11	9.22	9.58	9.4	9.48	9.255	9.2875	10.5725	9.0825
Turbidity (NTU)	36.8	32.7	24.2	13.3	9.6	12.2	15.2	19	18.4	38.75	32.75	63.75	21.75
Dissolved oxygen ($mg.l^{-1}$)	9.04	7.45	6.83	3.75	6.03	3.65	5.78	4.5	4.83	4.875	4.95	5.65	6
Water Temperature (ºC)	27.7	27.6	27.3	26.8	26.6	28.6	26.5	25.2	25.4	25.25	25.75	25.25	24.65
	Control												
	Day -2	**Day -1**	**Day 0**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Week 2**	**Week 3**	**Week 4**	**Week 5**
FRP ($mg.l^{-1}$)	0.08	0.06	0.09	0.09	0.07	0.08	0.07	0.06	0.08	0.22	0.72	0.22	0.36
Nitrate ($mg.l^{-1}$)	2.5	4.15	3.75	3.9	4.7	6.4	6.6	5.2	9.5	2.2	1.1	3.3	1.7
pH	9.824	9.63	9.791	9.69	9.4	9.77	9.93	10.01	10.19	9.55	9.41	10.77	8.92
Turbidity (NTU)	36.8	32.7	24.2	39	26	17	25	45	23	23	18	75	18
Dissolved oxygen ($mg.l^{-1}$)	9.04	7.45	6.83	4.4	6.5	4.4	5.8	5.2	4.2	4.6	4.9	5.1	5.6
Water Temperature (ºC)	27.7	27.6	27.3	26	27	29	25	25	25.2	25	25	24.6	24.1

Days –2 to 0 represent days before treatment (Day 0 samples taken immediately prior to treatment).
Day 1 onward represents post application sampling

Table 1 continued

Parameter	Week 6	Week 7	Week 9	Week 11	Week 13	Week 15	Week 18	Week 20	Week 22	Week 24	Week 26
FRP ($mg.l^{-1}$)	0.01	0.015	0.01	0.0125	0.005	0.0175	0.0125	0.0225	0.015	0.0075	0.015
Nitrate ($mg.l^{-1}$)	1.125	2.725	0.85	4.4	4.75	3.625	4.425	13.275	7.225	8.275	9.575
PH	10.0225	9.635	8.9025	8.935	9.1775	9.2525	9.44	8.8475	8.7075	8.8575	8.305
Turbidity (NTU)	45.5	78	92.5	55.75	69.25	54.5	28.25	15.75	11	20.5	12.5
Dissolved oxygen ($mg.l^{-1}$)	7.05	7.85	8.82	7.9	7.3	7.975	8.05	8.2	9.225	6.775	7.35
Water Temperature (ºC)	24.3	23.9	23.7	19.75	19.125	15.5	14.5	13.225	12.6	13.075	12.5
	Week 6	**Week 7**	**Week 9**	**Week 11**	**Week 13**	**Week 15**	**Week 18**	**Week 20**	**Week 22**	**Week 24**	**Week 26**
FRP ($mg.l^{-1}$)	0.2	0.24	0.13	0.18	0.13	0.05	0.03	0.02	0.04	0.06	0.04
Nitrate ($mg.l^{-1}$)	1	4.2	2.9	10.3	12.6	0.2	8.7	7.1	9.2	15.5	23.3
PH	8.77	9.62	9.41	8.99	9.15	9.38	9.55	8.91	8.65	9.01	8.61
Turbidity (NTU)	15	68	115	68	27	94	21	9	23	32	10
Dissolved oxygen ($mg.l^{-1}$)	6.2	8.1	9.6	8.8	7.2	9	10.8	9.5	8.3	8.3	8.5
Water Temperature (ºC)	24	23	23	20	19.5	17	15	14	13.4	13.6	13.1

Table 1 continued

Parameter	Week 28	Week 30	Week 33	Week 35	Week 37	Week 39	Week 41	Week 43
FRP ($mg.l^{-1}$)	0.0175	0.005	0.0225	0.015	0.005	0.0075	0.005	0.015
Nitrate ($mg.l^{-1}$)	5.35	1.275	1.475	5.925	5.45	5.85	7.15	2.125
pH	8.04	8.1325	8.0875	8.5275	8.5	9.0825	9.0875	9.9525
Turbidity (NTU)	8.5	16.25	5.5	14.25	17.75	16.5	33	22.25
Dissolved oxygen ($mg.l^{-1}$)	7.175	8.425	6.65	9.3	8.975	9.45	7.825	9.7925
Water Temperature (ºC)	13.7	15.65	17.875	19.8	22.675	23.275	22.025	25.125
	Week 28	**Week 30**	**Week 33**	**Week 35**	**Week 37**	**Week 39**	**Week 41**	**Week 43**
FRP ($mg.l^{-1}$)	0.09	0.14	0.2	0.2	0.26	0.3	0.29	0.32
Nitrate ($mg.l^{-1}$)	8.1	5.5	8.3	6.7	7.4	3.9	5.6	0.6
pH	8.24	8.04	8.13	8.53	8.56	9.08	9.18	9.68
Turbidity (NTU)	3	9	3	5	15	9	57	28
Dissolved oxygen ($mg.l^{-1}$)	6.4	6.9	7	9.1	9.2	7.9	10.6	11.8
Water Temperature (ºC)	13.7	14.9	14.9	19.3	21.8	23	22.9	24.5

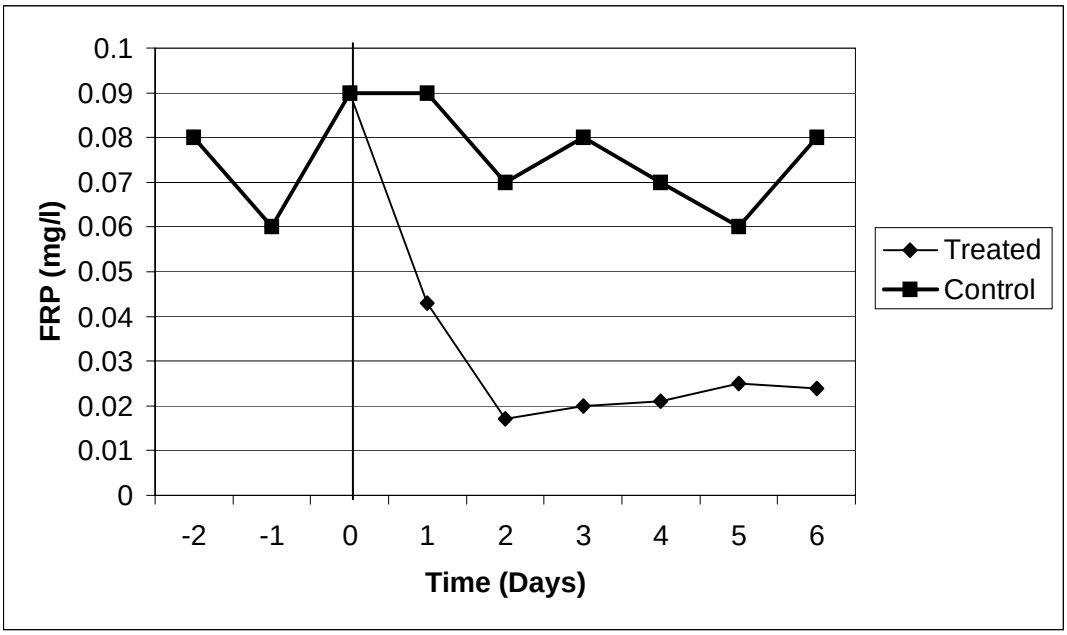

Figure 1: FRP values of the treated and control areas two days prior to treatment and 6 days after treatment (Day 0 represents the day of treatment)

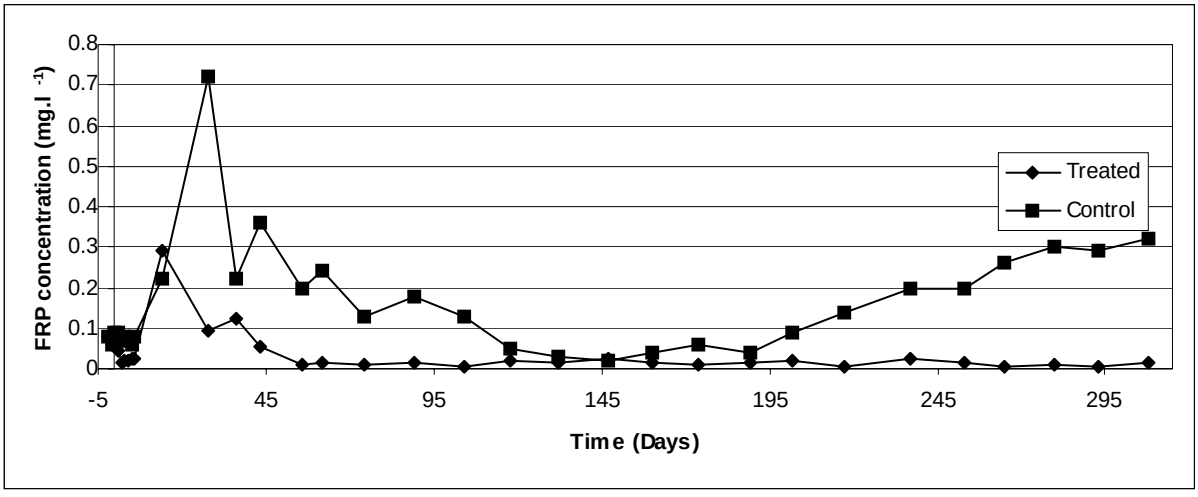

Figure 2: FRP values of the treated and control areas for the duration of the trial

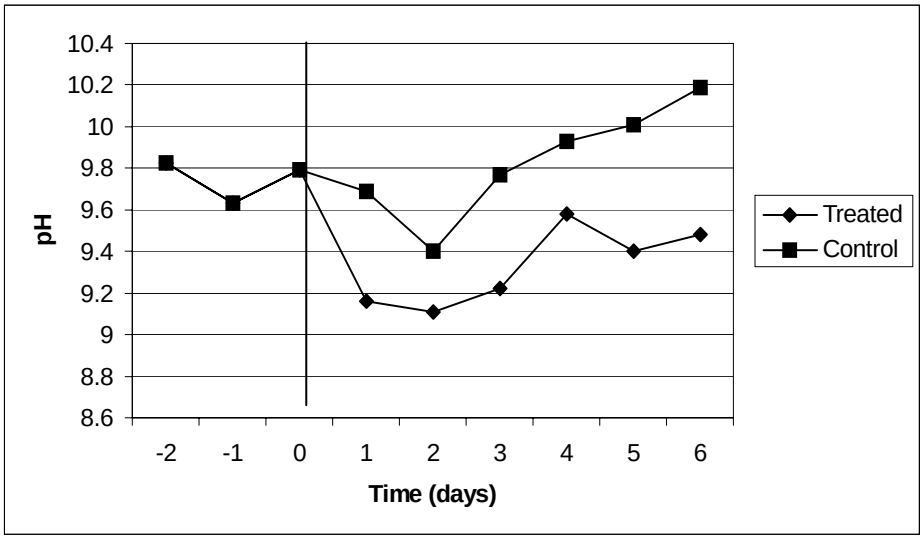

Figure 3: pH values of the treated and control areas two days prior to treatment and 6 days after treatment (Day 0 represents the day of treatment)

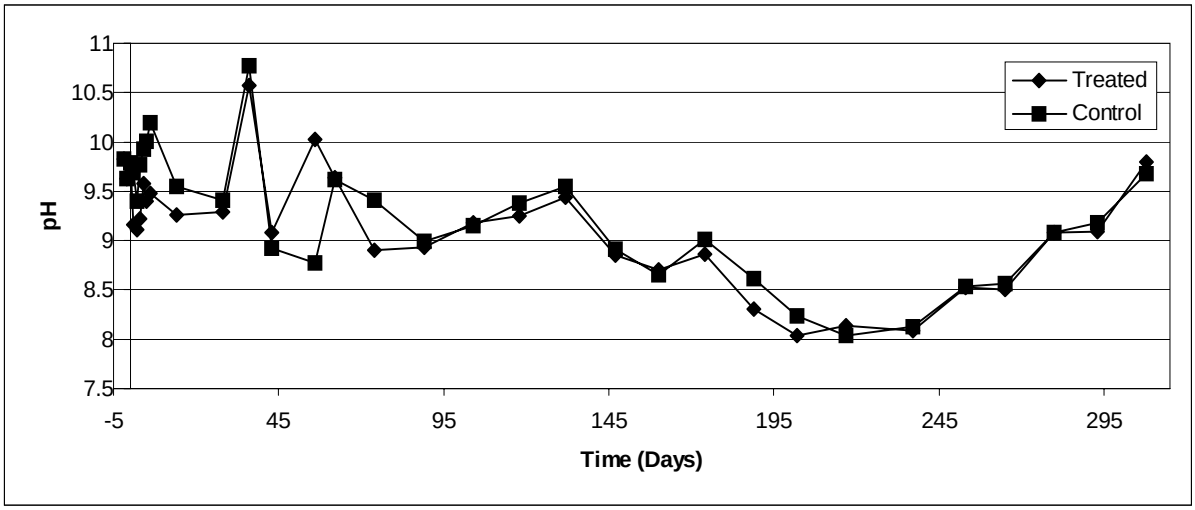

Figure 4: pH values of the treated and control areas for the duration of the trial

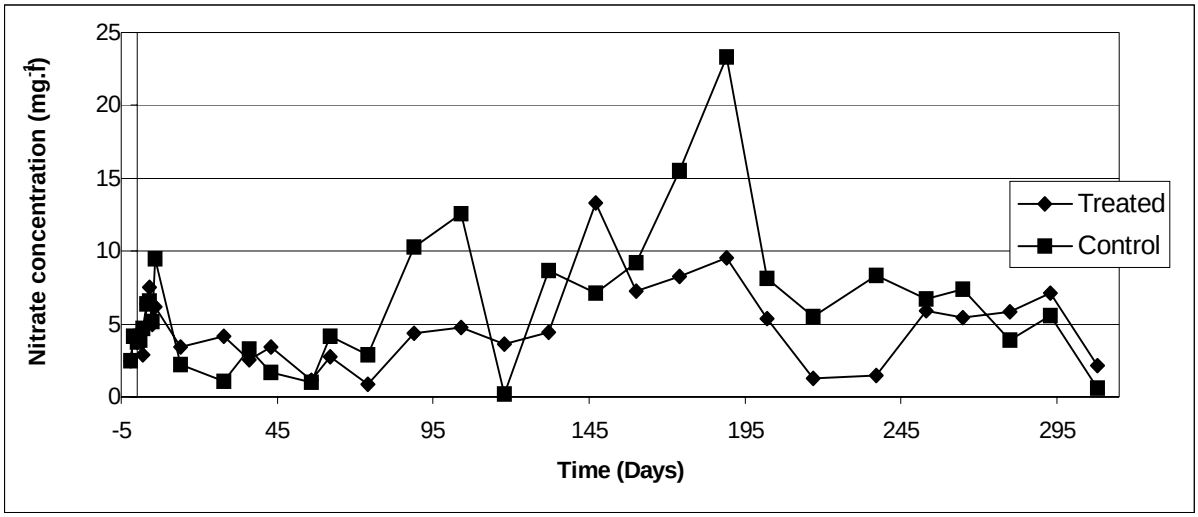

Figure 5: Nitrate concentration of the treated and control areas for the duration of the trial

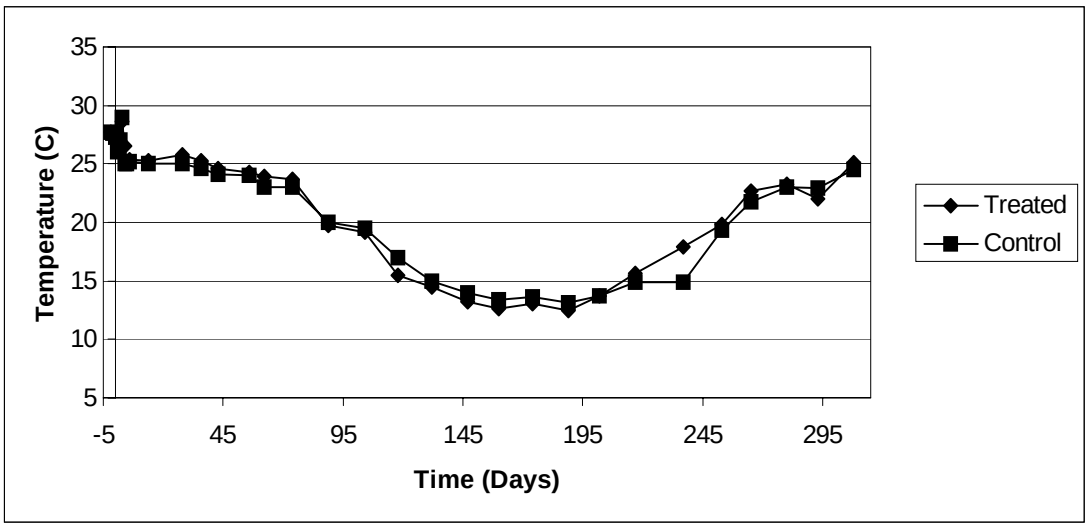

Figure 6: Water temperature of the treated and control areas for the duration of the trial

Discussion

The FRP was reduced by more than 50% in the 24h following Phoslock® application. There was no change in the control area over this period, so it can be concluded that Phoslock was responsible for removing the phosphorus from the water, despite the high pH of the surface waters. After 48h, the FRP concentration in the treated area decreased to 0.017mg.l^{-1}, and then stabilised at around 0.02mg.l^{-1} for the reminder of the first week of testing, whereas the FRP of the control area remained high. Phoslock® therefore successfully removed 73% of the FRP from the treated site. Because the amount of algae visible on the surface was reduced

immediately after treatment, and this did not reappear in the following 6 days after treatment, it can be concluded that Phoslock® also acted as an efficient flocculant of some of the algal cells.

Heavy rain in the second week of the trial caused the water level of the dam to rise substantially, and resulted in inflow of water and a large amount of algae into the test site. This caused an increase in FRP and nitrate concentrations in both the treated and control areas. However, the FRP concentration in the treated area did not increase to the same degree as the control area, and decreased at a much faster rate, and by week 6 the FRP concentration was once again below 0.02mg.l^{-1}. This may have been due to some remaining phosphorus binding potential of the Phoslock®. It is also possible that the FRP concentration decreased following the introduction of new algal cells to the site as a result of phosphorus uptake of the cells during growth. However, this does not explain why the phosphorus concentration of the control area did not show a similar decrease. The level of the boom was subsequently raised, to prevent the re-occurrence of such an event. The phosphorus concentration remained low in the treated area throughout the trial period, despite the fact that the algal cells died off as the water temperature decreased. The FRP concentration of the control area decreased from 0.72mg.l^{-1} in February, to 0.04 mg.l^{-1} in August. This was unexpected, as the decomposing algae release phosphorus back into the water. It is likely that the dying algae sank to the sediment, and the phosphorus concentration was subsequently increased at the sediment level, but not in the rest of the water body because of a lack of water circulation typical of the winter months due to the development of a thermocline. After week 26 (August), the FRP concentration increased steadily in the control area, but remained low (0.015mg.l^{-1}) in the treated area until November (week 43), by which time the control area had increased to 0.32mg.l^{-1}. The temperature of the water increased from 12ºC to 25ºC from August to November. It can therefore be concluded that the event of increased water circulation as the water warmed caused the nutrients at the sediment layer of the control area to be brought to the surface. The FRP concentration of the treated area remained low even after the water temperature increased and rainfall caused inflow of nutrient and algae laden water into the site. This means that Phoslock® effectively and irreversibly bound the FRP, and that there were still some available binding sites to cope with the inflow of phosphates after the rain.

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The pH values of the control and treated areas remained very similar throughout the trial period. After Phoslock® application, the treated area showed a decrease in pH when compared

to the control, but by the second week of the trial the two areas were once again of similar pH. Therefore the apparent pH lowering effect of Phoslock® is short lived, and is not a dominant feature of this product. It is possible that the lower pH value was as a result of increased water circulation in the treated site during treatment, and not a result of Phoslock® itself. The decrease in pH in both the control and treated areas throughout the winter months was most likely a result of the decrease in the amount of algae in the water. The pH increased in both areas from August to November. This is due to the increased water circulation and algal growth. It was not expected that the treated area would increase to the same degree as the control area because there was less growth in the treated area. This may be a result of mixing between the two areas, as well as the inflow of new water from the main dam.

Phoslock® had no effect on the concentration of nitrates in the treated area, which remained similar to that of the control area. The nitrate concentration varied in both the control and treated sites, but there was a general increase in the nitrate concentration in both areas from April to August and a decrease in the nitrate concentration from August to November. This decrease may be a result of uptake of nutrients by the algae, as well as due to the large amount of rain in October.

The amount of algal growth in the treated site did not appear to increase after the inflow from the dam, nor did it seem to decrease in the first 7 weeks after treatment, despite the fact that the FRP concentration was almost below detectable limits. Cyanobacteria have a substantial storage capacity for phosphorus. They can store enough phosphorus to perform two to four cell divisions, which corresponds to a 4-32 fold increase in biomass (Mur *et al*., 1999). This means that the algae present before treatment would still have had the ability to grow, despite the removal of large amounts of phosphorus. The fact that the FRP concentration remained low through winter despite the decomposition of algal cells indicates that active sites remained on the Phoslock® that were able to bind the phosphorus released from the algae. However, the decrease in water circulation as the water temperature dropped resulted in a similar decrease in the FRP concentration in the control area. As the water temperature increased to above 15ºC from August, the high phosphorus concentration at the sediment level of the control area caused an increase in the FRP concentration in the whole water body, up to 0.32mg.l^{-1} by November. This subsequently lead to the development of an algal bloom. The FRP concentration remained low (0.015mg.l^{-1}) in the treated area even after the water temperature increased to above 20ºC in October. Through winter the water level gradually

dropped to approximately 1m below the original level. During October the water level increased again by approximately 1m due to heavy rain, causing water from the main dam containing a high FRP concentration and algae to flow into the trial area. The FRP concentration in the treated area was unaffected by this inflow, indicating that active sites remained on the Phoslock® on the sediment. Therefore, because the FRP concentration remained low in the treated area despite the increased water circulation and inflow of additional FRP into the site, the Phoslock® treatment can be deemed to be a success.

Conclusion

It can be concluded that the product successfully reduced the phosphorus levels of the test site. Phoslock was also able to flocculate a noticeable amount of algae from the surface on application, and had no effect on the pH or nitrate concentration of the treated area. Following the increase in water circulation after winter, the phosphorus concentration remained low in the treated site when compared with the control, even after a large amount of nutrient containing water entered the site.

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