October 2007

Phoslock Water Solutions Ltd

Lake Restoration and Reservoir Management

Phoslock – the best in situ solution for the remediation of eutrophied lakes and reduction of blue green algae

This newsletter describes the mechanisms behind the effectiveness of Phoslock in significantly reducing Filterable Reactive Phosphorus (FRP) from water bodies. The product has been proven to successfully work in both freshwater and marine environments and has the added benefit of significantly reducing the concentrations of harmful blue green algae.

What is Phoslock?

Phoslock is a natural product, produced from modified bentonite clay and developed by the Land and Water Division of Australia's CSIRO (Commonwealth Scientific and Industrial Research Organisation) to significantly reduce the amount of Filterable Reactive Phosphorus (FRP) present in the water column and in the sediment pore water of a water body. FRP is an important growth limiting factor for blue green algae and other algae.

Bags containing Phoslock are easily loaded onto a boat or pontoon with the use of a shore-based belt conveyor. Once loaded onto the application device, the Phoslock is mixed using lake water into a slurry. It is then sprayed onto the surface of the water body in accordance with required dose rates. Phoslock can also be applied from land with the use of an applicator mounted on a vehicle.

How does it work?

As the Phoslock moves down through the water column, up to 95% of the FRP is rapidly removed and adsorbed onto the surface, forming an insoluble complex within the clay structure. As the Phoslock settles on the sediment-water interface it forms a 1-3 mm layer. This layer of Phoslock is capable of adsorbing the FRP from the sediment layer on its available binding sites. Once the FRP is bound to Phoslock, it is no longer bioavailabile for use by algae for assimilation and growth. The lack of nutrients in the water body has a direct impact on the proliferation of algae. One tonne of Phoslock is capable of removing 34kg of phosphate (PO_4), or 11 kg of phosphorus (P). Phoslock operates over a wide pH range ~ 4 to 11 and binds with phosphate even under anoxic conditions.

Benefits of Phoslock

Rapid reduction of FRP

Phoslock rapidly takes up FRP in the water body. Approximately > 90% of FRP is removed within four hours of application. FRP levels can be reduced to <0.01 mg / l. The FRP is removed from the water column, sediment pore water, inflow water and from internal sources such as algal degradation and excretion from aquatic organisms.

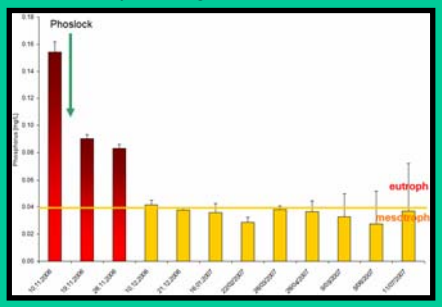


Figure 1: By using Phoslock, the overall phosphorus level was reduced from 160 µg to 36 µg in an application on the Silbersee (Germany).

Significant reduction in blue green algae

In an Australian drinking water body Phoslock effectively reduced the concentration of blue green algae in the reservoir and kept levels low (0 – 400 cells / ml) for up to four months post application (Figure 2). However, the concentrations of green and other algae slightly increased up to two months after the Phoslock application, after that the concentration remained steady.

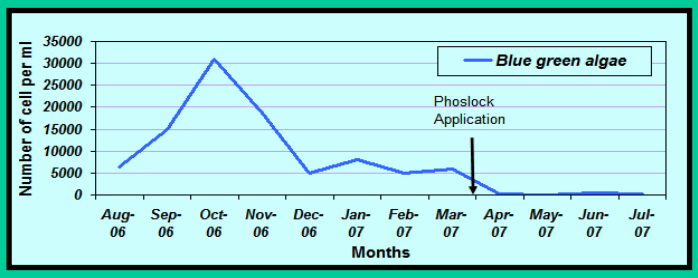


Figure 2: Concentrations (cells/ml) of blue green algae in Australian drinking water reservoir (0 – 8 m) before and after application of Phoslock (August 2006 to July 2007). n = 3 (Sampling points)

Safe for the environment

During the development of Phoslock, extensive laboratory testing was carried out on a range of test species using the United States Environmental Protection Agency toxicity testing criteria.

The CSIRO Centre for Advanced Analytical Chemistry assessed acute and chronic toxicology on a variety of aquatic species with no toxicity effects observed. Since then, the product has received approvals from NICNAS and the EPA in Australia. It can also be imported and sold in Europe under the EINECS system. Extensive ecotoxicology data compiled from independent and in-house sources is available upon request.

Phoslock – Lake Restoration

Eutrophication issues

Eutrophication is the enhancement of the natural process of biological production in rivers, lakes and reservoirs. It is caused by an increase in nutrient levels; usually phosphorus and nitrogen. Eutrophication can result in visible cyanobacterial or algal blooms, surface scums, floating plant mats and benthic macrophyte aggregations. Concentrations of phosphorus of < 0.1 mg / l are sufficient to cause a cyanobacterial (algal) bloom. The decay of this organic matter may lead to oxygen depletion in the water, which in turn can cause secondary problems such as fish kills and liberation of toxic substances or phosphates that were previously bound to oxidized sediment.

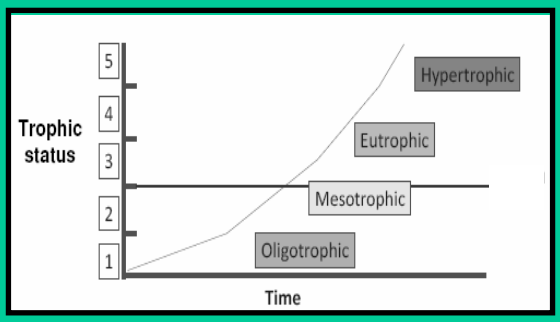


Figure 3: Effect of increasing phosphorus concentration on the trophic status of a water body.

Phosphate released from sediments accelerates eutrophication. Some lakes are naturally eutrophic, but in many other cases the excess nutrient input results from: (1) anthropogenic origin such as municipal wastewater discharges; (2) industrial effluents; and (3) runoff from fertilizers and manure spread on agricultural areas. Nutrient enrichment seriously degrades aquatic ecosystems and impairs the use of water for drinking, industry, agriculture and recreation.

Phosphorus as a limiting nutrient and the implications

Any nutrient can become a limiting nutrient in an ecosystem. For algae, the most obvious limiting nutrients are (1) nitrogen; (2) certain metals, and; (3) phosphorus. (1) Nitrogen removal is an expensive process, with high energy and chemical costs and specialised equipment. Certain microorganisms, including algae, are able to fix atmospheric nitrogen opportunistically. (2) Removal of metals may disrupt the local ecology, especially that of aquatic plants. (3) Phosphorus limitation is the most practical means of preventing the growth of toxic blue green algae.

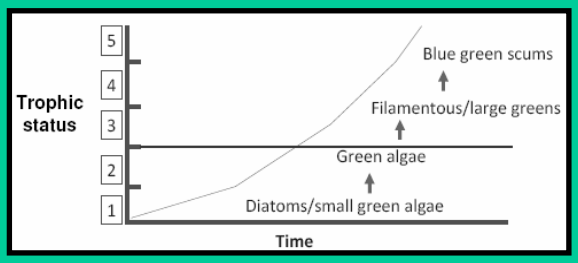


Figure 4: Effect of eutrophication on the algal population composition in a water body.

Figure 4 illustrates the effect of an increase in the trophic status of a water body on the algal population. In a healthy oligotrophic lake, it is normal for diatoms and small green algae to be present. However, as the trophic level of the water increases, a shift is seen in the algal population from small benign algal species, to larger filamentous green algae and toxic blue green algae. The presence of a large bloom of blue green algae in a lake indicates that it has reached a hypertrophic state. Limiting FRP in the system will cause a positive shift in the algal population back to the benign species, thus reducing the systems productivity and trophic status. Phoslock targets FRP, and in doing so, provides a permanent and sustainable management solution to eutrophication.

What can happen if you don't treat eutrophication and blue green algae issues

Common Remediation options

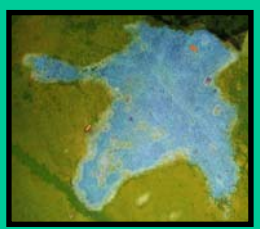
- **Biological treatment**
  - e.g. WTP Biological Nutrient Removal
  - •Only really suitable for point sources
- **Denitrification**
  - •N removal is expensive
  - •High energy (chemical costs) & equipment
  - •Nitrogen is refixed opportunistically

- **Chemical dosing**
  - •Not suitable for very low levels & natural waterways
  - •Remobilised under some conditions
  - •Al & Fe - pH & sludge problems
  - •Algicides - chemical or biological are unsustainable and have risky ecological impacts
- **Mechanical measures**
  - •Aeration – expensive
  - •Removal of nutrient rich water from the hypolimnion - unsustainable

Consequences of not treating

Eutrophication and blue green algal proliferation will only worsen without treatment. Some serious consequences of non-treatment are:

- Algal blooms
  - •toxin release
  - •ecology disruption with BGA
  - •Epiphyte impact on macrophytes
  - •DO stress with pH changes
- Ecology disruption
  - •Shift from oligotrophic to eutrophic & exotic species
- Microbial risk
  - •Biofilm increases
- Corrosion & biodeposition risk
  - •Taste / odour
  - •Coatings
  - •Corrosion



Features of Phoslock

Sequestering FRP from the water column and from the sediment pore water

Work undertaken by Phoslock Water Solutions Ltd has shown that the effects of Phoslock are sustained over time; the layer of Phoslock at the base of the water body ensures that future FRP is adsorbed (Figure 5), the reduction of FRP is maintained and blue-green algal concentrations are kept low (Figure 6).

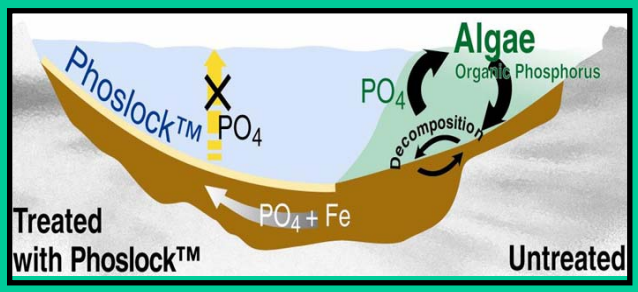


Figure 5: Diagram demonstrating how Phoslock will keep removing FRP from the water column and from the pore water contained in sediments even after application.

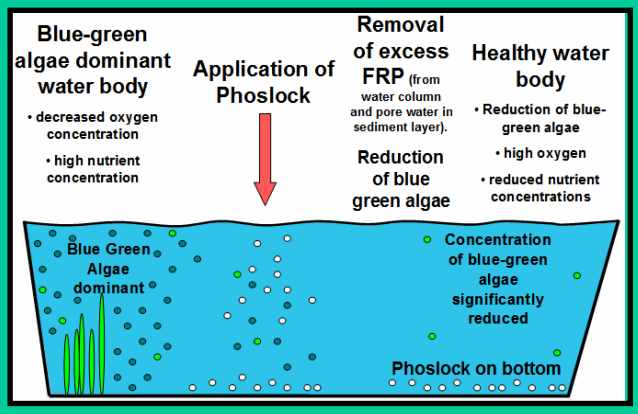


Figure 6: Effect of eutrophication on the algal population composition in a water body.

Removing FRP from inflow sources

A significant source of FRP (depending on the catchment) is contained in the inflow water. Water from catchment areas can contain concentrated amounts of P that run into water bodies during periods of rainfall. This input and the FRP released from the sediments are two of the most common long term issues relating to water body remediation (Figure 7).

Phoslock can be used to treat the inflow water before it enters the lake or reservoir (depending on flow rates) or it can be used as a management tool to maintain the concentration of FRP in the water body; reducing the impact of the inflow water.

During rainfall events, the inflow water may contain dissolved organic phosphorus (DOP). Degradation of this material in the water body will increase the concentration of FRP. Phoslock will remove this "hidden" source of FRP.

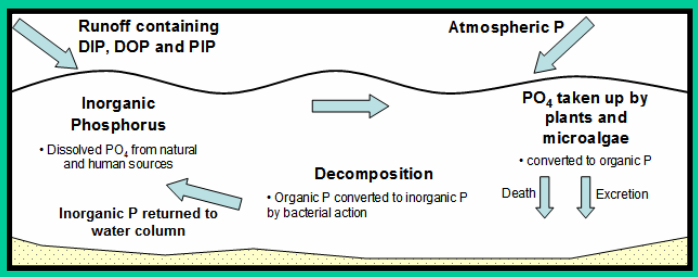


Figure 7: Diagram showing the possible inputs of P into a water body.

Manipulating the N:P ratio – Algal species shift away from blue green algae

The interpretation of data before and after the application of Phoslock in reservoirs and lakes shows the common trend that: the reduction of blue green algae was likely due to the alteration of the N:P ratio by the use of Phoslock. Filterable reactive phosphorus (FRP) in the water column and pore water at the sediment-water interface was "locked up", thus changing the N:P ratio. This resulted in P limiting conditions for growth and proliferation of blue green algae (Figure 8).

The concentration of blue green algae has also been observed to decrease over time after a Phoslock application. Once placed into a water body, Phoslock will sequester FRP. As the concentration of FRP is reduced in the water body, it becomes the limiting nutrient for blue green algae and inturn, the population decreases (in most applications, to well below regulatory standards).

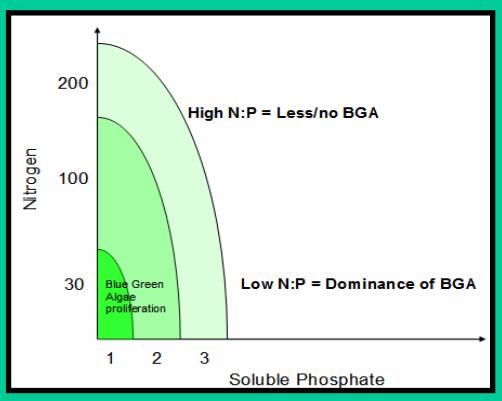


Figure 8: Schematic diagram showing the relationship between blue green algae and total N:P ratio.

Phoslock - Part of the reservoir management strategy

Phoslock can be used in conjunction with other management strategies for prevention of eutrophied water bodies and blue green algal outbreaks. Some of the other common management methods for lake/reservoir restoration/preservation are:

- Minimise input of nutrients (P) from diffuse and point sources
- Removal of contaminated sediments
- Removal of nutrient rich deep water
- Aeration
- Precipitation of phosphate (with the use of flocculation chemicals such as Al and Fe salts)

How Phoslock improves your water body

Other options for eutrophication control include various catchment control methods. Implementations of these methods may be environmentally sound, but can take up to 5 years to implement. These methods can be costly, and results are usually only apparent after 10-40 years, sometimes more. Diffuse and point source controls are other options, but there are disadvantages associated with these methods. Dredging is expensive and highly disruptive, and may not remove the source. The removal of dredged sediment is also a problem, as secondary disposal is now strictly regulated. Constructed wetlands provide a short term solution only, with the nutrients being remobilized unless there is regular nutrient removal. More importantly, internal recycling of nutrients is often the critical source. Phoslock has the ability to reset the ecological clock of an ecosystem (Figure 9).

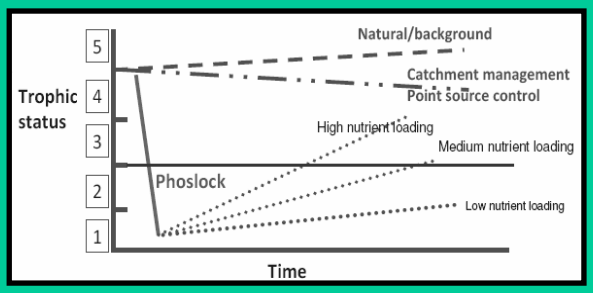


Figure 9: A Phoslock application resets the ecological clock of a water body, returning it to an oligotrophic status.

Phoslock applications

Since the commencement of commercial scale production, Phoslock has been applied to more than 100 large water bodies. At the time of this publication the amount of Phoslock that has been applied to water bodies was in excess of 800 MT in 20 countries. Applications can be tailor made depending on the application site, the severity of the problem, the climate and budget requirements.

Single dose application

Phoslock can be added to a water body in a single large application. This type of treatment is beneficial in situations where the concentration of FRP is above government regulations or where there is an immediate or predicted concern for human/environment health due to blue green algal proliferation. The results from a single does application are immediate and more obvious than smaller, multiple applications (Figure 10).

The dose rate for a single application is calculated upon the knowledge of the phosphorus mass balance for each of the water bodies treated. This calculation is based on the following P sources: (1) water column; (2) sediment pore water; (3) inflow water; (4) cycling of P from biomass and aquatic organisms; (5) atmospheric P (Figure 7).

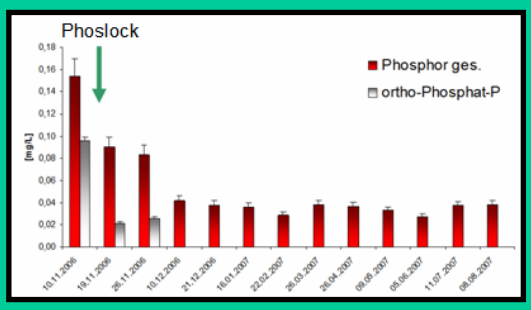


Figure 10: Phosphorus data from an application in a German lake. The FRP was significantly reduced after the application and maintained for the monitoring period (4 months after Phoslock was applied).

Smaller multiple doses over time

Phoslock also has the potential to be used as a eutrophication management tool, whereby the FRP [PO_4-P] is removed in a step-wise fashion over a period of 3-6 years (Figure 11). Although the result is not as immediate as with large doses, this approach does offer some advantages: (1) cost effectiveness (as the cost can be factored over a number of years); (2) easier and more practical applications; (3) long term management and monitoring; (4) flexible strategy where necessary to accommodate nutrient loading and influences from the climate.

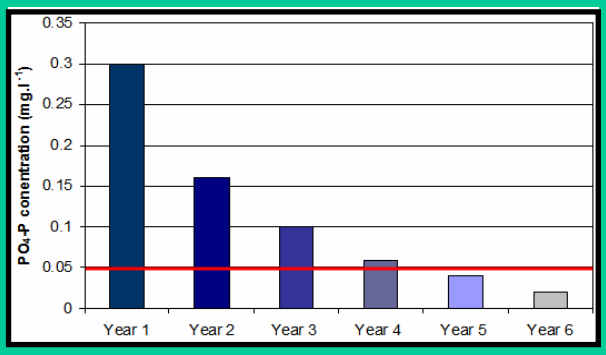


Figure 11: Conceptual graph of the reduction of FRP by applying Phoslock in measured doses over time

Eutrophication management strategy

The FRP concentration is reduced by 66% in year 1, 80% in year 2, and 100% in year 3 in a typical water body (Figure 11). Some FRP will remain in the first 2-3 years and algal activity will not disappear entirely. However, the reduced concentration of P ensures reduced algal activity, and a population shift from toxic cyanobacteria to benign green algae and diatoms.
Maintenance of a water body with Phoslock will ensure that there is a sufficient amount of Phoslock at the sediment-water interface to minimise the release of FRP from the sediment.

Highly eutrophic water bodies contain large reserves of P in the sediment and are likely to continue to release P for many years. For water bodies that contain higher than normal concentrations of FRP or deep water bodies, larger initial doses or larger yearly doses are suggested until there is an acceptable reduction in FRP. High concentrations of FRP from inflow sources or in flowing rivers will influence the maintenance treatment.

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