REVISION ONE

Lake Sediment Capping

Comparative evaluation of capping materials costs and related issues

Prepared for

Environment Bay of Plenty

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BY

ENVIROMEX NZ

4 WATERS 4 SEASONS 4 EVER

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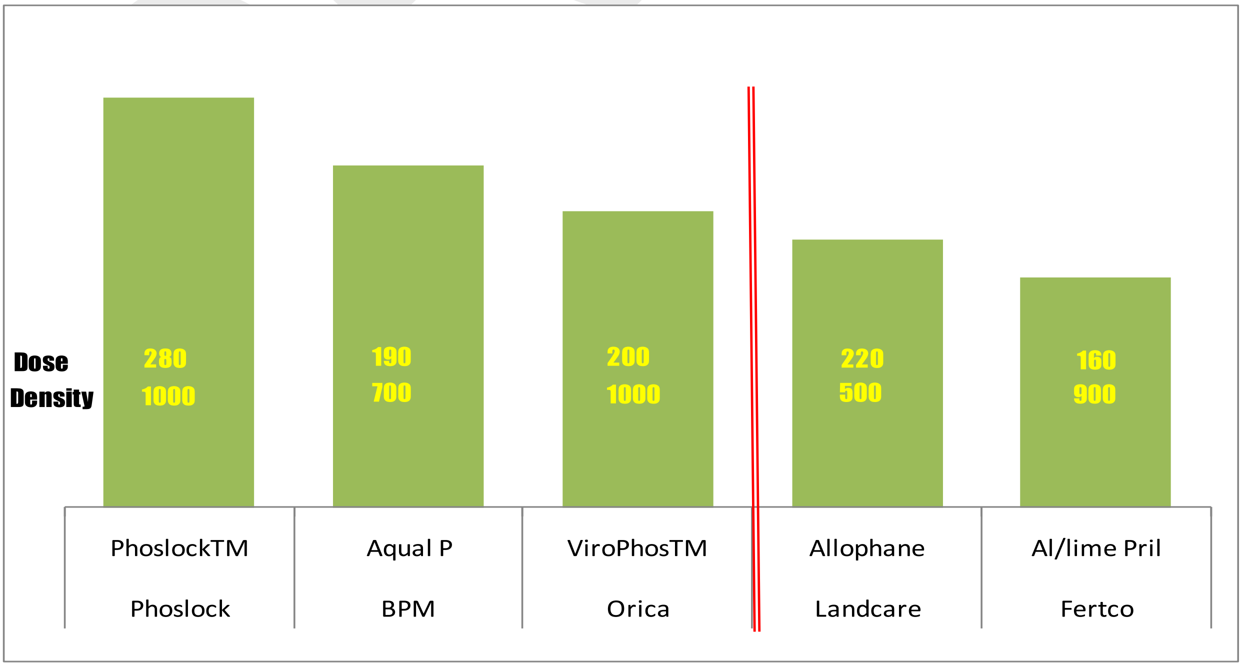
The production of this draft report completes Stage One of the brief outlined in Appendix A.

Project costs and logistics for purchase and application of sediment capping materials for Lake Rotorua have been investigated to provide guidance of preferred capping material(s) and certainty of future actions to deliver a successful project. Gaps and areas of risk have been identified in this draft report. The intention is that these gaps and risks be mitigated where practical and any additional costs or logistical precautions are included in the final report. Until knowledge gaps are filled and report is updated, this report will remain as draft status.

Stage One investigations included development of a cost model for each material, the output of which is summarised in Figure A1. The organisations contacted are shown with materials offered, their budget price and handling costs up to and including final application. Material capping rates are taken from a report[†] by NIWA that noted results of laboratory tests on many of the materials. Surrogate values have been selected for ViroPhos and Fertco products that were either not included in the laboratory work or only some component included, e.g. alum.

Figure A1 omits the alum option included in Table 3 in section 5.2.1 because the application of an aluminium based coagulant without buffering is expected to adversely affect lake water pH. Also, the physical difficulties of applying liquid alum + buffer to reach and remain within the target area when subject to lake current and water energy effects is a considerable risk that is to be avoided if practically possible. Various formulations of a rudimentary aluminium/lime pril (Fertco and McDonalds Lime) were developed during the study to counteract adverse pH effects and demonstrate granules can be formed from appropriate products that largely mitigate application constraints of equivalent liquids.

Figure A1 Relative cost ranking of sediment capping materials including coverage dose and material density.



Materials are ranked highest to lowest, left to right. The difference of highest to lowest of approximately $17 million is larger than anticipated. Material supply costs ranged from 65 to 85 percent of total project cost, stressing the importance of negotiating a good price for this component of the project.

A double line in Figure A1 partitions specialised proprietary materials suppliers to the left and a research group and fertiliser industry product manufacturer to the right. It also separates more proven materials from lesser proven options, although both allophane and alum performed well during NIWA trials. In fact, allophane performed admirably and even excelled when compared with proprietary materials. This is likely due to high concentrations of phosphorus adsorbing constituents of aluminium, iron and calcium contained in the allophane structure. In terms of cost, margins were added to allophane and Al/lime material supply costs to reflect knowledge gaps at the time of preparing this draft report.

While proprietary products are available in commercial quantities and have a proven supply capacity and delivery mechanism, only Aqua-P is currently shown to be available in pril form including a dispersant to provide material properties conforming to the current understanding of application requirements for Lake Rotorua. Phoslock proved most expensive of all materials and would not merit further consideration unless there was a marked change in supply price. ViroPhos is practically unknown at this stage and was not included in the NIWA trials. It would require laboratory trials or some supply incentive to justify going direct to in-lake trials.

Al/lime pril is also well advanced and allophane is in the mix. The active ingredients of Al/lime, and allophane material, were included in the work completed by NIWA. These materials have a degree of uncertainty in supply quantity and quality and/or pril formulation. However, the disparity of several million dollars supply cost for proprietary materials is viewed as adequate justification to invest effort into allophane and Al/lime materials to determine if there remain as yet unidentified limitations that will become more evident during more in-depth review of consenting requirements or formulation trials.

It is known that significant biologically generated gas emissions occur over a large proportion of the target application area. The effect of gas release on capping materials performance is a matter that would be best studied in some form of laboratory trial, or more realistically, an in-lake test area.

The application of materials to surface waters in a form that can rapidly sink and disperse at some depth (pril) to mitigate hypolimnion surface boundary effects has merit to more accurately achieve cap application rate, although does little to capture epilimnion nutrient unless applied as a fine particle or liquid. Liquid would be best applied to the hypolimnion at a time when maximum uptake of sediment released nutrient would take place and coagulant is less prone to being carried away from the target area during and immediately after settling due to generally calmer conditions. This is feasible from a cost perspective because pril manufacture costs would largely offset any development of injection lances needed to deploy coagulant and buffer at depth. It may also be accomplished with a pril or graded material applied by aircraft, but is yet to be demonstrated.

Any contract to apply materials during calmer climatic periods would need to be established well in advance for the successful applicator to schedule such a large project and make the necessary arrangements. The cost difference between barge and aircraft is not a deciding factor since they are for all intensive purposes the same. Barges have the advantage of physical application at depth, but are time limited. Aircraft application is as yet unproven particularly if seeking to target the hypolimnion, or disperse at depth, although aircraft would have a time advantage in good weather. From the investigations completed in this report both air and water application methods would be successful with air having slightly greater merit because of the time advantage and availability of several aircraft to rapidly complete the work.

Knowledge gaps that need further investigation to complete stage 2 are:-

1. Investigate formulated uniform granular materials containing active ingredients known to perform well such as alum, poly aluminium chloride, sodium aluminate, lime products and/or sodium bicarbonate with appropriate dispersant. Alum liquid with buffer is not thought practical at this time as the transport of aluminium out of the target area remains a concern. Some form of transport study might assist in understanding the mechanisms involved and provide detail of any window of opportunity for administering liquid coagulants with or without flocculent and nucleation enhancements.
2. Determine a buffer formulation and application method to keep pH within the range of 6.5 to 7.2[†] for application of liquid alum, or any other pH modifying substance.
3. Further develop allophane to determine the cost arising from consents and material changes to suit a preferred method of application, i.e. dry, grind or screen and pril.
4. ERMA requirements under HSNO legislation are noted in Section 4.4.

† Akhurst D.J, Jones G.B, Clark M, McConchie; Research Paper:- Phosphate Removal from Aqueous Solutions using Neutralised Bauxite Refinery Residues (Bauxsol™), CSIRO Publishing, 2006.

Table 1A below serves to highlight the knowledge gaps by summarising critical elements of the project in relation to supply and application activities for each material. It must be viewed in relation to other comments made in the report to avoid incorrect conclusions. For example, the ‘material form’ of aluminium based materials and allophane are described as needing further work. In the case of allophane, allowance has been made in pricing for reconstituting the material to a pril form which has as yet not been produced. There is also the issue of material purity and characteristics which will depend on the site selected for extraction. Al/lime pril however has been produced using readily available components although requires further work to mitigate potential shortfalls identified in the first product runs. Alum/buffer liquid components are also readily available although best form for application needs further work.

Table 1A Critical elements of supply and application of lake sediment capping materials.

Criteria	Phoslock	Aqua-P	ViroPhos	Allophane	Al/lime pril	Alum/buffer (Liquid)
Suitable for application by air	FW	Yes	U	FW	Yes	FW
Suitable for application by Barge	Yes	Yes	Yes	Yes	Yes	Yes
Material/component availability	Good	Good	Good	FW	FW	Good
Material form well developed	Yes	Yes	Yes	FW	FW	FW
Apply in all lake conditions	Yes	Yes	U	Yes	Yes	No
ERMA Approved (as at 2010)	Yes	Yes	U	NR	FW	Yes

FW further work required
U Unknown
NR Not required

1.1 Purpose

The purpose of this report is to establish the ranking of materials proposed to control nutrients in Lake Rotorua sediments by considering equivalency of available products, logistic factors associated with their use, application rate (dose), methods of application, application timeframe and estimated cost.

Over recent years significant progress has been made into investigating the type and form of materials to cap nutrient rich sediments within central North Island lakes. Much of this work is based on various laboratory and field trials that aim to determine the effectiveness of selected capping materials to encapsulate phosphorus (and to a lesser extent nitrogen) within the lake bed cap and sediments.

This report relies heavily on previously completed studies and trial work to compare a number of logistical factors as noted in the scope agreed with EBoP, dated 12 October 2009 (Refer Appendix A). The scope refers to several stages of the project, of which, only stages 1 and 2 are agreed at this time.

Objectives of this 'Stage One' report are summarised as:

1. To use capping material coverage rates to determine bulk delivery requirements.
2. To use bulk masses of each material to establish:
   - Purchase costs
   - Adequacy of existing stock quantities
   - Storage and handling criteria
3. To compare the likely methods of application, being:
   - Barge
   - Fixed wing
   - Helicopter
4. To review the technical information and highlight gaps in the information that requires further study.

1.2 Acknowledgements and Confidentiality

On behalf of Environment Bay of Plenty, Enviromex wish acknowledge and thank the following organisations for contributing to this report, which in alphabetical order are:-

- Aqua-Ag Air Boat Services
- Blue Pacific Minerals, (BPM)
- Eagle Transport Tauranga

- Fertco (manufacturer of products designed by others)
- Lakeview Helicopters
- Landcare Research
- McDonalds Lime
- NIWA Research
- Orica Chemnet
- Phoslock Water Solutions
- Scion
- Super Air

The quality of information and assistance provided by all participants is appreciated.

For reasons of confidentiality expressed by some suppliers two versions of this report will be produced:-

1. A confidential and comprehensive report including all evaluations that disclose potentially commercially sensitive information to EBoP. This report will be marked confidential on the front cover accompanied by a restricted distribution notice.

2. A modified version of the confidential report that excludes commercially sensitive information and comments. The presentation of costs is substantially modified.

2.1 Information Gathering

There are three stages to the collection of information required for this project:-

1. Preparation and distribution of a Data Information Request Form (DIRF example in Appendix B)
2. Receipt and review of information provided by suppliers in item 1,
3. Meet/correspond with suppliers to clarify and/or augment information in the DIRF

Not all information received is included in this report, e.g. some providers supplied relevant experience information in a video format, material samples and/or included information marked confidential.

2.2 Information Review

Received information was checked for completeness. Important omissions were recorded and further queries raised with the organisations concerned. These were generally addressed to a reasonable standard by the organisations concerned.

2.3 Assessment

In order to simplify the amount of effort required of transport and application service providers, all capping material movements were expressed as a ‘unit tonne’ measure. This allowed a bulk density factor to be applied to activities where volume constraints also apply.

Material properties used were advised by the product manufacturer or authorised agent. Where essential information for the assessment was not available surrogate values have been used based on equivalent material properties. Surrogate values were required to assess the volume of some products. The effect of surrogate value error on the report outcomes is expected to be negligible.

The differences between solid, liquid and slurry phases are commented under various section headings as appropriate.

2.4 Assumptions

The following assumptions apply to this report:-

a) All information and pricing provided by the various organisations contacted is representative of the materials or services and not subject to significant change beyond normal market escalation.

b) Technical information used in preparation of this report is representative of material performance to cap sediments at Lake Rotorua, e.g. material application rates and aerobic/anaerobic cycle response and pH responses/effects.

c) Consideration of nitrogen is not necessary as long as materials are not applied to permanently aerobic zones of the lake.

d) Products identified in earlier reports by others and used to calculate masses and volumes in this report are consistent with products properties advised by the suppliers.

e) Note that some correlation is included for Lake Rotoehu. Some differences in transport and application have been made, however the costs are considered indicative only and must be further refined.

f) International exchange rates are not less favourable than stated with Table 3.

g) Escalation of current value sums (2010) to reflect future value (2016) is not required at this time.

3.1 Material Delivery

3.1.1 Packaging

Phoslock, Virotec and BPM manufacturing is suited to the supply of material packaged in bulk bags. These bags have a volumetric capacity of around a cubic metre. The bulk density of material determines the mass contained within each bag. Storage of bulk bags in the open is not recommended. Water ingress will deteriorate contents.

Fertco and Landcare provide material in bulk.

Alum would be bulk liquid supply.

3.1.2 Transport and storage

There are several commercial bulk haulage organisations within reach of Rotorua that are well equipped to deliver and store large volumes of material. This study focused on Tauranga based operators to cover both imported goods and local supply. Road haulage is a highly competitive market which suggests the rates would vary little from those used.

Covered dry storage is readily available and is not a significant sum compared with materials supply.

Alum liquid requires careful coordination with production and delivery facilities to ensure it is produced and delivered in sufficient quantity for the lake application equipment. Orica Chemnet also have considerable storage capacity for liquid alum due to the large quantities used for water treatment. Any liquid option would require a temporary storage tank to facilitate road tanker – storage - craft loading. This will add to consent, safety and handling requirements.

3.2 Application Area Assumptions

A suggested application boundary has been added to figures in the following subsections to indicate alignments suited to both barge and aerial application methods. Run distances should be in the order of 500 metres to suit fixed wing equipment.

Both Figures 2-1 (for Lake Rotorua) and 2-2 (for Lake Rotoehu) include a highlighted yellow rectangular area of 500 metres by 50 metres on scale bar. This area requires 5 passes by a fixed wing aircraft to provide the nominal capping material coverage of 200g/m^2 at the water surface (i.e. 2 T/ha). Note that shorter runs are easily accommodated the pilot having full control of opening and closing the discharge chute. There is also adjustment of the application rate by altering outlet chute conditions.

In theory, helicopters and barge application methods do not have the restrictions of fixed wing aircraft. However, Figure 3-1 indicates the lake capping project scale is sufficiently large as to substantially mitigate any advantage barges or helicopters may offer.

3.2.1 Lake Rotorua

Figure 3-1 is a plan issued by EBoP that shows the proposed application of sediment capping material at greater than 12 metres depth (orange).

Superimposed over this plan is an approximate capping material application matrix for fixed wing aircraft, the most economic although nominally most restrictive of the application methods.

The matrix is based on the following assumptions for fixed wing aircraft:-

- A north-south (or east-west) alignment makes setting the application matrix easier and hence control by GPS easier,
- A capping material application rate of 2000 kg/hectare (200g/m^2),
- 1.0 to 1.3 tonne of material carried per load,
- Hoppers are suitable for liquids or solids,
- The full hopper is completely emptied along a run of just over 500 metres distance and effective width of around 10 to 12 metres (can open/close over several shorter runs),
- It is acceptable to rationalise application area margins to suit aircraft run lengths,
- Lake fluid effects attenuate any small inter-zone application rate differences,
- Application margin effects are minimal.

Other application methods also use grid or block setout areas that are monitored by on-board GPS to control the application of capping material. A printout of craft position shows passage within each grid and therefore a record of where capping material was deposited into surface waters.

3.2.2 Lake Rotoehu

Similar to Lake Rotorua in section 3.2.1, Figure 3-2 is also a plan of Lake Rotoehu issued by EBoP showing the proposed application of sediment capping material at greater than 12 metres depth (orange).

Superimposed over this plan is an approximate capping material application matrix for fixed wing aircraft.

Assumptions outlined in section 3.2.1 also apply to this section. Note however that the relatively small size of Lake Rotoehu (c.f. Lake Rotorua) results in some overlap of aircraft runs. As noted in the previous section, the aircraft pilot can stop and start the drop whenever necessary which will eliminate the overlaps and overrun areas shown. A refined application plan for the target area would be programmed into GPS by the applicator.

Figure 3-1 Lake Rotorua area and fixed wing application matrix

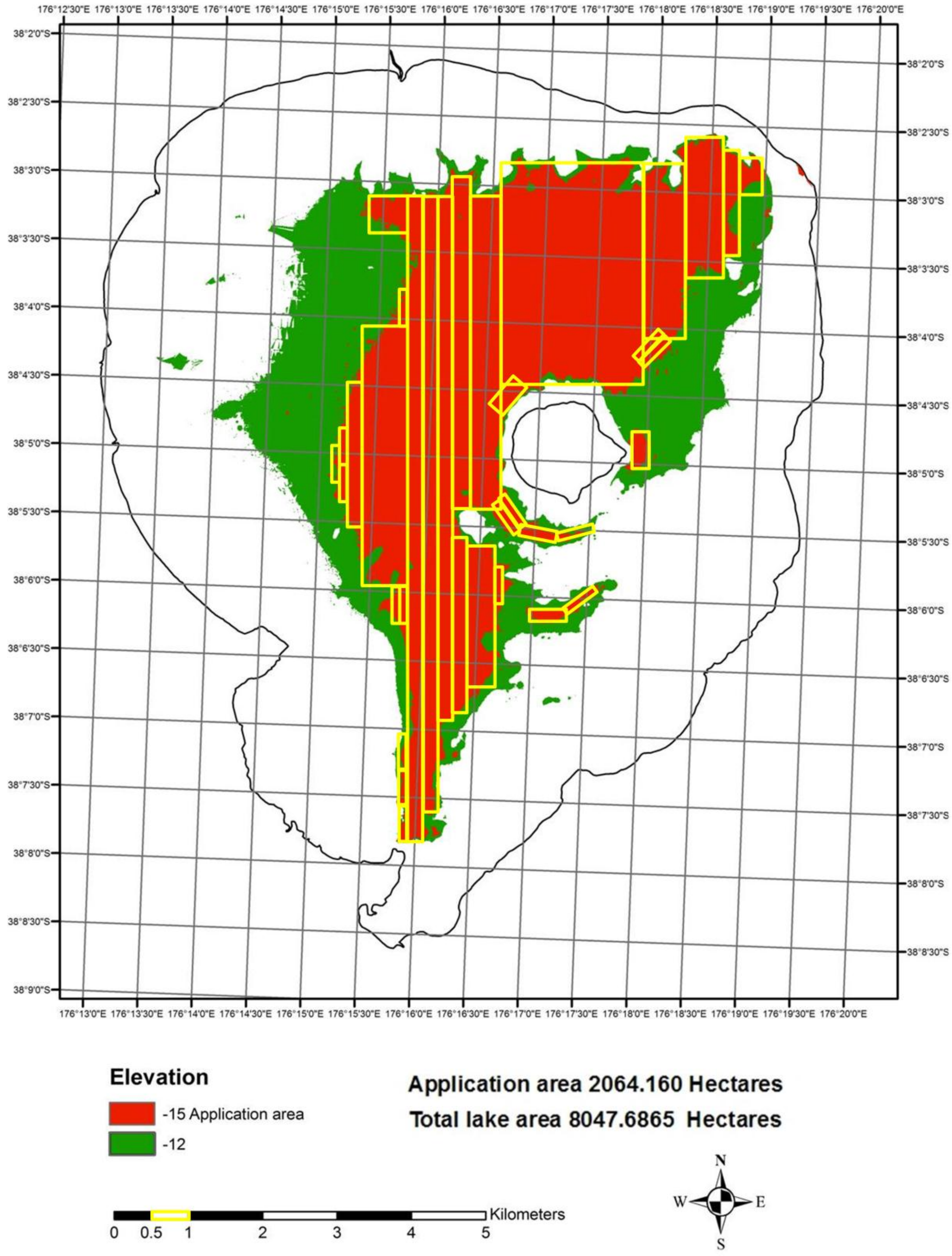
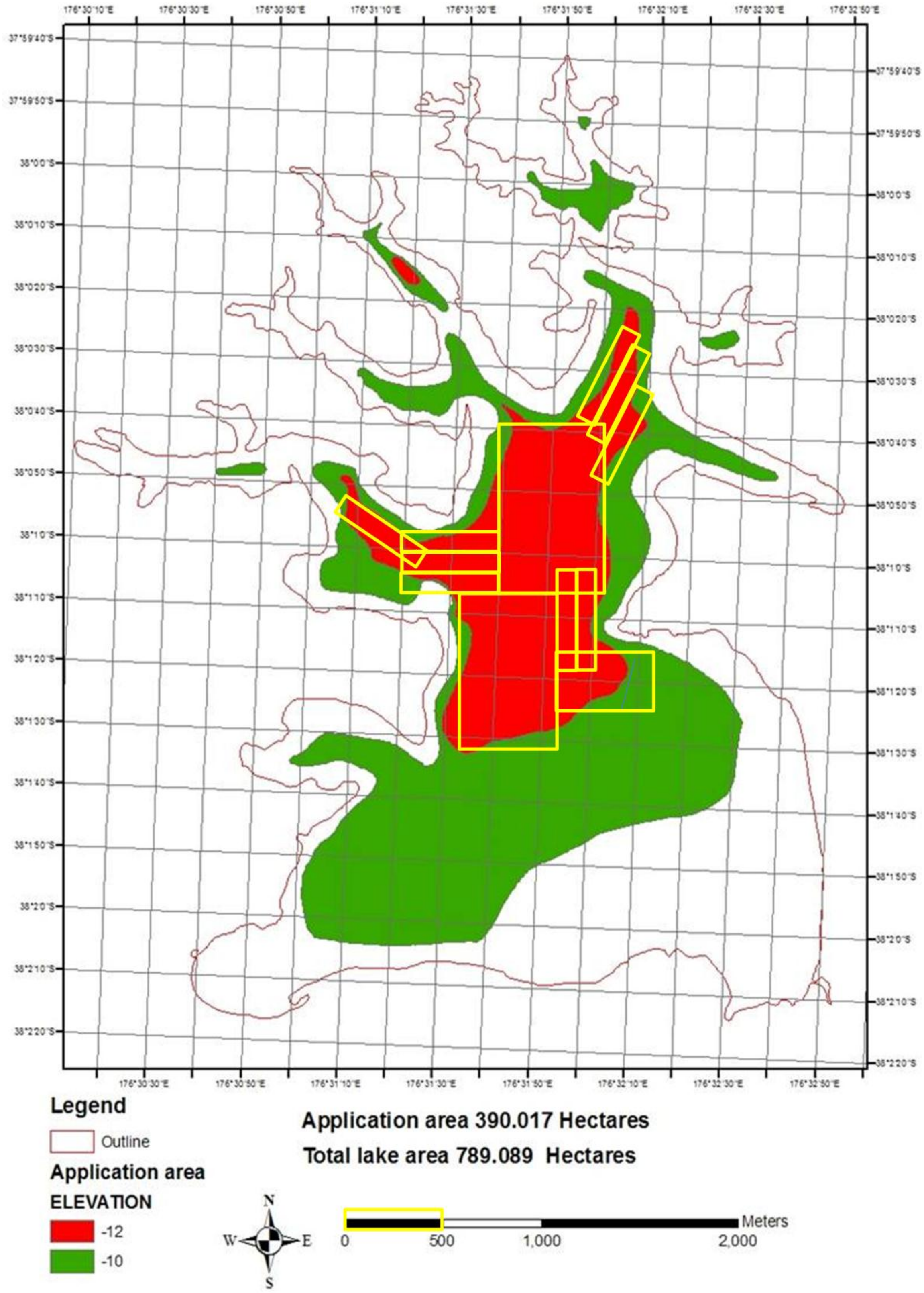


Figure 3-2 Lake Rotoehu area and fixed wing application matrix



4.1 Introduction

This section discusses aspects of capping materials as they relate to the present understanding of inactivating phosphorus within Lake Rotorua, and to a lesser extent, Lake Rotoehu.

4.2 Summary of Characteristics

Table 1 contains capping material properties and characteristics used in the preparation of this report.

Table 1 Selected capping materials properties and characteristics

Criteria	Aqua P	Allophane	Al/lime	Phoslock	Virophos	Alum
Granular	✓	✓	-	✓	✓	-
Pril	✓	✓	✓	-	-	-
Liquid	-	-	-	-	-	✓
Bulk Density (kg/m^3)	700	500		1000[a]	1400	1300
Colour	tan	brown	white	brown	-	clear
Capping rate (g/m^2) [c]	190	220	160[bd]	280	200[b]	77
Delivery	bag	bulk	bulk	bag	bag	bulk

a Ranges from 900 to 1200 kg/m^3 depending on screen grading.

b Assumed capping rate.

c Capping rate sourced or extrapolated from NIWA report, Comparison of efficacy of four P-inactivation agents on Lake Rotorua sediments, dated June 2008.

d Extrapolated value.

4.3 Application Matters

4.3.1 Material production

Commercial quantities of capping materials are generally produced to a specification that can be altered to a limited extent to suit customer requirements. Alterations are mostly restricted to changes that can be achieved using normal production equipment such as screens and crushers, i.e. particle size manipulations. Specific customer requirements, such as pril formation, is seldom a normal production activity and therefore incurs additional materials handling and adds to product cost.

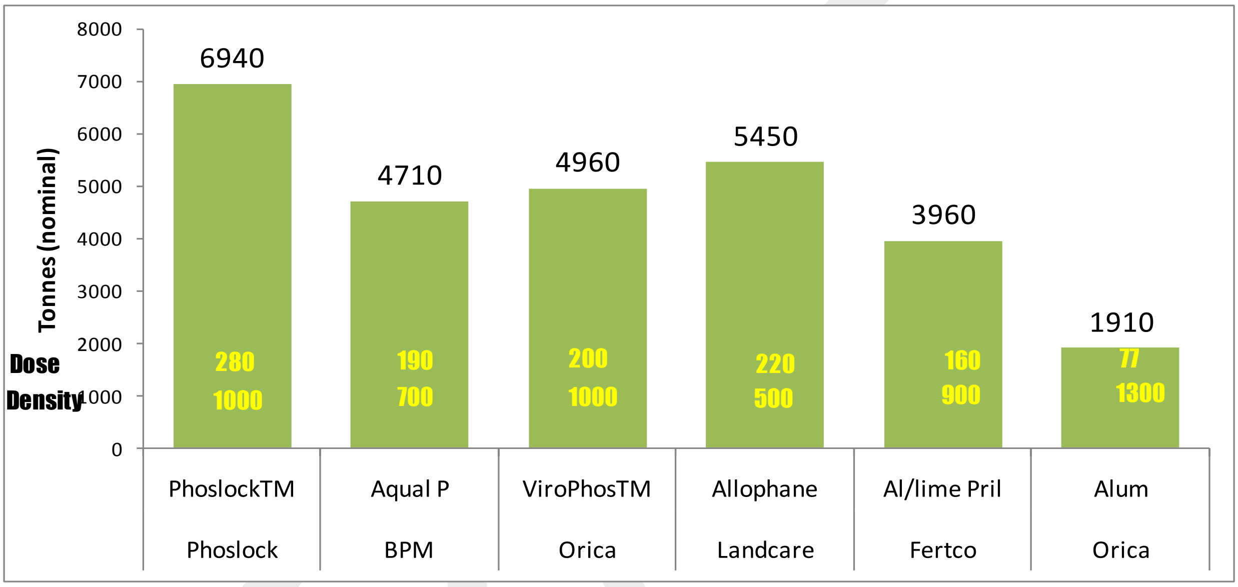
Products that offer greatest flexibility are those specifically formulated and developed to meet customer objectives. The proposed use of a pril means production rate will vary depending on supplier and the pril formation method used. The range of production is likely to be 3 T/h to 15T/h. It is therefore necessary that a supply contract be arranged well in advance of the application date. By comparison, the application rate is likely to be in the order of 25 to 30T/h for two fixed wing aircraft.

4.3.2 Material load masses

The following figures illustrate the relative mass loadings of materials considered in this study. A mass of material (tonnes) is noted above each column.

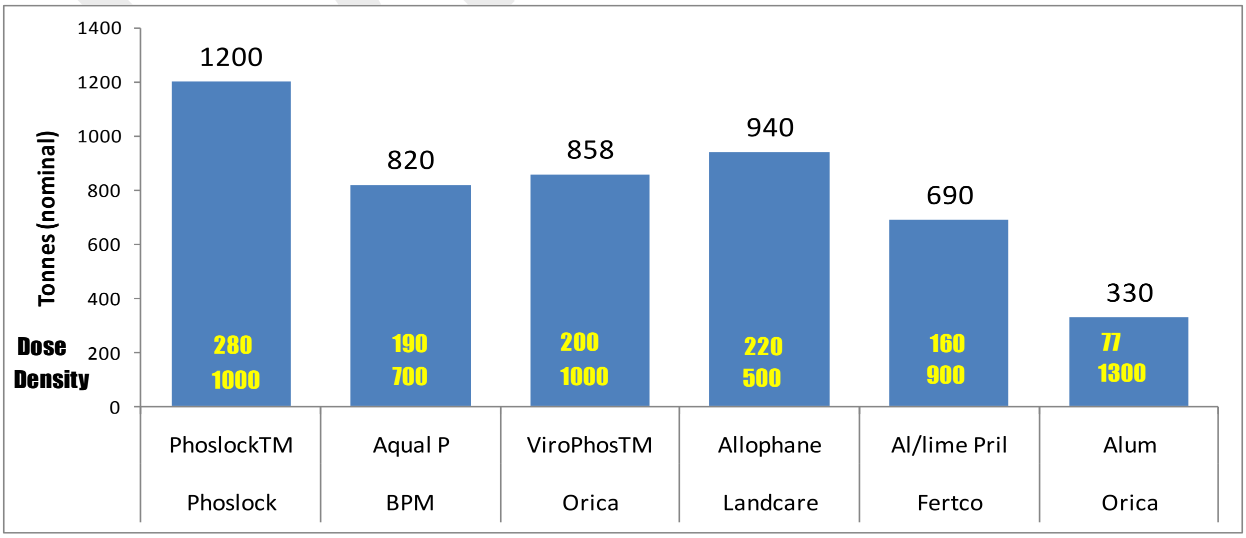
Dose information in g/m^2 is presented as extracted from laboratory trials conducted by NIWA, Ref; HAM2008-105 June 2008 (for full refer note c of Table 1). Density is bulk density in kg/m^3 as advised by material suppliers, except Fertco where no value was provided.

Figure 4-1 Material mass loads for Lake Rotorua



Values stated for Lake Rotoehu are based on Lake Rotorua information and therefore can be considered as indicative only. Actual dose will depend on Lake Rotoehu sediment characteristics, phosphorus mass and rate of release, amongst other factors.

Figure 4-2 Material mass loads for Lake Rotoehu



4.3.3 Application by aircraft

Helicopter and fixed wing aircraft are used extensively throughout the agricultural sector to apply large quantities of products in granule, pearl, powder-slurry and liquid forms. Aircraft reviewed for this study hold between 1 to 1.3 tonne which is the size typical of larger topdressing operators. Product is delivered loose measure (heap) on truck and trailer units or contained in bulk bags. Most larger operators prefer bulk ‘heap’ material because farmers often have large volume load out facilities that can be used in this project. All company’s contacted held NZAAA H&S and Spreadmark accreditations. They therefore have approved methods to calibrate application rates for the type of aircraft being used to give certainty that a specified capping rate is being achieved, at least at water surface level. All are familiar with types of materials proposed for capping lake sediments.

Aircraft use GPS mapped to an application area plan. This allows a number of aircraft to work over different sectors of the application area and coordinate with loading facilities. Good coordination is critical as an aircraft load cycle time is in the order of 5 minutes for the aircraft operators contacted during this study. It is recognised that larger aircraft operators exist that might bring some benefit to the application process, however, they have not been contacted at this stage because application cost is low compared with raw material costs. Also there are a number of other factors considered far more critical at this stage, e.g. material selection and cost.

Aircraft type and size aside, there are some precautions and restrictions to aerial application:-

i. Fine powders tend to be lost in the air after the payload is dropped, i.e. too light to readily settle in the target area. This will result in a loss of product where a material has a significant proportion of powder.

ii. Some form of notice will be required to restrict and/or coordinate the movement of persons and equipment from entering the target areas and buffer zones that are not directly involved. Some commercial operators on the lake may be affected by these restrictions. The Health Act and OSH policies will require policing of the restrictions.

iii. The Rotorua Airport borders Lake Rotorua. Various restrictions apply depending on the approaches being used. For the most part these do not affect the application area. However, some precautions and procedures are required;

  - Notify the Civil Aviation Authority (CCA) in Wellington around 6-months prior to material application activities by aircraft to advise the nature of activities so that an *Aviation Notae* may be issued to all air traffic organisations.
  - Rotorua airport’s Chief Controller advised airspace around the airport is ‘controlled air space’ which requires aircraft to comply with aviation authority requirements for the airspace designation. This is not thought to be a problem for the proposed activity. Agricultural aircraft operators are required to carry the correct certifications for operating at low altitude.

- communication with the airport tower to confirm and avoid any restricted airspace. There would be momentary delays while airport traffic transit specific air corridors, particularly if the south-western corridor is in use.

iv. Some form of agreement may be necessary to permit use of bulk load-out facilities owned by third parties, although this is best left to aircraft operators to organise and coordinate as part of the contracted work.

v. Noise might be cause for restricting aircraft movements. The passage of aircraft over populated residential and commercial areas can be largely avoided and excluding piston aircraft will reduce noise (turbine is significantly quieter). However there may be other as yet not identified restrictions that arise during the consent process that have some affect on outcomes stated in this report.

4.3.4 Application by barge

All previous sediment capping operations reviewed during preparation of this report were completed by some form of water bound vessel. Barges typically use GPS to coordinate movements in the application area and apply product via a boom or slurry or granule delivery systems.

There are a number of staging locations for transfer of bags from road to barge. As an initial assessment, the public ramp at Ngongotaha was thought practical because of the more remote location and lower frequency of use by the public compared with some other lake locations. Not less than two barges would operate each with a pay load of 10 tonne. Each would be fitted with a boom feeder of 15 to 18 metres width to evenly apply material across the full width of travel.

4.3.5 Timeframe to apply

Application time relies on a number of factors, some that can be controlled such as material form and supply to barge or aircraft, and some that cannot such as weather. Table 2 gives application times for all the materials considered in relation to mass and density as previously described in Figure 3-2. The affect of these differences for aircraft and barge is discussed below.

Aerial application would involve two or more aircraft working in coordinated areas. Each aircraft nominally applies 12 to 15 tonne per hour, which yields 5 days per 1000 tonne applied, assuming an 8 hour ‘air time’ operating day. For **two** aircraft over Lake Rotorua this gives a projected time of 7 to 50 full time flying days for 1900 tonne of alum and 5450 tonne of Allophane respectively. This range reflects differences in product density and tonnage. Any bad weather, consent condition time restrictions and down-time will extend these times accordingly. Conversely, days of greater than 8 hours air time or more than two aircraft would reduce the project timeframe. Aircraft can operate in winds of up to, or slightly greater than, 15 knots depending cross wind effects and product mass and delivery characteristics.

Barge application would also involve **two** vessels each capable of applying 3 to 4 tonne per hour operating over 2-shifts would yield 8 days per 1000 tonne applied assuming 14 hours operating per day. This would give a projected time of 16 to 57 days for 1910 tonne of alum and 6940 tonne of Phoslock™ respectively. Barges can also operate in winds of up to, or slightly greater than, 15 knots.

Bulk liquid would require a temporary shore-based transfer tank. The implications of such a tank have not been investigated in detail.

Table 2 Material application times (days)

Item	Phoslock Phoslock™	BPM Aqual P	Orica ViroPhos™	Landcare Allophane	Fertco Al/lime Pril	Orica Alum
Tonnes	6940	4710	4960	5450	3960	1910
Aircraft (d)	32	31	16	50	20	7
Barge (d)	57	39	41	45	33	16

4.3.6 Craft availability

Both aircraft and barges have a busy period February extending to early autumn. August through December is a period of building activity leading up to the busy period. June and July are months of low usage.

This may suit an application period somewhere during the period July to late October when the lake is less likely to be stratified. Conversely, a well designed pril or screened material could also perform well when the hypolimnion is established, thereby maximising capture of phosphorus and allowing capping material to establish in the lake sediment. If application into a stratified lake were decided, then a contract with an applicator would need to be established well in advance to enable work and resource scheduling and preparation for such a large project.

4.3.7 Form and characteristics of cap

Figure 4-3 attempts to illustrate the difference between a capping material that forms a homogeneous 'gelatinous floc' on lake sediments compared to a material that forms a suspension of individual particles within the surface sediments, i.e. a particulate matrix.

The important difference is hypothesised to be:-

- that the layer in Figure 4-3A most likely restricts natural processes such as gas transfer more than does Figure 4-3B. Exchange of oxygen from the water column to sediment is most likely severely restricted until the material settles into lake bed sediments. This is important because lake Rotorua sediments have quite large and approximately equal proportions of iron and aluminium and also contain smaller amounts of other phosphorus control substances. The cap must limit adverse phosphorus release effects of existing substances, including greater than 10,000 tonnes of natural aluminium and 10,000 tonnes of natural iron within top sediments of the application area;

- immediately after application, the layer in Figure 4-3A may be more easily disturbed and possibly relocated than a particulate matrix. However this is entirely speculative because the surface sediments in the application area of Lake Rotorua are themselves ‘fluffy’ and possibly also subject to re-suspension;
- Gas emissions from decomposition of sediment organics may have greater effect on one form of cap than the other;
- Phosphorus uptake may be limited for larger particles of media.

Figure 4-3 Representation of different sediment capping material form

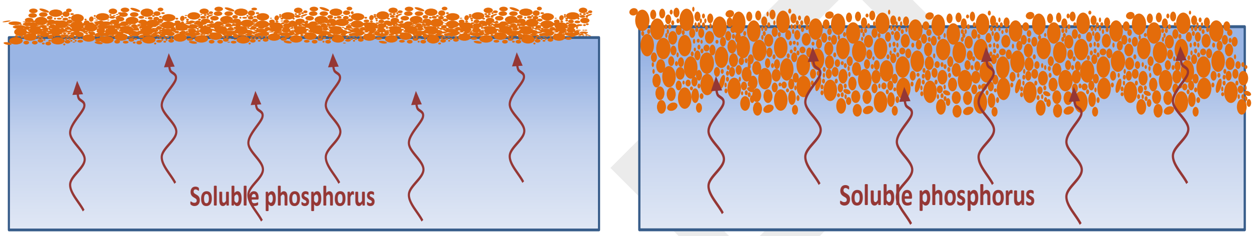


Figure 4-3A. Surface material interlocked by chemical bonding.

Figure 4-3B. Material interspersed in top sediments as discrete particles

Hence, there remains uncertainty of material performance and behaviour on, or within, the upper sediment layer. However, the difference is understood to be short-lived (pers. comm., Browne/Gibbs) as all materials, whether hydroxide or compound based, will integrate with surface sediments inactivating phosphorus as a permanently bound compound, even when conditions surrounding these solids ultimately change as they become buried within lake bed sediment. There is some division amongst experts as to the formation rate of permanently bound compounds and hence the effectiveness of capping materials that generate aluminium hydroxide intermediary as part of the stabilising mechanism. The fact is that numerous applications of aluminium based capping agents in Europe and the US with low macrophyte cover have proved an effective phosphorus inactivation method for periods of 12 to greater than 15 years[†] whereafter other factors dominate nutrient balance within the lake.

EBoP are considering application of selected material(s) to test areas within Lake Rotorua which would serve to fill knowledge gaps in:-

- material to sediment conditions,
- settling characteristics of pril,
- effect on the capping material of gas released from the sediment and,
- any re-suspension/ transfer mechanisms.

It would also seem sensible to extend the test programme to include Lake Rotoehu if it is to be part of the build-up to Lake Rotorua.

It is unlikely that reduction of phosphorus can be measured in the water column within a test area. Hence more than one test method should be used to collect all the relevant information pertaining to uptake of phosphorus from water column (i.e. mesocosm studies) and performance on test areas of Lake Rotorua sediments.

† Cooke D.G, Welch B. E, et al; Restoration and Management of lakes and reservoirs, CRC third edition, 2005.

4.3.8 Control of public and commercial activities

A buffer zone around the application target areas will be mandatory to control craft movements during this period. Some level of policing will also be necessary to deter protagonists and poorly informed craft owners. These details will be covered in the resource consent process.

The affect of the material application activity on commercial operations in and above Lake Rotorua has not been assessed. As the application period is expected to be quite long for some materials, operators of sight-seeing vessels and craft are most likely affected. Tourist based fishing on Lake Rotorua (if any are operating during the application period) would also be affected, possibly more an anticipated affect on captured fish quality rather than any substantive real effect.

4.4 Regulatory Requirements

The importation, transport, storage and application of the various materials considered in this report is influenced by a number of governmental acts and regulations, the most relevant being:-

Hazardous Substances and New Organisms Act, administered by ERMA.

Resource Management Act, administered by the Regional Council.

Health Act.

District Plans, administered by the Local Council.

In short, the regulatory findings of this report are:

1. ERMA has approved substances of a hazardous nature that are anticipated to be used in this project. Furthermore Water Treatment Chemicals Group Standards have been created for products that are used in the treatment of water. This includes algaecides, antifoams, biocides, boiler water chemicals, coagulants, disinfectants, flocculants, neutralizing agents, oxidants, oxygen scavengers, pH conditioners, resin cleaners, scale inhibitors and any other substance involved in the treatment of water. This also includes raw materials used in the manufacture of water treatment chemicals. ERMA will require further information on new ‘mixtures’ containing hazardous substances to decide if the group or other standards remain applicable.

2. EBoP will address RMA requirements during the resource consent application process.

3. Local council district plan requirements will need to be addressed during the resource consent process or when permitting special structures.

ERMA also noted in email correspondence between Browne/McCardle, 12th April,

“Currently, the term “water” has not been given a restrictive meaning although consideration is being given to exclude open water bodies, such as lakes, from its scope.”

Therefore, while ERMA approval is currently provided under the water treatment chemical group standards, a refinement of definitions may omit cover of natural waters. If changes are also made to omit natural waters from the individual standards, then a new application to ERMA for applying material to lake sediments is implied.

5.1 Costs origin

All costs presented in this report are sourced from material and service providers. In some instances interpolation of costs was necessary to assess transport components. However, as transport is significantly less than material supply and application costs, the overall accuracy of material options is essentially unchanged.

5.2 Capping Material Costs

5.2.1 Supply and application

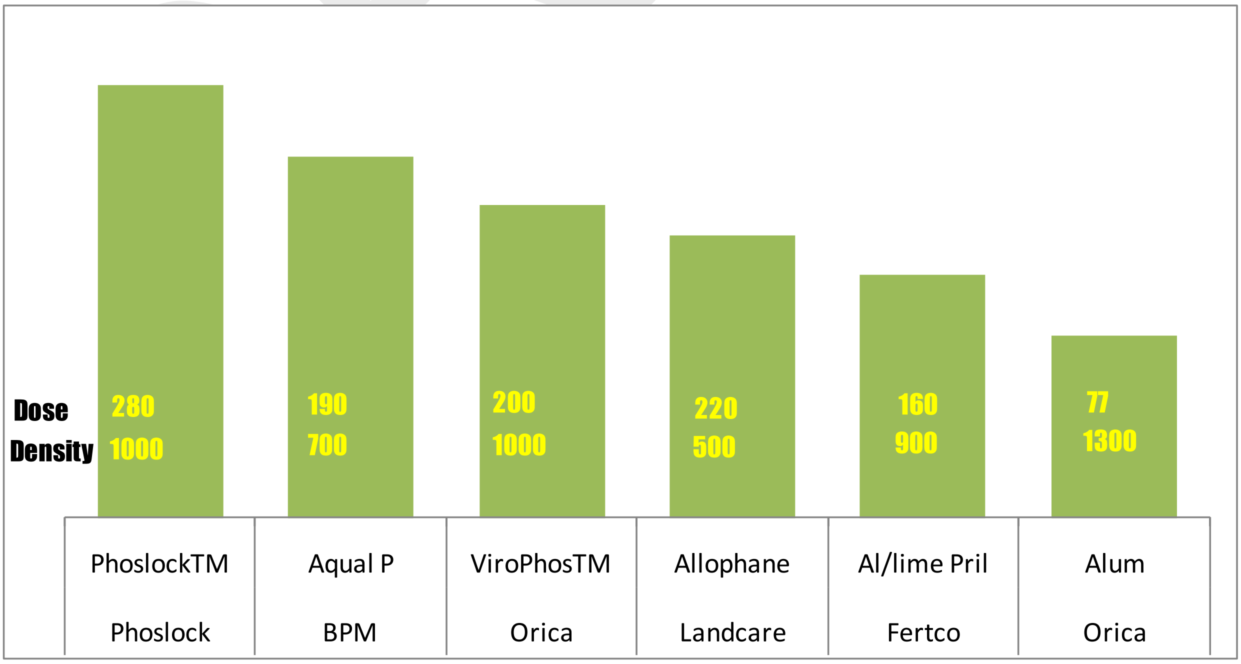
Figures 5-1 and 5-2 summarise supply and application costs as provided by named organisations. Figure 5-1 contains technical data of 'Dose' and material bulk 'Density' used to predict volumes and tonnages. In the absence of any other values, the same technical data is used in the determinations of, though not repeated in Figure 5-2 for Lake Rotoehu. All values are rounded. The sediment capping rates are those determined in relatively recent work by NIWA in a comprehensive report titled *Comparison of efficacy of four P-inactivation agents on Lake Rotorua sediments,* dated June 2008.

Table 3 Lake Rotorua sediment capping material supply and application costs

Not included in this version

Figure 5-1 shows the range of cost to apply various materials to Lake Rotorua. The difference between lowest and highest cost is in the order of $20 million.

Figure 5-1 Relative ranking of sediment capping materials costs for Lake Rotorua



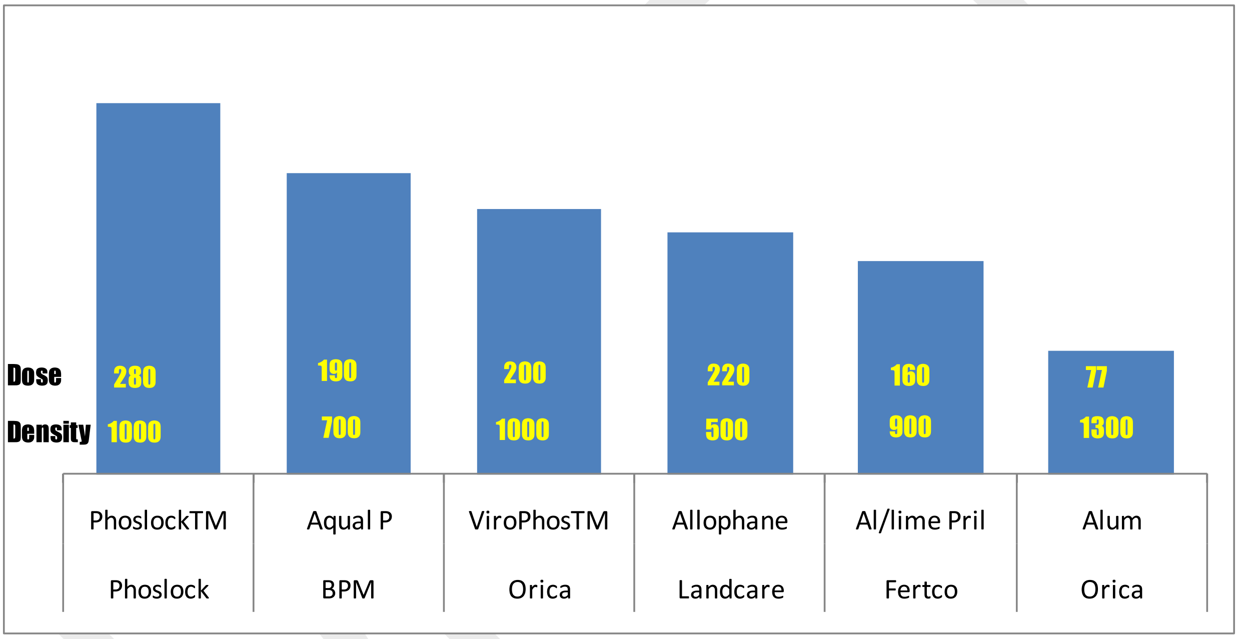
For Lake Rotoehu, variances between in-lake conditions could mean costs are at best indicative and at worst only suitable for relative comparison of material costs. Even a comparative analysis may be lead to poor conclusions where sediment conditions affect capping materials differently, i.e. the relative magnitude of capping rates is altered. Therefore a review of capping material application rates for Lake Rotoehu must be completed if it is to properly reflect the next stage of scale-up to Lake Rotorua. Refer to Figure 5-2 for the capping rates used, denoted as 'Dose'.

Table 4 Lake Rotoehu sediment capping material supply and application costs

Not included in this version

Figure 5-2 shows the range of cost to apply various materials to Lake Rotoehu. The difference between lowest and highest cost is in the order of $2 million.

Figure 5-2 Relative ranking of sediment capping materials cosst for Lake Rotoehu



5.2.2 Cost sensitivity

The costing model designed for this project allows a number of parameters to be adjusted to determine the effect of market changes. The following points are made:-

a) Project cost is most sensitive to material supply costs and sediment capping rate. In all cases material supply and capping rate is far more significant than transport cost, application costs and project contingencies, either singularly or in combination.

b) Material density and capping rate are the next most significant factors, i.e. [Table 3 omitted this version] clearly demonstrates this effect where PaCl/lime and Allophane have almost identical supply cost, but quite different total costs.

c) Aircraft hourly rates are significant. Due to the magnitude of these costs, it is critical that outages of bulk material be avoided. Contractual precautions must be taken to ensure the material supply train to application service providers is reliable and material stocks are complete.

5.2.3 Other cost factors

Other less significant factors are:-

i. Devanning of bags from bulk containers incurs a cost of around $8.50/T. Bagged materials also incur a small surcharge of $0.5/T for splitting and disposing of bags to make ready for loading into bulk transporters.

ii. A 10 percent contingency value is added to each total in Table 3.

iii. Storage of bulk materials was not considered to be a significant risk or cost. Some suppliers have adequate storage. Load out of bulk material costs around $2.50/T.

iv. Some flight restrictions might apply to eastern and in some instances south-eastern parts of the lake depending on aircraft movement into, and out of, Rotorua aerodrome. As aircraft movement restrictions have been advised to be brief (minutes) there is no indication that project costs will be affected.

6.1 Conclusions

The following conclusions can be made based on information gathered during preparation of this report:-

A. Proprietary and trademarked materials of Phoslock, Aqua-P and ViroPhos are specifically formulated for the purpose of capping nutrient rich sediments. They therefore allegedly present a lower risk to the purchaser. While it is accepted Phoslock and Aqua-P did out perform some of the lower cost alternatives to a degree in the NIWA laboratory trials, they did not out perform them all. As a result, EBoP needs to decide which future actions best meet the project objectives.
These actions are:

- to lessen the risk of lower cost options by further investigation and evaluation;
- to accept higher cost materials on the basis of proven performance;
- to apply lower cost materials on the basis that re-application costs are minimal should it be needed, or a lower cost material that is ultimately found to not meet all the project objectives could be over-coated with a proprietary material without adding greatly to the overall project cost of the new material;
- to do something else.

The remaining items on this section give guidance on the first two bullet points based on information and correspondence used to prepare the report.

B. There is a wide range in the supply cost of materials examined for capping of lake sediments. In general, proprietary capping materials are the most expensive at up to 85 percent of total project cost and lesser proven materials are least expensive, some as low as 65 percent of total project cost.

C. Because of the large disparity between costs it is concluded that lower cost materials based on aluminium coagulant products and natural allophane justify more intensive evaluation to establish material behaviour and limitations. Further laboratory analysis and/or test plots of Al/lime (or similar formulated products) and allophane pril within the lake may best serve this purpose. Alum alone is not recommended primarily for reasons of acid pH shift at the specified application rate and perceived mobility of the hydroxide floc.

D. The risk of selecting a manufactured product using an organisation such as Fertco to manufacture a formulated material (designed by others) holds little risk provided the test plots outlined in item C are completed and fully evaluated. Various forms of lime, aluminium based coagulants, and dispersing agents are readily available and Fertco as well as others have the equipment to manufacture granular products formulated by others to meet a client's requirement. Constituents and machinery are therefore available and well understood. The greatest risk is in formulating a product (but not effectiveness of the constituents) that robustly meets project requirements. This risk is overwhelmingly compensated by the disparity in the cost of comparative proprietary materials.

E. The manufacture of an allophane based product for application by vessel or aircraft is achievable and also offers considerable cost saving based on the values provided by Landcare Research. As a natural material that performed strongly in the NIWA test work, allophane carries negligible risk as a sediment capping material. Risks associated with allophane are to do with quantity of supply, purity, quarrying, processing, agreements, permitting and reinstatement.

6.2 Basis of Understanding

This section provides information describing the authors understanding various aspects of the project at the time of writing:

i. Capping material cost is highly dependent on the sediment cover rate. These ranged from 77 g/m^2 to 280 g/m^2 as in Table 1 of section 4.2. Note that some combination pril products recently developed use the alum rate of 77 g/m^2 increased to allow for buffering and disbursing agents (manufactured product). Other rates are used without modification.

ii. ViroPhos is a product manufactured by Virotec and offered by Orica for this project. As a late entrant only the technical data sheet provided with costing information has been briefly reviewed. This product has not been trialled under mimic aerobic/ anaerobic cycles of most other products and therefore has not been calibrated against New Zealand lake conditions. More work would be needed to raise confidence in ViroPhos as a suitable material for covering lake sediments.

iii. Phoslock material costs do not include formation of a granule or pril. The budget price numbers provided by the supplier set against the $US easily place this product as the most expensive.

iv. Aqua-P and manufactured materials (e.g. Fertco-manufacturing process only) are closest to achieving a pril that can be used in lake test trials.

v. Where capping material price is linked to foreign currency by the supplier, recent historical foreign exchange rate data has been reviewed to establish an average rate as a basis to predict a future value. The rates are noted with Table 3.

vi. Table 2 Material application times (days) shows that aircraft are not always quicker than vessels for applying sediment capping material because aircraft have limited hopper size. However, there are many aircraft in the topdressing industry that can easily compensate for any shortfall in carrying capacity and significantly reduce application times.

vii. Application cost monitoring and related expenses are not directly included in the costs. Note however the total project costs include a 10 percent contingency value.

viii. The number of organisations contacted has been limited intentionally for practical reasons in preparing this report. While there might be incremental benefits in contacting more participants, the report outcomes are unlikely to change.

ix. All organisations have responded in good faith to the questions and queries placed before them. There were no contractual obligations stated in any correspondence and therefore such matters as securities, performance guarantees and such are yet to be considered. Note allowance in item vii above.

x. At the application stage, there is a preference for delivery of material for aerial application in bulk form (truck and trailer units that tip into on-site hoppers), and for barge application in bulk bag form (for crane handling of material onto the barge).

xi. Pril formation is a significant cost for some suppliers. There may be cost advantage in investigating pril or granular formation more fully for some suppliers, e.g. allophane and a formulated product manufactured by an organisation like Fertco.

xii. There is practically no information available on lake sediment transport, water body currents and predicted transport of material out of, or redistribution within, the application area. NIWA have indicated very fine material may move up to 1.5 km from the point of entering at the water surface.

6.3 Further Work

The following are recognised to be limiting:-

a. Some materials such as alum or powder fractions may be dispersed during the application process due to factors such as lake water current. Also, re-suspension and relocation of delicate capping material should be avoided. Greater development is required of screening, grinding and pril formation for more uniform and predictable material behaviour to meet application constraints†.

   † Application constraints refers to lake conditions at the time of application (e.g. with or without hypolimnion and time of year), it does not refer to the method of application.

b. Given the large cost disparity of materials investigated in this report, further work is needed to refine costs for allophane including the available quantity, consenting issues, agreements, licenses, processing needs and any other supply constraints.

c. Alum is reported to be unsuitable as a capping agent for Lake Rotorua due to physical constraints raised as determined by the current level of understanding of lake conditions. If studies during the lead up to application identify windows, or mechanisms of opportunity where alum+buffer are suitable, then a most cost effective solution would be available.

d. Aluminium based coagulants with admixtures have not been examined in the reports reviewed. These are also expected to be highly cost effective and require a level of development by an appropriately qualified chemist.

e. Test areas within Lake Rotorua of selected materials would serve to fill knowledge gaps in:-

   - material to sediment conditions (including a. above),
   - settling characteristics of pril,
   - the effect of release of benthic gas,
   - any re-suspension/ transfer mechanisms,

f. Capping material application rates used for Lake Rotoehu are based solely on work completed for Lake Rotorua. The multiple possible differences between these lakes means capping costs for Lake Rotoehu have benefit as comparative costs only, and under no circumstances shall be used to determine overall project costs.

g. Notify CAA around 6 months prior to material application activities by aircraft.

h. All materials are certified by ERMA for the intended use under current legislation. Examples of product and water treatment chemical group standards are HSR003958, HSR004337, HSR004335, HSR006497, HSR005977, HSR002683, HSR002685 and others which can be viewed on the ERMA website below. Any new mixtures that behave differently to the properties approved by individual or group standards will need a separate approval by ERMA. It will also be necessary to follow any legislative changes over the time leading to material application. Refer example in Section 4.4.

http://www.ermanz.govt.nz/hs/groupstandards/standards/watertreatment.html

Limitations

Enviromex NZ Limited has prepared this report for the use of Environment Bay of Plenty in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the brief and for the purpose outlined in Appendix A of this report.

The methodology adopted and sources of information used by Enviromex NZ are outlined in this report. Enviromex has made no independent verification of this information beyond the agreed scope of works and Enviromex assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to Enviromex was false.

This report was prepared during January to April 2010 based on information provided and available at the time of preparation. Enviromex disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

To: John McIntosh

From: Peter Browne

CC: Andy Bruere

Date: October 12, 2009

Re: Lake Benthic Phosphorus: Application Feasibility Study

This message contains note of our meeting at Waikato University of 7th October to refine a brief to complete a study of various benthic phosphorus controls that may be applied to Rotorua district lakes.

This memorandum briefly works through all the phases needed to manage a comprehensive project of the nature proposed for Lake Rotorua, however stages one and two are most relevant to the work Enviromex NZ is to complete.

Purpose

The study purpose is principally to establish the preferred control agent taking into account equivalency of available products, logistic factors associated with their use, capping rate, methods of application and ultimately estimated cost of a lake benthic phosphorus treatment programme.

While the main focus of this study is on materials (control agents) historically used for control of benthic phosphorus, there may also arise the need to comment on control of non-benthic phosphorus as well.

Phosphorus Control Agents

In alphabetical order, the current list of control agents to be evaluated are:-

- Allophane
- Alum
- Modified Zeolite
- Phoslock

It is understood that iron and lime based control agents and aeration are not to be included in the study.

However, lime may be considered in conjunction with other agents for pH control purposes.

Scope

It is anticipated the work will be phased to accommodate known deficiencies in available information.

For this reason the following scope is proposed:-

Stage One: Feasibility

This is an information gathering phase where it will be necessary to:

a) Confirm with involved parties the required outcome for a given catchment, i.e. kg $P_{inactivated}$ /ha. and area to be treated, i.e. nominally Lake Rotorua, or part thereof.
b) Investigate and compare each product to determine range of comparative effectiveness for known lake water/ sediment conditions. The aim is to determine real or anticipated agent dose to achieve a required outcome and volume of material to be moved to the lake site.
c) Availability of supply, form and manufacture capacity.
d) Investigate transit and storage options;
   - Amount of agent material to be transported and distances involved,
   - Where and how stored and any time-related variables affecting application or product effectiveness,
   - Briefly identify the availability of adequate storage facilities to meet agent storage needs.
e) Review application methods in relation to agent form and success factors'
   - Liquid
   - Pril
   - Slurry
   - Powder,

   It is noteworthy that the prill form will be preferable based on work completed to date. Briefly comment on expected settlement and water transport characteristics of the various agent forms. Give some guidance on necessary application controls where applicable.

f) Contact contractors capable of applying these products in order to understand the economic and practical limits of each method, i.e. determine agent application cost plotted against increasing area for preferred methods.
g) Estimate (if possible) the amount of wastage associated with each method, or at least offer comment on this issue.
h) Determine an application cost per agent for equivalent treatment objectives.
i) Identify information gaps for each agent
j) Provide a 'basis of understanding' stating the reasons for conclusions and limits of the information provided.

Methodology

The proposed methodology is to:

1. Meet with EBoP to confirm and agree the scope.
2. Complete an initial review of available relevant information.
3. Prepare a questionnaire to each supplier identifying key information pertaining to the available product(s) and their production.
4. Extract key information from the questionnaires and conduct a site visit to each supplier to clarify the information provided, and such additional information as may be necessary for the report.
5. Complete initial calculations of product quantities to achieve required outcomes (or provide a range of quantity based on best available information).
6. Communicate with various learned institutes to confirm, amend or supplement initial determinations.
7. Obtain transport rates, if not already gained through the questionnaire.
8. Meet with prospective application companies to evaluate the effectiveness of their methods and variation of cost for a range of catchments.

9. Speak with a recognised commercial realtor in Rotorua to determine the type and availability of storage facilities, or such other method appropriate to the materials and packaging of materials to be stored.
10. Develop a cost model for each preferred agent.
11. Compile a preliminary report.
12. Present findings to interested parties.

Stage Two: Refinement

Stage Two is simply working under the instruction of EBoP to close the reported information gaps. It is expected that most work during this stage will be completed by others to refine agent manufacture, form, dose or other characteristics important to understanding product effectiveness and cost.

This information can then be 'plugged into' the cost model developed in Stage One. The cost margins can then be refined and recommendations finalised.

Stage Three: Project Development

Stage Three will be to gather any additional information needed to specify requirements of an agent application project. This will develop Stage Two outcomes into tender documents suitable for issue to contractors capable of completing the proposed work. These documents are designed to protect the interests of organisations involved in the project and to limit risks insofar as possible. They also state a means to redress any disputes.

Project documents generally include:

- Tender conditions,
- General conditions of contract,
- Special conditions of contract,
- Health and Safety obligations and requirements,
- Schedules of materials, free issue items and contractor prices,
- Particular specifications pertaining to material characteristics, performance requirements, conditions of application and other project specific requirements,
- Drawings identifying the area(s) of application, and any special variances in coverage. They may also include loading sites, flight paths or boundaries and like information,
- Appendices and attachments as may be required.

It might be necessary to have several co-existing contracts for say supply of materials contract, storage contract, application contract and quality control contract. It is often desirable to limit contract interfaces insofar as possible to avoid one contract delaying another. Delays are well recognised for increasing project costs.

Stage Four: Project Implementation

Stage Four is the implementation of a project. It includes the normal suite of project activities:

- Tendering
- Tender Evaluation and where necessary negotiation,

- Contract Award
- Contract Management/observation
- Quality Procedures
- Monitoring
- Reporting of outcomes

Stage Five: Project Delivery Controls

Stage Five is to set in place monitoring designed to:-

Provide feedback to the applicator that the method has met/not met the project objectives

Exclusions

1. Negotiation of permission or consultation,

   Some examples may be:

   - resource consents,
   - regulatory permits,
   - construction of temporary works,
   - land access,
   - commercial operations,
   - like matters

2. Laboratory or field time and analyses to prove or refine the validity of work completed by others on which the Stage One and Two reports will be based.

Data Information Request Form (example only)

APPENDIX B

PART A : ORGANISATION, SIZE AND FACILITIES

DATA REQUEST TO:	
Name of other Business Partners	
Product of interest to EBoP (POI)	
Other products that can be offered for capping phosphorus and/or nitrogen rich lake sediment	

	Electronic Copy Provided	
ORGANISATIONAL STRUCTURE & STAFF	**Yes**	**No**
Please attach an organisational structure indicating divisions and people that would be involved in this project		
Contact personnel and contact details advised		
SCHEMES MANAGED	**Yes**	**No**
Please indicate if all the schemes managed by your organisation are listed in your Documents (Attach relevant project experience).		
Company Profile		

CONTRACTUAL ARRANGEMENTS		**Yes**	**No**
Under what contractual or other arrangements have you	Supply and Deliver agreements only.		

Data Information Request Form (example only)

APPENDIX B

provided large volumes of treatment materials to Local Authorities and/or industry.	Facility outsourcing contracts (e.g. BOO, BOOT, DBO, Facility Management)		
	Other (Please note details below)		

FINANCIAL

Size of Contracts and Business.	Largest contract value: $
	Typical annual turnover: $
	Approx value of assets: $

OPERATIONAL FACILITIES (Owned and operated by the business)	**Yes**	**No**
Material Quarry Operation (or state lease/license expiry date)		
Processing Facilities		
Laboratories		
Office		
Other		

Data Information Request Form (example only)

APPENDIX B

PART B : DOCUMENTATION RELATING TO PROVISION OF MATERIALS

Note: The volume of material for this inquiry is in excess of 5000 tonne dry weight.

EXISTING KEY DOCUMENTS *Please provide an electronic copy of the following documentation:*	**Available Y/N**	**Electronic Copy Provided**
Site Management Plan		NR
Schedule of current resource consents/licenses noting expiry date		
Production Capability Statement		
ISO, BVQI or other Quality Assurance certification for business operations. State:		NR
Product specification (constituent substances, trace elements, particle size, forms)		

OTHER DOCUMENTS	**Yes**	**No**
Any other documents that assist with understanding the production of material supplied by this organisation.		
Please list:		

DOCUMENTATION AVAILABLE ON SITE *Will the following information be available for review during site visit:*	**Yes**	**No**
Quality Manual		
Operational Manual		

Data Information Request Form (example only)

APPENDIX B

Maintenance Procedures		
Emergency Response Procedures		
Health and Safety Plans and training records		

PART C : PRODUCTION CAPABILITIES AND PLANS

Availability, production capacity and can it be stored to await shipment?

CAPACITIES *Production of POI:*	**Current**	**Future / year**
Approx available resource and location:	Tonnes	at
Mineral Extraction	T/ann.	/
Processing	T/ann	/
Maximum Sustainable Production	T/day	/
Storage capacity (finished product ready for transport)	Tonnes	/
Shelf life		
Licensed extraction volume	Tonnes	

FORM *What are the normal means of bulk delivery?*	**Available**	**Size (kg/T/m^3)**
Forms of product: Liquid Powder Prill Granular (All less than 3mm absolute)		

Data Information Request Form (example only)

Other – specify		
Packaging IBC Bags – note weights Bulk – note form(s):-		
Relevant other (Specify)		

Data Information Request Form (example only)

PART D : VALUATION

Representative Costs

Budget Costs (Assuming 5000T) *What to budget?:*	**Ex-yard**	**Freight to Rotorua**
Cost for 5000 tonne: Include insurance value of shipment in freight	$	$
Cost per 1000 tonne (if different to the above): Include insurance value of shipment in freight	$	$
Cost per 200 tonne (if different to the above): Include insurance value of shipment in freight	$	$
Assumed packaging of shipment: State method:-		

APPLICATION *What does it cost to apply? (if known)*	**Experience in this type of operation** **Y/N**	**Indicative Amount**
Indicative cost to apply 5000T to 2000Ha of lake		$
Indicative cost to apply 1000T to a Lake		$
Indicative cost to apply 200T to a Lake		$
Type of equipment used. Specify:- 5000T 1000T 200T		

Data Information Request Form from Suppliers

Not included this version.

Not included in this version