REPORT (REVISION 2)

Second stage Phosphorus removal for Rotorua lakes/streams

Prepared for

Environment Bay of Plenty

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URS New Zealand Ltd report capital and operating costs for the purpose of reducing phosphorus in streams that discharge flow to Lake Rotorua. The streams identified in this report are Hamurana, Utuhina, Waingaehe, Puarenga and Awahou streams that all contain concentrations of phosphorus that contribute to the total phosphorus load entering Lake Rotorua. The investigations set out to achieve a reduction or inactivation of phosphorus greater than 33 percent of total flow of 9 m^3/s from five streams. The method of treatment described in this report indicates that much higher inactivation of phosphorus appears likely which means that only three of the five streams need treatment. Principal costs have been estimated for treatment at three streams for the preferred method of phosphorus inactivation.

This report updates the interim report of 11 March that examined chemical pre-treatment requirements for the 'removal' or 'locking' of phosphorus from Hamurana Stream as one of the streams contributing phosphorus to Rotorua Lake. Stream water samples were collected for laboratory trials, chemically treated in the URS laboratory and analysed by Hill Laboratories. The results were used to develop a concept treatment plan and estimate chemical operating costs as a first step. The interim report recognised the importance of operating costs in relation to other treatment methods and reported these to gain feedback from Council. As a result, it was decided to further evaluate the direct chemical addition method for two additional streams, the Utuhina and Puarenga Streams.

This report builds upon the previous and new test information to predict total capital and operating costs for two principal options of 'locking' or 'removal' of phosphorus.

Capital costs vary significantly depending upon the form of treatment adopted. These are two methods considered in this report:

Method 1	Phosphorus 'removal' by full chemical treatment involving flocculation, clarification, and chemical sludge dewatering facilities at a cost of around \$20 million capital and \$9.8 million per year operating cost for three plants, one each on Hamurana, Utuhina and Puarenga Streams.
Method 2	Phosphorus 'locking' by chemical addition only at a cost of around \$1.6 million capital and \$1.0 million per year operating cost for three plants, one each on Hamurana, Utuhina and Puarenga Streams.

The study examined and compared efficiencies of alum, ferric chloride and phoslock to remove the effect of phosphorus in the stream environment so that uptake of this nutrient by algae in the lake is restricted. Phoslock is a proprietary product that is normally suited to lake nutrient conditioning and control. The trial reported here, although less successful than other chemicals, in no way detracts from the performance of Phoslock for its designed purpose – encapsulation of phosphorus in lake bed sediments.

Total predicted project costs for all methods and chemicals are summarised in Section 6.

These analyses showed that aluminium based coagulants perform well to remove Dissolved Reactive Phosphorus ,DRP, the phosphorus form recognised in biochemical uptake processes as contributing to algal blooms. Aluminium based chemical products are shown to act quickly, are visually acceptable and are expected to exhibit a short cycle time once locked into the lake sediments.

2.1 Observed Stream Condition

A site visit shows that Hamurana (Figure 2-1 below) appears as a clear, and clean stream, and is visually a 'pristine' environment often visited by the public for fishing and relaxation.

Figure 2-1 A clear and clean Hamurana stream – Pristine environment

Utuhina is less picturesque, (Figure 2-2 below) is turbid and dark in appearance typical of the city and urban waterway environment, and is possibly geothermal influenced.

Puarenga (Figure 2-3 below) is a swiftly moving stream with water quality slightly less turbid in appearance than Utuhina. The Puarenga confluence was also reviewed to determine suitability for pilot trial work. Visual and laboratory analyses confirm that the Puarenga confluence is heavily affected by geothermal activities and not suitable for a pilot trial if retention of phosphorus in the confluence area is necessary.

Figure 2-2 Turbid and dark looking Utuhina stream –Urban-type environment

Figure 2-3 Puarenga Stream – Swift moving stream

2.2 Important Objective

These analyses seek to examine economic methods of removing phosphorus from being available to micro-organisms that cause algal bloom conditions. The study investigates two principal mechanisms to achieve this objective:

a) Remove phosphorus as economically possible from the stream water – method 1 of Section 1 of this report, or

b) Remove phosphorus from participating in biological growth by chemically complexation and dispose of the new complex by incorporating it in the lake sediments – method 2 of Section 1 of this report.

Method 1, or item a) above, involves processes that seek to reduce the phosphorus concentration in the stream water (and subsequently the lakes) by removing phosphorus and disposing elsewhere away from the lake environment.

Method 2, or item b) above, changes the chemical form of phosphorus and hence the availability for biological uptake by 'locking' the chemically complexed phosphorus into lake sediments. For this method it is important to understand the concept of phosphorus cycle time as it relates to lake bed sediments. The phosphorus cycle occurs when conditions change to cause reactive forms of phosphorus to be re-leased back into the water column. The elapsed time from the moment reactive phosphorus species are formed to the time when it is again chemically bound is the time where biological uptake may occur. The lowest risk of bloom conditions relating to phosphorus is gained by reducing the phosphorus cycle time to the minimum practically possible. Studies in the United States have found that cycle times can be substantially reduced and almost altogether eliminated by chemical complexation.

This study investigates and costs both the above methods and comments upon the relative merits of the chemicals used.

Jar tests were performed using various coagulants to assess the comparative removal efficiency of phosphorus from all stream waters. Coagulants examined were Alum, Ferric chloride and Phoslock. Unlike the other well-known coagulants, Phoslock is a proprietary chemical rich in lanthanum marketed in New Zealand by Primaxa.

3.1 Phosphorus locking/removal using Alum

These analyses set out to define the cost difference of 'locking' phosphorus against biological uptake while retained in the aquatic environment and comparing this with physical 'removal' of phosphorus in the form of a chemical sludge.

The following are results of tests performed on Hamurana, Utuhina, and Puarenga streams, and Puarenga confluence samples using Alum as the coagulant. Samples were pH adjusted to the optimal range for alum in some cases and not for others to determine any efficiency losses. It is important to note that the alum dose (in ppm) is refined by the aluminium dose (in mg/L).

3.1.1 Alkalinity

Alkalinity is critical to the proper performance of coagulants. Trivalent aluminium (Al^{3+}) provides approximately 10 times more coagulant effectiveness than a divalent ion. Hence, trivalent coagulant ions are widely used in modern water treatment plants.

The following sections examine the effectiveness of trivalent ions on Rotorua stream for phosphorus locking and removal. It should be noted that alkalinity has only been included in the results of interest and is not reported for test where alkalinity is artificially added. More detail is contained in Appendix A. Where alkalinity is not added, it is plotted to show the effect with alum dose without pH adjustment.

For alum (aluminium sulphate) the reaction (1) illustrates the importance of alkalinity where 2 moles of aluminium precipitate are formed by 6 moles of alkalinity expressed in the form of bicarbonate ion.

$$Al_2(SO_4)_3 + 6HCO_3^- \leftrightarrows 2Al(OH)_3^{2-}\downarrow + 3SO_4- + 6CO_2 \qquad (1)$$

It can be observed that CO_2, a weak acid is formed as part of the reaction. For this reason, alum is often dosed with lime or sodium carbonate to compensate the acidity. In contrast sodium aluminate can displace carbonate ions and dissolve any residual CO_2, thereby avoiding a pH shift as illustrated by the following reactions.

$$NaAlO_2 + Ca(HCO_3)_2 + H_2O \leftrightarrows Al(OH)_3\downarrow + CaCO_3\downarrow + Na^+ + HCO_3^- \qquad (2)$$

$$2NaAlO_2 + 2CO_2 + 4H_2O \leftrightarrows 2Al(OH)_3\downarrow + 2Na^+ + 2HCO_3^- \qquad (3)$$

The following sections report benchtop trials for removal of phosphorus using alum, although it should be noted that sodium aluminate also holds promise.

3.1.2 Hamurana Stream

Figure 3-1 Phosphorus locking/removal with pH adjustment using Alum for Hamurana Stream

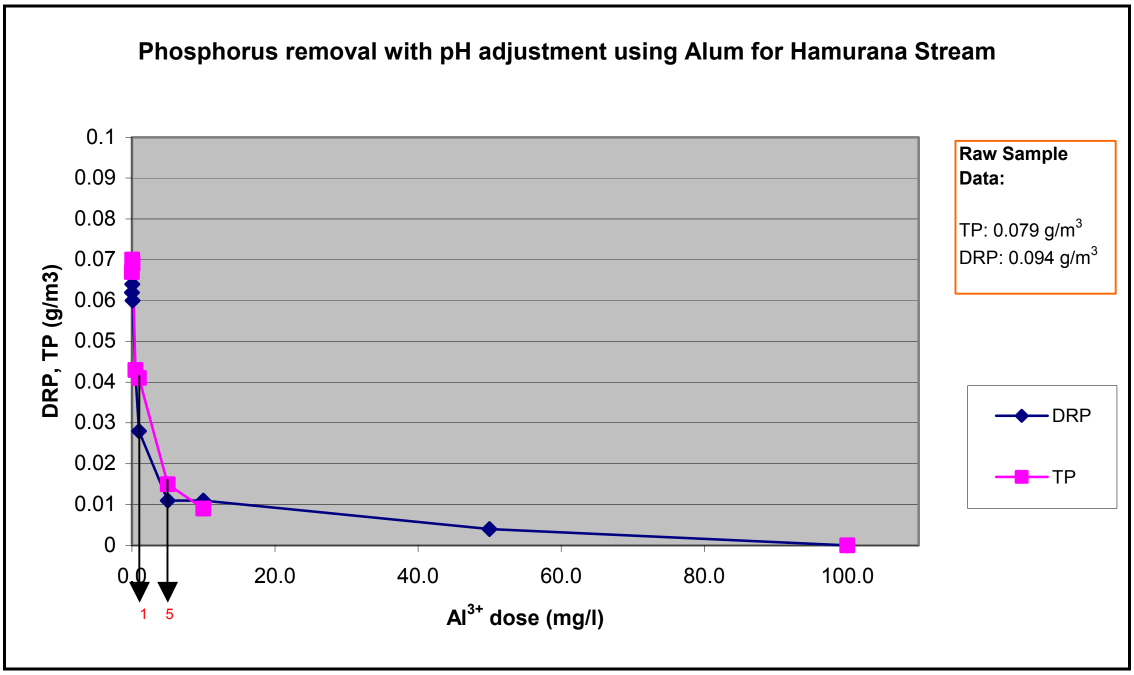


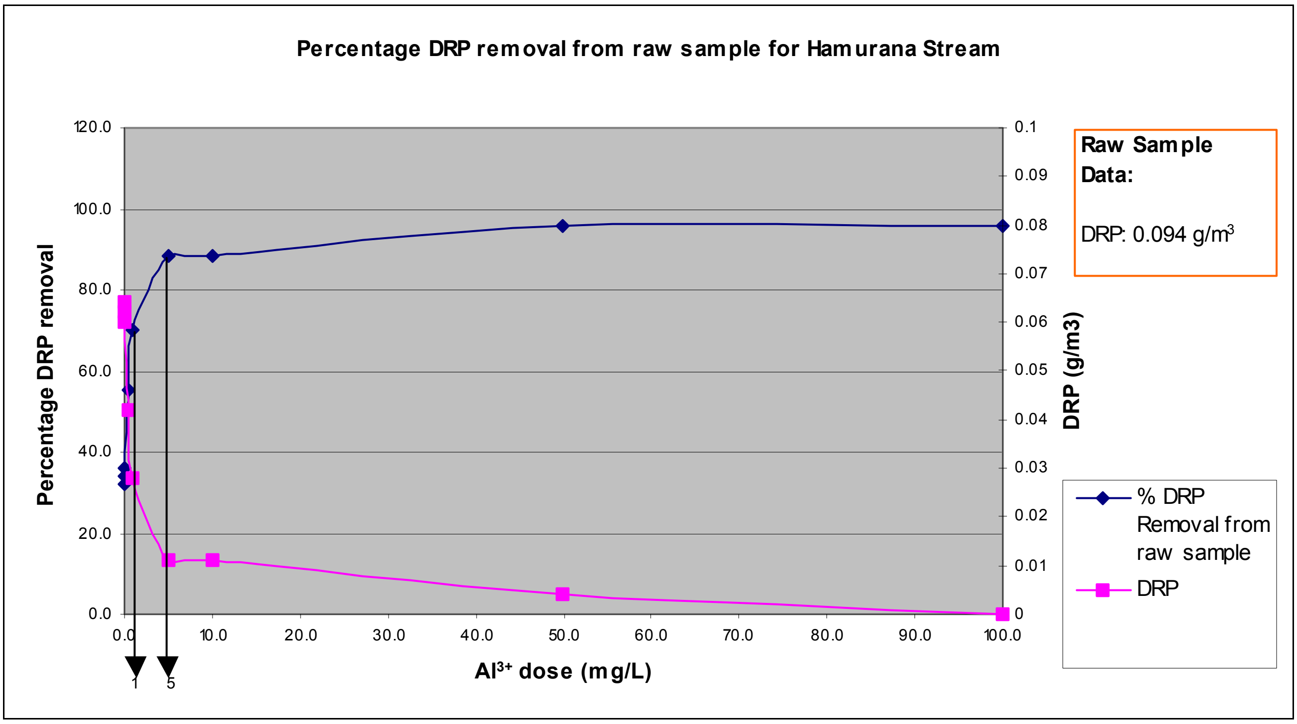
Figure 3-1 shows the Dissolved Reactive Phosphorus (DRP), and Total Phosphorus (TP) react with alum to gain an effective reduction of phosphorus for Hamurana stream water. The graph shows an expected trendline for both parameters, i.e., DRP and TP concentrations fall with the increase of alum dosage.

Note that Alum dose at 0 mg/L does not represent a blank stream water sample, but instead a sample with no added alum that has been filtered to observe the effects of filtering on DRP or TP. This effect is consistently observed for all samples analysed. Given that earlier analysis show the stream DRP to be at 0.094 mg/L concentration, Figure 3-1 shows that even without alum dosing, filtering through 0.45µm filter paper removes about 34% of DRP or 15% TP from the raw sample. This action is usually not expected of the reactive (DRP) phosphorus and implies the DRP is associated with fine particulate solids. We can also expect these solids to be removed by the coagulation process as indicated by the remaining results.

Alum dose rates of 1 mg/L and 5 mg/L as Aluminium is expected to chemically bond to, or coprecipitate, phosphorus to give an active phosphorus reduction of between 70% to 88% for DRP, and 48% and 81% for TP. (c.f. 33% advised requirement). Tabulated laboratory results used to prepare Figures 3-1 and 3-2 are recorded in Table A-1 of Appendix A.

However, it is essential to note that dosing coagulant at these low application rates will only be sufficient to chemically inactivate or **lock** phosphorus and will be insufficient to **remove** coagulated particles as sludge via water treatment separation processes. The development of particles that can be removed as sludge requires a higher dose rate, typically in the order of 5 to 10ppm aluminium. Figure 3-2 shows that even at a low aluminium dose rate of 1 to 5 mg/L, significantly more than 33% of DRP is locked in the water column.

Figure 3-2 Percentage DRP locking/removal from raw sample for Hamurana Stream



3.1.3 Utuhina Stream

Figure 3-3 Phosphorus locking/removal with pH adjustment using Alum for Utuhina

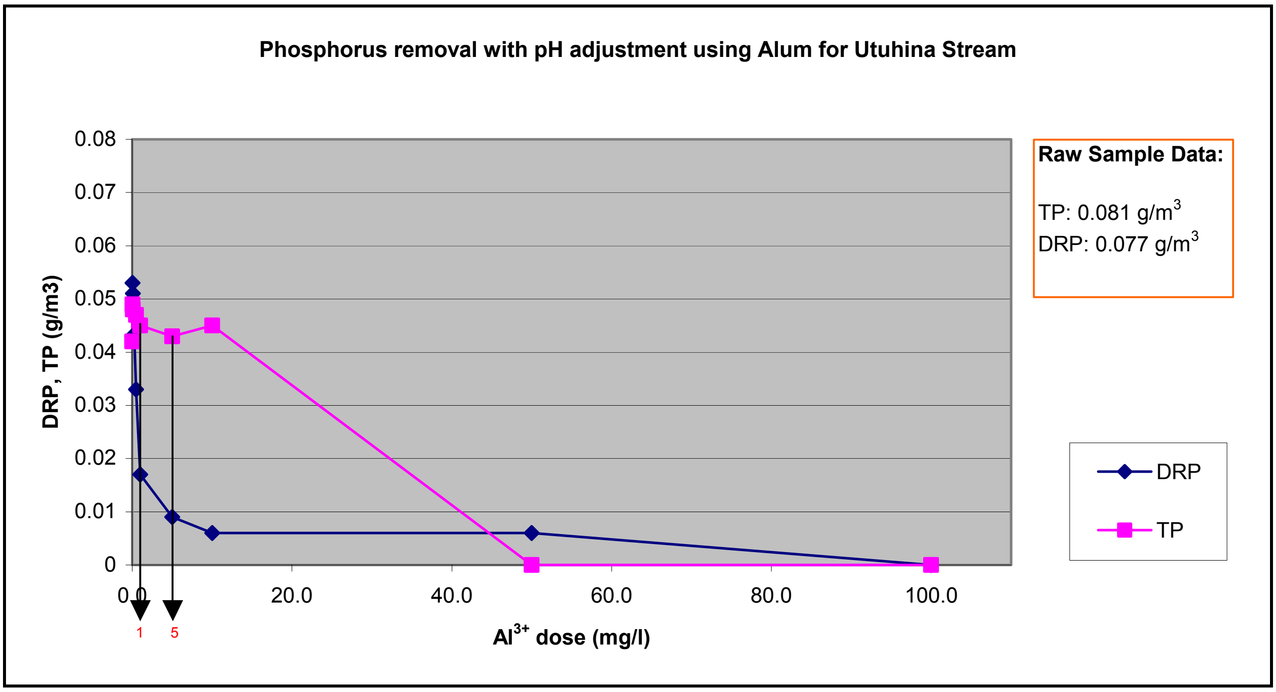


Figure 3-3 differs from the typical trendline of Figure 3-1. DRP reduced as expected, but TP did not change significantly until it reached an alum dose rate of 50mg/L. The low removal of TP, as initially observed, could be explained by a reaction of the reactive phosphorus with alum to form a fine precipitate or colloid. However, the particle formed was sufficiently small that it could not be retained on a filter medium during a standard laboratory analysis (by Hills). At higher alum dose rates however, larger precipitates were formed and TP were easily removed. Table A-2 in Appendix A shows the tabulated laboratory results for Utuhina.

In this sample, it can be observed that filtering removes 44% of DRP and 48% of TP from the raw sample.

Even with the above results, the 33% dissolved phosphorus removal requirement was achieved at low alum dose concentrations (as aluminium) of less than 0.5mg/L for TP, and 0.1 mg/L for DRP. However, a more conservative approach shows that an effective removal range is between 1 and 5mg/L. Alum dose rates of 1mg/L and 5 mg/L gives a phosphorus removal of between 77% and 88% for DRP, and 44% and 47% for TP. A lower removal rate for TP agrees with the argument that phosphorus in TP form were fine colloids that did not settle out or could not be filtered, thus, showing a lower removal rate.

Note: Baseline value for TP and DRP are measured in-stream concentrations taken from a sample on the same day as the laboratory bulk sample. Also note that the terms ‘alum dose’ applies to the aluminium ion concentration and not $AlSO_4$ with water of hydration.

Figure 3-4 Percentage DRP locking/removal from raw sample for Utuhina

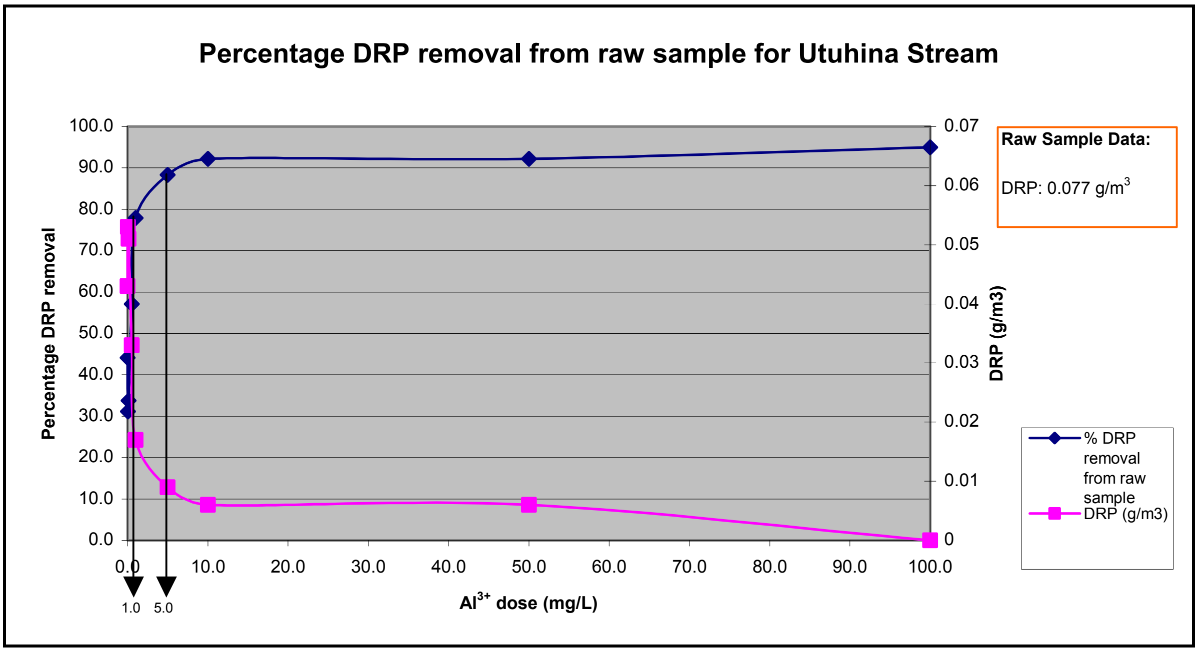
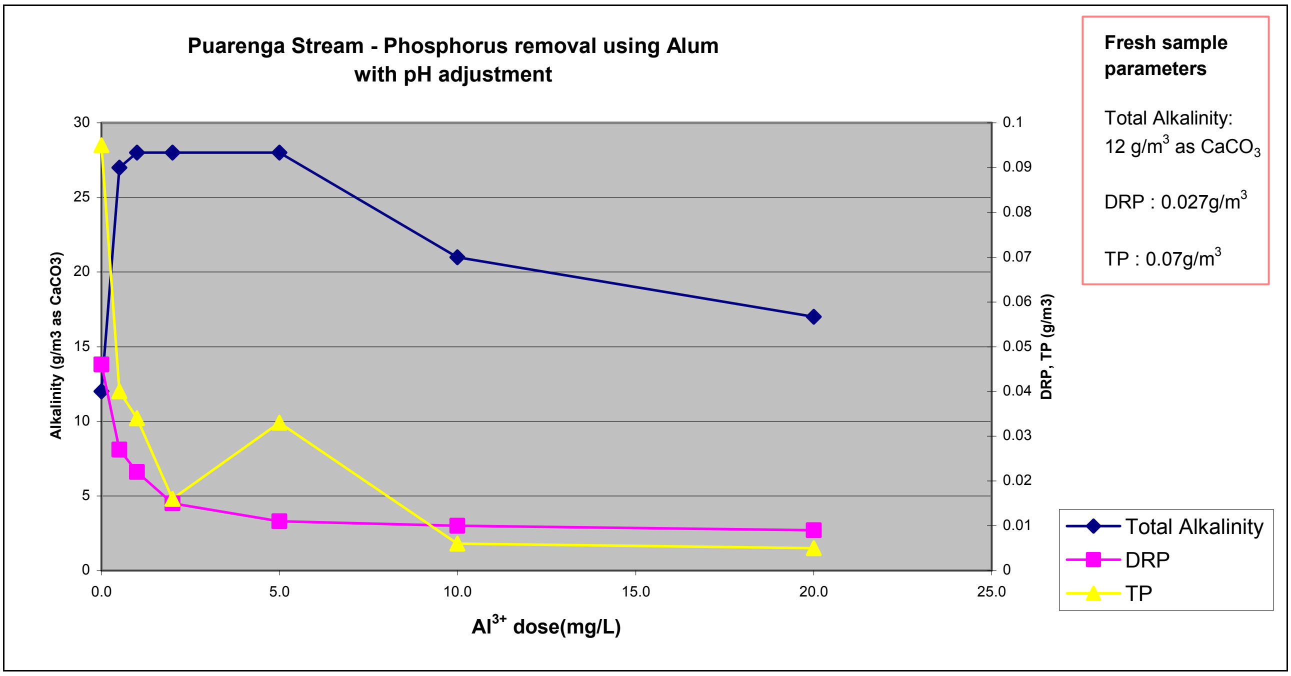


Figure 3-4 above shows the percentage DRP removal from raw sample for Utuhina. It can be observed that more than 33% of DRP is removed from the raw stream sample at Aluminium dose rates as low as 1.0 to 5.0 mg/L. This shows that Alum is a practical chemical for DRP removal at Utuhina.

3.1.4 Puarenga Stream

Puarenga stream with pH adjustment

Figure 3-5 Phosphorus locking/removal with pH adjustment using Alum for Puarenga Stream



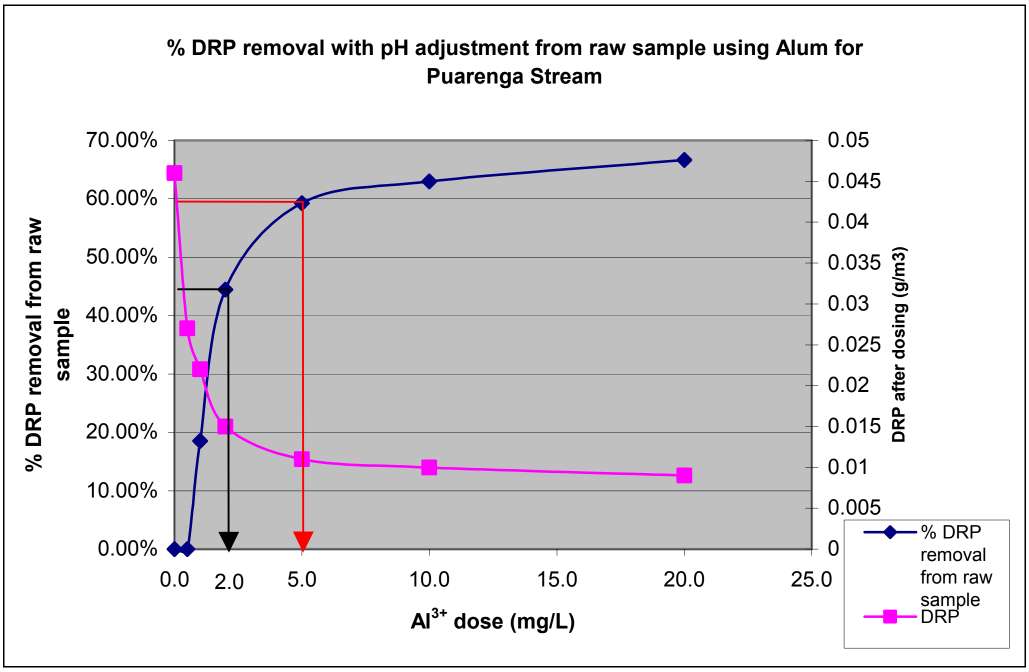
As explained previously, the Alum dose at 0 mg/L is a filtered sample without any other treatment to demonstrate the effects of filtering on DRP or TP. In this case, the results for alum dose rate of 0 mg/L gave anomaly results, i.e., the DRP and TP results were higher than the raw sample results.

Figure 3.5 shows overall results for phosphorus removal from Puarenga stream follow an expected trendline, where DRP and TP concentrations fall with increased alum dose. Alkalinity also drops with higher alum dosages however, pH adjustment to keep the pH within 6.5 to 7 prevented samples from losing its alkalinity buffering capacity. At aluminium dosages of 10 and 20 mg/L, the DRP values are lower than that of TP. This is due to analytical result accuracies that are further explained under sub-section 3.4. Figure 3-5 also shows that particulate phosphorus is effectively reduced by filtering and the dissolved phosphorus seems to sorp with alum floc, being locked from other reactions in the coagulation process.

Tabulated results used to generate Figure 3-5 can be found in Table A-3 of Appendix A. Table A-3 shows that a 44% removal of DRP from raw sample was achieved at a low aluminium dose rate of 2.0 mg/L. This percentage removal is higher than the Council’s requirement of 33% DRP removal. However, a more conservative approach is take the effective alum dose rates for DRP removal with aluminium between 2.0 and 5.0 mg/L. Aluminium dose rates of 2.0 and 5.0mg/L give a DRP removal of 44% and 59% respectively.

Figure 3-6 below shows the percentage of DRP removed from raw sample.

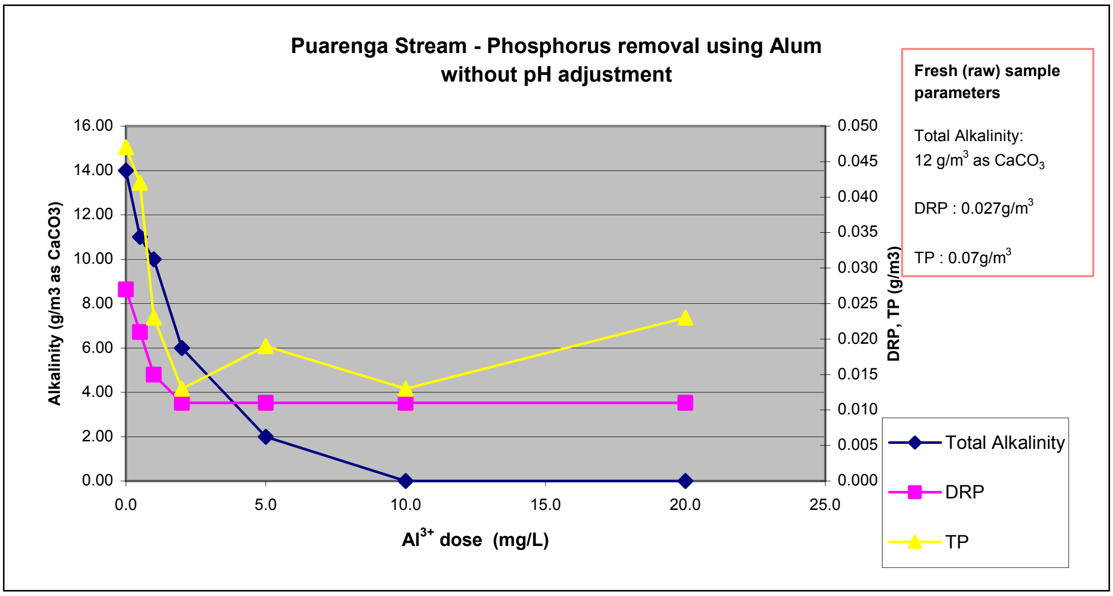
Figure 3-6 Percentage DRP locking/removal from raw sample using Alum and with pH adjustment for Puarenga Stream



For Puarenga Stream, Figure 3-6 above confirms that the optimum DRP removal was achieved between Aluminium dose rates of 2.0 mg/L and 5.0 mg/L. Note also that 33% DRP is removed at an alum dose rate of between 1.0 mg/L and 2.0 mg/L.

Puarenga stream without pH adjustment

Figure 3-7 Phosphorus locking/removal without pH adjustment using Alum for Puarenga Stream



Note that an Alum dose of 0 mg/L illustrates the effects of filtering on DRP or TP as discussed in earlier sections.

Figure 3-7 shows that overall results for phosphorus removal from Puarenga stream (without pH adjustment) follow an expected trendline. The DRP and TP trends show that the dissolved and particulate phosphorus compounds are removed until the point where alkalinity is fully consumed which inhibits the formation of more flocculated particles. In this case, DRP and TP are not locked with any greater benefit beyond an aluminium dose rate greater than 2.0 mg/L.

Tabulated results for Figure 3-7 can be found in Table A-4 of Appendix A. The results show that a 44.44% DRP locking from raw sample is achieved at an aluminium dose rate of 1.0 mg/L, and this meets the council requirement of 33% DRP removal. The maximum DRP removed from other reactions achieved was 59.26% at 2.0mg/L.

Figure 3-8 Figure shows the percentage locking/removal of DRP from raw sample using Alum and without pH adjustment for Puarenga Stream

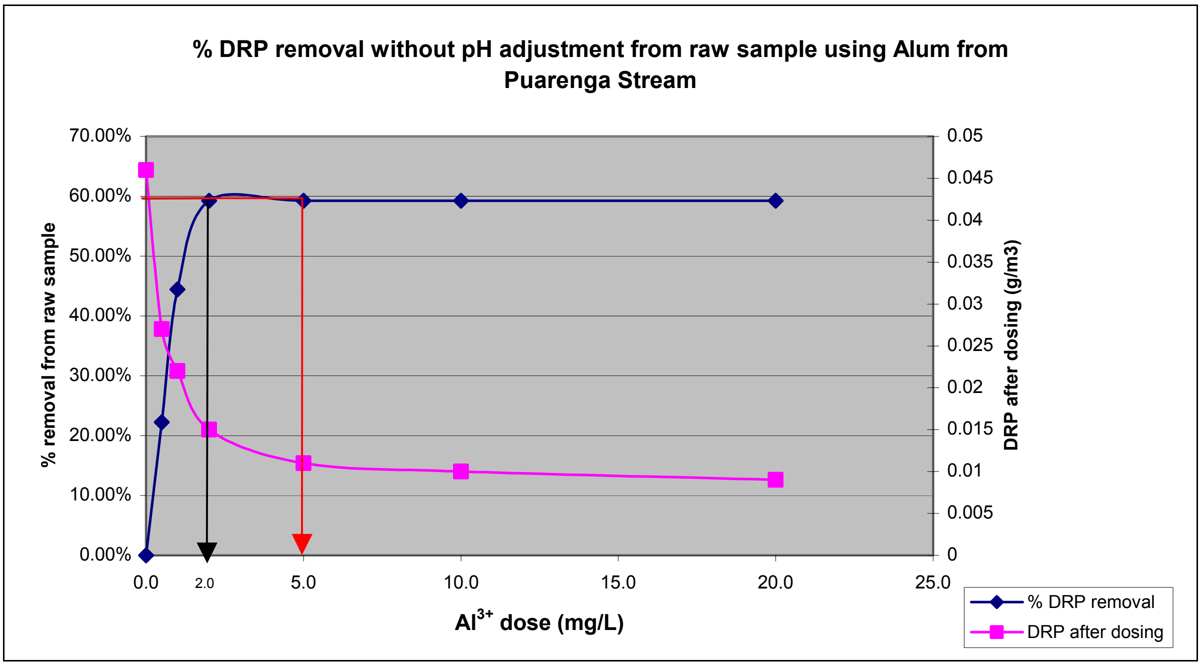


Figure 3-8 above confirms that the highest percentage achieved for DRP locking is at 2.0mg/L, i.e., 59.26% removal from raw sample. It can also be noted that 33% of DRP is locked at an aluminium dose rate of between 0.5 mg/L and 1.0 mg/L.

3.2 Sensitivity test of Alum locking power in lake sediments

A test was performed using raw sample water from Hamurana stream to examine the stability of aluminium locked phosphorus, at different pH values. This is an important consideration for the release of inactive chemically bound phosphorus where acid conditions could occur due to various biological and physical-chemical conditions within the lake and sediments. The analysis also shows the optimal pH range for coagulation of Alum.

The test included addition of Alum (as 1mg/L aluminium) to 200mL raw samples. Then, samples were adjusted to the following pH values; 7,6,5,4,3, and 2. The samples were filtered and filtrate sent to the laboratory to be tested for Alkalinity and DRP. To achieve the various pH values, Sodium hydroxide (NaOH) was used to raise pH and Hydrochloric acid (HCL) to reduce pH.

An aluminium dose rate of 1 mg/L was consistent with previous findings for Hamurana stream where a high DRP locking efficiency (70%), was achieved.

Figure 3-9 Effects of pH change on Hamurana stream for Phosphorus locking using Alum

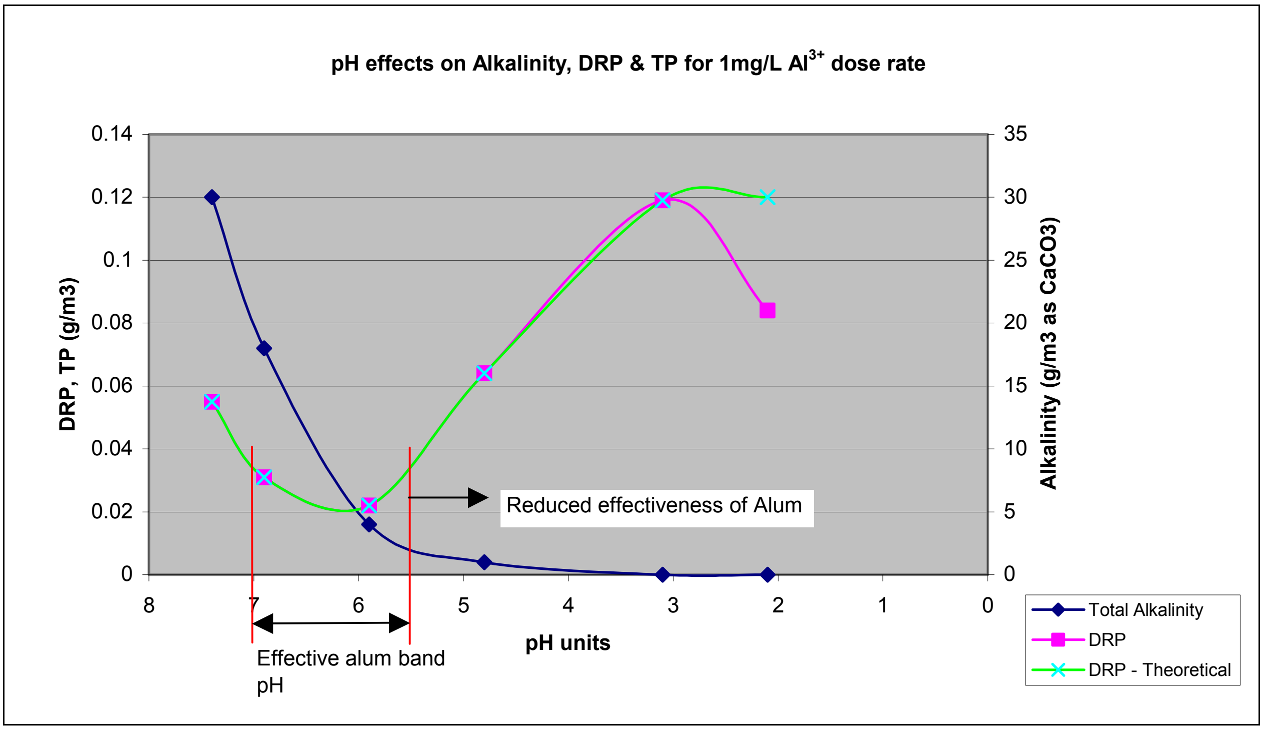


Figure 3-9 shows the effects of pH on Total Alkalinity and DRP. Below pH 5, it can be seen that Alkalinity is almost entirely consumed. This conforms with the theory that below pH 4.5, most carbonates are in the form of soluble carbonic acid (H_2CO_3) [1] that will not react with alum to form an aluminium hydroxide floc.

It also shows that alum effectively locks/removes DRP between pH 5.5 and 7. Below pH 5.5, the steep gradient of the graphed line indicated that DRP locking/reduction reduced rapidly as the alum dissolves and loses its ability to act as a coagulant. Below pH 3 a sudden increase in DRP locking occurred, which has no identifiable rational explanation and we expect would not be repeatable in the environment. There are two DRP trendlines presented, one is the DRP value from laboratory tests, and the other is the theoretical DRP line. The "theoretical" DRP trendline shows the predicted value where all phosphorus would be released into the water column under acid conditions.

Therefore, any DRP locked by alum in the lake sediments would begin to be released at pH 5.5 until substantially released at pH 4 and all pH 3. This also happens when the sample has a pH above pH 7. Therefore, the optimal pH range for Alum from this test is between pH 5.5 and 7. This conforms to normal water treatment practice that the optimal pH range for use of alum is between 5.5 and 6.5 [1]. For broader range applications polymeric aluminium products can extend the effective locking range, e.g. PAC, poly aluminium chloride and related commercial products.

Figure 3-10 Effective locking/removal efficiency of DRP using Aluminium dose rate of 1 mg/L

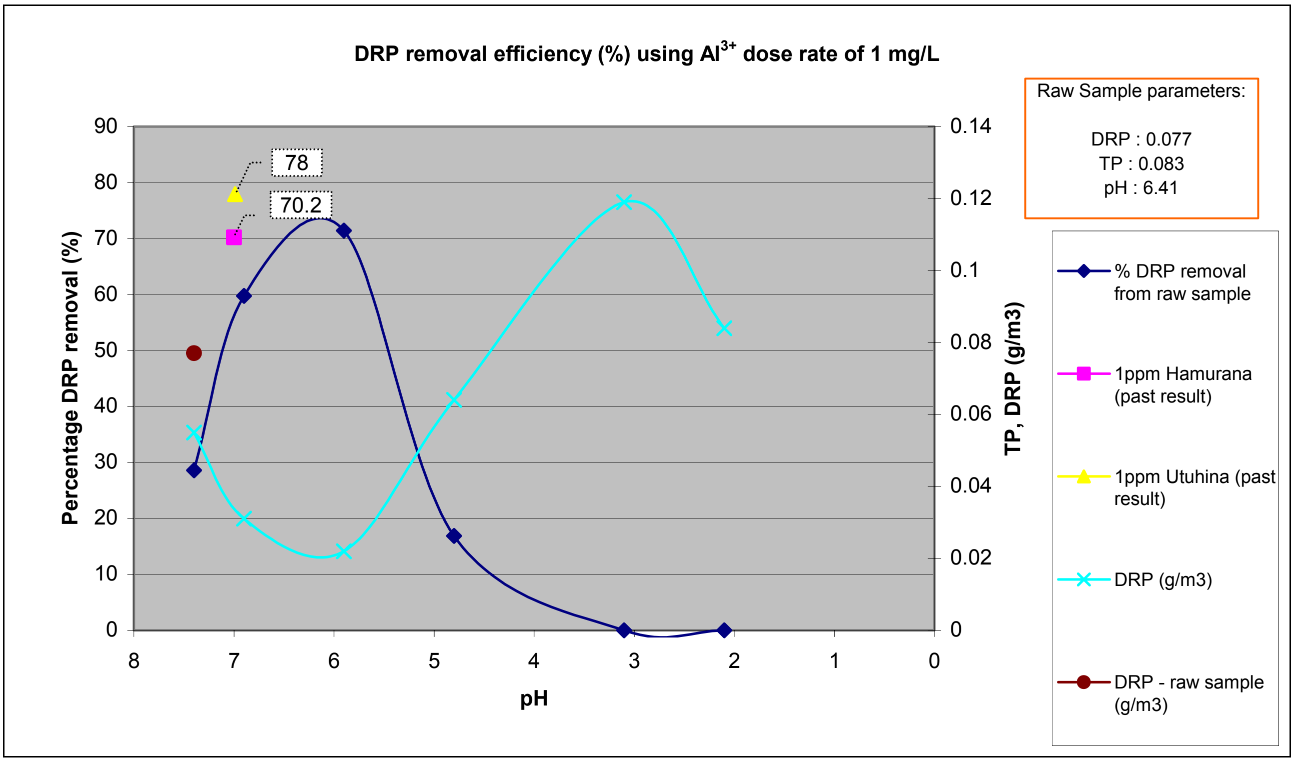


Figure 3-10 illustrates the locking/removal efficiency of DRP using 1mg/L aluminium over a pH range. The results show that the removal efficiency is significantly reduced outside of the pH range of 5.5 and 7. Past results for Hamurana stream have shown that 70.2% of DRP was locked from raw sample using 1mg/L aluminium. For the same dose rate on Utuhina, a 78% DRP removal from raw sample was achieved. Both Utuhina and Hamurana have a pH close to 7.

The above shows that alum is an effective coagulant for phosphorus locking/removal provided that the pH range remains between the optimal range of 5.5 and 7. The natural pH of Hamurana stream is 7.4. This shows that alum will be most effective when the stream pH is adjusted to pH 7, or slightly lower values. This pH shift is achieved by adding alum (acidic) without pH adjustment. Tabulated results where Figure 3-9 and 3-10 were generated from can be found in Table A-5 of Appendix A.

3.3 Phosphorus removal using Ferric Chloride

The following are results of tests performed on both Hamurana and Utuhina stream samples using Ferric Chloride a coagulant. It should be noted that the Ferric chloride is expressed in terms of ferric ion, Fe^{3+}, concentrations.

Figure 3-11 Phosphorus locking/removal with pH adjustment using Ferric Chloride for Hamurana

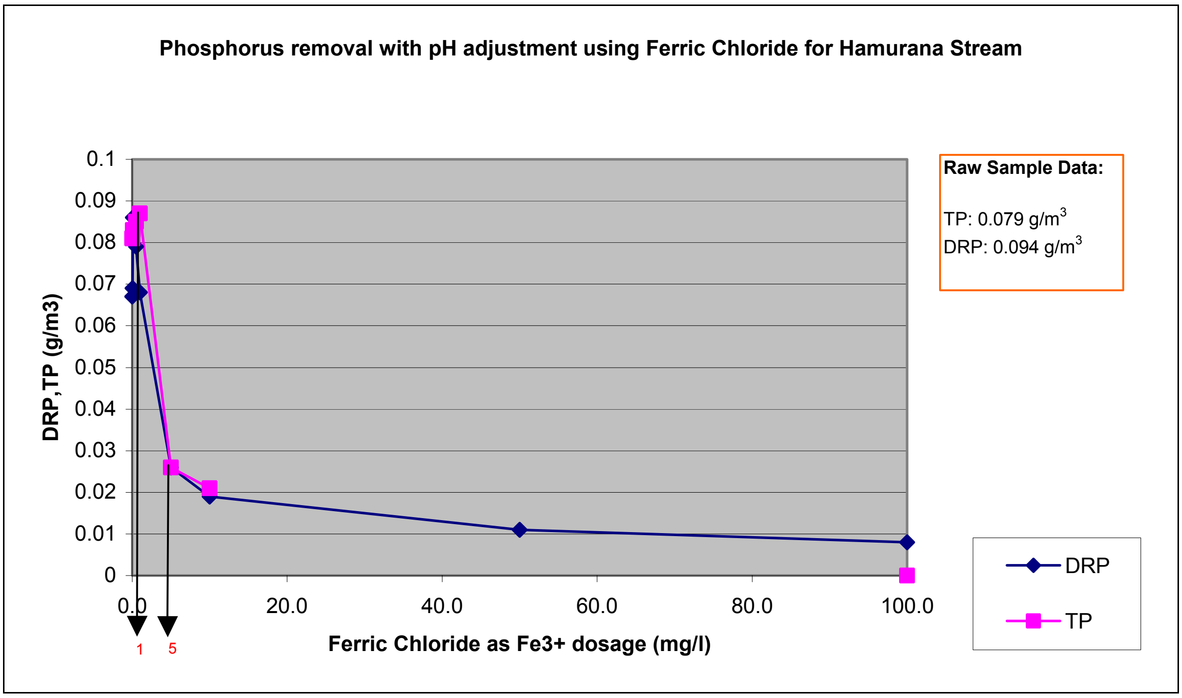


Figure 3-11 above shows the results of phosphorus removal for Hamurana using Ferric chloride. A similar trendline as Figure 3-1 (using Alum) is observed here, where the DRP and TP concentrations are reduced with increasing coagulant dosage. Laboratory results for Figures 3-11 and 3-12 are appended in Table B-1 in Appendix B.

Note that Ferric Chloride ($FeCl_3$) dosage of 0 mg/L as Fe^{3+}, does not represent a blank raw sample, but instead a sample with no added $FeCl_3$ that has been filtered to observe the effects of filtering on DRP and TP. In this case study, it is seen that filtering removes 28% of DRP from the raw sample. For this sample, TP at 0mg/L of $FeCl_3$ was higher than the raw sample data and thus, is disregarded.

A 33% phosphorus removal was achieved between 1mg/L and 5mg/L Fe^{3+}. Ferric chloride added to give 1mg/L and 5 mg/L as Fe^{3+} gave phosphorus locking/removal of 28% and 72% for DRP, and 0% to 67% for TP.

Note that the 50mg/L chemical dose result for total phosphorus is not plotted. The laboratory result gave a value higher than the initial untreated water concentration and is therefore ignored. Also note the baseline TP and DRP results appear to be reversed, i.e., DRP is higher than TP. An explanation is provided in Section 3.4.

Figure 3-12 Percentage DRP locking/removal from raw sample for Hamurana Stream using Ferric Chloride

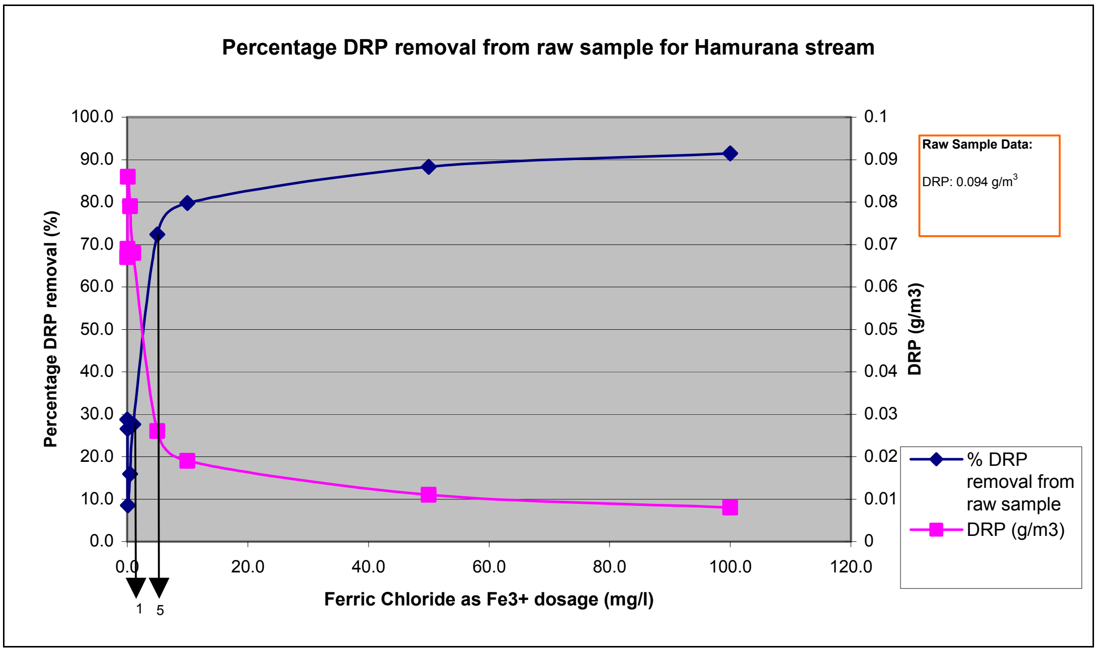


Figure 3-12 illustrates the effectiveness of Ferric Chloride in the removal of reactive phosphorus. It showed that 1 and 5 mg/L Fe^{3+} dose rates locked about 27% and 72% of DRP respectively. This is a good removal rate and shows that Ferric Chloride works well for phosphorus removal at Hamurana.

Figure 3-13 Phosphorus locking/removal using Ferric chloride for Utuhina Stream

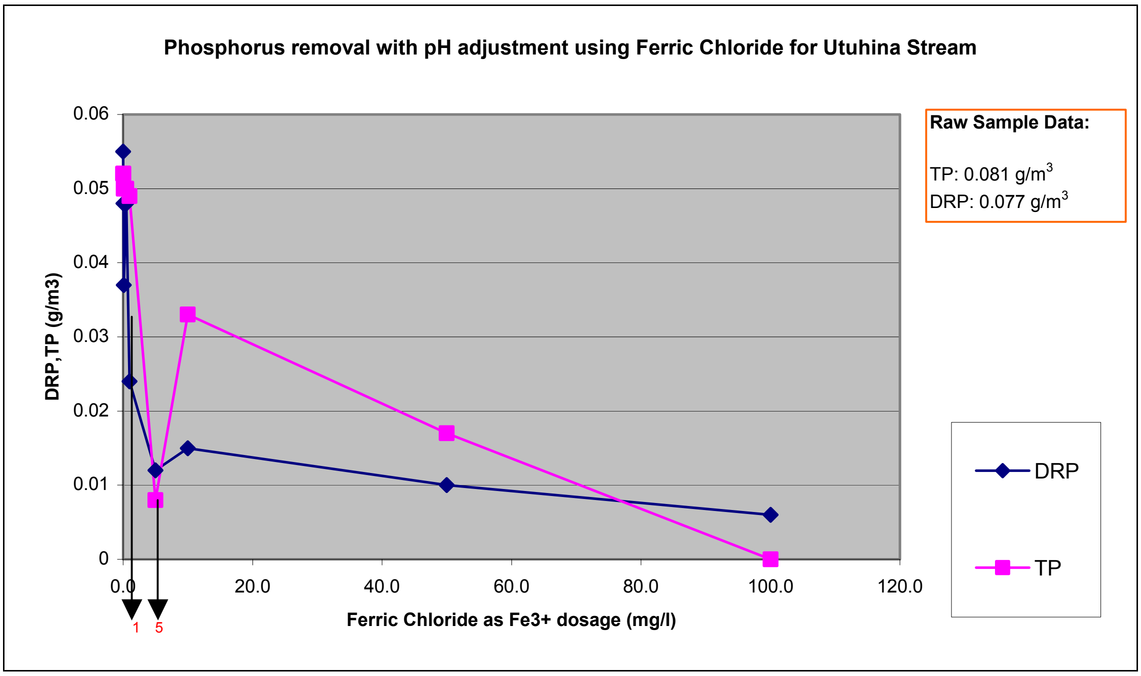


Figure 3-13 indicates an expected result where the DRP reduced as Ferric chloride dose rates were increased. An increase in the concentration of TP value was observed after 10 mg/L of Ferric chloride was added. This is probably a result of the formation of a metal ion complex between the iron and the phosphorus of unknown nature at this time. This complex appears to result in a decrease in the biologically available fraction of the phosphorus as measured by the dissolved reactive phosphorus. The long-term stability of this compound is not known, although as concentration of Ferric chloride is increased the phosphorus complex is removed by precipitation, which is shown by the continual decrease in both TP and DRP.

Note that Ferric Chloride ($FeCl_3$) dosage of 0 mg/L does not represent a blank raw sample, but instead a sample with no added Ferric chloride that has been filtered to observe the effects of filtering on DRP or TP. In this case study filtering removes 28% of DRP and 35% of TP from the raw sample. Laboratory results can be found in Table B-2, Appendix B.

The TP trendline for $FeCl_3$ is similar to that of the TP trendline for Alum in Figure 3-3 above. A higher TP is observed due to effects outlined in Section 3.1 under Figure 3-3. At higher Ferric chloride dose rate, the TP was removed as expected.

Figure 3-14 Percentage DRP locking/removal from raw sample for Utuhina Stream using Ferric Chloride

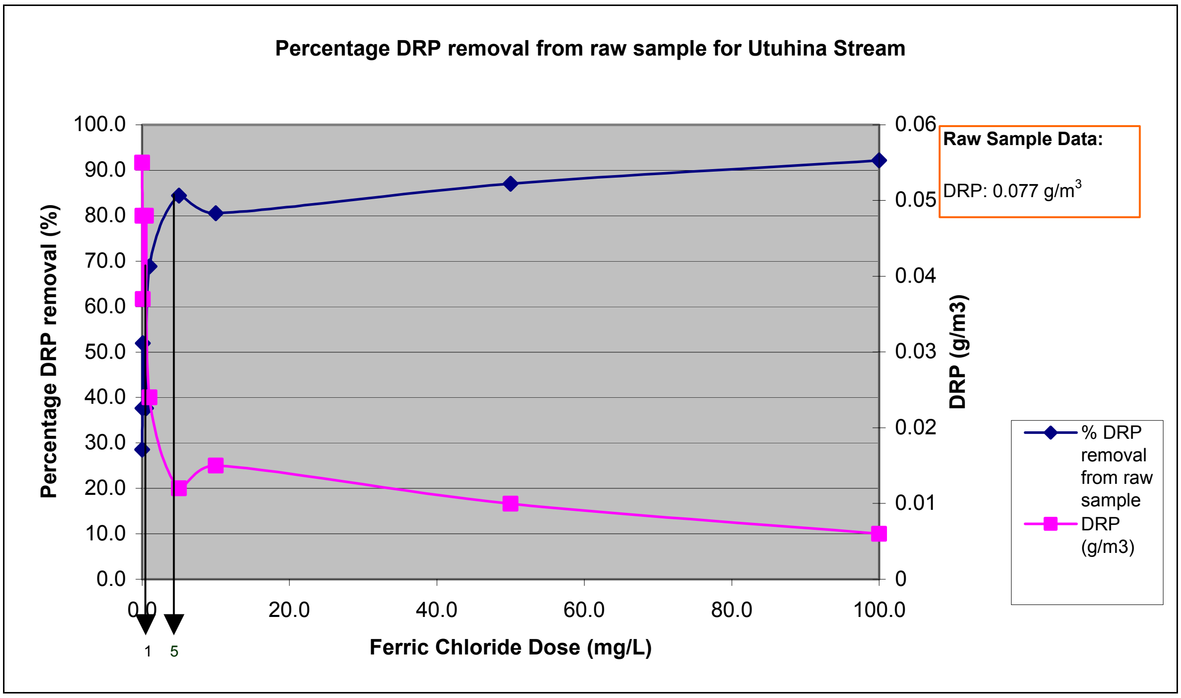


Figure 3-14 shows the percentage locking/removal of DRP for Utuhina stream is most economically achieved between the 1 and 5 mg/L dose rate. The locking/removal efficiencies are 68% for 1 mg/L Fe^{3+} and 84% for 5 mg/L Fe^{3+}. Those two values are substantially above the council's objective of 33% DRP removal from the stream.

3.4 Explanation for DRP values being higher than that of TP

DRP values are usually lower than TP values. Tables A-1 to A-5 in Appendix A, Tables B-1 to B-2 in Appendix B, and Tables C-1 to C-3 in Appendix C, show that sometimes DRP values are higher than TP values. The explanation offered by the analytical laboratory is that analyses have an acceptable accuracy range defined by ± limits. When measuring very low concentrations of substances, the acceptable limits can overlap and the most likely result number may appear to conflict with other substance limits, i.e. soluble phosphorus appears to be greater than total phosphorus. This in conjunction with individual sample differences is sufficient to explain apparent anomalies in the range of results reported between different analyses.

3.5 Chemical Addition By-products

The addition of coagulant chemicals will release chemical by-products such as chloride, sulphate or sodium into the receiving environment. In the case of alum 1 mole of Al^{3+} added to water releases 1.5 mole of SO_4. Refer Section 3.1.1 for reaction equations. Therefore, controlling the amount of chemical added to the minimum practicable value has considerable advantage. Of the options studied, ‘locking’ of phosphorus will use the minimum amount of coagulant with the phosphorus/coagulant complexes remaining in solution until flushed from the lake water body or retained in the lake sediments. To ‘remove’ phosphorus will release in the order of 5 to 10 times more chemical by-products than ‘locking’ because of the amount of coagulant needed to form a stable flocculated particle. Coagulant aids (flocculants) assist in minimising the amount of coagulant.

On this basis, phosphorus locking has considerable merit over full removal processes. Refer also to Section 4 for capital and operating cost comparisons for the two different approaches.

3.6 Phosphorus removal using Phoslock

Phoslock is specially modified clay designed to permanently bind phosphorus and removing it from the lake water column as a phosphorus/phoslock complex that settles to be incorporated in the lake sediments, thereby avoiding biological uptake and consequential contribution to algal blooms. Phoslock can be applied to a water column in the form of slurry, powder, or granules. The marketed product is granulated and includes dispersing agents to assist the non-soluble mud to migrate throughout the water column and contact with phosphorus.

As phoslock travels through the water column, soluble phosphorus is adsorbed onto Phoslock where the combined floc settles at the bottom of the water column to be included in the lake sediment. [2]

Phoslock was evaluated for locking phosphorus in the streams as it was understood it could work over a wider pH range than Alum. In comparison to Ferric Chloride, Phoslock is expected to have no effect on colour of the receiving water. Ferric Chloride however is expected to result in discolouration of surfaces over a period of time.

The Phoslock manufacturers recommend a dose rate of 100 grams Phoslock per gram of phosphorus. Figures 3–15 and 3-17 show various Phoslock doses for known Phosphorus concentrations in the Hamurana and Puarenga streams.

These figures also indicate the assessed dose rate (gram Phoslock added per gram Phosphorus) in order to determine Phoslock consumption for a calculated phosphorus removal efficiency. Figures 3-16 and 3-18 show the effective phosphorus removal efficiency using Phoslock.

3.6.1 Hamurana Stream

Figure 3-15 Phosphorus locking using Phoslock on Hamurana Stream

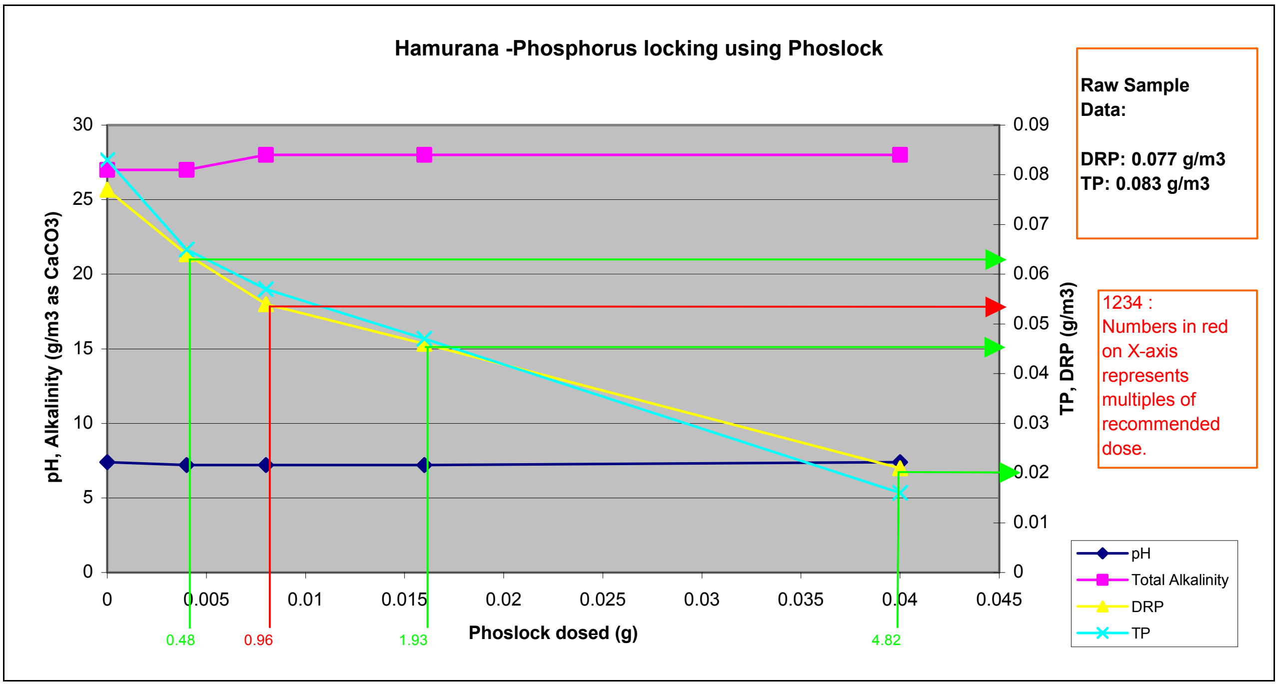


Figure 3-15 examines different dosages of Phoslock to determine the locking efficiency on DRP and TP for a Hamurana raw sample. Also shown is that Phoslock has no effect on pH of the raw sample. Unfortunately, it also showed that there was very little decrease in DRP until a substantial quantity of Phoslock is added. It should be noted that the numbers in red and green on X-axis represent multiples of recommended dose. For example, the first number 0.48 corresponds to the strength of Phoslock added at a rate of 48g Phoslock per 1g phosphorus. The red line drawn on the graph shows the recommended dose rate by the Phoslock manufacturer (i.e. ratio is 100g Phoslock:1g phosphorus) whilst the green lines show the effect of different Phoslock strengths used to lock phosphorus. Table 3-1 below explains the numbers in red in terms of Phoslock strength.

Table 3-1 Actual strength of Phoslock values in graph

Phoslock stoichiometric ratio values from graph	**Corresponding values (strength of Phoslock**
0.48	0.5 times Phoslock
0.96	1 time Phoslock (supplier recommended 100: 1)
1.93	2 times Phoslock
4.82	5 times Phoslock

Figure 3-15 above indicate that the TP and DRP values locked at the same rate, which is consistent with the result that phosphorus is mostly in the dissolved reactive form. Therefore, Figure 3-16 below indicates only the DRP values to compute the percentage of DRP locked to Phoslock, when compared to the raw sample phosphorus concentration. Tabulated results where Figures 3-15 and 3-16 were generated from can be found in Table C-1 of Appendix C.

Figure 3-16 Percentage locking of DRP from raw sample for Hamurana Stream

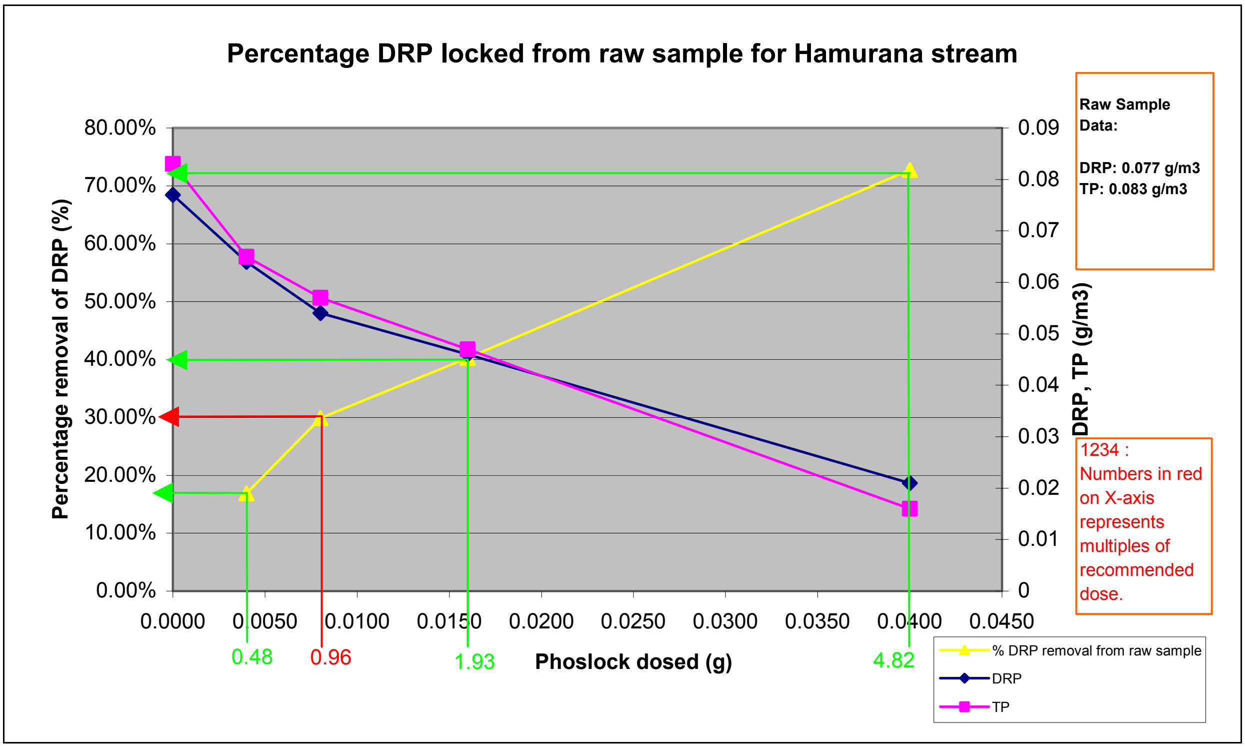


Figure 3-16 and Table C-1 of Appendix C shows that about 30% DRP is locked at the recommended Phoslock dose (100:1 dose rate equals 0.008g Phoslock added per 1000mL sample). The DRP removal achieved at twice the recommended Phoslock application rate is close to 40%. Therefore, Phoslock locks phosphorus in the same manner as alum and ferric chloride from Hamurana stream.

3.6.2 Puarenga Stream

Figure 3-17 examines different dosages of Phoslock to determine the locking efficiency on DRP and TP for a Puarenga stream raw sample. It should be noted that Phoslock dose of 0mg/L represents the results of blank sample. All samples (including the blank) were filtered. Consistent with findings for other chemicals, filtering removed particulate bound phosphorus. It also shows there was not a significant amount of dissolved phosphorus removed as Phoslock dose increased. If the effect of both filtering and Phoslock are considered, there was a good portion of DRP locked into particulate material.

Figure 3-17 shows that pH is not affected when Phoslock is added to the raw sample. Tabulated results for values in Figure 3-18 (below) are in Table C-2 of Appendix C.

As for section 3.5.1 the numbers in red and green on X-axis represents the multiples of recommended Phoslock dose. The red line drawn on the graph shows the dose rate recommended by the Phoslock manufacturer whereas the green lines show different Phoslock strengths used in the study. Table 3-1 above explains the ratios in terms of Phoslock strength.

Figure 3-17 Phosphorus locking from Puarenga Stream using Phoslock.

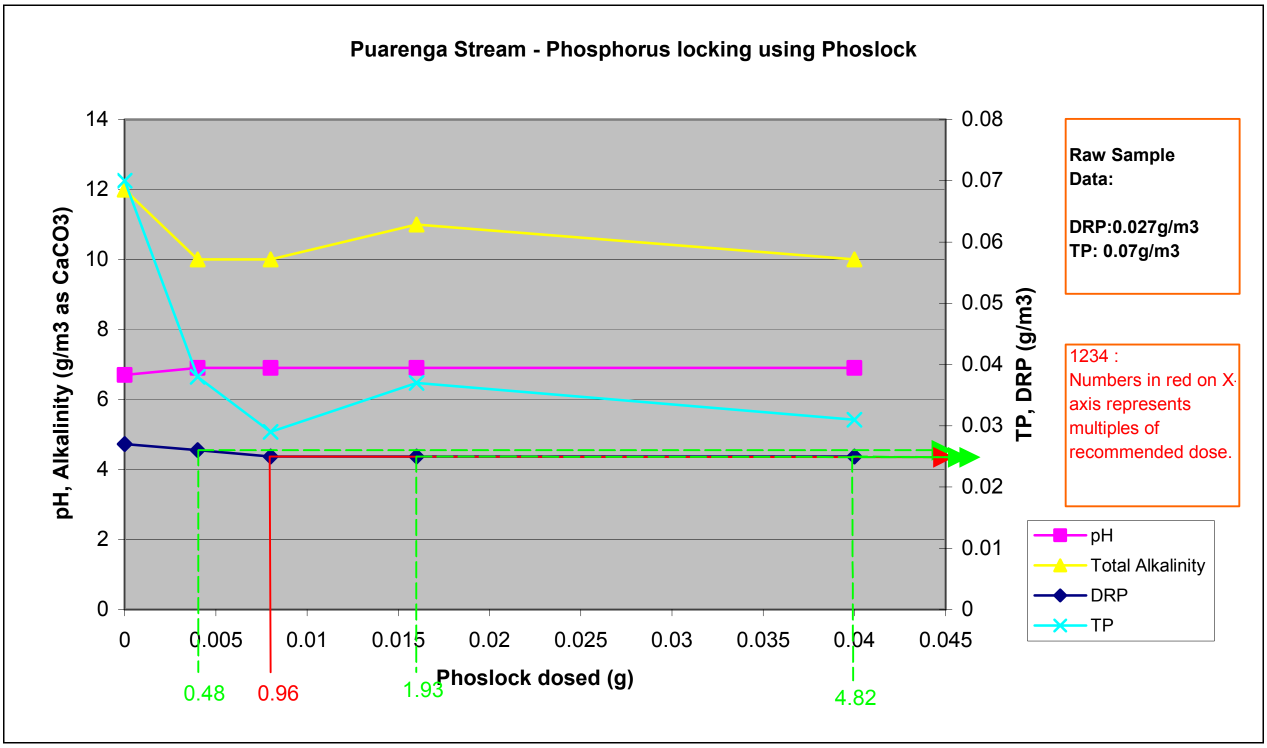


Figure 3-18 Percentage locking of DRP from raw sample for Puarenga Stream

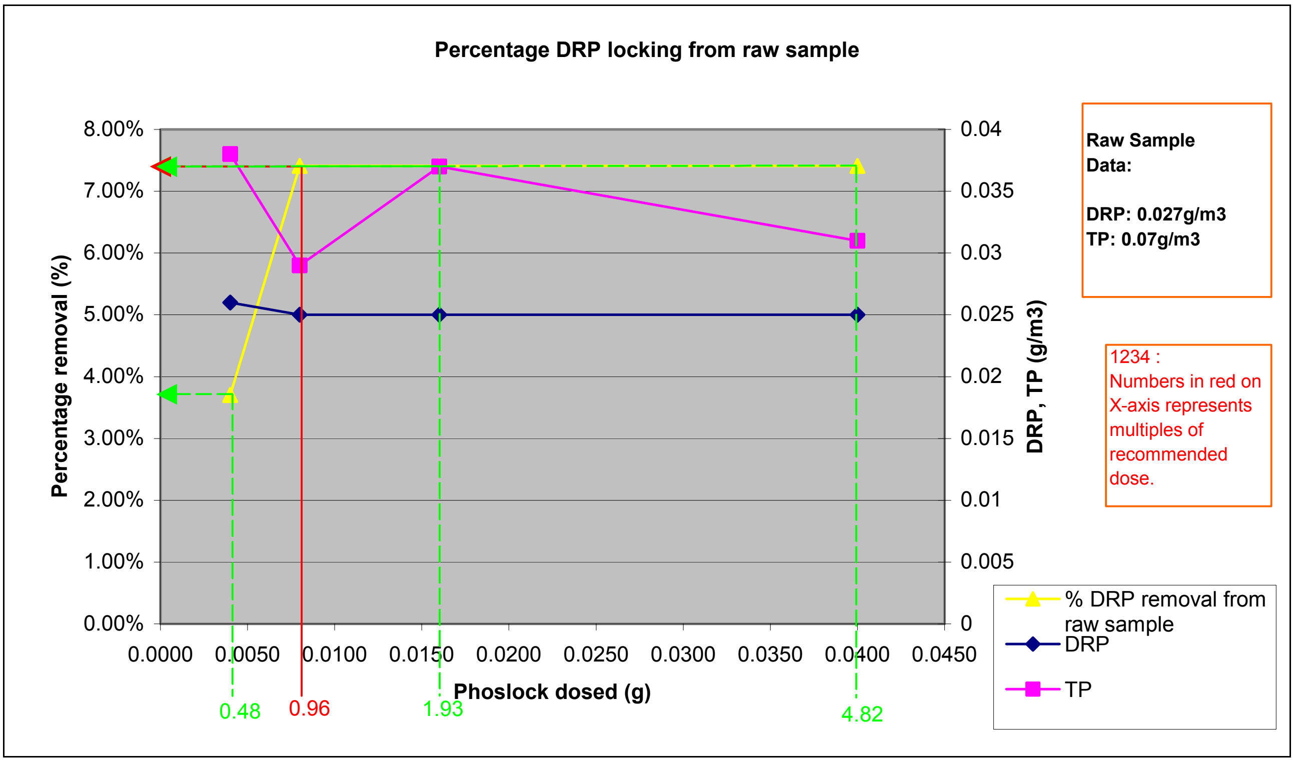


Figure 3-18 shows the percentage DRP locked from the raw sample. As for Figure 3-17, the red and green lines represent the ratios of recommended dose rate by the Phoslock manufacturer to lock phosphorus from further reactions. At first glance, it would appear that Figure 3-18 indicates that Phoslock was not an effective chemical for removing DRP with a removal efficiency of only 7 % greater than the filtered blank sample. However, a more realistic explanation is that phoslock had insufficient time to fully react with DRP for the limited contact time used for these analyses. It is therefore more suited to lake application than to control of phosphorus in the streams.

3.7 Puarenga Confluence

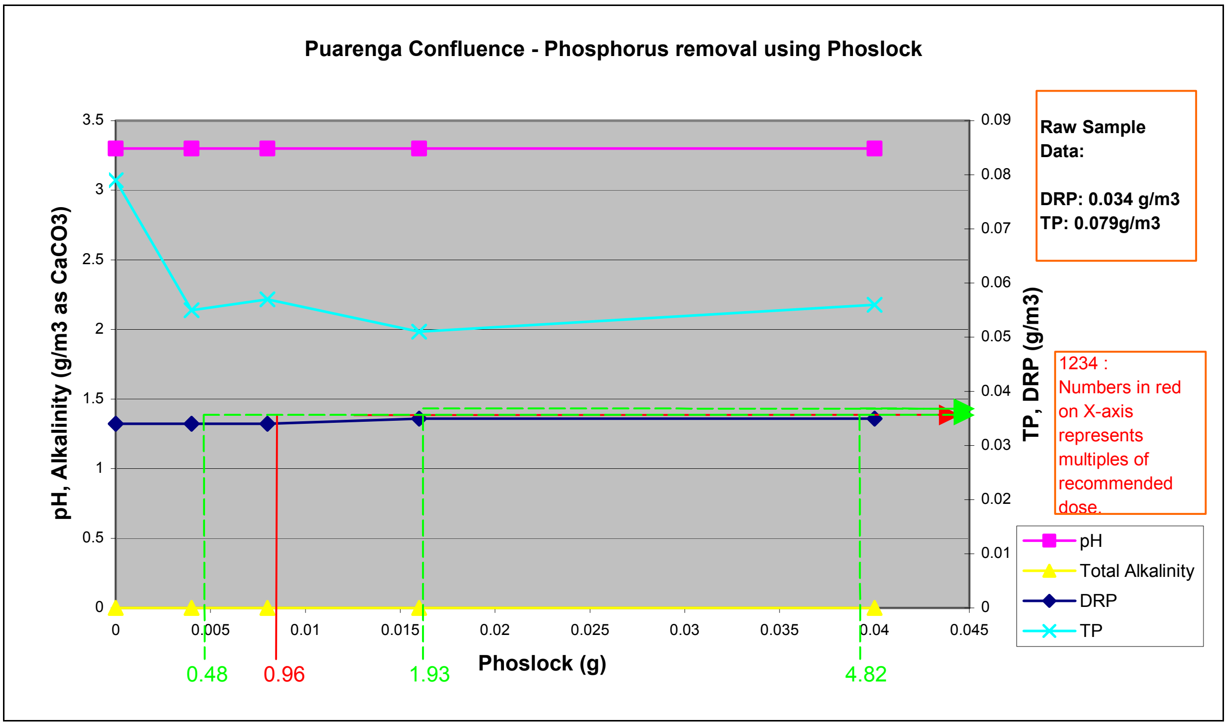
Initially, the Puarenga Stream was considered to be suitable for pilot trials since the confluence area has significant geothermal activity and was thought to be unaffected by any chemical deposition. This would mean the in-stream phosphorus locking efficiency could be monitored over a portion of the stream and any effects on the stream/confluence environment observed and recorded.

3.7.1 Alum for Phosphorus removal

Raw samples from the Puarenga confluence were dosed with Alum over a range of rates. However, results showed that no reaction occurred even at high dose rates of 20 mg/L. The reason for this is that the natural pH of the Puarenga confluence's raw sample was pH 3.3, which is outside the optimum coagulation pH range for Alum of 5.5 to 8 [1]. Also, at pH values lower than 5.0, aluminium hydroxide formation reduces and therefore is an ineffective coagulant. No further tests were pursued for Puarenga Confluence with Alum.

3.7.2 Phoslock for Phosphorus removal

Figure 3-19 Phosphorus locking from Puarenga Confluence using Phoslock



Raw samples from Puarenga Confluence were dosed with Phoslock at different strengths and its effects on TP and DRP removal observed. Phoslock was not effective in removing dissolved phosphorus for Puarenga Confluence, although some particulate phosphorus was removed by the filtering process. It was found from results that the Confluence had a pH of 3.3 that appears to be equally effective at eliminating the locking power of Phoslock as it does for all other chemical examined. The Alkalinity of the confluence was also observed to be very low.

Figure 3-19 examines the effects on DRP and TP as different Phoslock dose rates added to the Puarenga Confluence raw sample. It should be noted that a Phoslock dose of 0mg/L represents the results of blank sample. Tabulated results of values used in Figure 3-20 (below) are in Table C-3 of Appendix C.

As previously discussed the recommended Phoslock ratios are also shown. Table 3-1 above explains the numbers in red in terms of Phoslock strength.

Figure 3-19 shows that pH is not affected when Phoslock is added to the raw sample. Note that the DRP curve relates to the right hand scale. All the phoslock locking efficiencies are flat lines.

Figure 3-20 Percentage DRP locked from raw sample for Puarenga Confluence

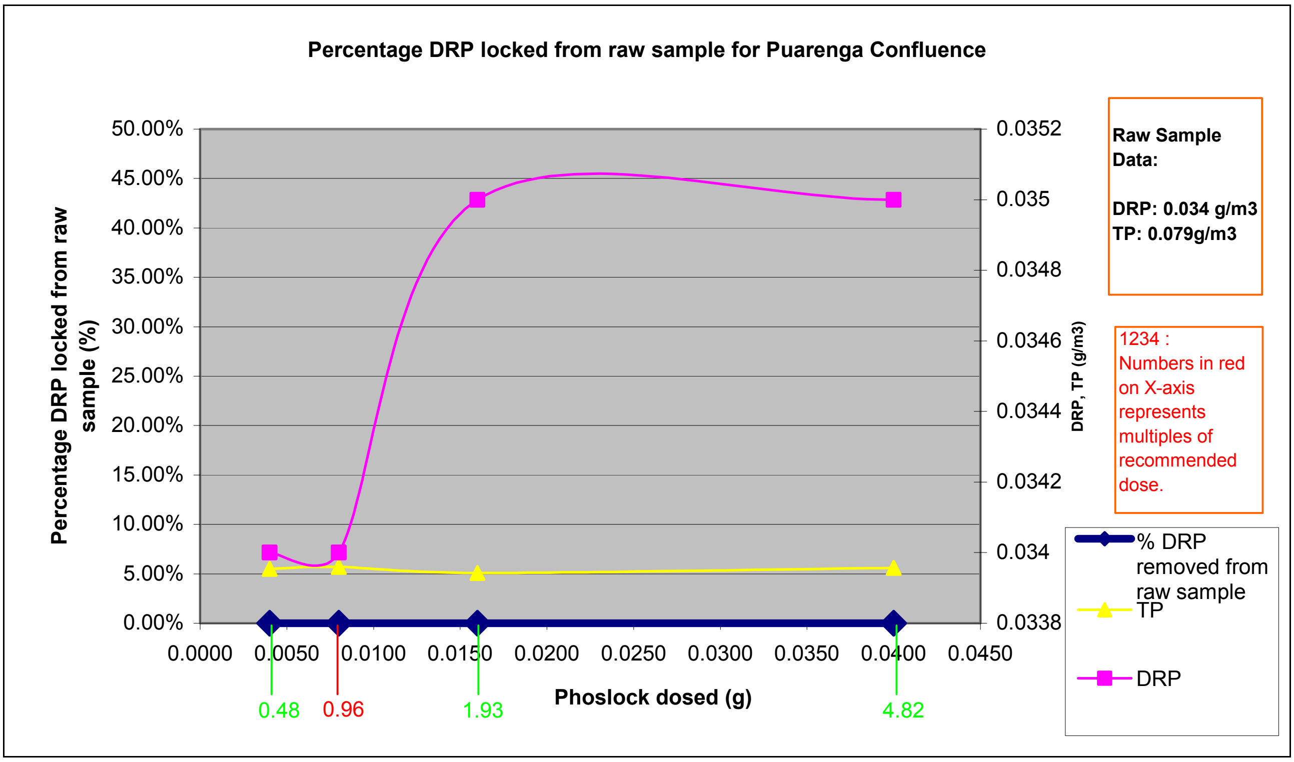


Figure 3-20 above shows that no reactive phosphorus was removed when Phoslock was used. Therefore, Phoslock is not recommended to remove DRP in streams. It does however, remain a viable option for control of phosphorus within lake environments – the designed purpose of phoslock.

3.7.3 Puarenga Stream Trials

Puarenga Stream exhibits a 'middle of the range' water quality of the streams examined. Other factors lend this stream to the progressing of in-stream trials to further evaluate the option and chemicals.

These factors are:

1. Available land and services for a trial plant,
2. Security,
3. Proximity to support staff,
4. Remoteness from the general public,
5. Conditions at the outfall.

All the above are reasonably self explanatory, except item 5 relating to outfall conditions. The explanation is the existing poor water quality at the outfall of Puarenga Stream into the Bay that includes Rocky Point and

Sulphur Point. The water is a particularly turbid, acidic and low water quality area of the lake. Chemicals added to the stream confluence will be dosed at the low rates of Method 2 of this report and dispersed throughout the bay. Any chemicals that reach the interface of the bay water with lake body water will be well dispersed, of no toxic concern, and effectively negligible compared with other substances already naturally within the bay water.

Puarenga Stream is therefore the best available stream to conduct trials that are designed to improve the lake water quality of Lake Rotorua and other down gradient lakes and waterways.

Capital Costs

4.1 Costs Overview

In preparing capital costs for this project, two treatment methods have been considered:

Method 1	Full chemical treatment inclusive of solids separation and dewatering to entirely remove the separated phosphorus from the aquatic environment.
Methods 2	Chemical addition only to lock phosphorus into lake sediments.

Method One includes the following equipment:

c) In-stream diversion works.

d) Low-lift pump station.

e) Chemical storage and preparation.

f) Chemical dosing and rapid mixing.

g) Water/chemical flocculation.

h) Clarification.

i) Treated water return to the stream.

j) Clarifier sludge underflow to temporary sludge storage.

k) Sludge dewatering.

l) Dewatered solids load-out facilities.

Method Two includes items c) and d) only from the above list, although those components are smaller than for option one due to a much lower chemical demand.

The reason for a large disparity between methods 1) and 2) is due to a fundamental difference in treatment strategy.

Method One - full chemical treatment - provides all the treatment components necessary to “remove” phosphorus from the stream water.

Method Two - chemical addition only - provides only those facilities that dose chemical directly into the stream. This option relies on a fundamental principle that the introduced chemical will remain in the environment and ‘lock’ the stream-water phosphorous into a compound that will not be available for biochemical processes (i.e. biological activity). Phosphorus/alum floc that is sufficiently large or associated with particulate matter will settle to be incorporated into lake sediments, whereas fine floc may remain suspended for some time to be transported to more remote locations.

As indicated in earlier sections of this report, several chemicals have been bench top tested to examine the efficiencies of phosphorous reduction for both methods 1) and 2).

All costs are presented in the following sections. By far the most significant cost is the ongoing commitment to chemicals needed to effect removal of phosphorus at each stream.

4.2 Capital Costs

4.2.1 Method One: Full Chemical Treatment and Solids Removal

A number of treatment systems were considered in order to assess the lowest cost treatment method.

Some of the methods considered are:

- Clarifiers and solids dewatering.
- Settlement ponds and sludge consolidation.
- Dissolved air flotation, DAF.
- Dual media filters.

Only clarifiers with solids dewatering provided a good balance between predicted water quality, operating cost, capital cost and maintenance flexibility.

In brief, fatal flaws for other alternatives included heavy land investment for settlement ponds and difficulty in retaining and handling accumulated sludge. Dual media filters and DAF demand sophisticated controls and are capital and operating costs intensive.

The preferred method of phosphorous removal is illustrated schematically in Figure 4-1.

4.2.2 Cost Exclusions

Not all possible costs have allowances in the assessed costs. Most of these are recognised as a risk for the phosphorus ‘removal’ option (option one) and are a much lower risk for the phosphorus ‘locking’ option (option two). Exclusions are:

- Land purchase costs
- Difficult geotechnical conditions
- Geothermal activity
- Resource consents
- Legal costs
- Consultation
- Ongoing monitoring (operational)
- Costly access or services supply costs

Figure 4-1 Schematic diagram of Method 1: Phosphorus Removal

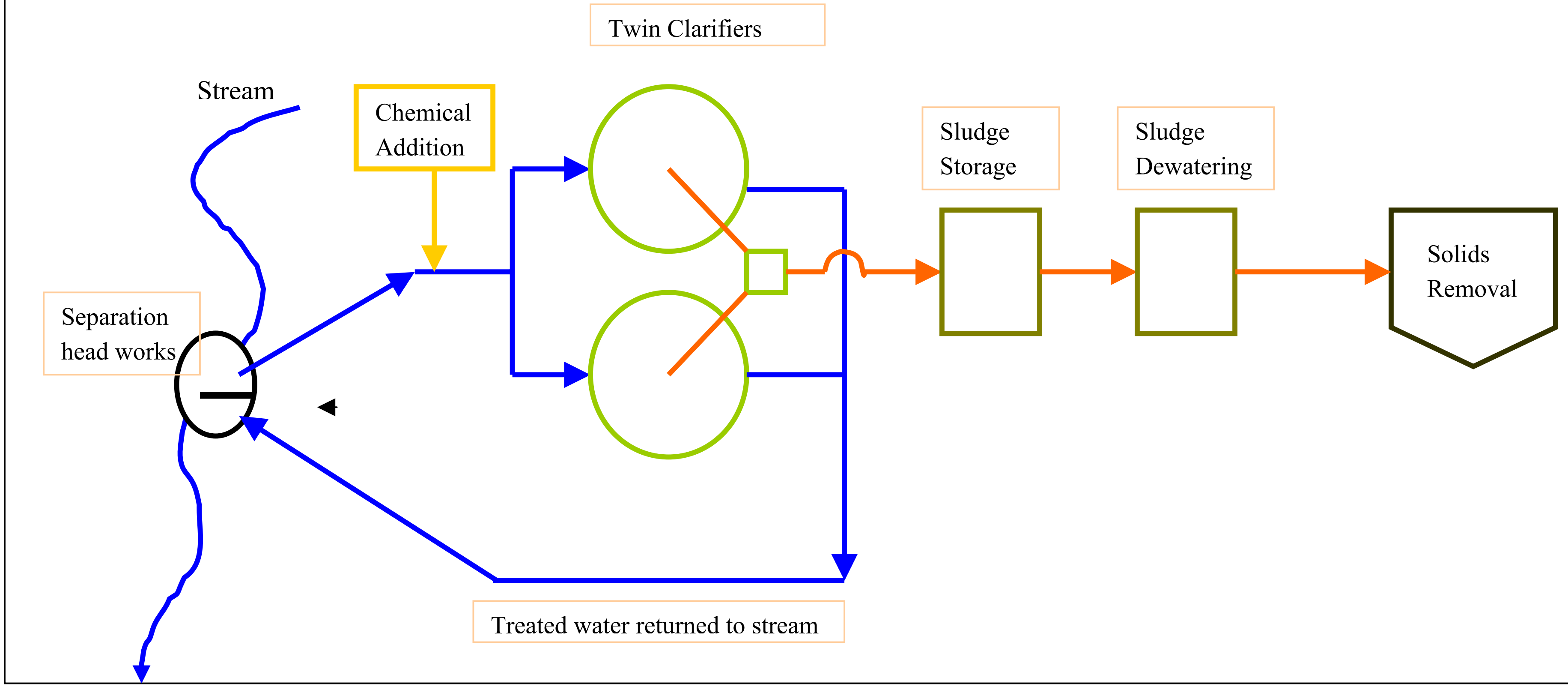
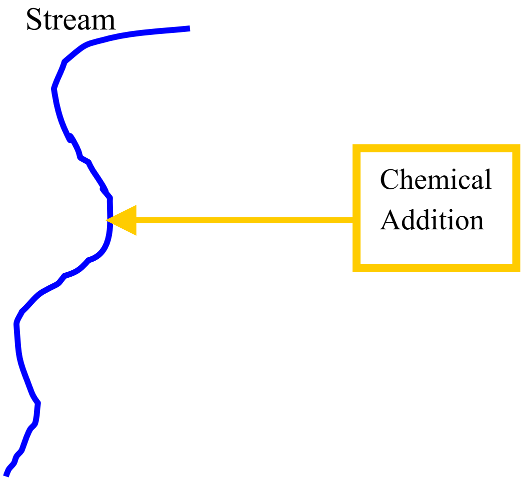


Figure 4-2 Schematic diagram of Method 2: Phosphorus Locking



Capital Estimate

Option One: Full Chemical addition and Solids Separation for phosphorus ‘removal’.

General Civil	430,000
Inlet works & low lift pump station	1,070,400
Chemical Storage & dosing	110,000
Clarifiers (solids separation)	2,880,000
Sludge Handling	882,000
General Pipework	414,600
Electrical/Control/Services	472,000
Contingency @15%	937,350
Round up total	**$7,200,000**

Method Two: Chemical Dosing only for phosphorus 'locking'

General Civil	170,000
Rock diffuser	43,000
Chemical Storage & dosing	80,000
Pipework	75,000
Chemical/stream inlet structure	20,000
Electrical/Control/Services	62,000
Contingency @15%	69,000
Round up total	**$550,000**

Note: the above costs include allowances for project management and building consents.

Chemical Costs

The most significant ongoing costs will be the chemical supply costs. These are given in detail below.

Chemical costs were calculated based on the jar tests regime performed earlier. The main chemicals used were alum, ferric chloride, Phoslock, and caustic soda. Costs were calculated on a monthly basis and do not include costs for polyelectrolytes.

Note that the price for caustic is subjected to the world market fluctuations, and in the worst case, could double if the New Zealand dollar weakens.

5.1 Range of predicted annual major chemical operating costs for streams dosed with Alum

Alum chemical costs have been calculated for a unit dose rate of 1mg/L (as aluminium). This dose rate is also the desirable dose rate for 'phosphorus locking' in most streams studied. To achieve the unit dose rate of 1 mg/L of Al^{3+}, 1.02×10^{-5} litres of Alum is required, or;

1.02×10^{-2} L Alum /m^3 of water gives 1 mg/L dose rate..…………………………………………….(1)

At a supply cost of $0.30/L alum gives a stream chemical demand for Alum (as aluminium at a unit dose rate of 1 mg/L) of treated water is:

$\$0.30 \times 1.02 \times 10^{-2} = \$0.003/m^3$……….…………………………….………………….……….…….(2)

Relationship (1) can be used to calculate the cost of alum consumed and relationship (2) the cost. Costs have been expressed as monthly totals to match normal accounting payment practice. Annual costs are summarised at the end of this section.

Caustic was used to adjust the pH to between pH 6.5 and 7 to achieve optimal alum dose efficiency. Based on a dosage of 0.6 mL of NaOH 0.1M in a 1-litre sample, and the Hamurana Stream flowrate, the monthly requirement for 48% NaOH is 23.17 m^3.

5.1.1 Hamurana stream with pH adjustment

Hamurana has a stream flowrate of 2.7 m^3/s

At this flowrate, 0.6 ml/L NaOH as 48% solution per litre of sample = 23,167 L/ month, or 38,611L/month at 1mL dose rate.

Chemical Type	Chemical price ($/L)	Caustic dose (mL/L of sample)	Chemical volume (L)	Alum required (L/s)	Cost per second ($)	Cost per month ($)
Alum	$0.30			0.02754	$0.0082620	$21,415
Caustic Soda	$0.68	1.00	38611			$26,255
					TOTAL:	***$47,670***

To provide sufficient chemical to form a flocculated particle sufficiently large to lock and remove phosphorus would demand a dose rate in the order of 5 to 10 mg/L aluminium (5 to 10 ppm alum) and a small dose of polyelectrolyte. This is 5 to 10 times more expensive than the above values, which equates to a chemical costs range of $250,000 to $500,000 per month. These costs are considered prohibitive in comparison with the lesser values associated with chemically locking phosphorus from biological activity and remaining in the aquatic environment.

5.1.2 Utuhina stream with pH adjustment

Utuhina has a stream flowrate of 2.3 m^3/s

At this flowrate, 0.6 ml NaOH as 48% solution per litre of sample = 19,734 L/ month, or 32890 L/mth at 1mL dose rate

Chemical Type	Chemical price ($/L)	Caustic Dose (mL/L of water)	Chemical volume (L)	Alum required (L/s)	Cost per second ($)	Cost per month ($)
Alum	$0.30			0.02346	$0.007	$18,242
Caustic Soda	$0.68	0.50	16445			$11,183
					TOTAL:	***$29,425***

5.1.3 Puarenga stream

With pH adjustment

Puarenga has a stream flowrate of 2.137 m^3/s.

Puarenga Stream dosed with alum and caustic (for pH adjustment) achieved 33% phosphorus locking at 2mg/L Al^{3+} dose rate.

At this flowrate, 0.6 mL NaOH as 48% solution per litre of sample = 18,336 L/ month, or 30560 L/mth at 1mL dose rate.

Chemical Type	Chemical price ($/L)	Caustic Dose (mL/L of water)	Chemical volume (L)	Alum required (L/s)	Cost per second ($)	Cost per month ($)
Alum	$0.30			0.0435948	$0.0130784	$33,900
Caustic Soda	$0.68	0.50	15260			$7640
					TOTAL:	***$41,540***

Without pH adjustment

A trial was run to observe the effect of alum without pH adjustment. The results show that a dose rate of 1 mg/L (as Al^{3+}) the council's requirement of 33% removal of phosphorus was achieved. Therefore the chemical cost was estimated based on a dose rate of 1mg/L.

We note however that close to 60% phosphorus locking was achieved at 2 mg/l dose rate, which equates to $33,900/mth as noted in the above table.

At 1mg/L dose rate without pH correction and Puarenga Stream flowrate of 2.137 m^3/s

Chemical Type	**Chemical price ($/L)**	**Stream Flow (m^3/s)**	**Alum required (L/s)**	**Cost per second ($)**	**Cost per month ($)**
Alum	$0.30	2.137	0.0217974	$0.006	$16,950
				TOTAL:	***$16,950***

5.2 Range of predicted annual major chemical operating costs for streams dosed with Ferric Chloride ($FeCl_3$)

Chemical costs were predicted based on a unit dose rate of 1mg/L as Ferric (Fe^{3+}) ion.

To achieve the dose rate of 1 mg/L of Fe^{3+}, 4.88 x 10^{-6} litres of Ferric chloride is required.

For every cubic metre of water treated;

4.88 x 10^{-3} litres Ferric chloride was consumed……………………………………………………….(3)

At a price of $1.00/L $FeCl_3$ the cost per cubic metre treated is:

$1.00 x 4.88 x 10^{-3} = $0.00488/$m^3$……………………………………………………………………..(4)

Caustic consumption remains as set out at the beginning of Section 5.1.

5.2.1 Hamurana stream with pH adjustment

Hamurana has a stream flowrate of 2.7 m^3/s and gave good phosphorus locking results at a dose rate of 1 mg/L Fe^{3+} and 1.1 mg/L of NaOH.

Chemical Type	Chemical price ($/L)	Caustic dose (mL/L of water)	Vol of Chemical (L)	Alum required (L/s)	Cost per second ($)	Cost per month ($)
Ferric Chloride	$1.00		2.7	0.013176	$0.0131760	$34,152
Caustic Soda	$0.68	1.10	42472			$28,881
					TOTAL:	***$63,033***

5.2.2 Utuhina stream with pH adjustment

Utuhina has a stream flowrate of 2.3 m^3/s and gave good phosphorus locking results at a dose rate of 1 mg/L Fe^{3+} and 0.6 mg/L of NaOH.

Chemical Type	Chemical price ($/L)	Caustic dose (mL/L of water)	Vol of Chemical (L)	Alum required (L/s)	Cost per second ($)	Cost per month ($)
Ferric Chloride	$1.00			0.011224	$0.0112240	$29,092
Caustic Soda	$0.68	0.60	19735.00			$13,420
					TOTAL:	***$42,510***

A comparison of costs for ferric chloride and alum showed alum to be more efficient in the control phosphorus. Therefore ferric chloride did not feature in later tests. In addition, there was concern that iron salts may have an undesirable aesthetic effect by causing colour changes at some sites.

5.3 Range of predicted annual major chemical operating costs for streams dosed with Phoslock

The stoichiometric equation for Phoslock is: 100 grams of Phoslock removes 1 gram of phosphorus. It was found that the stoichiometric amount was sufficient in achieving the phosphorus removal limit as set by the Council. To achieve stoichiometric amount in a litre sample, 0.008 grams of Phoslock was consumed. The price of Phoslock was quoted by Primaxa was $2,000 per tonne.

Hamurana Stream

Hamurana has a stream flowrate of 2.7 m^3/s or 2,700 L/s.

Phoslock added (g/L)	Flow (L/s)	Phoslock required per second (g/s)	Phoslock required per second (Tonnes/s)	Cost per second ($)	Cost per month ($)
0.008	2700	21.6	0.0000216	$0.04	$111,974
				TOTAL:	***$111,974***

Phoslock dosed at the manufacturers recommended dose rate locked 31% of total phosphorus and about 30% of dissolved reactive phosphorus. Results from tests show that a high DRP percentage removal can be achieved at high Phoslock dose rates of between 2 to 5 times the manufacturers recommended dose.

The above table shows that Phoslock has a high cost per month. The comparatively linear adsorption curve for Phoslock means that a 40% locking rate would cost at least $220,000 for Phoslock per month. This therefore suggests that the Phoslock is not cost effective in locking phosphorus for Hamurana.

When the effects of filtration are isolated, the results from section 3 show Phoslock to be largely ineffective for treatment at both Puarenga Stream and Puarenga Confluence.

5.4 Chemical Cost Summary

Table 5-1 summarises calculated monthly chemical consumption costs assuming pH correction of stream waters is not needed.

Table 5-1 Summary of monthly chemical cost for different streams for Method 2

Stream	Alum	Ferric Chloride	Phoslock
Hamurana	$21,415	$34,152	$111,974
Utuhina	$18,242	$29,092	N/c
Puarenga stream	$33,900	N/c	N/c

N/c: Not considered.

The above table summarises the total chemical cost for phosphorus locking (Method 2) at the three streams tested. The optimal dose rate for the streams to exceed a 33% Phosphorus removal was 1mg/L for all streams, except Puarenga stream where 2 mg/L gave the desired level of treatment.

The table shows that aluminium based chemical coagulants consistently proved to be more cost effective than ferric chloride or Phoslock.

5.5 Overall Chemical Costs

5.5.1 Total Flows and Mass Loads

Information provided by Council for the Puarenga, Hamurana, Awahou, Waingaehe and Utuhina streams suggest a cumulative flow from all sources studied of approximately 9 m^3/s. The total mass load of phosphorus into Lake Rotorua from these sources is in the order of 0.9 g/s and 0.07 g/s respectively for total phosphorus and dissolved phosphorus.

To inactivate 33% of phosphorus from the **five** streams studied would require inactivating 7.1 tonnes of DRP. At 1 mg/L Al^{3+} dose rate to **three** streams a 58% overall reduction rate is achieved to inactivate 12.8 tonnes of DRP, thereby easily meeting the desired removal rate.

Treating all streams in Section 5.2.1 using alum will require that at least three of the five streams need to be treated. Awahou and Waingaehe could be left untreated, while the overall goal of 33% phosphorus mass load could be achieved by treating the other streams. On this assumption the total flow treated would be around 7.0 cumecs.

5.5.2 Phosphorus locking within Streams

The following table summarises chemical costs (assuming pH adjustment is not needed) to lock phosphorus into non-soluble compounds for three streams:

Stream	Flow (L/S)	Chemical ($/mth)	Chemical ($/ann)
Hamurana	2530	$21,415	257,000
Utuhina	2335	$18,242	219,000
Puarenga	2137	$33,900	407,000
Totals	7000	73,500	883,000

The costs for treating 7.0 m^3/s at 1 mg/l aluminium with an adjustment to allow for using sodium aluminate or polymeric aluminium products would be a total annual chemical cost for phosphorus locking in the order of $1,000,000.

6.1.1 Operating Costs

Refer Section 5 for chemical costs. Operator costs for three plants based on an average of 1 hour per plant per normal working day.

Operator 3 hour/d average @ $40/h gives	$31,200/year
Maintenance at 6% of mechanical plant for three plants gives	$27,000/year
General consumables for servicing three plants (excluding chemical)	$5,000/year
Total operating costs for three plants (excluding chemical)	$63,200

6.1.2 Total Costs

Method 2: Phosphorus Locking

These costs are assessed on the following basis:

- A dose rate of 1 mg/L Al^{3+} as alum (or similar product) is assumed to be dosed to Hamurana and Utuhina Streams and 2 mg/L Al^{3+} as alum to Puarenga Stream to achieve a 58% phosphorus reduction, calculated from the total phosphorus load of five stream inputs to Lake Rotorua examined in this study.
- Chemical dosing facilities are used for 12 months of the year. However additional savings may be possible if dosing only occurs at critical times of the year, i.e. prior to seasonal bloom periods,

The following costs apply:

Stream	Flow (L/S)	Capital	Chemical ($/ann.)	Operating ($/ann.)	Total operating ($/ann.)
Hamurana	2530	550,000	257,000	22,000	280,000
Utuhina	2335	550,000	219,000	22,000	241,000
Puarenga	2137	500,000	407,000	22,000	430,000
Totals	7000	**$1,600,000**	883,000	66,000	**RND$950,000**

If chemical dosing were to be continuous throughout the year, then the operating costs would be close to $1,000,000/ann. for 1 mg/L dose rate for 58% inactivation of DRP.

Method 1: Phosphorus Removal

The above compare favourably with the more expensive option to remove phosphorus from the aquatic environment as summarised below. Capital costs have been pro-rata based on Hamurana estimates. Chemical costs include for pH adjustment to avoid significant change in stream alkalinity.

Stream	Flow (L/S)	Capital	Chemical ($/ann.)	Operating ($/ann.)	Total operating ($/ann.)
Hamurana	2530	7,200,000	4,050,000	150,000	4,200,000
Utuhina	2335	6,630,000	2,700,000	150,000	2,850,000
Puarenga	2137	6,000,000	2,500,000	150,000	2,650,000
Totals	7000	**RND$20,000,000**	9,250,000	450,000	**RND$9,700,000**

Clearly, treatment costs to physically remove phosphorus using Method 1attract a heavy premium over phosphorus inactivation (locking), Method 2.

Limitations Statement

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

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The Ownership of Data, Designs and Documents.

The provisions in Section 8.6 of the ACENZ/IPENZ document “The Briefing & Engagement of Consulting Engineers” dated July 1997 shall apply.

Appendix A

Laboratory results for tests using Alum

Appendix A
Laboratory results for tests using Alum

Table A-1 Laboratory results for Hamurana for phosphorus locking/removal using Alum with pH adjustment

				Sample ID								
				SWR 086	SWR 087	SWR 088	SWR 089	SWR 090	SWR 091	SWR 092	SWR 093	SWR 094
			Fresh Sampled Water	**Alum Dosage ppm (Al^{3+} mg/l)**								
				0.0	0.05	0.1	0.5	1.0	5.0	10.0	50.0	100.0
Removal Range (%)			**DRP (%)**	34.0	31.9	36.2	55.3	70.2	88.3	88.3	95.7	95.7
			TP (%)	15.2	11.4	12.7	45.6	48.1	81.0	88.6	100.0	95.0
NaOH (mL)				0.00	0.20	0.18	0.16	0.20	1.00	2.12	11.85	24.50
pH	pH units	pH	7.2									
Turbidity	NTU	Turb	0.15									
Total Suspended Solids	g.m-3	SS	< 3									
Volatile Suspended Solids	g.m-3	VSS	< 3									
Dissolved Calcium	g.m-3	CaSI	2.8									
Dissolved Magnesium	g.m-3	MgSI	1.79									
Total Hardness	g.m-3 as CaCO3	HardSI	14									
Total Ammoniacal-N	g.m-3	NH4N	< 0.01									
Total Kjeldahl Nitrogen (TKN)	g.m-3	TKNfia	< 0.1	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
Nitrate-N + Nitrite-N (TON)	g.m-3	NOxN	0.687	0.666	0.668	0.663	0.652	0.658	0.638	0.601	0.639	0.595
Nitrate-N	g.m-3	NO3N	0.686									
Nitrite-N	g.m-3	NO2N	< 0.002									
Dissolved Reactive Phosphorus	g.m-3	DRP	0.094	0.062	0.064	0.060	0.042	0.028	0.011	0.011	0.004	<0.004
Phosphate-P	g.m-3	PO4Pic	< 0.2									
Phosphate	g.m-3	PO4ic	< 0.4									
Total Phosphorus	g.m-3	TP	0.079	0.067	0.070	0.069	0.043	0.041	0.015	0.009	0	<0.004
Carbonaceous Biochemical Oxygen Demand (CBOD~5^)	g.O~2^.m-3	CBOD5	< 1									
Total COD	g O~2^.m-3	CODL	< 6									

Appendix A
Laboratory results for tests using Alum

Table A-2 Laboratory results for Utuhina for phosphorus locking/removal using Alum with pH adjustment

				Sample ID								
				SWR 095	SWR 096	SWR 097	SWR 098	SWR 099	SWR 100	SWR 101	SWR 102	SWR 103
			Fresh Sampled Water	**Alum Dosage ppm (as Al^{3+} mg/L)**								
				0.0	0.05	0.1	0.5	1.0	5.0	10.0	50.0	100.0
Removal Range (% removal)			**DRP (%)**	44.2	31.2	33.8	57.1	77.9	88.3	92.2	92.2	95.0
			TP (%)	48.1	39.5	40.7	42.0	44.4	46.9	44.4	95.0	95.0
NaOH (mL)				0.00	0.10	0.05	0.05	0.10	0.90	2.35	12.40	23.66
pH	pH units	pH	7.4									
Turbidity	NTU	Turb	3.23									
Total Suspended Solids	g.m-3	SS	18									
Volatile Suspended Solids	g.m-3	VSS	3									
Dissolved Calcium	g.m-3	CaSI	2.37									
Dissolved Magnesium	g.m-3	MgSI	1.25									
Total Hardness	g.m-3 as CaCO3	HardSI	11									
Total Ammoniacal-N	g.m-3	NH4N	0.01									
Total Kjeldahl Nitrogen (TKN)	g.m-3	TKNfia	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.5	0.3
Nitrate-N + Nitrite-N (TON)	g.m-3	NOxN	0.539	0.547	0.558	0.545	0.542	0.546	0.516	0.491	0.54	0.494
Nitrate-N	g.m-3	NO3N	0.538									
Nitrite-N	g.m-3	NO2N	< 0.002									
Dissolved Reactive Phosphorus	g.m-3	DRP	0.077	0.043	0.053	0.051	0.033	0.017	0.009	0.006	0.006	< 0.004
Phosphate-P	g.m-3	PO4Pic	< 0.2									
Phosphate	g.m-3	PO4ic	< 0.4									
Total Phosphorus	g.m-3	TP	0.081	0.042	0.049	0.048	0.047	0.045	0.043	0.045	< 0.004	< 0.004
Carbonaceous Biochemical Oxygen Demand (CBOD~5^)	g.O~2^.m-3	CBOD5	< 1									
Total COD	g O~2^.m-3	CODL	< 6									

Appendix A
Laboratory results for tests using Alum

Table A-3 Laboratory results for Puarenga Stream for phosphorus locking/removal using Alum with pH adjustment

				Sample ID						
				SWT 323	SWT 324	SWT 325	SWT 327	SWT 328	SWT 329	SWT 330
			Fresh Sample	Alum Dosage ppm (as Al^{3+} mg/l)						
			Lab analysis (Hills)	0.0	0.5	1.0	2.0	5.0	10.0	20.0
Removal Range (%)		DRP		0.00%	0.00%	18.52%	44.44%	59.26%	62.96%	66.67%
		TP		0.00%	42.86%	51.43%	77.14%	52.86%	91.43%	92.86%
NaOH - 0.1M (mL)	mL			0.0	7.00	8.0	9.0	13.0	18.0	30.0
Initial pH (URS lab)	pH units	pH	6.7	5.99	5.83	6.06	6.07	5.8	6.1	5.9
pH after Alum addition (URS lab)	pH units	pH		-	5.71	5.66	5.4	4.96	4.7	4.51
pH with NaOH	pH units	pH		-	6.5	6.85	6.77	6.86	6.7	6.95
Total Alkalinity	g/m3 as CaCO3		12	12	27	28	28	28	21	17
Dissolved Reactive Phosphorus	g.m-3	DRP	0.027	0.046	0.027	0.022	0.015	0.011	0.01	0.009
Total Phosphorus	g.m-3	TP	0.07	0.095	0.04	0.034	0.016	0.033	0.006	0.005
		pH drop:		-	0.1	0.4	0.7	0.8	1.4	1.4

Appendix A
Laboratory results for tests using Alum

Table A-4 Laboratory results for Puarenga Stream for phosphorus locking/removal using Alum without pH adjustment

				Sample ID						
				SWT 364	**SWT 365**	**SWT 366**	**SWT 367**	**SWT 368**	**SWT 369**	**SWT 370**
			Fresh Sample	**Alum Dosage ppm (as Al^{3+} mg/l)**						
			Lab analysis (Hills)	**0.0**	**0.5**	**1.0**	**2.0**	**5.0**	**10.0**	**20.0**
Removal Range (%)		**DRP**		0.00%	22.22%	44.44%	59.26%	59.26%	59.26%	59.26%
		TP		32.86%	40.00%	67.14%	81.43%	72.86%	81.43%	67.14%
Initial pH (URS lab)	**pH units**	**pH**	6.7	6.65	6.10	6.12	6.12	6.13	6.06	6.18
pH after Alum addition (URS lab)	**pH units**	**pH**		-	6.02	5.89	5.69	5.01	4.68	4.52
pH(lab)	**pH units**	**pH**		6.70	6.70	6.6	6.20	4.80	4.5	4.30
Total Alkalinity	**g/m3 as CaCO3**		12	14.00	11.00	10	6.00	2.00	< 1	< 1
Dissolved Reactive Phosphorus	**g.m-3**	**DRP**	0.027	0.027	0.021	0.015	0.011	0.011	0.011	0.011
Total Phosphorus	**g.m-3**	**TP**	0.07	0.047	0.042	0.023	0.013	0.019	0.013	0.023
		pH drop		-	0.08	0.23	0.43	1.12	1.38	1.66

Table A-5 Laboratory results for Sensitivity test of Alum over a pH range

1 ppm alum (0.1%)

& NaOH (0.1M) for pH addition

& HCL (1mol/L0 added for pH reduction

			Fresh Sample	**Sample ID**					
			Lab analysis (Hills)	**SWT 662**	**SWT 663**	**SWT 664**	**SWT 665**	**SWT 666**	**SWT 667**
				pH unit					
			7.4	7.00	6.00	5.00	4.00	3.00	2.00
Removal Range (%)		**DRP**		28.57%	59.74%	71.43%	16.88%	-54.55%	-9.09%
		TP		6.02%	-30.12%	-22.89%	-21.69%	-28.92%	13.25%
NaOH added	mL			2.10					
HCL added	mL				0.30	0.90	1.10	3.30	26.10
Initial pH	pH units	pH	-	6.45	6.41	6.41	6.41	6.41	6.41
pH adjusted to	pH units	pH	-	7.00	6.00	5.00	4.00	3.00	2.00
pH at Hills	pH units	pH	7.4	7.4	6.9	5.9	4.8	3.1	2.1
Total Alkalinity	g/m3 as CaCO3		27	30	18	4	1	< 1	< 1
Dissolved Reactive Phosphorus	g.m-3	DRP	0.077	0.055	0.031	0.022	0.064	0.119	0.084
Total Phosphorus	g.m-3	TP	0.083	0.078	0.108	0.102	0.101	0.107	0.072

Appendix B
Laboratory results for tests using Ferric Chloride

Appendix B
Laboratory results for test using Ferric Chloride

Table B-1 Laboratory results for Hamurana for phosphorus locking/ removal using Ferric chloride

				Sample ID								
				SWR 104	SWR 105	SWR 106	SWR 107	SWR 108	SWR 109	SWR 110	SWR 111	SWR 112
			Fresh Sampled Water	**$FeCl_3$ Dosage ppm (as Fe^{3+} mg/l)**								
				0.0	0.05	0.1	0.5	1.0	5.0	10.0	50.0	100.0
Removal Range (% removal)			DRP	28.7	26.6	8.5	16.0	27.7	72.3	79.8	88.3	91.5
			TP	0.0	0.0	0.0	0.0	0.0	67.1	73.4	-	95.0
NaOH (mL)				0.00	0.01	0.20	0.20	0.22	0.50	0.88	5.00	8.50
pH	pH units	pH	7.2									
Turbidity	NTU	Turb	0.15									
Total Suspended Solids	g.m-3	SS	< 3									
Volatile Suspended Solids	g.m-3	VSS	< 3									
Dissolved Calcium	g.m-3	CaSI	2.8									
Dissolved Magnesium	g.m-3	MgSI	1.79									
Total Hardness	g.m-3 as CaCO3	HardSI	14									
Total Ammoniacal-N	g.m-3	NH4N	< 0.01									
Total Kjeldahl Nitrogen (TKN)	g.m-3	TKNfia	< 0.1	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.4	0.2
Nitrate-N + Nitrite-N (TON)	g.m-3	NOxN	0.687	0.709	0.707	0.701	0.696	0.69	0.685	0.674	0.672	0.649
Nitrate-N	g.m-3	NO3N	0.686									
Nitrite-N	g.m-3	NO2N	< 0.002									
Dissolved Reactive Phosphorus	g.m-3	DRP	0.094	0.067	0.069	0.086	0.079	0.068	0.026	0.019	0.011	0.008
Phosphate-P	g.m-3	PO4Pic	< 0.2									
Phosphate	g.m-3	PO4ic	< 0.4									
Total Phosphorus	g.m-3	TP	0.079	0.081	0.081	0.083	0.085	0.087	0.026	0.021		< 0.004
Carbonaceous Biochemical Oxygen Demand (CBOD~5^)	g.O~2^.m-3	CBOD5	< 1									
Total COD	g O~2^.m-3	CODL	< 6									

Appendix B
Laboratory results for test using Ferric Chloride

Table B-2 Laboratory results for Utuhina for phosphorus locking/ removal using Ferric chloride

				Sample ID								
				SWR 113	SWR 114	SWR 115	SWR 116	SWR 117	SWR 118	SWR 119	SWR 120	SWR 121
			Fresh Sampled Water	**$FeCl_3$ Dosage ppm (as Fe^{3+} mg/l)**								
				0.0	0.05	0.1	0.5	1.0	5.0	10.0	50.0	100.0
Removal Range (% removal)			DRP	28.6	37.7	51.9	37.7	68.8	84.4	80.5	87.0	92.2
			TP	35.8	35.8	38.3	38.3	39.5	90.1	59.3	79.0	95.0
NaOH (mL)				0.00	0.15	0.12	0.05	0.12	0.35	0.83	4.27	8.30
pH	pH units	pH	7.4									
Turbidity	NTU	Turb	3.23									
Total Suspended Solids	g.m-3	SS	18									
Volatile Suspended Solids	g.m-3	VSS	3									
Dissolved Calcium	g.m-3	CaSI	2.37									
Dissolved Magnesium	g.m-3	MgSI	1.25									
Total Hardness	g.m-3 as CaCO3	HardSI	11									
Total Ammoniacal-N	g.m-3	NH4N	0.01									
Total Kjeldahl Nitrogen (TKN)	g.m-3	TKNfia	0.2	0.2	0.3	0.3	0.3	0.2	0.4	0.2	0.3	0.2
Nitrate-N + Nitrite-N (TON)	g.m-3	NOxN	0.539	0.562	0.558	0.564	0.555	0.556	0.551	0.541	0.544	0.524
Nitrate-N	g.m-3	NO3N	0.538									
Nitrite-N	g.m-3	NO2N	< 0.002									
Dissolved Reactive Phosphorus	g.m-3	DRP	0.077	0.055	0.048	0.037	0.048	0.024	0.012	0.015	0.01	0.006
Phosphate-P	g.m-3	PO4Pic	< 0.2									
Phosphate	g.m-3	PO4ic	< 0.4									
Total Phosphorus	g.m-3	TP	0.081	0.052	0.052	0.050	0.050	0.049	0.008	0.033	0.017	< 0.004
Carbonaceous Biochemical Oxygen Demand (CBOD~5^)	g.O~2^.m-3	CBOD5	< 1									
Total COD	g O~2^.m-3	CODL	< 6									

Appendix C

Laboratory results for test using Phoslock

Appendix C
Laboratory results for test using Phoslock

Table C-1 Laboratory results for Hamurana Stream –locking/ removal of Phosphorus using Phoslock

			Fresh Sample	**Sample ID**			
			Lab analysis (Hills)	**SWT 425**	**SWT 425**	**SWT 425**	**SWT 425**
			Phoslock (g)	**Phoslock (g)**			
			0	0.0040	0.0080	0.0160	0.0400
Phoslock strength (times Phoslock)				0.5 times	1.0 times	2.0 times	5.0 times
Removal Range (%)		**DRP**		16.88%	29.87%	40.26%	72.73%
		TP		21.69%	31.33%	43.37%	80.72%
g Phoslock/ g Phosphorus removed				0.48	0.96	1.93	4.82
pH	**pH units**	**pH**	7.4	7.2	7.2	7.2	7.4
Total Alkalinity	**g/m3 as CaCO3**		27	27	28	28	28
Dissolved Reactive Phosphorus	**g.m-3**	**DRP**	0.077	0.064	0.054	0.046	0.021
Total Phosphorus	**g.m-3**	**TP**	0.083	0.065	0.057	0.047	0.016
			pH drop:	0.2	0.2	0.2	0.0

Appendix C
Laboratory results for test using Phoslock

Table C-2 Laboratory results for Puarenga Stream –locking/ removal of Phosphorus using Phoslock

			Fresh Sample **Lab analysis (Hills)**	**Sample ID**			
				SWT 426	**SWT 426**	**SWT 426**	**SWT 426**
				Phoslock (g)			
			0	**0.0040**	**0.0080**	**0.0160**	**0.0400**
Phoslock Strength				**0.5 times**	**1 time**	**2 times**	**5 times**
Removal Range (%)		**DRP**		3.70%	7.41%	7.41%	7.41%
		TP		45.71%	58.57%	47.14%	55.71%
g Phoslock/ g Phosphorus removed				0.48	0.96	1.93	4.82
pH	**pH units**	**pH**	6.7	6.9	6.9	6.9	6.9
Total Alkalinity	**g/m3 as CaCO3**		12	10	10	11	10
Dissolved Reactive Phosphorus	**g.m-3**	**DRP**	0.027	0.026	0.025	0.025	0.025
Total Phosphorus	**g.m-3**	**TP**	0.07	0.038	0.029	0.037	0.031
			pH drop:	-0.2	-0.2	-0.2	-0.2

Appendix C
Laboratory results for test using Phoslock

Table C-3 Laboratory results for Puarenga Confluence – locking/removal of Phosphorus using Phoslock

			Fresh Sample	Sample ID			
			Lab analysis (Hills)	SWT 427	SWT 427	SWT 427	SWT 427
				Phoslock strength			
			0	0.0040	0.0080	0.0160	0.0400
Removal Range (%)		DRP		0.00%	0.00%	0.00%	0.00%
		TP		30.38%	27.85%	35.44%	29.11%
g Phoslock/ g Phosphorus removed				0.48	0.96	1.93	4.82
pH	pH units	pH	3.3	3.3	3.3	3.3	3.3
Total Alkalinity	g/m3 as CaCO3		<1	< 1	< 1	< 1	< 1
Dissolved Reactive Phosphorus	g.m-3	DRP	0.034	0.034	0.034	0.035	0.035
Total Phosphorus	g.m-3	TP	0.079	0.055	0.057	0.051	0.056
			pH drop:	0.0	0.0	0.0	0.0

References

1. Davis, M.L., Cornwell, D.A. (1991). *Introduction to Environmental Engineering.* 2nd edition. McGraw-Hill. Inc.. Singapore.

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