



**INDEPENDENT EVALUATION OF VIROFILTER
TECHNOLOGY FOR ENHANCED PHOSPHATE
REMOVAL**

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INDEPENDENT EVALUATION OF VIROFILTER TECHNOLOGY FOR ENHANCED PHOSPHATE REMOVAL

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SUMMARY

I BENEFITS

The study has quantified the potential of Bauxsol™ pellets as a suitable media for removing phosphorus, and given a realistic indication of the performance that can be expected in a flow-through bed at a wastewater treatment works (WwTW).

II OBJECTIVES

The objectives of the study were to:

- Examine the hydraulic characteristics of a suitable flow-through bed;
- Evaluate the effect of influent pH and bed residence time on the extent of phosphorus removal;
- Calculate the P-removal capacity and predict the bed-lifetime from the collected data;
- Determine any other beneficial aspects of the media regarding improvements to effluent quality, e.g. COD, BOD, SS.

III REASONS

Ever-stricter consents are coming into force requiring very low P-concentrations in the discharged effluent from WwTW. At small WwTW serving less than 2000PE, there is a need for cost-effective solutions to achieve these targets. Bauxsol™ media can be used as a low-cost technology in a tertiary bed. Following successful laboratory-scale studies which suggest a bed lifetime significantly longer than that required for other types of media, the technology needed to be tested at a larger-scale. Incorporating media with a high affinity for P into such beds offers an ideal long-term solution for P removal at small WwTW.

IV CONCLUSIONS

The current studies in a horizontal-flow bed have shown that operation at high loading rates over a period of 6 months has not resulted in breakthrough of P into the treated effluent demonstrating the promising potential for Bauxsol™ media.

The P-removal capacity based on the current study is greater than 5 kg P/tonne and the minimum predicted bed lifetime is longer than 10 years. Compared to a conventional reed bed containing gravel media with a bed lifetime of about 6 months, the potential lifetime of a bed filled with Bauxsol™ pellets will be greater than twenty times that of a conventional mineral media.

Average P removal efficiencies of 80 to 85% were achieved during the trial. The trial also indicated that a two bed in series configuration may be the optimum treatment set up.

Bauxsol™ media is suitable not only for use as a tertiary bed at a small WwTW instead of chemical dosing but also at larger WwTW where it can provide a tertiary polishing stage downstream of chemical dosing, to meet a strict P consent.

V RECOMMENDATIONS

Test work undertaken by Virotec Europe Limited (Hogan *et al* 2005) over a longer period than the current study has shown that the P removal capacity achieved by Bauxsol™ media is at least 14 kg P/tonne. This test work is continuing with the aim of determining the ultimate P removal capacity of the media.

Further work is required at a Water Company Site to prove the process under the diurnally-varying operating conditions at a WwTW and the disposal of the media, in particular to:

- Investigate vertical flow configurations to examine whether they provide a more even distribution of final effluent through the bed of media and higher P removal capacity;
- Evaluate the potential for recycling spent media to agriculture with emphasis on phosphorus bioavailability;
- Conduct a long-term test on a tertiary bed of Bauxsol™ media at a small WwTW;
- Undertake a similar test at a larger WwTW with very strict P-standards where chemical dosing is retained to remove the majority of the phosphorus and the tertiary bed is used for polishing.

VI RESUMÉ OF CONTENTS

Chapter 1 discusses the background and objectives of the study, and outlines previous work done in the area. Chapter 2 describes the pilot-scale rig that was erected at WRC's testing facilities, along with the testing regime implemented. Chapters 3 and 4 present the results of the 6-month trial. Chapters 5 and 6 discuss the results and present the conclusions of the study. A list of recommendation for further work is given in Chapter 7.

1. INTRODUCTION

1.1 Background

Virotec Europe Limited has developed a product called Bauxsol™. This media is produced from the chemical and physical transformation of a by-product of aluminium extraction into a sustainable product for use in the treatment of water, wastewater or soils, to remove phosphate. It also removes metals, which are held in a form that is non-leachable and non-bioavailable. The media can be made as pellets and used as passive, flow-through beds to remove phosphorus from effluent at wastewater treatment works (WwTW). Virotec has commissioned WRc to undertake a full-scale evaluation of their product for P removal.

With ever-tighter consents on final effluent discharges, many WwTWs face more stringent P standards. The latest Price Review indicates that many smaller WwTW serving less than 2,000 population equivalent (PE) will have a Total-P standard of 2 mg/l. At small WwTWs, there is a need for low technology solutions that are sustainable with minimal power and maintenance requirements as an alternative to chemical dosing. Passive flow-through beds are suited to such applications.

1.2 Objectives

The objectives of the project were to evaluate the phosphate adsorption capacity of the Bauxsol™ media from sewage effluent. In particular:

- Examine the hydraulic characteristics of the flow-through system;
- Evaluate the effect of influent pH and bed residence time on the extent of P removal;
- Calculate the P-removal capacity and predict the bed-lifetime from the collected data;
- Determine any other beneficial aspects of the media regarding the removal of COD, BOD, and SS.

Adsorption of P by the gravel media used in horizontal-flow reed beds has a limited lifetime of about 6 months in normal circumstances before its capacity is exhausted. If the Bauxsol™ media could be left for a significantly longer period (e.g. 10 years or more) before replacement, then it would be very advantageous to WwTW operators.

1.3 Previous Studies

Bauxsol™ media is available as highly porous pellets and is composed of haematite, magnesium minerals, calcium carbonate and titanium oxide. Phosphorus and metal removal occurs by a variety of adsorption, substitution, recrystallisation, and precipitation reactions within the pellet matrix.

Virotec undertook testing of Bauxsol™ media initially at their laboratories to evaluate the capacity and removal efficiency of the pellets for phosphorus removal from secondary sewage effluent (Hogan *et al* 2005). The initial Virofilter™ system tested at laboratory scale consisted

of a 250ml reactor containing a bed of 200g of A2 pellets (size range 2 - 4 mm). The bed was operated in an upward flow mode fully submerged in secondary effluent obtained from a full-scale WwTW. The pH of the effluent was adjusted from about 8 to 6.5 prior to feeding into the reactor to optimise P removal. The flow rate was adjusted to maintain a final Total-P concentration in the effluent below 2 mg/l Total-P. Initial results were extremely encouraging, showing removal efficiencies exceeding 80% and a P bed capacity of greater than 12 kg Total-P/ tonne pellets (or greater than 8.7 kg/m³ assuming a bulk density of 730 kg/m³). At the time of writing, the trial has been in operation for about 18 months, the effluent quality has continued to comply with a Total-P limit of 2 mg/l and the bed capacity is around 14 kg Total-P/tonne.

For the next stage of development, Virotec required an evaluation of their product at greater scale in a bed suitable for use at small WwTW. WRc was contracted to design, build, operate and evaluate a system.

1.4 **Bed Configurations**

There are various configurations of passive flow-through bed in use at small UK WwTWs that may be suitable for tertiary P removal. The main types are described below:

- **Submerged horizontal-flow reed bed:** Influent flows continuously in a horizontal path through a bed of gravel (3-6 mm) to the outlet. Beds are typically about 0.6 m deep and 10 m long. Horizontal-flow systems tend to be oxygen-limited and essentially remove organic matter by settlement and filtration but do not oxidise ammonia. Their simple design and construction suit the topographies of most sites and they continue to find widespread use in the UK as a final polishing stage at small WwTW.
- **Intermittently submerged vertical-flow bed:** Intermittent doses of influent are applied to the top of the bed to flood the surface. During the phases between doses, the liquid drains down through the bed and natural ventilation provides the oxygen necessary for nitrification. This bed is between 0.5 and 0.8 m deep containing gravel with a top layer of sand to assist with the distribution of flow across and through the bed. A problem with vertical-flow reed beds is clogging of the sand layer which can lead to the surface accumulation of water and anaerobic conditions within the bed. This limits their use in the UK, although they have been used in other countries more widely.
- **Biological or percolating filter:** A rotating distributor disperses effluent over the surface of the bed. This bed is usually about 1.8 m deep and filled with suitable media (e.g. 50 mm blast furnace slag). Treatment occurs through sewage trickling over the surface of medium covered in carbonaceous and nitrifying bacteria, which remove BOD and oxidise ammonia, respectively. Air to oxidise the pollutants ventilates by natural convection between the media through spaces, which allow the passage of effluent. Debris such as detached biofilm, larvae and worms present in effluent gravitates through underdrains to humus tanks for clarification. While biological filters have been used in the UK since the early 1900s, their use is diminishing because of fly nuisance.

WRc recommended a horizontal-flow bed to test the Bauxsol™ media because of its greater UK use. The trial was set up in WRc's custom-built pilot plant evaluation centre to simulate a horizontal-flow reed bed. Effluent was supplied from pilot activated sludge plants at site, and the trial was carried out over a period of 6 months.

2. PILOT PLANT DESCRIPTION

2.1 Bed Design

Virotec requested that two separate rigs be operated in parallel both treating secondary effluent in order to compare phosphorus removal efficiency with and without pH adjustment of the feed.

Two horizontal pipes (0.2m diameter x 6m length constructed from medium density polyethylene) were set up and labelled Reactor A and Reactor B. End caps were bolted onto the pipes using Viking Johnson flange adaptors. The inlet and outlet ports had internal diameters of 12mm, and were at a height of 50mm and 150mm, respectively, above the base of the pipe. The difference in height between the inlet and outlet ports was required to maintain a constant liquid level and minimise any short-circuiting that could occur within each reactor.

Sample ports were spaced at a distance of 0.5m from the inlet side of the reactor, and at intervals every 1m thereafter to obtain a P removal profile along the full length of each reactor. The first and last 0.5m of each reactor was filled with 10mm gravel to assist flow distribution and simulate the flow distributors used in reed beds installed at small WwTW. After the end of the project, the reactors were opened, and it was evident that the gravel in Reactor A extended for 1 m rather than 0.5 m at the outlet end. The remainder of the volume of the reactors was filled with the Bauxsol™ media. Figure 2.1 shows the rigs as they were laid out.

2.2 Selection of Media Size

Virotec is able to engineer Bauxsol™ pellets with specific characteristics for different applications, and in a variety of graded sizes. The size must ensure that pores will adsorb P and not rapidly block up from accumulation of SS present in the final effluent.

Selection of the media size was partly based on what had previously been used on the laboratory scale to enable a comparison of the results at the two different scales and also on reed beds which have media sizes between 2 and 12 mm. The majority of the media chosen for this project was A2 Bauxsol™ pellets (2-8mm in size), except for the first 2 m of Reactor B, which was filled with pellets in the size range from 5-12mm.

2.3 Operating Modes

2.3.1 Stage 1 - Parallel Operation

For the main period of the project (23 weeks for Reactor A and 22 weeks for Reactor B), the two rigs were operated as two independent reactors in parallel. The pH of the wastewater entering Reactor A was reduced from an average of 7.4 down to pH 6.5 - 6.8 by dosing hydrochloric acid into a mixing tank prior to pumping the influent into the rig. The influent entering the Reactor B was not pH adjusted. A direct comparison of the performance between the two systems could therefore be made in terms of P removal efficiency.

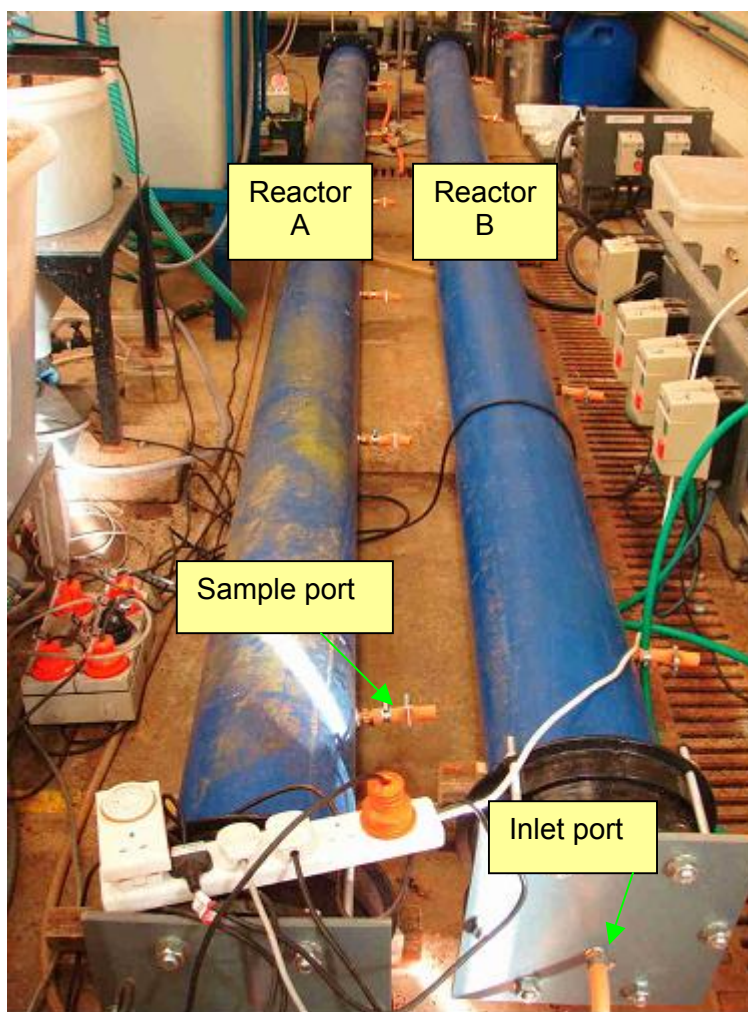


Figure 2.1 Reactors A and B with Inlet and Sample Ports

2.3.2 Stage 2 – Series operation

In the final 5 weeks of operation, the configuration in the reactors was changed to in-series operation, and acid dosing was discontinued to investigate the effect of path length on P removal. The effluent from Reactor A was pumped into Reactor B before passing to the drain. Figure 2.2 is a schematic for the layout of the two pipes showing acid dosing into Reactor A during parallel operation, and also in series operation.

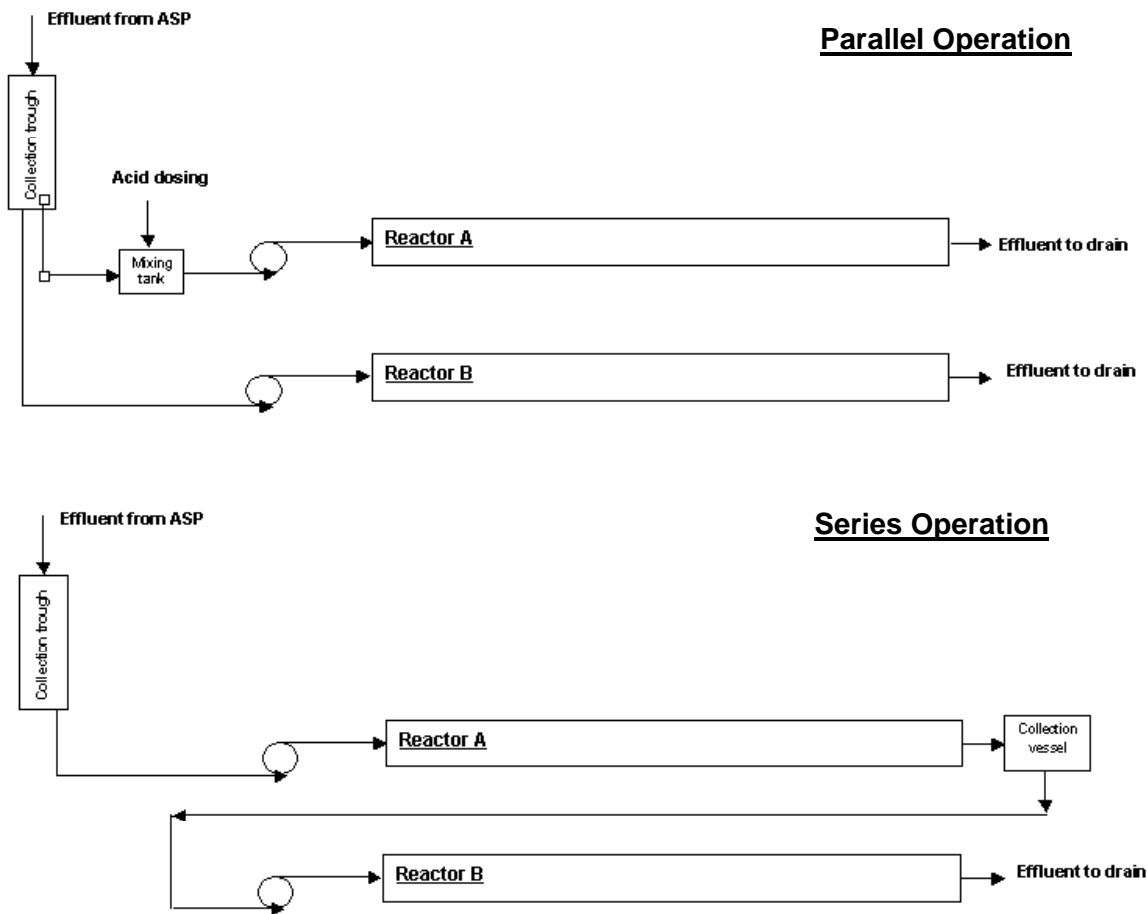


Figure 2.2 Reactor Layout - Parallel and Series Operation

2.4 Protocol for Setting Flow Rates

The flow rates in both rigs was calculated with the following assumptions:

- The total reactor volume is derived from the formula $\pi R^2 l$ (where R is the internal radius of each reactor and l is the length) to give 0.188m³,
- The working reactor volume is equivalent to the liquid occupied in the space below the outlet port and includes the coarse gravel media within the flange ends. The volume calculated is 0.150m³;
- Neither volume takes into account the voidage space within the pellets.

Earlier laboratory-scale work by Virotec reported results as working reactor volumes (bed volumes). The hydraulic retention times (HRTs) used were based on the working reactor volume and expressed in terms of either time or as the number of bed volumes of influent that had been treated.

The start-up flow rate for both rigs was chosen to give an HRT of 4 hours, which is much shorter than the HRT that would be used for a full-scale bed of Bauxsol™ media. This HRT maximised the phosphate loading onto the bed to better evaluate the P removal capacity within the time restrictions of the project. As the effluent P concentration began to rise in each reactor, the influent flow rates were dropped to reduce the applied P load and thereby maintain effluent P concentrations of less than 2mg/l Total-P.

While the flow rates tested during parallel operation were adjusted to achieve HRTs between 4 and 12 hours, during in-series operation the overall flow rate through both reactors was set to achieve HRTs of between 12 and 16 hours.

2.5 Monitoring

Daily monitoring of the temperature and flow rates through both reactors (including the acid dosing pump) was performed. Influent and effluent samples were taken weekly from each rig for the analysis of:

- pH
- SS, BOD and COD
- NH₄-N and NO₃-N

Samples from each port down the length of the reactors were taken daily and combined once a week to give a 5-day composite sample. The composite samples were analysed for Total-P concentration to give a profile down each reactor. The settled sewage used in the tests is domestic in origin and the soluble orthophosphate was usually over 95% of the Total-P.

The pH of the samples down the length of the reactors was also measured on a spot sample basis. The odour of the influent and effluent samples was qualitatively compared once a week but there were no unusual odours generated.

2.6 Tracer Testing

A tracer test was performed in each reactor on two separate occasions (March 2005, and May 2005). The objective of this test was to compare the hydraulic distribution in the reactors and identify any short-circuiting problems.

A dilute rhodamine solution was prepared at the same concentration for each test. The inlet tubing from the reactor was placed into the rhodamine solution for 1 minute to deliver the spike using the feed pump operating at its normal flow rate. The effluent was diverted into fluorimeter to determine the dye concentration. Each test lasted for a sufficient period until the concentration of dye present in the effluent fell to a low value (about 10% of the peak concentration).

3. PARALLEL OPERATION RESULTS

3.1 Bed Retention Times and Phosphorus Removal

Reactors A and B were commissioned on the 7th and 18th of March 2005, respectively. Daily results for each reactor can be found in the Appendix.

Figure 3.1 presents the influent and effluent composite Total-P concentrations during the period of parallel operation. The data are presented as 3 week rolling averages to show the gradual increase in influent P levels from 6 to 9 mg/l during the trial. Midway through the trial the HRT in Reactor A was increased from 4 to 6 hours and that of Reactor B from 4 to 8 hours, to maintain a low effluent P concentration. Towards the end of the trial, the HRT in Reactor B was increased to between 11 and 12 hours to control effluent P.

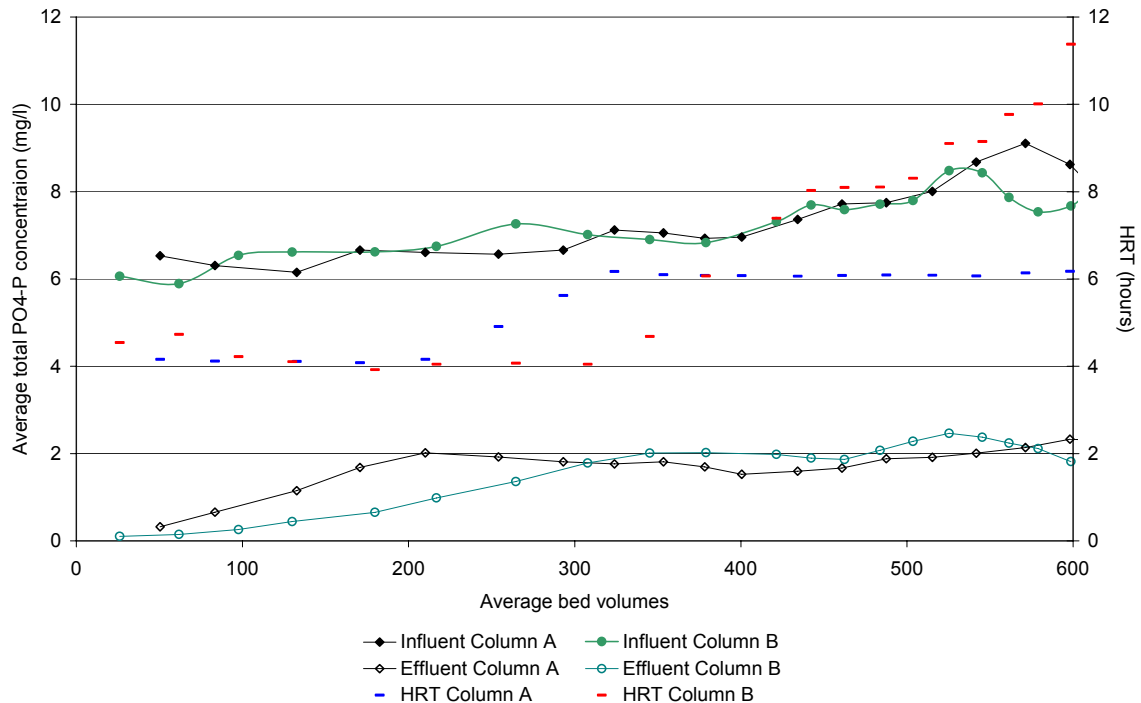


Figure 3.1 P Composites for Reactors A and B in Parallel Operation

Table 3.1 summarises the HRTs in the reactors along with the average influent and effluent composite Total-P concentrations during each period. It shows that the HRT needed to be increased over time in order to maintain low levels of effluent P. Over the entire period of parallel operation, the average % Total-P removal in Reactor A was 76%, and in Reactor B it was 80%. The expected improvement in P removal in Reactor A as a result of acidifying the influent (as derived from Virotec's laboratory-scale tests) was not apparent in these pilot-scale studies. Thus acid dosing is not necessary for the domestic sewage effluent under test.

Table 3.1 Average Phosphorus Removal in Reactors A and B

| Reactor | Period | Average HRT (hrs) | Average influent composite Total-P concentration (mg/l) | Average effluent composite Total-P concentration (mg/l) | Average phosphorus removal ^A (%) |
|---------|------------|-------------------|---|---|---|
| A | Wk 1 - 6 | 4.2 | 6.60 | 1.0 | 85 |
| | Wk 7 - 20 | 6.1 | 7.55 | 1.9 | 75 |
| | Wk 21 - 23 | 11.8 | 7.97 | 2.0 | 75 |
| | Total | | | | 76 |
| B | Wk 1 – 11 | 4.2 | 6.62 | 0.9 | 86 |
| | Wk 12 – 19 | 8.4 | 7.90 | 2.1 ^B | 73 |
| | Wk 20 - 22 | 11.9 | 7.67 | 1.8 | 76 |
| | Total | | | | 80 |

^A % Removal reported as an average of each period (see Figure 4.3 for P removals achieved by Reactor B)

^B This point is explained by the HRT – reducing the flow rate improved the effluent P in Wk 20-22

Figure 3.2 presents the P removed in each reactor during parallel operation as cumulative Total-P entering and leaving the reactors against the bed volumes of effluent that have been treated. The % removal on the secondary Y-axis is calculated from the difference in the cumulative P concentrations per tonne of bed entering and leaving the reactors.

The results show that the removal capacity of the beds up to the end of parallel operation was as follows:

- Average P removal across bed: Reactor A = 5.70 mg/l; Reactor B = 5.75 mg/l
- Number of bed volumes: Reactor A= 700; Reactor B = 630
- Bulk density of media: 730 kg/m³

The P removal capacity is calculated by the following formula:

$$\text{P removal capacity} = \text{Average P removal} \times \text{Bed volumes passed} / \text{bulk density}$$

For each reactor, the capacity is therefore:

Reactor A

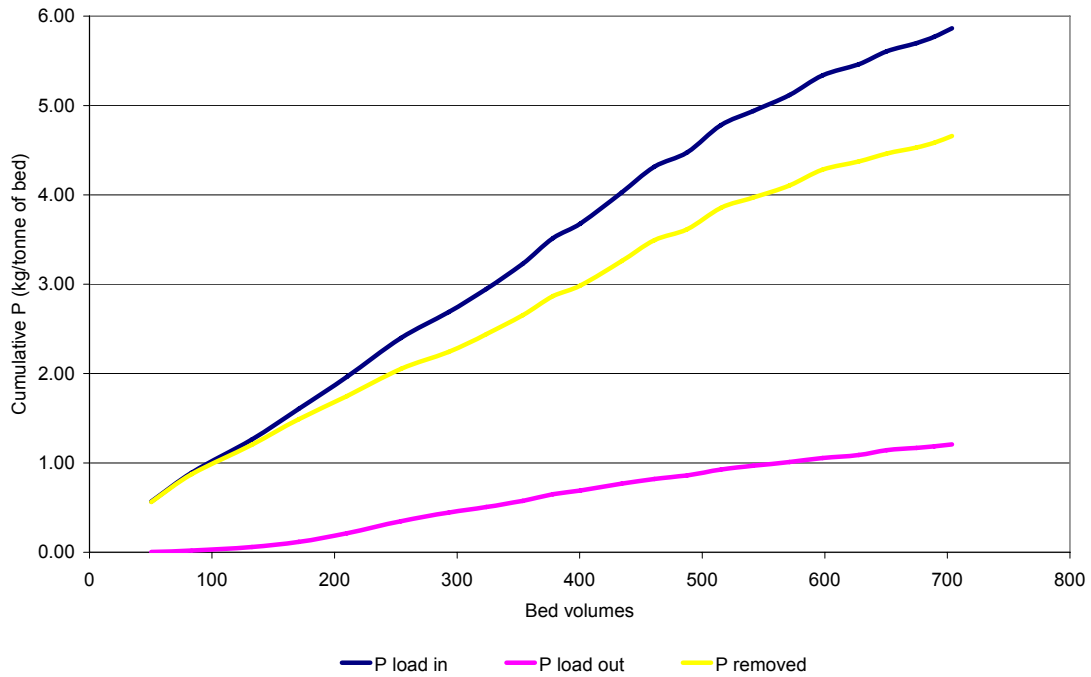
$$5.70 \text{ mg/l} \times 700 / 730 \text{ kg/m}^3 = 5.46 \text{ kg/tonne}$$

Reactor B

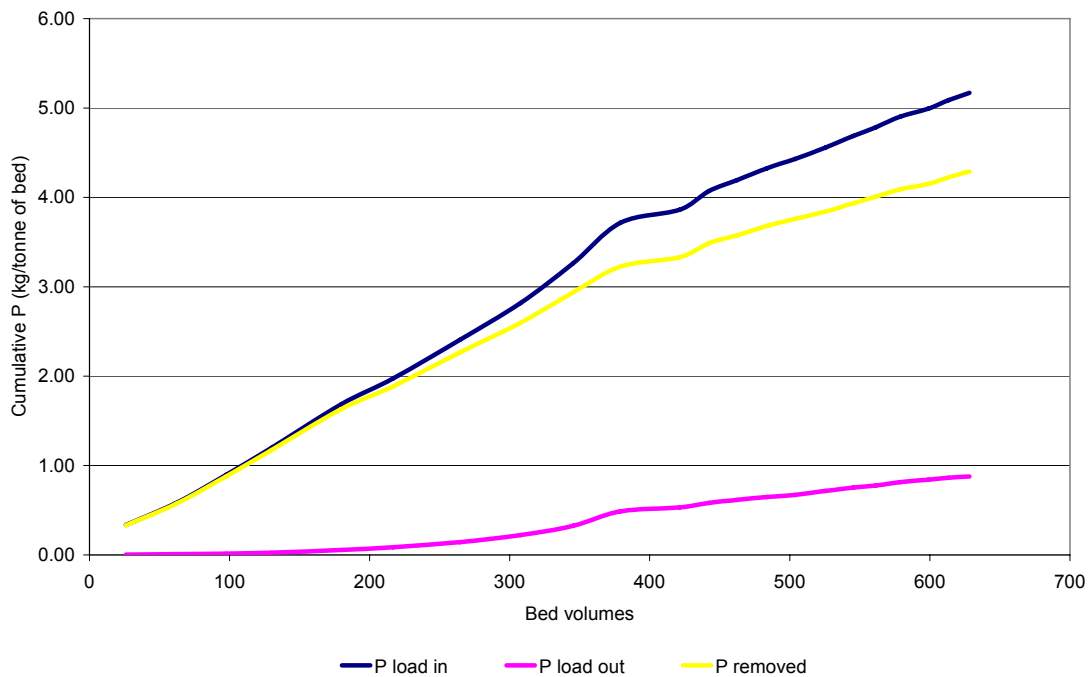
$$5.75 \text{ mg/l} \times 630 / 730 \text{ kg/m}^3 = 4.96 \text{ kg/tonne}$$

It should be noted that the test beds had not reached their ultimate P removal capacity after 6 months of operation.

Reactor A



Reactor B



N.B. % P removal of secondary axis calculated by subtracting cumulative load out from cumulative load in

Figure 3.2 Total P Removal Capacity of Reactors A and B in Parallel Operation

3.2 Reactor Phosphorus Profile

Figure 3.3 presents the average P profile along the length of Reactors A and B over the whole period of parallel operation. It also includes the pH profile down the length of each reactor as an average of 3 sets of spot pH samples from Reactor A and 2 sets of spot samples from Reactor B; both sets of spot samples were taken between weeks 4 and 9.

The results show that in the first 4m of Reactor A, the P concentration is lower than in Reactor B. However, the concentration converges thereafter, so that the effluent P concentrations are virtually the same for each reactor. This may be explained by differences between the P capacities of the different batches of Bauxsol™ pellets installed in each reactor rather than the impact of dosing acid into the influent of Reactor A.

Up to the first 400 bed volumes of operation, the results for Reactor A show that P concentration is lower in the effluent than at the penultimate sample port located at a distance of 5.5 m from the inlet. After this time, the P concentration in the effluent from Reactor A is greater than that from the penultimate sample port. In Reactor B, the P concentration in the effluent is usually less than that from its penultimate sample port (located at a distance of 5.5 m from the inlet) for the whole period of operation.

An explanation is that the gravel has limited capacity for P removal for the first 400 bed volumes, beyond this time the adsorbed P was released back into the effluent. In the case of Reactor A, the volume of gravel at the outlet (about 1 m) spanned the 5.5 m sample point and is sufficient to cause higher P concentrations observed in the treated effluent for operation beyond 400 bed volumes. In the case of Reactor B, the volume of gravel at its outlet is much less (about 0.5 metres), and there may be sufficient Bauxsol™ pellets to provide P removal between the 5.5 m sample point and the outlet. Thus the greater volume of gravel at the outlet of Reactor A (1.0 metre) may explain the increase in P concentration observed between its penultimate sample point (at the distance of 5.5 m from the inlet) and its outlet.

These results demonstrate the importance of maximising the reactor volume filled with Bauxsol™ media, and minimising the amount of gravel media used for distribution. Typically, if gravel media is used for either the inlet or outlet distributor, the width of the gravel at either end of the bed should not be greater than 0.5 m.

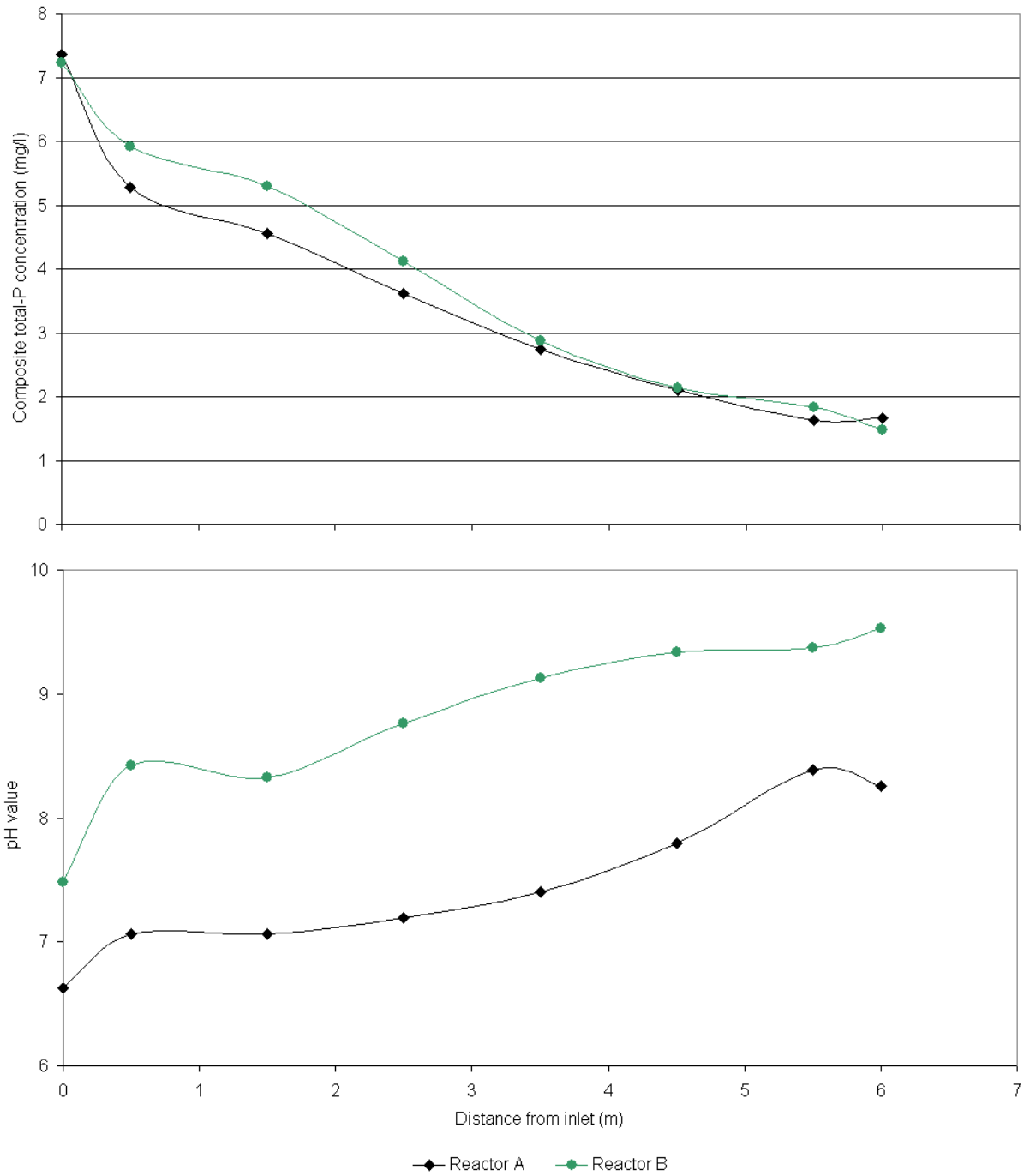


Figure 3.3 Average P Profile/pH along Reactors A and B for Parallel Operation

(Note that while the gravel at the end of reactor A extended between 5.0m and 6.0m distance, the gravel in reactor B extended from 5.5 to 6.0m. This explains the higher P concentration in the sample taken at the 6m distance in reactor A).

3.3 COD and BOD Removal

Spot samples of the influent and effluent were taken once a week and measured for total COD and BOD (5-day-ATU). Table 3.2 illustrates that both reactors removed quite significant levels of COD averaging 27 % in Reactor A and 31% in Reactor B.

Table 3.2 Average COD Removal in Reactors A and B

| Reactor | Average Influent COD (mg/l) | Average Effluent COD (mg/l) | Average COD removal (%) |
|---------|-----------------------------|-----------------------------|-------------------------|
| A | 47 | 33 | 27 |
| B | 48 | 32 | 31 |

In terms of BOD removal, the levels in feed of the reactors were already very low at a concentration of approximately 5mg/l in both reactors. Nevertheless, passage through the each bed of Bauxsol™ media was able to reduce the levels down to an average of 2mg/l in both reactors, with the most common values being less than 1mg/l. The most likely cause is removal of particulate BOD.

3.4 Suspended Solids Removal

The weekly influent and effluent samples were also tested for suspended solids (SS). During the first two weeks of operation, it was observed that the effluent SS concentration was much higher than the influent; this was attributed to washout of powdered Bauxsol™ media present amongst the pellets.

The influent SS concentrations were already relatively low at an average of 11 and 12 mg/l in both reactors, respectively. Excluding the first two weeks of results, the levels were reduced even further to 4mg/l \pm 3 from both reactors. Thus the reactors displayed high removals of SS.

3.5 N-removal

In terms of N-removal, the once-weekly spot samples tested for NH₄-N and NO₃-N showed no significant difference between the influent and effluent concentrations. As a result analysis for these two parameters was discontinued after 10 weeks of operation.

Despite the anoxic/anaerobic conditions being suitable for denitrification, it is apparent from the unchanged oxidised nitrogen (NO₃-N) levels present in the influent and effluent that the biology for denitrification to occur did not establish itself. An explanation is that the duration of the test was insufficient for this to occur.

3.6 Tracer Test Results

A tracer test was performed on Wednesday 23rd March (Reactor A) and on Thursday 24th March (Reactor B) to assess the initial hydraulic characteristics. Two further tracer tests (one

on each reactor) were performed two months later to investigate any significant changes. During the first two tracer tests, each reactor treated secondary effluent at a daily flow rate of about 0.9 m³/d. In the tracer test that was run two months later, the flow rate in Reactor A only had reduced to 0.6 m³/day.

Figure 3.1 presents the normalised test results in terms of the number of bed volumes of effluent that passed through each reactor and the dye concentration divided by flow rate to normalise the results for changes in the influent flow rate using the method advised by Levenspiel (1972), where:

$$C = \frac{[c]}{Q}$$

Where;

- C = Normalised concentration curve
- [c] = Spike concentration
- Q = Area under a concentration-time curve

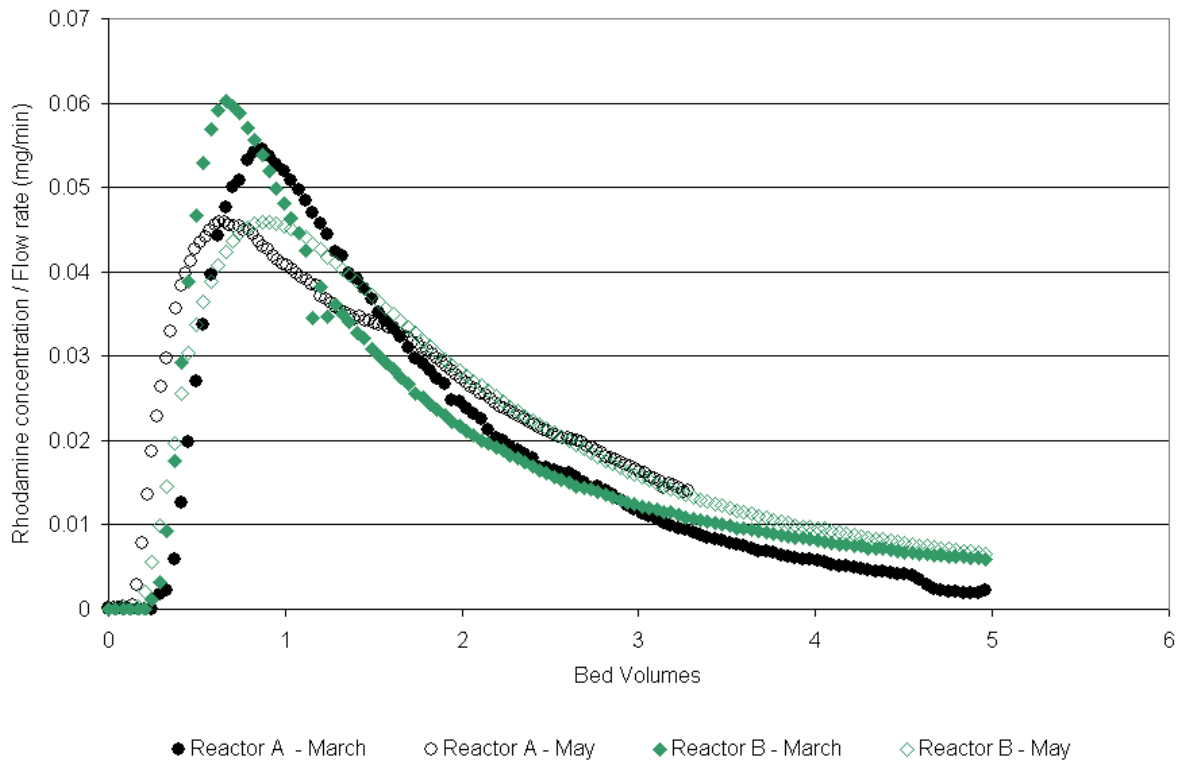


Figure 3.4 Tracer Study Curves for Reactors A and B in March and May 2005

Figure 3.4 indicates the following:

- The shape of the curve with a short period before any dye emerges with a broad peak indicates that a significant level of back-mixing takes place in each reactor.
- The tracer outputs have an extended tail. This type of curve is explained by adsorption of the dye on the surface of the solid media and also by hold up in the many small stagnant regions present at the contact points of the media.
- The peak concentrations are lower in the second tracer tests – explained by the build-up of solids within the spaces between pellets and increased backmixing.

Overall, the shapes of the curves show no evidence of a significant deterioration in back-mixing after two months of operation. The similarity of the results signifies that the hydraulic distribution within both reactors is comparable.

3.7 Odour and Colour

Typically the influent had an odour characteristic of secondary sewage effluent and the effluent from the bed of Bauxsol™ media exhibited a more earthy odour, which is common for tertiary filter bed systems. While the influent was a straw colour, the effluent from the bed of Bauxsol™ media was relatively clear. Thus passage through the Bauxsol™ media bed was beneficial in terms of odour and colour removal.

4. IN-SERIES OPERATION RESULTS

4.1 Reactor Phosphorus Profile

After 23 weeks of operating Reactor A and 22 weeks for Reactor B, the configuration of the reactors was changed from parallel operation to in-series to evaluate the effect of a two stage system on the efficiency of P removal and its capability to comply with low Total-P consents of 1 mg/l P (see Figure 2.2). The results below cover the subsequent 5 weeks of operation for both reactors.

The HRT of both reactors was adjusted to 12 hours for the first 3 weeks by controlling the flow to give an HRT of 5 hours in Reactor A and 7 hours in Reactor B. The HRT was raised to 16 hours in the last two weeks of operation (HRT of 7.5 hours in Reactor A and 8.5 hours in Reactor B). The increase from 12 hours to 16 hours didn't have any effect on the outlet P concentration.

Figure 4.1 represents the profile in both reactors during in-series operation. The graph shows that the phosphorus profile (rate of concentration fall along the length of a reactor) is similar for both Reactors (A and B).

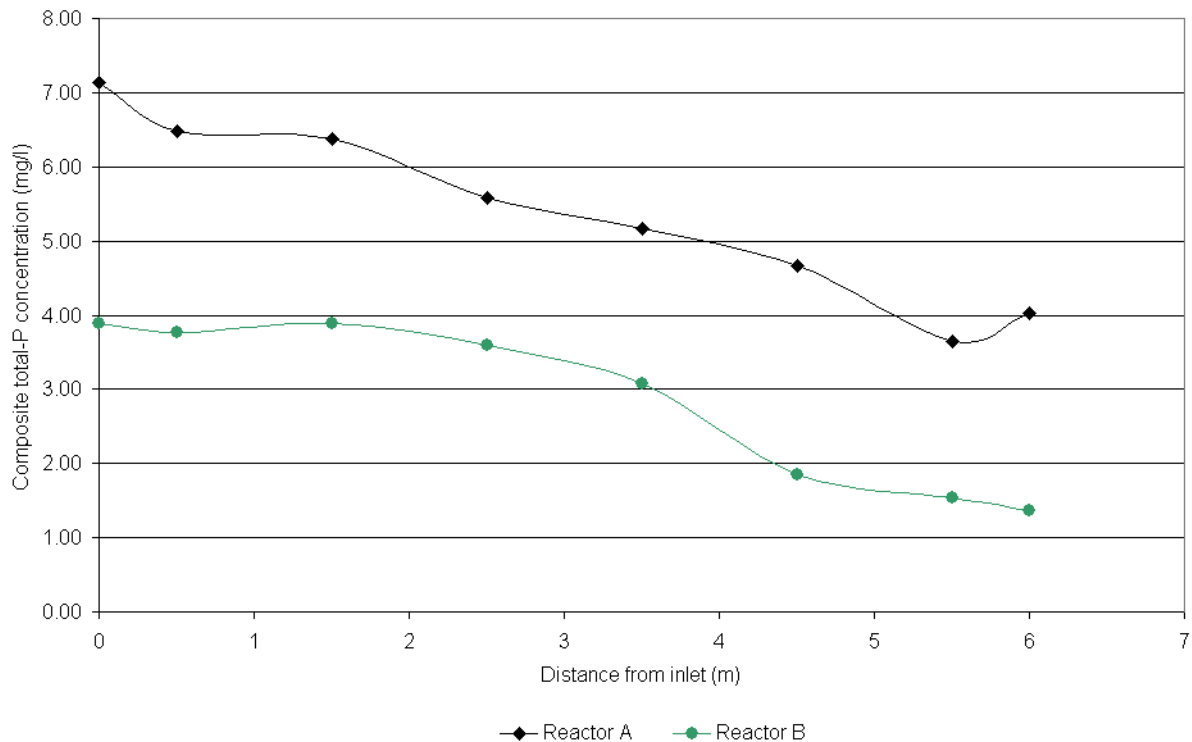


Figure 4.1 Average P Profile along Reactors A and B during Series Operation

(Note that while the gravel at the end of reactor A extended between 5.0m and 6.0m distance, the gravel in reactor B extended from 5.5 to 6.0m. This explains the higher P concentration in the sample taken at the 6m distance in reactor A)

As with the profile during parallel operation, the P concentration in the effluent at the outlet was always higher than at sample point located 5.5 metres from the inlet. This is explained by the presence of 1m of gravel in the final metre of Reactor A.

4.2 Phosphorus Removal

Figure 4.2 presents the phosphorus removal and effluent P from both reactors over the five-week period of in-series operation. It shows that the effluent P concentration was maintained below 2mg/l in the range between 1.3 and 1.5 mg/l.

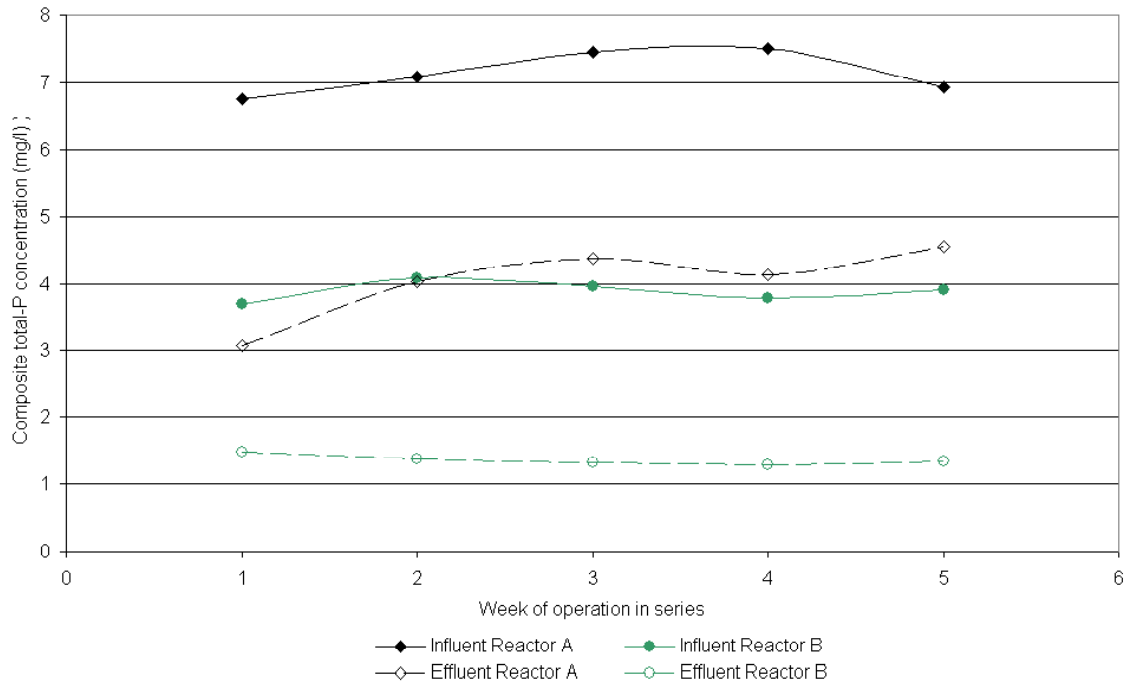


Figure 4.2 P Composites for Reactors A and B in Series Operation

Figure 4.3 compares the phosphorus removals achieved by Reactor B for parallel operation and also when Reactors A and B were configured for in series operation over the five-week period at the end of the trial. The results represent 4 week rolling averages to permit assessment on a monthly basis for the entire period of the trial. It shows that the effluent P concentration during in-series operation gave a removal efficiency of 78 to 82%.

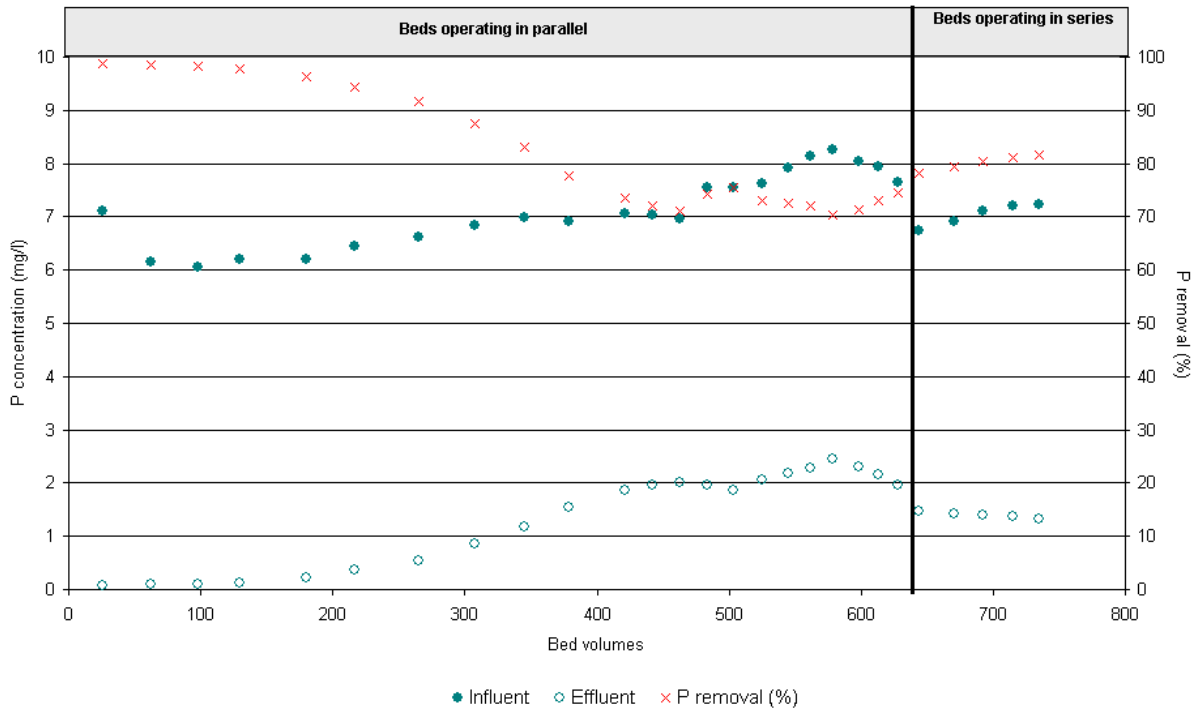


Figure 4.3 P Removals for Parallel and Series Operation in Reactor B (Influent from Reactor A for Series Operation)

4.3 COD and BOD Removal

The COD removal from each reactor and across the two reactors is presented in Table 4.1. It shows that the overall COD removal is about 50%. Most of the removal is achieved through the first reactor (40%) so that the removal efficiency in the second reactor is much lower at only 14%. The COD removals are much higher for in-series operation than those achieved during parallel operation (27% previously - see Table 3.2).

The limitation to these results is that they are based on only 5 spot samples; for greater confidence and assessment of longevity of performance, a larger number of results over a longer period of operation is required.

Table 4.1 Average COD Removal per Reactor and Combined Reactors

| Reactor | Average Influent COD (mg/l) | Average Effluent COD (mg/l) | Average COD removal (%) |
|----------|-----------------------------|-----------------------------|-------------------------|
| A | 43 ± 9 | 25 ± 2 | 40 ± 10 |
| B | 24 ± 4 | 21 ± 38 | 14 ± 15 |
| Combined | 43 ± 9 | 21 ± 38 | 51 ± 5 |

4.4 Suspended Solids Removal

It is evident from Figure 4.4 that the SS concentration in the final effluent being fed to Reactor A increased over the first 3 weeks of in-series operation due to higher concentrations present in influent.

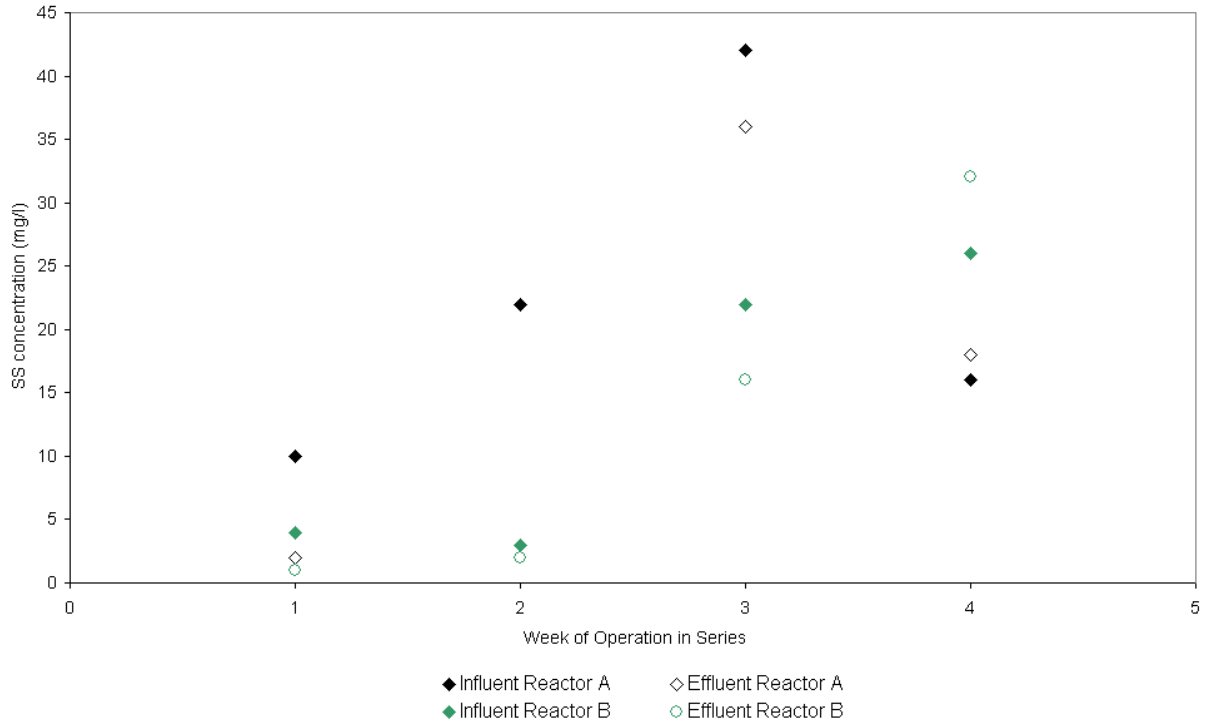


Figure 4.4 SS in Influent and Effluent of Reactors A and B for Series Operation

Reactor A was able to buffer these relatively high solids for a period of about 2 weeks, after which high SS were evident in the effluent of Reactor A. The same does not hold true for Reactor B as the effluent SS concentration in the effluent of this reactor was matched by a high SS concentration in the influent.

It is possible that the filtering action of the Bauxsol™ media in the first reactor (A) removed the large-sized SS particles only, while the finer particles were able to pass through the beds of media in both the first-stage reactor (A) and second-stage reactor (B). The overall removal through both reactors exceeded 80% (excluding the value from the final week where there seemed to be a wash-out of some solids from Reactor B).

5. DISCUSSION

5.1 Mechanism of P Removal

The following section discusses the possible mechanisms involved in P-removal by the Bauxsol™ media, and compares the P-removal capacity of the pellets with other types of media.

The possible mechanisms of phosphorus removal in passive flow-through beds comprise plant uptake, assimilation by micro-organisms and physico-chemical processes associated with the media in the bed.

The results from this evaluation show that the Bauxsol™ media has a high affinity for phosphorus. Since the test bed is not planted with reeds, the removal is not associated with uptake by plants. This fits in with the experience of the first horizontal-flow reed beds installed in the UK. Monitoring of these beds indicated that the initial high P removals attributed to uptake by the reeds were not maintained, and after a period of several months, influent and effluent P concentrations rapidly converged. It became clear that removal occurred through physical/chemical processes within the bed rather than plant uptake (Griffin and Upton 1999). This has also been observed for vertical flow reed beds (Weedon 2003).

Studies have been undertaken to elucidate the P removal mechanism. Batch isotherm tests undertaken to evaluate the adsorption capacity of 13 Danish sands for P removal have indicated that sands with high calcium or high iron content have the greatest affinity for P removal. The results indicate that P adsorption is closely related to the physico-chemical properties of the sand (Del Bubba *et al* 2003).

Of the physico-chemical removal processes, adsorption on to the surface of the media and precipitation reactions are considered to play important roles. Both of these processes are complex and can occur simultaneously. Cooper *et al* (1996) indicates that the mechanism depends on a combination of the pH and the type of minerals present in the bed of media:

- High iron or aluminium content under acid conditions – favours adsorption of P and may precipitate insoluble iron and aluminium phosphate.
- High calcium content under alkaline conditions – promotes the precipitation of calcium phosphate.

While it is unclear whether precipitation or adsorption reactions dominate, the properties of the media should be selected to maximise the sites available for adsorption or precipitation. Ideally the grains of media should have a large internal porosity to maximise the available sites, and form a bed with sufficient spaces to avoid dead spots and maintain adequate hydraulic conductivity.

5.2 Comparison Between Different Types of Media

Many different types of media have been used in flow-through beds to remove phosphorus. Table 5.1 presents a comparison of the Bauxsol™ media with the different types that have been used. The results are described below.

Sand and gravels - Del Bubba *et al* (2003) estimated that the adsorption capacity of a tertiary horizontal-flow reed bed filled with the most efficient sand would be used up in a period of about 6 months, while for less efficient sands P removal would only continue for 2 months. Rustige *et al* (2003) evaluated the P removal capacity of 62 sand-based subsurface flow constructed wetlands in Germany, Austria and Switzerland. The study found that while 50% of all the horizontal-flow units had an average P output concentration of less than 2.1 mg/l P, the vertical-flow units had an output concentration of 3.3 mg/l P. This indicates that vertical flow beds with an average operating time of 5 years were less effective than horizontal flow units with an average operating time of 8.5 years.

Expanded clay - The Centre for Soil and Environmental Research, Norway has used lightweight expanded clay aggregates (known as Norwegian Leca/Filtralite) in reed beds (Mæhlum and Stålnacke 1999; Zhu *et al* 2003). Its P removal capacity was about 0.5 kg/m³. It has the advantage over most mineral media that once P removal capacity has been reached and the media requires replacement, it can be used as an agricultural fertiliser if waste management licensing permits.

Calcite media - Tests (Arias *et al* 2003) indicate that this type of media has a P sorption capacity of about 2 kg P/m³. The study undertaken by Arias *et al* (2003) found that the P removal capacity in the calcite filters was about tenfold lower than that found under laboratory conditions. It was reported that the formation of biofilms on the calcite or the short retention time in the filter may explain its reduced effectiveness for P removal.

Table 5.1 indicates that the BauxsolTM media has a high removal capacity, which exceeds the capacity of the other types of media. Again since the P removal capacity of the BauxsolTM media had not been exhausted, its ultimate capacity will be higher than that in Table 5.1.

5.3 Flow-through Bed Configuration

In order to implement the results obtained from the pilot scale studies at full scale, it is important to take into account the bed configuration. The bed arrangement should provide uniform dispersal of the wastewater over the surfaces of the grains of media at both average and peak flows to obtain an even distribution through the entire bed and maximise use of its available P removal capacity. Suitable arrangements are given below:

- Horizontal-flow beds – a suitable inlet distributor comprising either a buried pipe installed along the inlet side of the bed fitted with riser pipes or a channel with vee-notch weirs (Cooper *et al*, 1996). A suitable outlet consists of a perforated agricultural drain-pipe enclosed in a 0.5 m wide gabion filled with large graded stones (50 to 200 mm) running along the opposite side of the bed from the inlet.
- Vertical-flow beds – a pipe distributor system located above the bed facilitates the dispersal of effluent across the top of the bed and a drain at the bottom of the bed to promote the even collection of treated effluent. A shallow sand layer, commonly-laid across the surface of a vertical-flow reed bed to ensure an even distribution by intermittently flooding of the top surface, is prone to blockages. Intermittent high flow rates increase the opportunity for short-circuiting, reducing bed effectiveness.

In taking designs forward to full-scale implementation, careful consideration of the bed configuration and the flow distribution is paramount. At present there is limited information to confirm the above design, and this will need to be addressed in full-scale applications.

Table 5.1 Studies of Different Types of Media for P Removal

| Bed type and size | Media type and size | Influent P (mg/l) | Effluent P (mg/l) | Loading rate | P removal capacity and bed life | Reference |
|--|--|-------------------|-------------------|---------------------------------------|--|--|
| Bauxsol™ – (6m x 0.2m horizontal column) | A2 pellets, 2-8 mm | 7.4 | 1.7 | 0.3 kg/tonne bed (average HRT 6hrs) | 5 kg P/m ³ (6 months) 8 kg P/m ³ | Current on-going work (pellets not exhausted) |
| HF reed bed (5 m ² x 0.6 m) | Gravel, 4-8 mm | 12.7 | 2.4 | 75 mm/d | 0.4 kg P/m ³ (4 months) | Wolstenholme and Bayes (1990) |
| VF reed bed (16.75 m ² x 0.8 m deep) | Layer of sand over layer of 6 - 12 mm gravel | 20 | 1 | 39 mm/d | 0.4 kg P/m ³ (1 year) | Weedon (2003) |
| HF reed bed | Sand | N/A | 2.1 | 10 mm/d | N/A | Rustige <i>et al</i> (2003) |
| VF reed bed | Sand | N/A | 3.3 | 70 –90 mm/d | N/A | Rustige <i>et al</i> (2003) |
| From batch isotherm tests | Sand | 10 | N/A | N/A | 0.1 to 0.4 kg P/m ³ (2 to 12 months equivalent) | Del Bubba <i>et al</i> (2003) |
| VF sand filter (6 m ² x 1 m deep) and 2 HF reed beds (60 m ² x 0.8 m depth & 40 m ² and 0.9 m deep) | Expanded clay (2 mm size) | 10 | 0.5 | 20 mm/d | 0.5 kg P/m ³ (6 years) | Zhu <i>et al</i> (2003), Mæhlum and Stålnacke (1999) |
| VF beds (3 x 0.4 m diameter x 0.7 m deep) | Calcite (2 mm size or less) | 5.7 | 1.4 | 90 m/d (retention time of 33 minutes) | 2.2 kg P/m ³ (1 year) | Arias <i>et al</i> (2003) |

Note that the outlet concentrations and loading rates are not directly comparable and should be treated with caution. It should be noted that the P removal capacity of the Bauxsol™ under test had not become exhausted and its ultimate P removal capacity is higher than that shown.

5.4 Predicted Bed Life

At the end of the trial, the proven P removal capacity stood at 5.46 kg P/tonne of media. From these data, a prediction of the minimum lifetime of the Bauxsol™ pellet bed can be made using a suitable hydraulic loading rate based on the following assumptions:

- Applied hydraulic loading rate – 3 m² bed area per person equivalent at a depth of 0.6 m (1.8 m³ bed per person equivalent);
- Per capita P production - 2.5 g P per person per day.
- Per capita P removal @80% removal – 2.0 g P per person per day

A 1.8 m³ bed of Bauxsol™ pellets would contain approximately 1,314 kg (based on a bulk density of 730 kg/m³). At a phosphorus removal capacity of 5.46 g/kg for Reactor A (based on the results from this study), the minimum lifetime of a person equivalent bed is given by:

- Lifetime = (5.46 x 1314)/2.0 days = 3587 days (~10 years)

This compares favourably with bed lifetimes of other systems.

5.5 Disposal of Exhausted Media

Once the bed reached the end of its working life, disposal of the media would be required. Given the small size of media (e.g. 2mm) it can be crushed into powder suitable for disposal to agricultural land. Further work is planned by Virotec to test the used media from these pilot scale studies and assess its fertiliser value. Tests are also planned to evaluate its potential for use in brick and cement manufacture.

6. CONCLUSIONS

The main conclusions of the pilot scale study are given below.

1. Examine the hydraulic characteristics of the flow-through system.

The design chosen for evaluating the P-removal capacity of the Bauxsol™ pellets was based on the most common reed bed configuration in the UK, which is horizontal flow. Two 6m long reactors were filled with the media and final effluent passed through them. A tracer test performed twice on each reactor showed that the hydraulic distribution was satisfactory.

2. Evaluate the effect of influent pH and bed residence time on the extent of phosphorus removal.

The pH of the influent of Reactor A was reduced to between 6.5 and 6.8, while that of Reactor B was unaltered, and remained at pH 7.5. The results for P removal showed no evidence of a significant difference in P removal between the reactors.

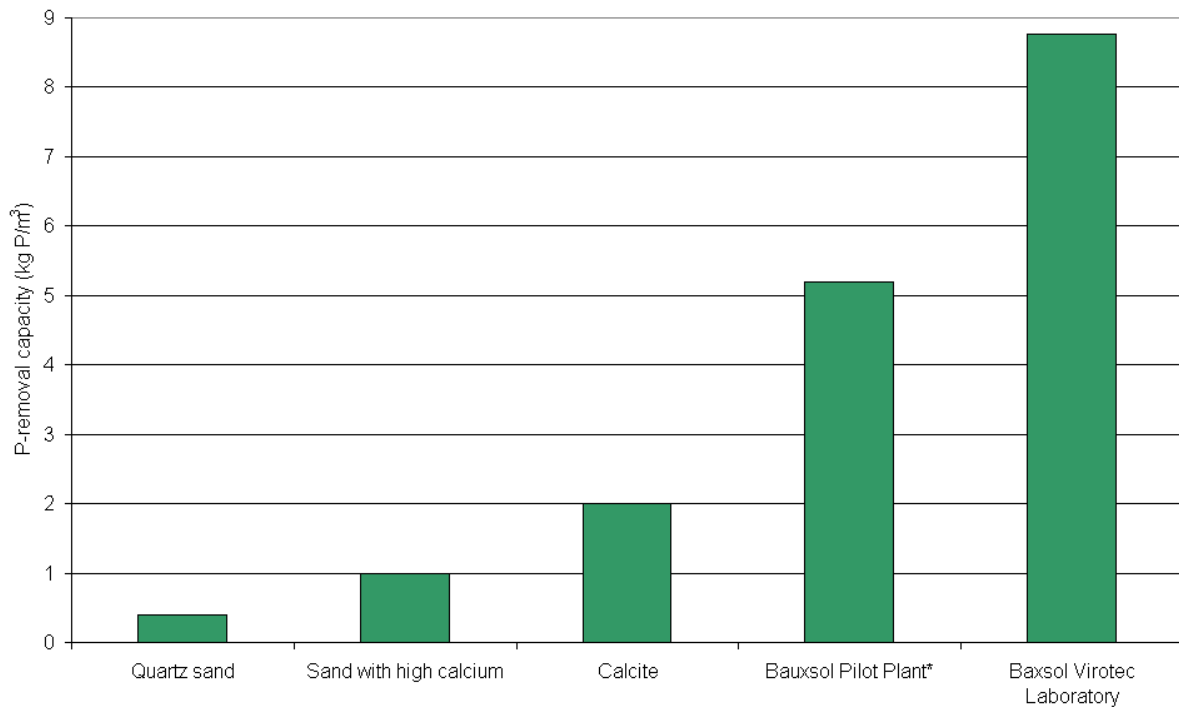
The start-up HRT within both Reactors was 4 hours. In order to maintain an effluent Total-P concentration of less than 2mg/l, the HRT had to be increased after approximately 300-400 bed volumes. By the end of parallel operation, the required HRT reached about 12 hrs. An overall P removal efficiency of 80% was achieved on Reactor B over the 6 months trial.

Operating the reactors in series configuration with an overall HRT of 12 hours showed that a steady phosphate removal occurred through both reactors. Operation of the reactors in series showed an increased P removal of 82 to 85% suggesting that a two bed in series configuration may offer optimal treatment.

3. Calculate the P-removal capacity and predict bed-lifetime from the collected data.

The P-removal capacity of Reactor A and B was calculated at 5.46 kg/tonne and 4.96 kg/tonne, respectively. This compares very favourably against other types of commonly-used media, as demonstrated in Figure 6.1. After 6 months of parallel operation, it was possible to predict the minimum lifetime of the reactors. The results indicated a minimum lifetime of 10 years based on P production of 2.5 g/head.day and a reed bed volume of 1.8m³ *per capita*.

On-going trials undertaken by Virotec have achieved a P removal capacity of 14 kg P/tonne of media without the P removal capacity being exceeded.



*Average of Reactor A and B from pilot-scale test at WRc after 6 months

Figure 6.1 Comparison of P-removal Capacity for Different Media Types

4. Determine any other beneficial removal aspects of the media regarding other quality parameters such as COD, BOD, SS.

Although the influent was of a high quality, the Bauxsol™ media demonstrated an ability to further reduce the COD levels by approximately 30%, maintain final effluent BOD levels frequently below 1mg/l (this was dependant on the influent BOD), and effluent SS of about 4mg/l during parallel operation.

During in-series operation, Reactor B acted as a polishing stage, reducing the levels of the aforementioned quality parameters even further, as long as no consistent high organic load was being fed to the reactors.

In terms of N-removal, the Bauxsol™ pellets showed no beneficial aspects in removal of either NO₃-N or NH₄-N.

7. RECOMMENDATIONS

Overall, the pilot-scale trial has shown the potential for the Bauxsol™ media to be used in full-scale applications. From the results obtained, the following is recommended:

- The optimum media and pore-size for Bauxsol™ pellets should be determined to gain maximum P-removal;
- Vertical flow configurations at pilot-scale should be investigated to promote a more even distribution of final effluent across the media;
- The potential for recycling spent media to agriculture land with emphasis on phosphorus bioavailability should be investigated;
- The Bauxsol™ media should be trialled in a tertiary bed at a WwTW that needs to meet very strict P-standards using tertiary treatment and chemical removal. The reed bed would not be a substitute for chemical dosing, but act as a final polishing stage to comply with stringent P limits of less than 1 mg/l.

Bauxsol™ pellets also have the capability for metals removal. This will become increasingly important in the future at WwTW as the number of effluent consents with metal limits increase. Laboratory tests are underway to investigate this more closely.

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APPENDIX EXPERIMENTAL DATA

REACTOR A – PARALLEL FLOW

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp DegC | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|--------------|----------|------|-------|------|------|--------------------|--------------------|----------|------|-------|------|------|--------------------|--------------------|-------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | Tot-P |
| | | | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 07-Mar | 0 | 0 | 13 | | 11 | | | | | | | 34 | | | | | | |
| 08-Mar | 1 | 6 | | | | 7.5 | | | | | | 0.07 | | | | | | |
| 08-Mar | 1 | | 13 | | | | | | | | | | | | | | | |
| 09-Mar | 2 | 11 | 12 | 7.6 | 13 | 4.1 | 56 | 15 | 14 | 16 | 11.8 | 16 | 0.15 | 48 | 2 | 16 | 17 | |
| 10-Mar | 3 | 18 | 13 | 6.7 | | | | | | | | | | | | | | |
| 11-Mar | 4 | 22 | 12 | | | | | | | | | | | | | | | |
| 14-Mar | 7 | 38 | 12 | 6.7 | | | | | | | | | | | | | | |
| 15-Mar | 8 | 43 | 14 | 6.6 | | | | | | | | | | | | | | |
| 16-Mar | 9 | 48 | 16 | 7.0 | 2 | | 40 | | 3 | 8 | 10.1 | 4 | | 32 | | 3 | 7 | |
| 17-Mar | 10 | 54 | 17 | 6.7 | | | | | | | | | | | | | | |
| 18-Mar | 11 | 60 | 16 | 6.8 | | | | | | | | | | | | | | |
| 21-Mar | 14 | 77 | 16 | 6.8 | | | | | | | | | | | | | | |
| 22-Mar | 15 | 83 | 16 | | | | | | | | | | | | | | | |
| 23-Mar | 16 | 88 | 18 | 6.9 | 8 | | 48 | | 14 | 12 | 9.7 | 7 | | 40 | | 17 | 12 | |
| 24-Mar | 17 | 94 | 12 | | | | | | | | | | | | | | | |
| 29-Mar | 22 | 124 | 16 | 7.4 | 20 | | 56 | 7 | 4 | 16 | 9.5 | 2 | | 40 | 1 | 15 | 6 | |
| 30-Mar | 23 | 130 | 16 | | | | | | | | | | | | | | | |
| 31-Mar | 24 | 136 | 16 | | | | | | | | | | | | | | | |
| 01-Apr | 25 | 141 | 16 | | | | | | | | | | | | | | | |
| 04-Apr | 28 | 160 | 16 | 6.5 | 25 | | 63 | 6 | 2 | 14 | 8.2 | 1 | | 34 | <1 | 1 | 14 | |
| 05-Apr | 29 | 165 | 14 | | | | | | | | | | | | | | | |
| 06-Apr | 30 | 171 | 15 | | | | | | | | | | | | | | | |
| 07-Apr | 31 | 177 | 14 | | | | | | | | | | | | | | | |
| 08-Apr | 32 | 181 | 13 | | | | | | | | | | | | | | | |
| 11-Apr | 35 | 199 | 16 | 6.5 | 5 | | 36 | 3 | 0.1 | 19 | 8.8 | 3 | | 28 | 2 | 0 | 20 | |

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp DegC | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|--------------|----------|------|-------|------|------|--------------------|--------------------|----------|------|-------|------|------|--------------------|--------------------|-------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | Tot-P |
| | | | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 12-Apr | 36 | 204 | 15 | | | | | | | | | | | | | | | |
| 13-Apr | 37 | 210 | 11 | 6.6 | | | | | | | 8.8 | | | | | | | |
| 14-Apr | 38 | 217 | 16 | | | | | | | | | | | | | | | |
| 15-Apr | 39 | 221 | 14 | | | | | | | | | | | | | | | |
| 18-Apr | 42 | 241 | 15 | 6.5 | 6 | 6 | 36 | 6 | 0.1 | 22 | 8.6 | 7 | 28 | 3 | 0 | 22 | 2.2 | |
| 20-Apr | 44 | 252 | 16 | | | | | | | | | | | | | | | |
| 21-Apr | 45 | 258 | 13 | | | | | | | | | | | | | | | |
| 22-Apr | 46 | 266 | 17 | | | | | | | | | | | | | | | |
| 25-Apr | 49 | 282 | 16 | 6.6 | 7 | | 40 | | 0.1 | 20 | 8.2 | 4 | 27 | | 0 | 21 | 2.1 | |
| 26-Apr | 50 | 288 | 16 | | | | | | | | | | | | | | | |
| 27-Apr | 51 | 294 | 16 | | | | | | | | | | | | | | | |
| 28-Apr | 52 | 300 | 15 | 6.7 | | | | | | | 8.1 | | | | | | | |
| 03-May | 57 | 318 | 17 | | | | | | | | | | | | | | | |
| 04-May | 58 | 322 | 18 | 6.5 | 4 | | 37 | 8 | 0.1 | 16 | 8.2 | 1 | 33 | 2 | 1 | 16 | 1.5 | |
| 06-May | 60 | 330 | 17 | | | | | | | | | | | | | | | |
| 11-May | 65 | 349 | 16 | 7.3 | 8 | | 40 | | 0.1 | 17 | 8.1 | 4 | 32 | | 1 | 18 | 1.9 | |
| 12-May | 66 | 354 | | | | | | | | | | | | | | | | |
| 13-May | 67 | 357 | 15 | 6.6 | | | | | | | 7.9 | | | | | | | |
| 16-May | 70 | 369 | 17 | 6.8 | 7 | | 45 | 4 | 1 | 18 | 7.9 | 3 | 34 | 1 | 1 | 18 | 1.9 | |
| 18-May | 72 | 378 | 17 | | | | | | | | | | | | | | | |
| 19-May | 73 | 381 | 17 | | | | | | | | | | | | | | | |
| 20-May | 74 | 385 | 17 | | | | | | | | | | | | | | | |
| 23-May | 77 | 396 | 17 | 6.4 | 7 | | 38 | 5 | | | 7.8 | 2 | 28 | <1 | | | 1.6 | |
| 24-May | 78 | 401 | 17 | | | | | | | | | | | | | | | |
| 25-May | 79 | 404 | 18 | | | | | | | | | | | | | | | |
| 31-May | 85 | 428 | 17 | 6.4 | 6 | | 36 | 1 | | | 7.6 | 2 | 29 | <1 | | | 1.5 | |
| 01-Jun | 87 | 433 | 17 | | | | | | | | | | | | | | | |
| 02-Jun | 87 | 436 | 17 | | | | | | | | | | | | | | | |
| 03-Jun | 88 | 440 | 18 | | | | | | | | | | | | | | | |
| 06-Jun | 91 | 452 | 17 | 6.6 | 6 | | 37 | 1 | | | 7.6 | 2 | 29 | 1 | | | 1.4 | |

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp DegC | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|--------------|----------|------|-------|------|------|--------------------|--------------------|----------|------|-------|------|------|--------------------|--------------------|-------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | Tot-P |
| | | | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 08-Jun | 93 | 460 | 18 | | | | | | | | | | | | | | | |
| 09-Jun | 94 | 464 | 18 | | | | | | | | | | | | | | | |
| 10-Jun | 95 | 468 | 18 | | | | | | | | | | | | | | | |
| 13-Jun | 98 | 480 | 18 | 6.6 | 14 | | 37 | 6 | | | 7.4 | 8 | | 27 | 2 | | 1.9 | |
| 14-Jun | 99 | 484 | 18 | | | | | | | | | | | | | | | |
| 15-Jun | 100 | 488 | 19 | | | | | | | | | | | | | | | |
| 16-Jun | 101 | 492 | 19 | | | | | | | | | | | | | | | |
| 17-Jun | 102 | 496 | 19 | | | | | | | | | | | | | | | |
| 20-Jun | 105 | 507 | 23 | | | | | | | | | | | | | | | |
| 21-Jun | 106 | 511 | 21 | 6.6 | 4 | | 29 | 1 | | | 7.5 | 6 | | 22 | <1 | | 1.7 | |
| 22-Jun | 108 | 516 | 24 | | | | | | | | | | | | | | | |
| 23-Jun | 108 | 519 | 22 | | | | | | | | | | | | | | | |
| 24-Jun | 109 | 523 | 21 | | | | | | | | | | | | | | | |
| 27-Jun | 113 | 535 | 20 | 6.5 | 12 | | 38 | <1 | | | 7.4 | 6 | | 27 | 2 | | 2.1 | |
| 28-Jun | 113 | 538 | 22 | | | | | | | | | | | | | | | |
| 29-Jun | 114 | 542 | 20 | | | | | | | | | | | | | | | |
| 01-Jul | 116 | 551 | 20 | | | | | | | | | | | | | | | |
| 04-Jul | 119 | 562 | 20 | 6.4 | 2 | | 35 | 2 | | | 7.3 | 2 | | 21 | <1 | | 2.0 | |
| 06-Jul | 121 | 570 | 17 | | | | | | | | | | | | | | | |
| 07-Jul | 122 | 574 | 17 | | | | | | | | | | | | | | | |
| 08-Jul | 123 | 578 | 18 | | | | | | | | | | | | | | | |
| 11-Jul | 126 | 590 | 20 | 6.5 | 7 | | 50 | 8 | | | 7.3 | 2 | | 29 | 1 | | 2.0 | |
| 12-Jul | 127 | 594 | 22 | | | | | | | | | | | | | | | |
| 13-Jul | 128 | 598 | 25 | | | | | | | | | | | | | | | |
| 14-Jul | 130 | 603 | 26 | | | | | | | | | | | | | | | |
| 15-Jul | 130 | 606 | 25 | | | | | | | | | | | | | | | |
| 20-Jul | 135 | 623 | 20 | 6.6 | 34 | | 93 | 4 | | | 7.4 | 10 | 2.16 | 71 | 4 | | 2.5 | |
| 21-Jul | 136 | 628 | 20 | | | | | | | | | | | | | | | |
| 22-Jul | 138 | 633 | 19 | | | | | | | | | | | | | | | |
| 25-Jul | 140 | 644 | 19 | 6.7 | 9 | | 51 | | | | 7.4 | 0 | | 39 | | | | |

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp DegC | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|--------------|----------|------|-------|------|------|--------------------|--------------------|----------|------|-------|------|------|--------------------|--------------------|-------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | Tot-P |
| | | | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 26-Jul | 141 | 647 | 19 | | | | | | | | | | | | | | | |
| 27-Jul | 142 | 651 | 19 | | | | | | | | | | | | | | | |
| 29-Jul | 144 | 659 | 18 | | | | | | | | | | | | | | | |
| 01-Aug | 147 | 669 | 19 | 6.6 | 22 | | 69 | 4 | | | 7.3 | 8 | | 33 | 2 | | | 2.5 |
| 02-Aug | 148 | 673 | 20 | | | | | | | | | | | | | | | |
| 03-Aug | 149 | 675 | 20 | | | | | | | | | | | | | | | |
| 04-Aug | 150 | 677 | 20 | | | | | | | | | | | | | | | |
| 05-Aug | 151 | 679 | 20 | | | | | | | | | | | | | | | |
| 08-Aug | 154 | 685 | 21 | 6.7 | 17 | | 56 | 6 | | | 7.2 | 3 | | 36 | 2 | | | 1.9 |
| 09-Aug | 155 | 687 | 22 | | | | | | | | | | | | | | | |
| 10-Aug | 156 | 689 | 20 | | | | | | | | | | | | | | | |
| 11-Aug | 157 | 691 | 21 | | | | | | | | | | | | | | | |
| 12-Aug | 158 | 693 | 21 | | | | | | | | | | | | | | | |
| 15-Aug | 161 | 700 | 20 | 6.7 | 16 | | 62 | 7 | | | 7.1 | 4 | | 35 | 4 | | | 2.0 |
| 16-Aug | 163 | 702 | 21 | | | | | | | | | | | | | | | |
| 17-Aug | 163 | 704 | 21 | | | | | | | | | | | | | | | |
| 18-Aug | 164 | 706 | 21 | | | | | | | | | | | | | | | |
| 19-Aug | 165 | 708 | 19 | | | | | | | | | | | | | | | |
| 22-Aug | 168 | 714 | 18 | 6.2 | 20 | | 36 | | | | 7.0 | 12 | | 35 | | | | 1.9 |

REACTOR B – PARALLEL FLOW

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|------|----------|------|-------|------|------|--------------------|-------------------|----------|------|--------|------|------|--------------------|--------------------|---------------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ N | pH | SS | Tot-P* | COD | BOD | NH ₄ -N | NO ₃ -N | Comp Tot-P |
| | | | DegC | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 18-Mar | 0 | 0 | 16 | | | | | | | | | | | | | | | |
| 21-Mar | 3 | 17 | 16 | 7.5 | | | | | | | | | | | | | | |
| 22-Mar | 4 | 23 | 16 | | | | | | | | | | | | | | | |
| 23-Mar | 5 | 29 | 18 | 7.6 | 7 | | 48 | | 13.8 | 12.0 | 11.2 | 32 | | 40 | | 17 | 12 | 0.1 |
| 24-Mar | 6 | 34 | 12 | | | | | | | | | | | | | | | |
| 29-Mar | 11 | 55 | 16 | 7.5 | 6 | | 50 | 7 | 3.6 | 16.4 | 10.4 | 44 | | 45 | 1 | 15 | 5 | 0.1 |
| 30-Mar | 12 | 59 | 16 | | | | | | | | | | | | | | | |
| 31-Mar | 13 | 64 | 16 | | | | | | | | | | | | | | | |
| 01-Apr | 14 | 69 | 16 | | | | | | | | | | | | | | | |
| 04-Apr | 17 | 87 | 16 | 7.5 | 25 | | 65 | 6 | 2.6 | 13.6 | 10.1 | 1 | | 22 | <1 | 1.2 | 14 | 0.1 |
| 05-Apr | 18 | 92 | 14 | | | | | | | | | | | | | | | |
| 06-Apr | 19 | 98 | 15 | | | | | | | | | | | | | | | |
| 07-Apr | 20 | 104 | 14 | | | | | | | | | | | | | | | |
| 08-Apr | 21 | 108 | 13 | | | | | | | | | | | | | | | |
| 11-Apr | 24 | 119 | 16 | 7.3 | 5 | | 36 | 3 | 0.1 | 18.8 | 10.0 | 3 | | 27 | 2 | 0.2 | 20 | 0.2 |
| 12-Apr | 25 | 123 | 15 | | | | | | | | | | | | | | | |
| 13-Apr | 26 | 129 | 16 | 7.5 | | | | | | | 9.8 | | | | | | | |
| 14-Apr | 27 | 136 | 11 | | | | | | | | | | | | | | | |
| 15-Apr | 28 | 141 | 14 | | | | | | | | | | | | | | | |
| 18-Apr | 31 | 166 | 15 | 7.2 | 6 | | 36 | 6 | 0.1 | 22.2 | 9.6 | 4 | | 26 | 3 | 0.3 | 22 | 0.4 |
| 20-Apr | 33 | 178 | 16 | | | | | | | | | | | | | | | |
| 21-Apr | 34 | 184 | 13 | | | | | | | | | | | | | | | |
| 22-Apr | 35 | 191 | 17 | | | | | | | | | | | | | | | |
| 25-Apr | 38 | 208 | 16 | 7.2 | 8 | | 41 | | 0.1 | 20.0 | 9.3 | 0 | | 27 | | 0.2 | 21 | 0.7 |
| 26-Apr | 39 | 214 | 16 | | | | | | | | | | | | | | | |
| 27-Apr | 40 | 220 | 16 | | | | | | | | | | | | | | | |

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|------|----------|------|-------|------|------|--------------------|-------------------|----------|------|--------|------|------|--------------------|--------------------|---------------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ N | pH | SS | Tot-P* | COD | BOD | NH ₄ -N | NO ₃ -N | Comp Tot-P |
| | | | DegC | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 28-Apr | 41 | 226 | 15 | 7.5 | | | | | | | 9.2 | | | | | | | |
| 03-May | 46 | 255 | 17 | | | | | | | | | | | | | | | |
| 04-May | 47 | 262 | 18 | 7.4 | 4 | | 38 | 8 | 0.1 | 15.9 | 9.1 | 0 | | 32 | <1 | 0.3 | 16 | 0.9 |
| 06-May | 49 | 274 | 17 | | | | | | | | | | | | | | | |
| 11-May | 54 | 302 | 16 | 7.3 | 9 | | 42 | | 0.1 | 18.6 | 8.9 | 4 | | 31 | | 1.4 | 18 | 1.4 |
| 12-May | 55 | 308 | | | | | | | | | | | | | | | | |
| 13-May | 56 | 314 | 15 | | | | | | | | | | | | | | | |
| 16-May | 59 | 331 | 17 | 7.5 | 5 | | 50 | 4 | 1.3 | 18.3 | 8.7 | 1 | | 34 | 2 | 1.2 | 17 | 1.8 |
| 18-May | 61 | 344 | 17 | | | | | | | | | | | | | | | |
| 19-May | 62 | 350 | 17 | | | | | | | | | | | | | | | |
| 20-May | 63 | 356 | 17 | | | | | | | | | | | | | | | |
| 23-May | 66 | 373 | 17 | 7.4 | | | | 5 | | | 8.6 | | | 29 | 1 | | | 2.1 |
| 24-May | 67 | 379 | 17 | | | | | | | | | | | | | | | |
| 25-May | 68 | 385 | 18 | | | | | | | | | | | | | | | |
| 31-May | 74 | 412 | 17 | 7.4 | 7 | | 42 | 1 | | | 8.6 | 2 | | 28 | <1 | | | 2.1 |
| 01-Jun | 76 | 420 | 17 | | | | | | | | | | | | | | | |
| 02-Jun | 76 | 424 | 17 | | | | | | | | | | | | | | | |
| 03-Jun | 77 | 427 | 18 | | | | | | | | | | | | | | | |
| 06-Jun | 80 | 436 | 17 | 7.4 | 8 | | 40 | 1 | | | 8.6 | 0 | | 28 | <1 | | | 1.8 |
| 08-Jun | 82 | 441 | 18 | | | | | | | | | | | | | | | |
| 09-Jun | 83 | 444 | 18 | | | | | | | | | | | | | | | |
| 10-Jun | 84 | 448 | 18 | | | | | | | | | | | | | | | |
| 13-Jun | 87 | 456 | 18 | 7.3 | 15 | | 40 | 6 | | | 8.6 | 9 | | 28 | 4 | | | 2.0 |
| 14-Jun | 88 | 459 | 18 | | | | | | | | | | | | | | | |
| 15-Jun | 89 | 462 | 19 | | | | | | | | | | | | | | | |
| 16-Jun | 90 | 465 | 19 | | | | | | | | | | | | | | | |
| 17-Jun | 91 | 469 | 19 | | | | | | | | | | | | | | | |
| 20-Jun | 94 | 478 | 23 | 7.4 | 6 | | 28 | 1 | | | 8.6 | 7 | | 22 | <1 | | | 1.9 |
| 21-Jun | 95 | 481 | 21 | | | | | | | | | | | | | | | |

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|------|----------|------|-------|------|------|--------------------|-------------------|----------|------|--------|------|------|--------------------|--------------------|---------------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ N | pH | SS | Tot-P* | COD | BOD | NH ₄ -N | NO ₃ -N | Comp Tot-P |
| | | | DegC | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 22-Jun | 97 | 484 | 24 | | | | | | | | | | | | | | | |
| 23-Jun | 97 | 487 | 22 | | | | | | | | | | | | | | | |
| 24-Jun | 98 | 490 | 21 | | | | | | | | | | | | | | | |
| 27-Jun | 102 | 499 | 20 | 7.4 | 11 | | 39 | <1 | | | 8.4 | 6 | | 26 | 2 | | | 1.7 |
| 28-Jun | 102 | 501 | 22 | | | | | | | | | | | | | | | |
| 29-Jun | 103 | 505 | 20 | | | | | | | | | | | | | | | |
| 01-Jul | 105 | 510 | 20 | | | | | | | | | | | | | | | |
| 04-Jul | 108 | 519 | 20 | 7.4 | 4 | | 37 | 2 | | | 8.4 | 3 | | 23 | <1 | | | 2.6 |
| 06-Jul | 110 | 525 | 17 | | | | | | | | | | | | | | | |
| 07-Jul | 111 | 528 | 17 | | | | | | | | | | | | | | | |
| 08-Jul | 112 | 531 | 18 | | | | | | | | | | | | | | | |
| 11-Jul | 115 | 539 | 20 | 7.4 | 11 | | 54 | 8 | | | 8.4 | 2 | | 31 | <1 | | | 2.5 |
| 12-Jul | 116 | 542 | 22 | | | | | | | | | | | | | | | |
| 13-Jul | 117 | 545 | 25 | | | | | | | | | | | | | | | |
| 14-Jul | 118 | 549 | 26 | | | | | | | | | | | | | | | |
| 15-Jul | 119 | 551 | 25 | | | | | | | | | | | | | | | |
| 20-Jul | 124 | 558 | 20 | 7.3 | 46 | | 109 | 4 | | | 8.4 | 8 | 2.22 | 61 | 4 | | | 2.3 |
| 21-Jul | 125 | 562 | 20 | | | | | | | | | | | | | | | |
| 22-Jul | 127 | 565 | 19 | | | | | | | | | | | | | | | |
| 25-Jul | 129 | 574 | 19 | 7.6 | 7 | | 49 | | | | 8.4 | 0 | | 38 | | | | |
| 26-Jul | 130 | 577 | 19 | | | | | | | | | | | | | | | |
| 27-Jul | 131 | 580 | 19 | | | | | | | | | | | | | | | |
| 29-Jul | 133 | 585 | 18 | | | | | | | | | | | | | | | |
| 01-Aug | 136 | 594 | 19 | 7.4 | 21 | | 63 | 4 | | | 8.2 | 8 | | 33 | 1 | | | 2.4 |
| 02-Aug | 137 | 597 | 20 | | | | | | | | | | | | | | | |
| 03-Aug | 138 | 599 | 20 | | | | | | | | | | | | | | | |
| 04-Aug | 139 | 601 | 20 | | | | | | | | | | | | | | | |
| 05-Aug | 140 | 603 | 20 | | | | | | | | | | | | | | | |
| 08-Aug | 143 | 609 | 21 | 7.4 | 9 | | 48 | 6 | | | 8.3 | 2 | | 34 | 3 | | | 2.1 |

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp | Influent | | | | | | | Effluent | | | | | | | |
|--------------|---------------------------|-------------------------------------|------|----------|------|-------|------|------|--------------------|-------------------|----------|------|--------|------|------|--------------------|--------------------|---------------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ N | pH | SS | Tot-P* | COD | BOD | NH ₄ -N | NO ₃ -N | Comp Tot-P |
| | | | DegC | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 09-Aug | 144 | 611 | 22 | | | | | | | | | | | | | | | |
| 10-Aug | 145 | 613 | 20 | | | | | | | | | | | | | | | |
| 11-Aug | 146 | 615 | 21 | | | | | | | | | | | | | | | |
| 12-Aug | 147 | 618 | 21 | | | | | | | | | | | | | | | |
| 15-Aug | 150 | 624 | 20 | 7.4 | 17 | | 59 | 7 | | | 8.2 | 5 | | 39 | 11 | | | 1.9 |
| 16-Aug | 152 | 626 | 21 | | | | | | | | | | | | | | | |
| 17-Aug | 152 | 628 | 21 | | | | | | | | | | | | | | | |
| 18-Aug | 153 | 630 | 21 | | | | | | | | | | | | | | | |
| 19-Aug | 154 | 632 | 19 | | | | | | | | | | | | | | | |
| 22-Aug | 157 | 638 | 18 | 7.3 | 17 | | 43 | | | | 8.2 | 11 | | 33 | | | | 1.5 |

REACTOR A – SERIES FLOW

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp DegC | Influent | | | | | | | Effluent | | | | | | | | |
|--------------|---------------------------|-------------------------------------|--------------|----------|------|-------|------|------|--------------------|--------------------|----------|------|-------|------|------|--------------------|--------------------|---------------|------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | Comp Tot-P | |
| | | | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 22-Aug | 168 | 714 | 18 | | | | | 2 | | | | | | | | | | <1 | |
| 23-Aug | 170 | 719 | 21 | | 11 | | 47 | 5 | 4 | 16 | | 4 | | 33 | 2 | 5 | 15 | | |
| 24-Aug | 170 | 723 | 20 | | 8 | | 14 | 3 | 5 | 4 | | 3 | | 10 | 1 | 7 | 5 | | |
| 25-Aug | 171 | 728 | 21 | | | | | | | | | | | | | | | | |
| 26-Aug | 172 | 733 | 20 | | | | | | | | | | | | | | | | |
| 30-Aug | 176 | 750 | 22 | 7.4 | 10 | | 31 | 3 | | | 7.3 | 2 | | 23 | <1 | | | | 3.1 |
| 31-Aug | 177 | 755 | 23 | | | | | | | | | | | | | | | | |
| 01-Sep | 178 | 759 | 20 | | | | | | | | | | | | | | | | |
| 02-Sep | 179 | 764 | 20 | | | | | | | | | | | | | | | | |
| 05-Sep | 183 | 778 | 22 | 7.4 | 22 | | 49 | 4 | | | 7.6 | 3 | | 28 | 3 | | | | 4.0 |
| 06-Sep | 183 | 782 | 21 | | | | | | | | | | | | | | | | |
| 07-Sep | 184 | 786 | 20 | | | | | | | | | | | | | | | | |
| 08-Sep | 185 | 789 | 20 | | | | | | | | | | | | | | | | |
| 09-Sep | 186 | 793 | 21 | | | | | | | | | | | | | | | | |
| 12-Sep | 190 | 804 | 20 | 7.6 | 42 | | 50 | 3 | | | 7.8 | 36 | | 26 | <1 | | | | 4.4 |
| 13-Sep | 190 | 807 | 20 | | | | | | | | | | | | | | | | |
| 14-Sep | 191 | 810 | 20 | | | | | | | | | | | | | | | | |
| 15-Sep | 192 | 813 | 21 | | | | | | | | | | | | | | | | |
| 16-Sep | 193 | 816 | 21 | | | | | | | | | | | | | | | | |
| 19-Sep | 197 | 827 | 21 | 7.6 | 16 | | 43 | 7 | | | 7.9 | 18 | | 25 | 3 | | | | |
| 20-Sep | 197 | 829 | 20 | | | | | | | | | | | | | | | | |
| 21-Sep | 198 | 832 | 20 | | | | | | | | | | | | | | | | |
| 22-Sep | 200 | 836 | 20 | | | | | | | | | | | | | | | | |
| 23-Sep | 200 | 838 | 19 | | | | | | | | | | | | | | | | |

REACTOR B – SERIES FLOW

| Date 2005 | Total run time days | Cumulative no. of bed volumes | Temp DegC | Influent | | | | | | | Effluent | | | | | | | |
|--------------|------------------------------|-------------------------------------|--------------|----------|------|-------|------|------|--------------------|--------------------|----------|------|-------|------|------|--------------------|--------------------|---------------|
| | | | | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | pH | SS | Tot-P | COD | BOD | NH ₄ -N | NO ₃ -N | Comp Tot-P |
| | | | | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 22-Aug | 157 | 638 | 18 | | | | | 2 | | | | | | 3 | | | | |
| 23-Aug | 159 | 642 | 21 | | 12 | | 48 | 5 | 2.4 | 17.3 | | 4 | | 32 | 3 | 4 | 16 | |
| 24-Aug | 159 | 644 | 20 | | 10 | | 16 | 2 | 4.4 | 3.2 | | 3 | | 8 | 3 | 7 | 5 | |
| 25-Aug | 160 | 648 | 21 | | | | | | | | | | | | | | | |
| 26-Aug | 161 | 651 | 20 | | | | | | | | | | | | | | | |
| 30-Aug | 165 | 665 | 22 | 7.3 | 4 | | 22 | 3 | | | 8.1 | 1 | | 17 | 2 | | 1.5 | |
| 31-Aug | 166 | 668 | 23 | | | | | | | | | | | | | | | |
| 01-Sep | 167 | 672 | 20 | | | | | | | | | | | | | | | |
| 02-Sep | 168 | 675 | 20 | | | | | | | | | | | | | | | |
| 05-Sep | 172 | 686 | 22 | 7.6 | 3 | | 20 | 4 | | | 8.1 | 2 | | 22 | 2 | | 1.4 | |
| 06-Sep | 172 | 689 | 21 | | | | | | | | | | | | | | | |
| 07-Sep | 173 | 692 | 20 | | | | | | | | | | | | | | | |
| 08-Sep | 174 | 696 | 20 | | | | | | | | | | | | | | | |
| 09-Sep | 175 | 699 | 21 | | | | | | | | | | | | | | | |
| 12-Sep | 179 | 710 | 20 | 7.8 | 22 | | 31 | 3 | | | 8.2 | 16 | | 24 | <1 | | 1.3 | |
| 13-Sep | 179 | 712 | 20 | | | | | | | | | | | | | | | |
| 14-Sep | 180 | 715 | 20 | | | | | | | | | | | | | | | |
| 15-Sep | 181 | 718 | 21 | | | | | | | | | | | | | | | |
| 16-Sep | 182 | 721 | 21 | | | | | | | | | | | | | | | |
| 19-Sep | 186 | 730 | 21 | 8.3 | 26 | | 25 | 7 | | | 8.3 | 32 | | 20 | 1 | | 1.3 | |
| 20-Sep | 186 | 732 | 20 | | | | | | | | | | | | | | | |
| 21-Sep | 187 | 735 | 20 | | | | | | | | | | | | | | | |
| 22-Sep | 189 | 738 | 20 | | | | | | | | | | | | | | | |
| 23-Sep | 189 | 740 | 19 | | | | | | | | | | | | | | | |