Natural England Commissioned Report NECR221

Phosphorous in Package Treatment Plant effluents

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Nutrient enrichment from diffuse sources is a major issue for freshwater SSSI sites not meeting favourable condition and for water bodies not meeting good ecological status under the Water Framework Directive (WFD). Therefore, failure to tackle diffuse water pollution effectively presents a significant risk to the delivery of Biodiversity2020 and the WFD.

There is growing evidence that small sewage discharges (SSDs) may pose a significant environmental risk to freshwater habitats under certain circumstances. However, the extent of this risk and its potential impact across the freshwater SSSIs are not well understood. Linked to this, it is often difficult to confidently judge where they can be safely located in terms of eutrophication from phosphorus and what type of system will pose the lowest risk to sites.

To improve our advice on the suitability of different types of SSD (package treatment plants and septic tanks), sampling of package treatment plant systems was undertaken for Natural England by the Centre for Ecology & Hydrology (CEH), with contributions from the Environment Agency.

The main aims of this work were to:

- Characterise the different package treatment plant SSD systems available and the different manufacturer designs, detailing how they treat phosphorous in particular.
- Sample on a monthly basis 6 package treatment plants for soluble reactive phosphorous, total phosphorous and total dissolved phosphorous.
- Compare this to recent research on the effluent quality of septic tanks to understand if there is a difference.

The findings contained within this report have allowed Natural England to further understand the risk of SSDs related to the different types of systems. It is hoped that the findings will also help steer further applied research in this area within the wider scientific community.

This report should be cited as:

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Further information
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Summary

Diffuse water pollution (DWP) is a major cause of SSSI waterbodies failing to meet favourable condition and/or water quality objectives that have been set under the EU Water Framework and Habitats Directives. Diffuse water pollution can come from a variety of sources. These include agriculture, small point source discharges, and runoff from roads or urban areas. Currently, 166 SSSIs have a DWP plan assigned to whole or part of the site. Many of these plans mention small sewage discharges (SSDs), such as those from septic tanks (STs) and package treatment plants (PTPs), as potential sources of nutrients within the catchment. Discharges of phosphorus (P) are highlighted as a particular problem.

To address this issue, Natural England requires a better understanding of how different treatment systems and management options affect the quality of the effluent being discharged in relation to its P content. There is a widely held belief that the effluent from PTPs is much ‘cleaner’ than that from STs (eg EHS and others, 2006) but this may not be true in relation to P content, because system design and improvement in recent years has tended to focus only on emissions that are subject to regulation in England, and across Europe as a whole (European Standard EN 12566-3; European Committee for Standardisation, 2005), ie ammoniacal nitrogen (20 mg l^{-1}), suspended solids (30 mg l^{-1}) and biological oxygen demand (20 mg l^{-1}).

There are very few data available in the published literature on the P content of discharges from PTPs. This is of particular concern because, when STs are replaced by PTPs or similar systems, they are often permitted to discharge effluent directly to a watercourse due to a perceived improvement in their effluent quality in comparison to the original system that they are replacing. In fact, recent evidence suggests that most of the P removal within on site systems probably occurs within the soil soakaway rather than within the tank itself (May and others, 2015c). If this is true, replacing STs with PTPs and allowing them to discharge directly to water is likely to exacerbate, rather than solve, existing water quality problems.

There is also some evidence within the available literature that P concentrations in the effluents from both STs and PTPs vary greatly over time (May and Woods, 2014). If this is the case, it may be impossible to assess the quality of the effluent from a tank accurately from a single sample, which would have implications for the operational monitoring of effluent from these systems.

This project was undertaken to test two hypotheses:

1) The level of P in the effluent from a PTP is similar to that from a comparable ST.

2) There is considerable temporal variation in the levels of P in the effluent of any given PTP, so a single sample collected on one occasion does not adequately reflect the longer term situation and is inadequate for monitoring purposes.

The results from this study, albeit based on a small number of samples from a small number of systems, suggest that the average concentrations of SRP and TP in PTP discharges are about 5.6 mg l^{-1} and 9.7 mg l^{-1}, respectively. They also show that concentrations from any given tank vary markedly over time. Overall, these measured concentrations seem to be about 49% lower for SRP and 37% lower for TP than those determined for effluent from more traditional STs (May and others, 2015c). However, the STs studied by May and others (2015c) were single source (one household) systems that were sampled once, only, whereas the PTPs being monitored were multiple source systems sampled repeatedly over a period of time. So, the results are not directly comparable and a wider range of systems would be needed to determine how large the difference is more accurately.

In terms of the wider literature, Lowe and others (2007) reviewed 150 publications from the US to determine likely effluent TP concentrations from the systems studied. During this review, Lowe and others (2007) found it difficult to compare their results to published values due to inconsistencies in

the way that P concentrations were reported; most were reported as TP, but many were reported as orthophosphate or organic phosphorus. To ensure comparability of results, Lowe and others (2007) focused their analyses only on data that were reported as TP. These were supplemented by a study of 17 field sites to characterise the composition of modern, single, residential STs in more detail (Lowe and others, 2009).

The results of the literature review undertaken by Lowe and others (2007) are summarised in Table 10. The average effluent TP concentrations reported from single source domestic STs was found to be about 12.2 mg P l^{-1}, with a range of 3-40 mg P l^{-1}, whereas the corresponding values from multiple source STs were found to be about 7 mg P l^{-1} and 5-10 mg P l^{-1}, respectively. The authors concluded that effluent TP concentrations from multiple source STs were, on average, generally lower than those from single source STs. The reason for this is unclear but, if this is the case, the effluent TP concentrations from the multiple source PTPs sampled in this project should probably be compared to those from multiple source STs to determine whether the TP concentrations in the effluents of the PTPs studied, are lower than those from comparable STs. The values determined for multi-source STs by Lowe and others (2007) suggest a much smaller difference between effluent TP concentrations from PTPs (9.7 mg l^{-1}) and those from comparable STs (7 mg l^{-1}), with PTPs discharging higher concentrations of P than STs.

Considerable temporal variation was observed in effluent P concentrations from the six PTPs studied, over time. This is consistent with results from other studies. It is unclear why P concentrations in the effluent from STs and PTPs vary so dramatically over time, but these results raise questions over whether a single effluent sample collected for operational and monitoring purposes adequately represents the longer term situation.

It should be noted, however, that the above results and discussion are based on effluent P concentrations and not P load. Phosphorus concentrations, alone, do not provide accurate information on the actual amount of P entering the environment as this is affected by the amount of flow through the system. This will be larger in higher capacity systems than smaller systems. In terms of determining impacts on standing waters downstream of these systems, load rather than concentration may be the more important driver of water quality.

The main conclusions from this study are as follows:

- The average TP concentration in PTP effluent was 9.7 mg l^{-1}; this value is lower than the average value of 12.2 mg l^{-1} TP published for single source STs but greater than that reported for more comparable multi-source STs 7 mg l^{-1} TP (see Table 10).
- The average SRP concentration in PTP effluent was found to be about 5.6 mg l^{-1}; this is 49% lower than published values for single source STs.
- In general, TP concentrations in effluent from PTPs were found to be about 28% lower than those from more traditional single source STs.
- Effluent TP concentrations vary considerably over time for any given PTP.
- It is unlikely that the results obtained from a single effluent sample collected for monitoring purposes adequately represents the longer term situation.
- Most studies of P pollution from on-site waste water treatment systems focus on determining effluent P concentrations, but P loads are more likely to be important drivers of water quality and environmental impact where the downstream waterbodies are standing waters.
- Impacts of PTP and TP discharges on receiving waters need to be assessed, especially in relation to their pattern of discharge (via a soakaway or through direct discharge to water).

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Glossary

DWP	Diffuse water pollution
P	Phosphorus
PP	Particulate phosphorus; the fraction of phosphorus in a sample that is attached to particles
PTP	Package treatment plant
SRP	Soluble reactive phosphorus; soluble fraction of phosphorus in a sample, mainly consisting of orthosphosphate (PO_4)
SSSI	Site of special scientific interest
ST	Septic tank
SURP	Soluble unreactive phosphorus
TDP	Total dissolved phosphorus; all soluble forms of phosphorus in a sample
TP	Total phosphorus; the total amount of phosphorus in a sample

1 Introduction

Background

1.1 Diffuse water pollution (DWP) is a major cause of SSSI waterbodies failing to meet favourable condition and/or water quality objectives that have been set under the EU Water Framework and Habitats Directives. Diffuse water pollution can come from a variety of sources. These include agriculture, small point source discharges, and runoff from roads or urban areas. Currently, 166 SSSIs have a DWP plan assigned to whole or part of the site. Many of these plans mention small sewage discharges (SSDs), such as those from septic tanks (STs) and package treatment plants (PTPs), as potential sources of nutrients within the catchment. Discharges of phosphorus (P) are highlighted as a particular problem.

1.2 To address this issue, Natural England requires a better understanding of how different treatment systems and management options affect the quality of the effluent that is being discharged from these systems in relation to its P content. Traditional septic tanks (STs) retain only a small proportion of the P in the influent wastewater (Canter & Knox, 1985) and little has changed in this respect for more than 50 years (May and others, 2015b). However, there is a widely held belief that the effluent from package treatment plants (PTPs) is much ‘cleaner’ than that from STs and that P concentrations in effluents from these systems are much lower in P content than those from standard STs.

1.3 This belief is reflected in the ‘Pollution guidelines for the treatment and disposal of sewage where no foul sewer is available’ (EHS and others, 2006), which state that STs must have additional treatment before being discharged to the water environment whereas a PTP may be discharged to a watercourse if consent is obtained. The guidelines also state, that “if … your drainage field requires a better quality effluent of than that from a septic tank, a package sewage treatment plant might be the most appropriate method”.

1.4 However, it should be noted that the assumptions underlying these statements may not be true in the P content of effluent, because system design and improvement in recent years has tended to focus on emissions that are subject to regulation in England, and across Europe as a whole (European Standard EN 12566-3; European Committee for Standardisation, 2005). These are ammoniacal nitrogen (20 mg l^{-1}), suspended solids (30 mg l^{-1}) and biological oxygen demand (20 mg l^{-1}); targets for effluent P concentrations are not included in the regulations.

1.5 There are very few data in the published literature that report the P content of discharges from PTPs. However, the few data that do exist suggest that P discharges from these systems may be almost as high as those from traditional STs. For example, May and others (2015c) sampled effluent from a state-of-the-art Klargester BioDisc® tank in England and found the effluent TP concentration to be about 13 mg P l^{-1}. Similarly, Brownlie and others (2014) recorded an average value of 10 mg P l^{-1} for the effluent from a PTP in southern Scotland.

Table 1 Comparison of effluent total phosphorus (TP) concentrations reported from studies of septic tank and package treatment plant discharges, where n is the number of tanks.

TYPE OF SSD	AVERAGE EFFLUENT TP CONCENTRATION (MG P L^{-1})	SOURCE OF INFORMATION
Septic tank (n=5)	15	May and others (2015c)
Klargester Biodisc® (n=1)	13	May and others (2015c)
Package treatment plant (n=1)	10	Brownlie and others (2015)

1.6 There is now a growing body of unpublished evidence held by CEH and others that seems to indicate that P emissions from standard STs and from PTPs are essentially similar – with both types of system averaging about 10-15 mg P l^{-1} (Table 1). This is of particular concern because, when STs are replaced by PTPs or similar systems, they are often permitted to discharge effluent directly to a watercourse due to a perceived improvement in their effluent quality in comparison to the original system that they are replacing (Paragraph 1.4). However, the example in Table 1 indicates P discharges from PTPs are slightly lower than those from STs (average 15 mg P l^{-1} *cf*. average 11.5 mg P l^{-1}). Also, recent evidence suggests that most of the P removal within on-site systems occurs within the soil soakaway rather than within the tank itself (May and others, 2015c). So, replacing STs with PTPs and allowing them to discharge directly to water rather than through a soakaway is likely to exacerbate, rather than solve, existing water quality problems in relation to P pollution. It should also be noted that these results are based on a small sample size (Table 1).

1.7 There is also some evidence within the available literature that P concentrations in the effluents from both STs and PTPs vary greatly over time. If this is the case, it may be impossible to assess the quality of tank effluent accurately from a single sample, which would have implications for the operational monitoring of effluent from these systems.

1.8 This project was undertaken to test two hypotheses:

1) The level of P in the effluent from a PTP is similar to that from a comparable ST.

2) There is considerable temporal variation in the levels of P in the effluent from any given PTP, so a single sample collected on one occasion does not adequately reflect the longer term situation and is inadequate for monitoring purposes.

1.9 This study addresses the issues raised above by exploring temporal variation in P concentrations in the effluents discharged from six PTPs over a 3-6 month period. The PTPs that were monitored varied in size; most served 5-25 people but one was much larger, serving about 350 people. Three different types of PTPs were studied.

2 Methods

2.1 Samples of effluent were collected from each of six study tanks at roughly three weekly intervals over a 6 month (Table 2). The exception was Tank 4, which was sampled at 1-2 week intervals over a shorter period of only 3 months. Samples were sent to the chemistry laboratory at CEH Wallingford where they were analysed for P content within 36 hours of collection.

Table 2 Sampling start and end dates, and sampling frequency, for each of the tanks in this study

Site	Start date	End date	Frequency of sampling
Tank 1	11 August 2104	9 February 2015	Every 3 weeks
Tank 2	11 August 2104	9 February 2015	Every 3 weeks
Tank 3	11 August 2104	9 February 2015	Every 3 weeks
Tank 4	10 November 2104	16 February 2015	Every 1-2 weeks
Tank 5	9 August 2104	16 February 2015	Every 3 weeks
Tank 6	9 August 2104	16 February 2015	Every 3 weeks

2.2 Samples for soluble reactive phosphorus (SRP) determinations were analysed using a Seal AA3 spectrophotometer. The SRP concentrations were determined by colorimetry using the molybdenum blue method. A six-point calibration curve with a range of 0-1.5 mg l^{-1} PO_4-P was used and the detection limit was 0.007 mg l^{-1} PO_4-P. Samples with a known standard concentration of P were also measured for quality assurance/quality control (QA/QC) purposes. Samples that were found to be over-range were diluted with de-ionised water and re-analysed.

2.3 Samples for total phosphorus (TP) and total dissolved phosphorus (TDP) determinations were analysed using a Varian Cary 50 spectrophotometer. The samples were digested with acidified potassium persulphate in an autoclave at 121^{o}C. Then, TP and TDP concentration was determined by colorimetry using the molybdenum blue method. A ten-point calibration with a range of 0-0.7 mg l^{-1} PO_4-P was used and the detection limit was 0.007 mg l^{-1} PO_4-P. Known concentrations in standard solutions were measured for QA/QC purposes. Samples that were found to be over-range were diluted with de-ionised water and re-analysed.

2.4 Particulate phosphorus (PP) values, i.e. the amount of P that is bound to particles of solid waste escaping from the outflow, were derived from the above as follows:

$$PP = TP – SRP$$

2.5 Similarly, concentrations of soluble unreactive phosphorus (SURP) were calculated as follows:

$$SURP = TP – TDP$$

3 Types of package treatment plants sampled

3.1 Three types of package treatment plants were sampled. Their design and the main principles of their operation are described below.

Type 1 package treatment plant

3.2 The Type 1 package treatment plant treats wastewater to a high standard and using no chemicals. So, it is claimed, its effluent can be safely discharged to a soakaway, watercourse or ditch. However, although it is clearly stated that the system complies with European and UK performance requirements, those requirements do not include limits on effluent P concentrations (see Paragraph 1.3).

3.3 In this type of system, waste water enters through an inlet pipe and is temporarily stored in the first chamber. Here it is stirred and aerated by air bubbles that are introduced through a pipe or “air-line”. The bubbles re-suspend any particles that settle out, moving them back into the waste treatment zone.

3.4 When more wastewater enters the first chamber *via* the inlet tube, the partially treated effluent is displaced into an outer tank. As there is no aeration in this outer tank, any remaining particulate material settles to the bottom of tank where it becomes entrained in the air lift system again and receives further processing. The clarified liquid in the upper zone is then discharged *via* a ‘scum board’, which removes any floating scum, and through an effluent discharge pipe.

Type 2 package treatment plant

3.5 The Type 2 package treatment plant has a rotating biological contactor that develops a biologically active film onto which aerobic micro-organisms that are naturally found in sewage become established.

3.6 Wastewater flows into the primary settlement tank where solids are settled out and retained as sludge. The partially clarified liquor then flows upwards into the first stage of the biozone and any suspended solids are returned to the primary settlement tank. The liquor is then transferred to the second stage biozone for further treatment.

3.7 Any remaining solids are settled out in a final settlement tank and the clarified effluent is discharged to a soil soakaway, *via* a covered inspection chamber. According to the manufacturer, the processed effluent from this system is suitable for discharge to a watercourse. However, as above, this system simply complies with European and UK performance requirements that do not include limits on effluent P concentrations (see Paragraph 1.3).

Type 3 package treatment plant

3.8 In the Type 3 package treatment plant, the incoming wastewater enters a primary settlement zone that removes most of the incoming particulate material. Flow from the primary zone then passes forward into the biozone *via* an airlift system.

3.9 The biozone comprises a number of sections that contain loose plastic media with a high surface area. These encourage the growth of bacteria and other organisms that treat the wastewater. Air is then introduced below these media by means of above ground blowers. This oxygenates the wastewater and removes excess biomass.

3.10 The combination of treated wastewater and excess solids is then transferred into a settlement zone where solids settle to the bottom of the tank. Treated effluent is discharged *via* an outlet pipe at the top of the chamber. The manufacturer does not comment on suitability of the treated effluent for discharge directly to water.

4 Descriptions of tanks sampled

4.1 The effluent from six PTPs of three different types was sampled over the study period. The individual PTPs are described below.

Tank 1

4.2 Tank 1 was a Type 1 package treatment plant that was installed in 2010. The system serves a small group of people in a commercial property and, when the system was installed, it was estimated that it would need to serve a population equivalent of about 10-15 people per year. However, inputs vary on a day-to-day basis because the building is not used at the weekends and, on weekdays, a nearby meeting room is used occasionally for up to 25 people. The operation of the tank is checked at 6 monthly intervals (August and February), but it has never accumulated enough sludge to require de-sludging. Discharge from the tank is pumped to the sewer network via a holding tank, because the soil soakaway system that was installed originally developed hydraulic failure and could not be repaired.

Plate 1 Location and sampling point for Tank 1, showing inspection cover and effluent sampling point within the inspection chamber

4.3 The discharge from the PTP outlet enters a covered inspection chamber (Plate 1) where effluent was sampled for this project. The system suffered a breakdown during the sampling period, in late August 2014. This was believed to be caused by failure of the aeration pump. The tank appears to have been repaired in early September 2014.

Tank 2

4.4 Tank 2 was a Type 2 package treatment plant. This tank is believed to be about 5-8 years old and is located on a farm where it serves an estimated population of 5-8 permanent staff and some seasonal students. The system discharges to a constructed wetland.

4.5 Samples of the effluent from this tank were collected from the inspection chamber shown in Plate 2.

Plate 2 Location and sampling point for Tank 2, showing the location of the cover that provided access to the inspection chamber

Tank 3

4.6 Tank 3 was also a Type 2 system. This tank is believed to be about 10 years old and is located on a farm where it serves an estimated population of approximately 8 permanent staff and some seasonal students.

4.7 The system discharges directly to a nearby watercourse. Samples of the effluent from this tank were collected from the inspection chamber shown in Plate 3.

Plate 3 Location and sampling point for Tank 3, showing the location of the cover that provided access to the inspection chamber

Tank 4

4.8 Tank 4 was a Type 3 package treatment system. The tank is believed to be about 1 year old and is located within the grounds of a primary school. As such, it is only used during term time when it serves a population of about 350 students. The effluent samples from Tank 4 were collected from the inspection chamber shown in Plate 4. The tank discharges to a soil soakaway.

Plate 4 Location and sampling point for Tank 4, showing inspection cover and effluent sampling point within the inspection chamber

Tank 5

4.9 Tank 5 was a Type 2 package treatment system that was installed in 2005. It has a 6,000 litre primary settlement tank and as 6,250 litre biological filter. The tank serves a visitor centre that has about 25 staff and hosts school visits throughout the year. The centre is also used as a wedding venue at weekends.

4.10 Little information was available on the management and maintenance of this tank, but the tank is believed to have been installed about 2-3 years ago. Since then, it has been de-sludged annually.

Plate 5 Location and sampling point for Tank 5, showing inspection cover and effluent sampling point within the inspection chamber

4.11 The tank discharges to two treatment ponds and ultimately to a soil soakaway, *via* a ‘French drain’ that is 1 m wide, 1 m deep and filled with limestone. Effluent from Tank 5 was sampled from the inspection chamber shown in Plate 5.

Tank 6

4.12 Tank 6 was a Type 2 package treatment system. The tank serves a small study centre and farmhouse with a population equivalent of about 20 people. It is used continuously and discharges to a soil soakaway. The age of this system is unknown.

Plate 6 Location and sampling point for Tank 6, showing inspection cover and effluent sampling point within the inspection chamber

4.13 Effluent from Tank 6 was sampled from the inspection chamber shown in Plate 6.

5 Results

Tank 1

5.1 Changes in P concentrations in the effluent from Tank 1 over time are shown in Figure 1. The first sample from this tank contained 1.79 mg P l^{-1} of TP of which 1.72 mg P l^{-1} was TDP and 1.57 mg P l^{-1} was SRP. There was very little (<0.07 mg P l^{-1}) of PP in this sample.

5.2 However, P concentrations in the next sample were very much higher (21 mg P l^{-1} TP; 20 mg P l^{-1} TDP; 18.35 mg P l^{-1} SRP) and the level of PP in the sample had risen to 1 mg P l^{-1}. These results suggest that the tank was not working properly for at least the period between late August and late September 2014. It is believed that this may have been due to a pump failure, but the actual cause of the breakdown has not been confirmed. The main pump in this system is an air lift pump that re-suspends particles of waste material to ensure more effective breakdown into soluble components. If this had failed, it would be expected that more unprocessed, particulate material would have been lost from the system in the form of PP, or that less soluble P would have been discharged because sludge was not being broken down effectively, but neither of these possible impacts were recorded. In contrast, most of the additional P discharged was in soluble form. So, the exact reason for this sudden and very large increase in P in the effluent from this system remains unknown.

5.3 Effluent P levels had begun to fall again by 13 October 2014 and were back to pre 'failure' levels by early November. Levels remained low (<2 mg P l^{-1}) from early November 2014 until late January 2015, then increased to 5.53 mg P l^{-1} TP in early February 2015. The reason for this increase is unclear.

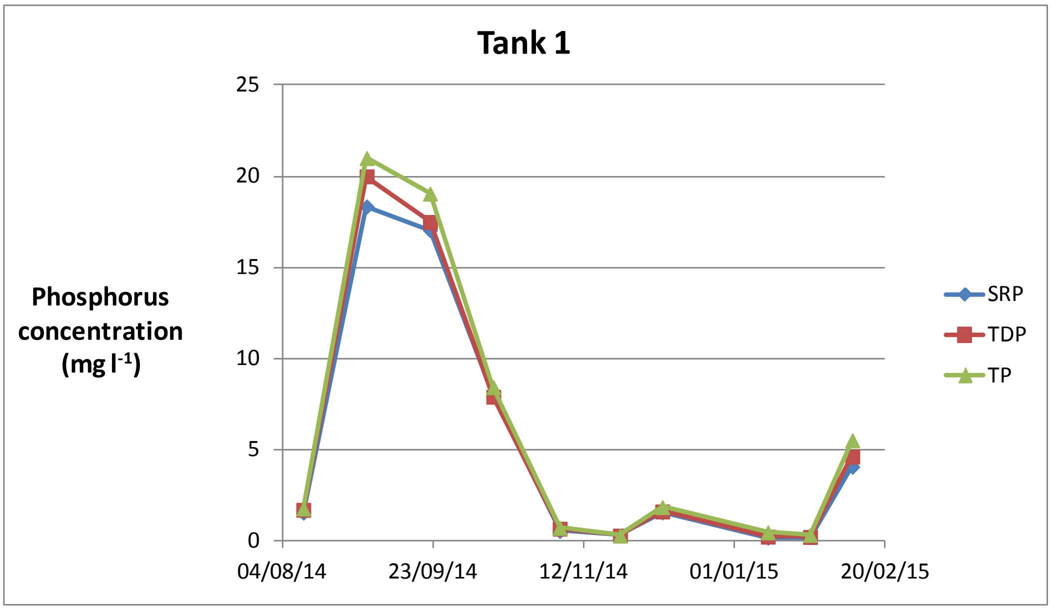

Figure 1 Variation in phosphorus concentrations over time in the effluent from Tank 1 (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; TP = total phosphorus)

5.4 Over the period of study, effluent SRP, TDP and TP concentrations changed considerably from one sampling occasion to another. The average, minimum and maximum values of these parameters are shown in Table 3. Overall, the average TP concentration in the tank effluent was 6 mg P l^{-1}, but values ranged between 0.3 and 21 mg P l^{-1}.

Table 3 Descriptive statistics for phosphorus concentrations in effluent from Tank 1 across sampling dates (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; PP = Particulate phosphorus; TP = total phosphorus); n=10

	CONCENTRATIONS (MG P L^{-1})			
	SRP	**TDP**	**PP**	**TP**
Average	5.2	5.5	0.5	6.0
Maximum	18.4	20.0	1.6	21.0
Minimum	0.2	0.2	0	0.3
Standard deviation	7.0	7.4	0.5	7.9

Tank 2

5.5 Changes in P concentrations in the effluent from Tank 2 over time are shown in Figure 2. Values were relatively stable throughout the monitoring period, with TP concentrations ranging between 0.82 mg P l^{-1} on 12 January 2015 and 3.02 mg P l^{-1} on 9 February 2015.

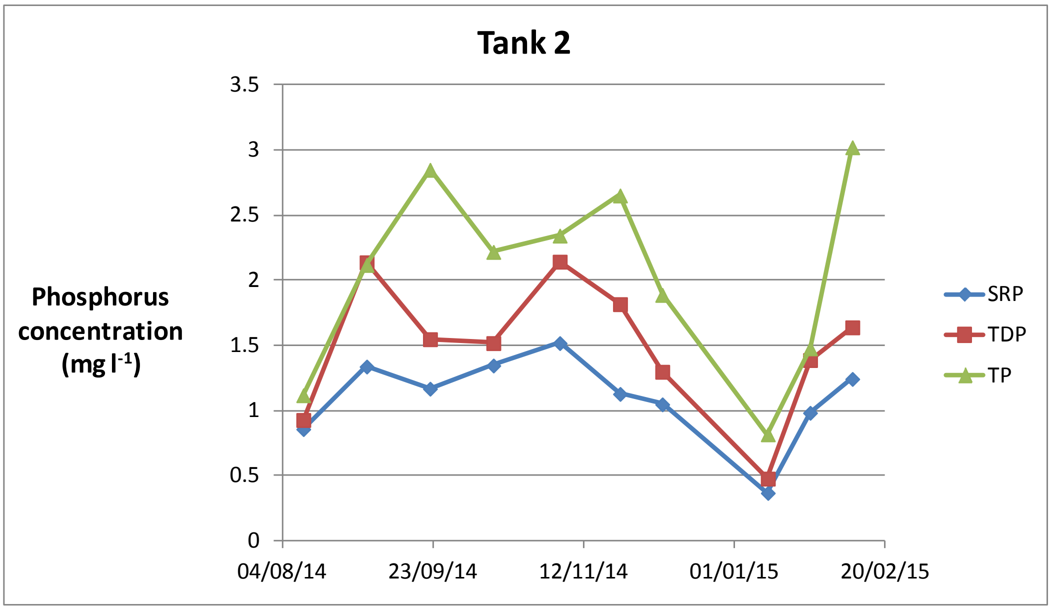

Figure 2 Variation in phosphorus concentrations over time in the effluent from Tank 2 (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; TP = total phosphorus)

5.6 Over the period of study, effluent SRP, TDP and TP levels changed very little between one sampling occasion and another. The average, minimum and maximum values of these parameters are shown in Table 4. Overall, the average TP concentration in the effluent was 2.1 mg P l^{-1}, although values ranged between 0.8 and 3.0 mg P l^{-1}.

Table 4 Descriptive statistics for phosphorus concentrations in effluent at Tank 2 across sampling dates (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; PP = Particulate phosphorus; TP = total phosphorus) ; n=10

	CONCENTRATIONS (MG P L^{-1})			
	SRP	**TDP**	**PP**	**TP**
Average	1.1	1.5	0.6	2.1
Maximum	1.5	2.1	1.4	3.0
Minimum	0.4	0.5	0.0	0.8
Standard deviation	0.3	0.5	0.5	0.7

Tank 3

5.7 Changes in P concentrations in the effluent from Tank 3 over time are shown in Figure 3. After an initially low value of 1.21 mg TP l^{-1}, values were relatively stable throughout the remainder of the monitoring period, with TP concentrations ranging between 3.24 mg P l^{-1} on 9 February 2015 and 8.72 mg P l^{-1} on 4 November 2014.

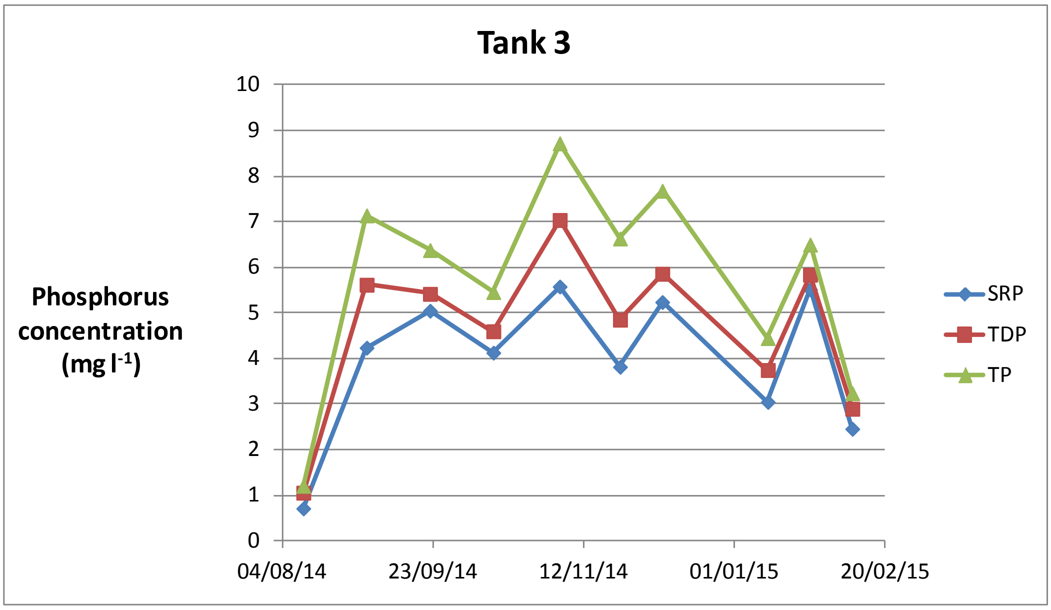

Figure 3 Variation in phosphorus concentrations over time in the effluent from Tank 3 (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; TP = total phosphorus)

5.8 Over the period of study, effluent SRP, TDP and TP levels changed considerably between one sampling occasion and another. The average, minimum and maximum values of these parameters are shown in Table 5. Overall, the average TP concentration in the effluent was 5.7 mg P l^{-1}, although values ranged between 1.2 and 8.7 mg P l^{-1}.

Table 5 Descriptive statistics for phosphorus concentrations in effluent from Tank 3 across sampling dates (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; PP = Particulate phosphorus; TP = total phosphorus); n=10

	CONCENTRATIONS (MG P L^{-1})			
	SRP	TDP	PP	TP
Average	4.0	4.7	1.0	5.7
Maximum	5.6	7.0	1.8	8.7
Minimum	0.7	1.1	0.2	1.2
Standard deviation	1.5	1.7	0.6	2.2

Tank 4

5.9 Changes in P concentrations in the effluent from Tank 4 over time are shown in Figure 4. Between 10 November 2014 and 27 January 2015, TP concentrations were relatively stable at between 3.2 and 5.6 mg P l^{-1}. However, TP concentrations rose to 8.4 mg P l^{-1} on 2 February 2015 and then to 10.9 mg P l^{-1} on 16 February 2015. This suggests a potential fault with the system. This is further supported by the fact that, on 16 February 2015, the level of PP being discharged from the system was high (about 5.7 mg P l^{-1}, compared to previous values of < 2 mg P l^{-1}).

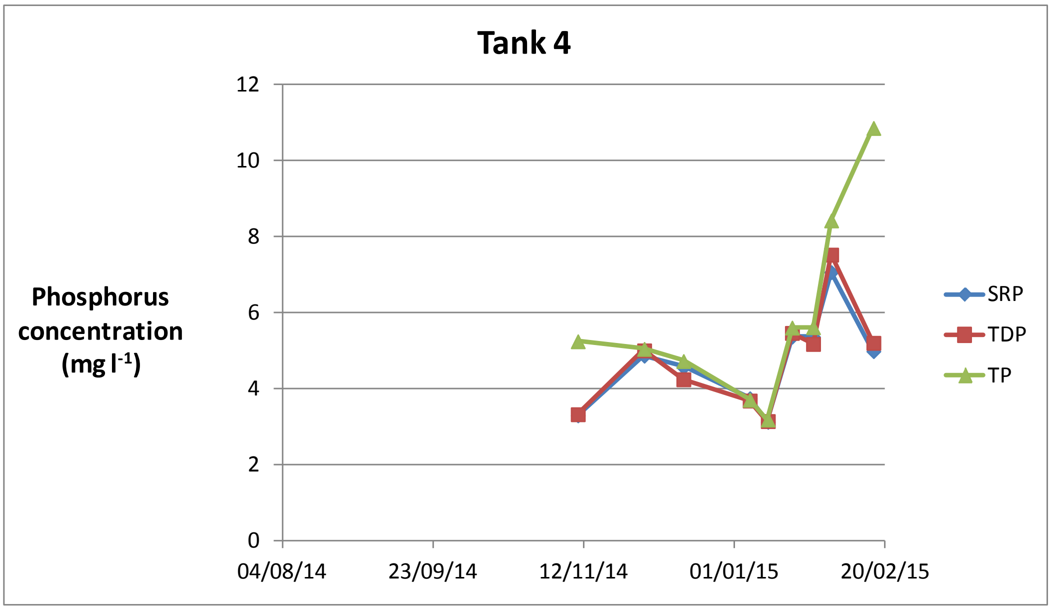

Figure 4 Variation in phosphorus concentrations over time in the effluent from Tank 4 (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; TP = total phosphorus)

5.10 Over the period of study, effluent SRP, TDP and TP levels remained relatively stable from one sampling occasion to another until February when values increased slightly and then decreased. The average, minimum and maximum values of these parameters over the period of sampling are shown in Table 5. Overall, the average TP concentration in the effluent was 5.8 mg P l^{-1}, but values ranged between 3.2 and 10.9 mg P l^{-1}.

Table 6 Descriptive statistics for phosphorus concentrations in effluent from Tank 4 across sampling dates (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; PP = Particulate phosphorus; TP = total phosphorus); n=9

	CONCENTRATIONS (MG P L^{-1})			
	SRP	**TDP**	**PP**	**TP**
Average	4.7	4.8	1.1	5.8
Maximum	7.1	7.5	5.7	10.9
Minimum	3.1	3.2	0.0	3.2
Standard deviation	1.2	1.4	1.8	2.4

Tank 5

5.11 Total P concentrations in the effluent from Tank 5 were relatively high, at between 8.8 and 14.2 mg P l^{-1} throughout most of the study period. However, values fell steadily between August 2014 and early January 2015 before rising steeply between early January 2015 and mid February 2015 (Figure 5). The reason for this is unclear.

5.12 The different fractions of phosphorus behaved differently, with SRP and TDP concentrations continuing to fall throughout the study period, while TP concentrations rose sharply to 10.9 and subsequently to 15.9 mg P l^{-1}. This was associated with a sudden rise in PP concentration. Although the reason for this is unclear, the sudden discharge of more particulate material from this tank tends to indicate a system failure. As the run of data finishes at this point, it is unclear whether this system failure was temporary, e.g. caused by a sudden flush of water through the system, or permanent and requiring system maintenance to cure a fault.

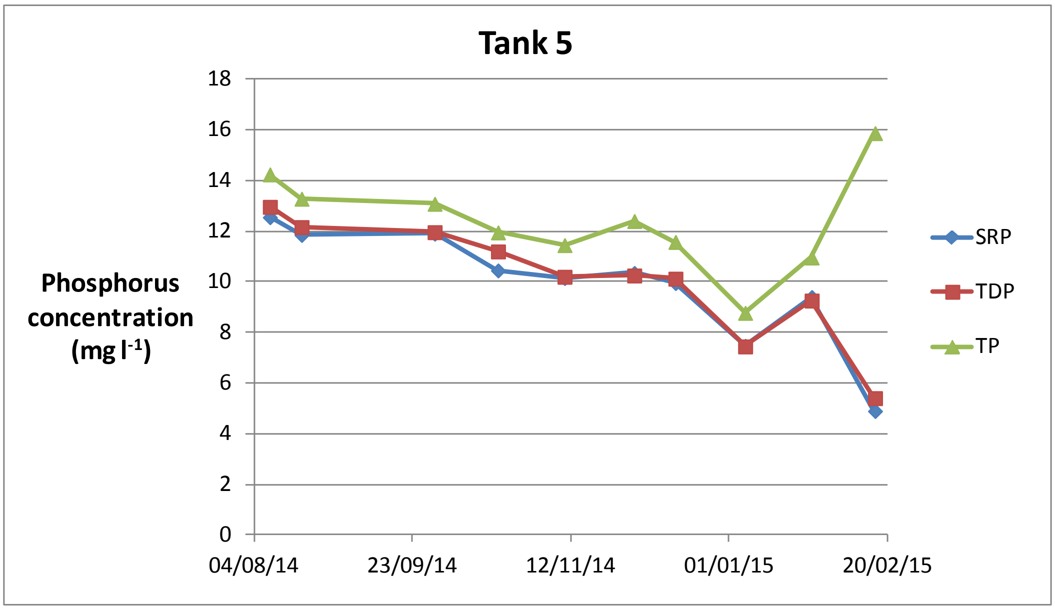

Figure 5 Variation in phosphorus concentrations over time in the effluent from Tank 5 (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; TP = total phosphorus)

5.13 The average, minimum and maximum values of SRP, TDP and TP concentrations recorded in this study are shown in Table 7. Overall, the average TP concentration in the effluent was 12.4 mg P l^{-1}, but values ranged between 8.8 and 15.9 mg P l^{-1}.

Table 7 Descriptive statistics for phosphorus concentrations in effluent from Tank 5 across sampling dates (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; PP = Particulate phosphorus; TP = total phosphorus); n=10

	CONCENTRATIONS (MG P L^{-1})			
	SRP	**TDP**	**PP**	**TP**
Average	9.9	10.1	2.3	12.4
Maximum	12.6	13.0	10.5	15.9
Minimum	4.9	5.4	0.8	8.8
Standard deviation	2.3	2.3	2.9	1.9

Tank 6

5.14 Total P concentrations in the effluent from Tank 6 were very variable throughout the monitoring period (Figure 6). In general, values ranged between 2 and 20 mg P l^{-1}, but very high values of 74.2 and 73.4 mg P l^{-1} were recorded on 20 October 2014 and 6 January 2014, respectively.

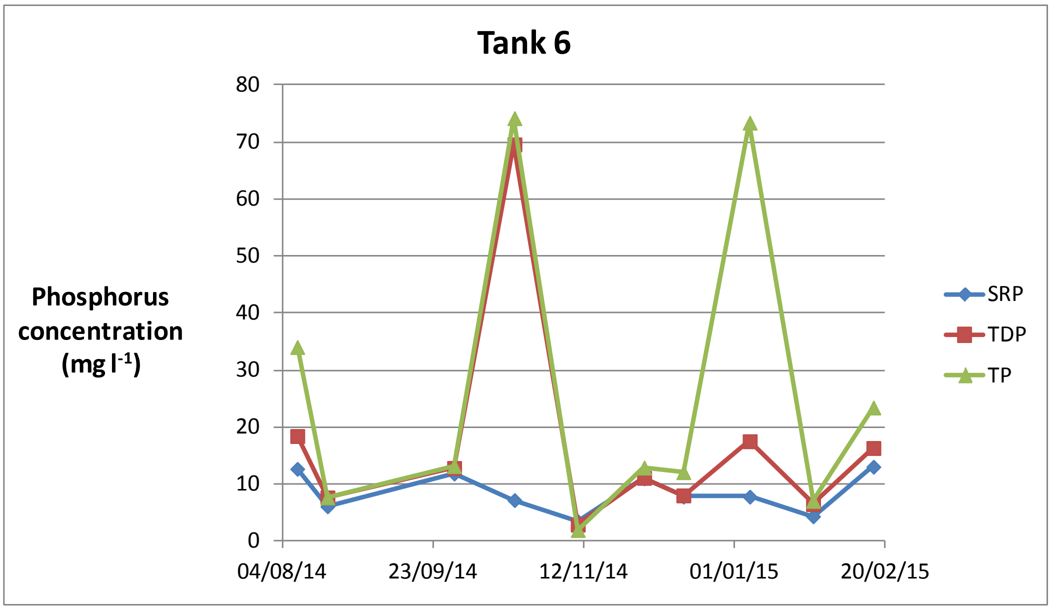

Figure 6 Variation in phosphorus concentrations over time in the effluent from Tank 6 (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; TP = total phosphorus)

5.15 The first increase was caused by the sudden release of a large amount of soluble unreactive P (SURP), otherwise known as organic phosphorus, from the system. This was calculated as the difference between SRP and TDP concentrations; the source of this SURP is unclear but it is often associated with the use of P-based detergents. The second was caused by the sudden release of a high amount of PP from the system, as calculated from the difference between TDP and TP concentrations. The reasons for this are unclear, but the results suggest that a large amount of particulate material that would normally have settled to the bottom of the tank as sludge was being discharged into the environment.

Table 8 Descriptive statistics for phosphorus concentrations in effluent from Tank 6 across sampling dates (SRP = soluble reactive phosphorus; TDP = total dissolved phosphorus; PP = Particulate phosphorus; TP = total phosphorus); n=10

	CONCENTRATIONS (MG P L^{-1})			
	SRP	**TDP**	**PP**	**TP**
Average	8.5	17.1	8.9	26.0
Maximum	13.1	69.6	55.9	74.2
Minimum	3.5	2.9	0.0	2.0
Standard deviation	3.4	19.1	17.2	26.8

5.16 The average, minimum and maximum values of SRP, TDP and TP concentrations recorded in the effluent from Tank 6 during this study are shown in Table 8. Overall, the average TP concentration in the effluent was 26 mg P l^{-1}, but values ranged between 2 and 74.2 mg P l^{-1}.

Comparison of results across tanks

5.17 A comparison of the average, minimum and maximum TP concentrations recorded in effluents across the different tanks is shown in Figure 7. The output concentrations from Tanks 1-5 were very similar, with average concentrations ranging from 2.1 to 12.4 mg P l^{-1}. However, the average effluent TP concentration from Tank 6 was much higher, i.e. about 26 mg P l^{-1}.

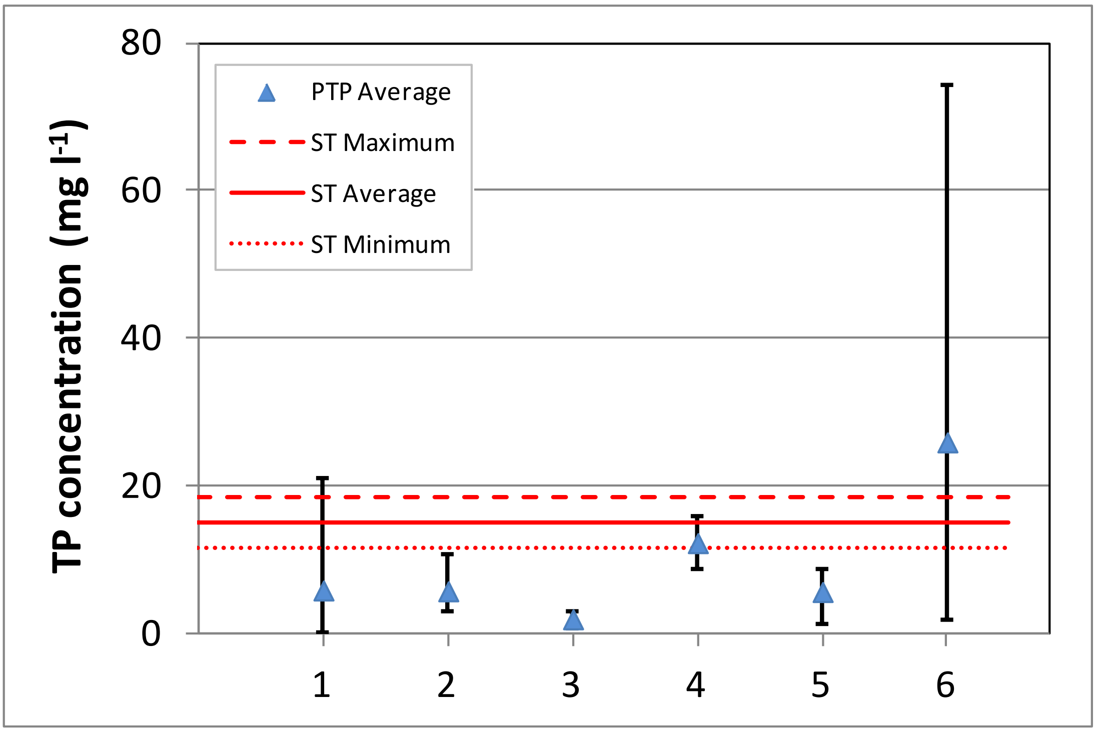

Figure 7 Variation in average, minimum and maximum total phosphorus (TP) concentrations in package treatment plant (PTP) effluents in comparison to those in effluent from traditional septic tanks (ST), as determined by May and others (2015c). Maximum and minimum values for PTPs are shown as vertical bars.

5.18 The data are compared to the average TP concentration measured in the effluent from traditional STs by May and others (2015c). However, it should be noted that these values correspond to a single sampling occasion per septic tank and are not taken from a time series. Values from PTPs 1, 2, and 5 were about 60% lower than the effluent TP concentration from a traditional tank. That from Tank 3 was 86% lower. However, average TP concentrations in the effluent from Tanks 4 and 6 were 18% lower and 73% percent higher than those expected from a traditional tank. Overall, the average TP concentration across all PTPs was 9.7 mg P l^{-1}, a number that is about 36% lower than the estimated average discharge of TP from a traditional septic tank (May and others, 2015c).

5.19 A comparison of the average, minimum and maximum SRP concentrations recorded in effluents across the PTPs is shown in Figure 8. The output concentrations from Tanks 1, 2 and 4 were very similar, with average concentrations ranging from 4.0 to 5.2 mg P l^{-1}. However, the average effluent SRP concentration from Tank 3 was much lower, ie about 1.1 mg P l^{-1} and those from tanks 4 and 5 were much higher, ie 9.9 and 8.5 mg P l^{-1}, respectively.

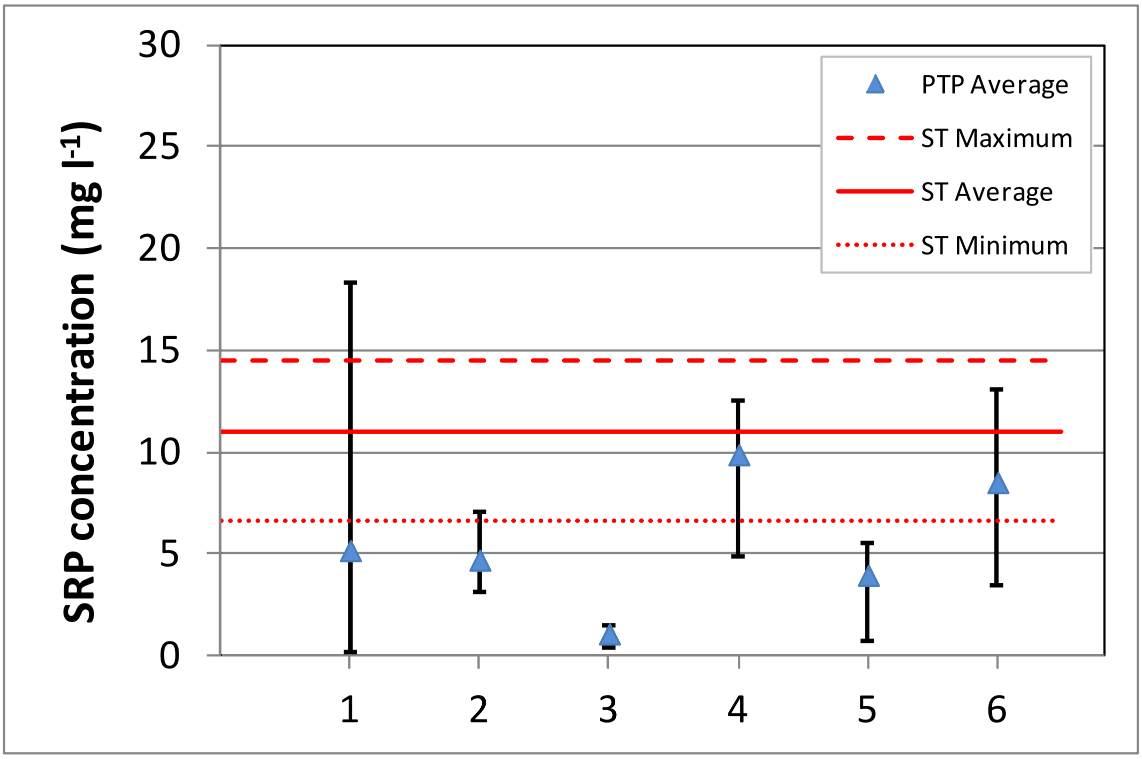

Figure 8 Variation in average, minimum and maximum soluble reactive phosphorus (SRP) concentrations in package treatment plant (PTP) effluents in comparison to those in effluent from traditional septic tanks (ST), as determined by May and others (2015c). Maximum and minimum values for PTPs are shown as vertical bars.

5.20 The data are compared to the average, and maximum and minimum, SRP concentration measured in the effluent from traditional septic tanks by May and others (2015c) in Figure 8. However, it should be noted that these values correspond to a single sampling occasion per septic tank and are not taken from a time series. Values from PTPs 1, 2, and 5 were about 53-64% lower than the effluent SRP concentration from a traditional tank. That from Tank 3 was 90% lower, and average SRP concentrations in the effluent from Tanks 4 and 6 were only 10% and 22% percent lower than those expected from a traditional tank. Overall, the average SRP concentration across all PTPs was 5.6 mg P l^{-1}, ie about 49% lower than the estimated average discharge of SRP from a traditional septic tank (May and others, 2015c).

5.21 A comparison of the average, minimum and maximum particulate phosphorus (PP) concentrations recorded in effluents across the different tanks is shown in Figure 9. The output concentrations from Tanks 1, 2, 3 and 5 were very similar, with average concentrations ranging from 0.5 to 1.1 mg P l^{-1}. However, the average effluent PP concentration from Tank 4 was a little higher at 2.3 mg P l^{-1} and that from Tank 6 was much higher, i.e. about 9 mg P l^{-1}.

5.22 The data are compared to the average PP concentration measured in the effluent from traditional septic tanks by May and others (2015c). However, it should be noted that these values correspond to a single sampling occasion per septic tank and are not taken from a time series. Values from PTPs 1, 2, 3 and 5 were about 73-88% lower, on average, than the effluent PP concentration from a traditional tank. However, average PP concentrations in the effluent from Tanks 4 and 6 were 43% lower and 125% percent higher, respectively, than those expected from a traditional tank. Overall, the average PP concentration across all PTPs was 2.4 mg P l^{-1}, a number that is about 40% lower than the estimated average discharge of PP from a traditional septic tank (May and others, 2015c).

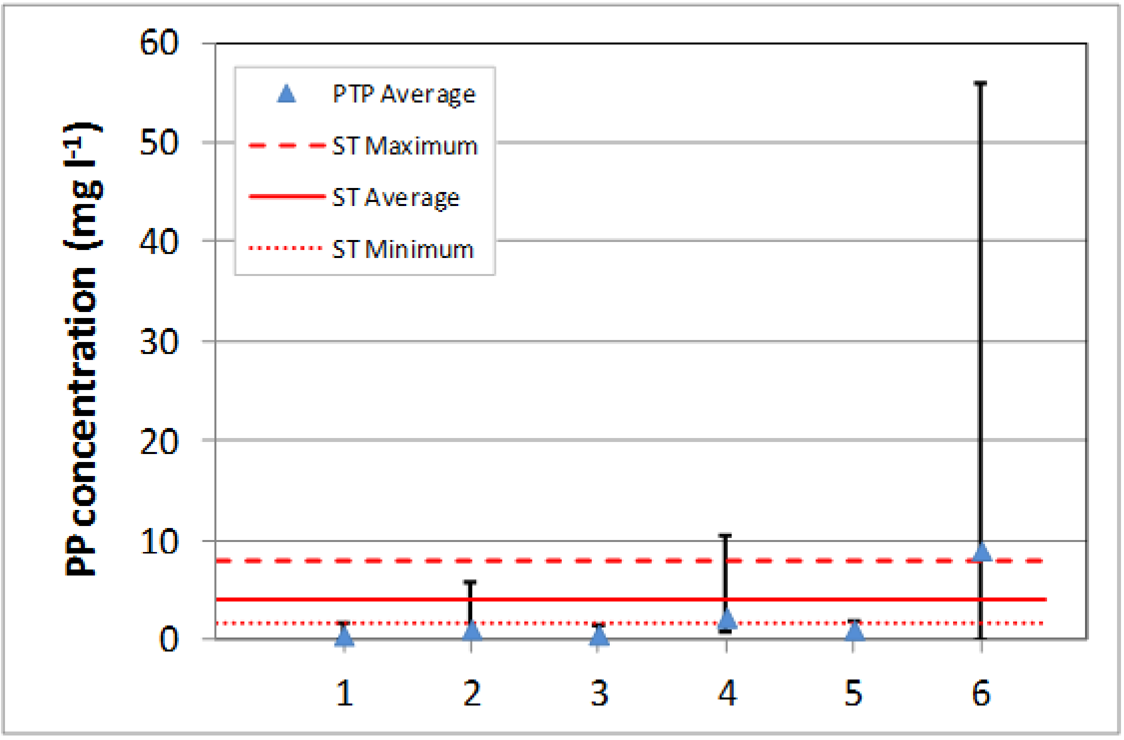

Figure 9 Variation in average, minimum and maximum particulate phosphorus (PP) concentrations in package treatment plant (PTP) effluents in comparison to those in effluent from traditional septic tanks (ST), as determined by May and others (2015c). Maximum and minimum values for PTPs are shown as vertical bars.

5.23 It is difficult to determine from the limited amount of data available whether one type of tank performs better than another, because of the uneven distribution of tank types and the large range in tank sizes (Table 9). However, in general, all tanks were quite variable in their output of TP and PP over time and there was large variability in effluent P concentrations even across tanks of the same type and of similar size. Only one of the six systems appeared to be working effectively and consistently throughout the period of monitoring.

5.24 However, most apparent failures seemed to be associated with an increase in PP discharges, which indicates an increase in suspended solids being discharged from the systems. This can occur for many reasons, but the most likely cause is probably occasional disturbance of settled sludge by turbulence in the tank content induced by an unusually high volume of water entering the system (O'Keeffe et al., 2015). This problem is usually more common in tanks that have not been de-sludged regularly, those that are too small for their current usage, and/or those that receive sudden high inputs of water from roof runoff. However, it is unclear whether any of these problems apply to the six PTPs in this study.

Table 9 Descriptions of each tank and the associated average SRP, TDP and TP concentrations in the effluent

TANK NUMBER	TANK TYPE	ESTIMATED SIZE (AS POPULATION EQUIVALENT)	AVERAGE EFFLUENT CONCENTRATIONS (MG P L^{-1})				Comment
			SRP	TDP	PP	TP	
1	Type 1	10-15	5.2	5.5	0.5	6.0	Very high effluent TDP concentrations in early samples; may have been caused by pump failure; no related increase in PP concentrations.
2	Type 2	5-8	4.7	4.8	1.0	5.8	Relatively high discharge of PP throughout, especially in final sample; reason unclear but indicative of system failure.
3	Type 2	8	1.1	1.5	0.6	2.1	Tank effluent quality very good in relation to P concentrations; no evidence of system failure.
4	Type 3	350	9.9	10.1	2.3	12.4	Tank effluent quality mostly good in relation to P concentrations; possible evidence of system failure in final sample where PP concentrations were high.
5	Type 2	25	4.0	4.7	1.1	5.7	Tank effluent quality mostly good in relation to P concentrations; possible evidence of system failure in final sample where PP concentrations were high.
6	Type 2	20	8.5	17.1	9.0	26.0	Tank effluent quality variable with high TDP on one occasion and high PP later; may indicate intermittent system failure.

6 Discussion

6.1 Septic tanks (STs) and package treatment plants (PTPs) are widely used for the on-site treatment of waste water, especially domestic sewage. Septic tanks are known to discharge P to nearby watercourses, either directly or *via* a soil soakaway. Although new ST installations are not permitted to discharge directly to water, many of the older ones do discharge directly the a nearby watercourse. In some cases discharges from STs and PTPs are believed to be an important source of the P that is responsible for downgrading water quality across the freshwater SSSI series.

6.2 When STs are found to be causing pollution problems, owners are often advised to replace their tanks with more modern systems such as PTPs (EHS and others, 2006). Because effluents from PTPs are believed to be much cleaner than those from STs, they are often permitted to discharge directly to water. However, until now, there has been very little information available on the level of P discharges from these systems and how it compares to those from STs. Concerns have been raised that the cleaner effluent applies only to concentrations of BOD, suspended solids and ammoniacal nitrogen (NH_4), but not to P, as these systems have been developed to meet EU and UK legislative requirements that do not include P.

6.3 The results from this study, albeit based on small number of samples from a small number of systems, suggest that the average concentrations of SRP and TP in PTP discharges are about 5.6 mg l^{-1} and 9.7 mg l^{-1}, respectively. They also show that concentrations from any given tank vary markedly over time. Overall, these measured concentrations seem to be about 49% lower for SRP and 37% lower for TP than those determined for effluent from more traditional STs (May and others, 2015c). However, the STs studied by May and others (2015c) were single source (one household) systems that were sampled once, only, whereas the PTPs being monitored were multiple source systems sampled repeatedly over a period of time. So, the results are not directly comparable and a wider range of systems would be needed to determine how large the difference is more accurately.

6.4 In terms of the wider literature, Lowe and others (2007) reviewed 150 publications from the US to determine likely effluent TP concentrations from the systems studied. During this review, Lowe and others (2007) found it difficult to compare their results to published values due to inconsistencies in the way that P concentrations were reported; most were reported as TP, but many were reported as orthophosphate or organic phosphorus. To ensure comparability of results, Lowe and others (2007) focused their analyses only on data that were reported as TP. These were supplemented by a study of 17 field sites to characterise the composition of modern, single, residential STs in more detail (Lowe and others, 2009).

6.5 The results of the literature review undertaken by Lowe and others (2007) are summarised in Table 10. The average effluent TP concentrations reported from single source domestic STs was found to be about 12.2 mg P l^{-1}, with a range of 3-40 mg P l^{-1}, whereas the corresponding values from multiple source STs were found to be about 7 mg P l^{-1} and 5-10 mg P l^{-1}, respectively. The authors concluded that effluent TP concentrations from multiple source STs were, on average, generally lower than those from single source STs. The reason for this is unclear but, if this is the case, the effluent TP concentrations from the multiple source PTPs sampled in this project should probably be compared to those from multiple source STs to determine whether the TP concentrations in the effluents of the PTPs studied are lower than those from comparable STs. The values determined for multi-source STs by Lowe and others (2007) suggest a much smaller difference between effluent TP concentrations from PTPs (9.7 mg l^{-1}) and those from comparable STs (7 mg l^{-1}), with PTPs discharging higher concentrations of P than STs.

6.6 Overall, when systems are compared like-for-like, it seems questionable whether PTPs discharge lower concentrations of TP in their effluent than traditional STs. This raises a question over whether these systems can be discharged safely to a watercourse in terms of risks from P pollution where this is biodiversity importance.

Table 10 Descriptive statistics for septic tank (ST) effluent total phosphorus (TP) concentrations reported in literature from the US (*after Lowe and others, 2007*)

	EFFLUENT TOTAL PHOSPHORUS CONCENTRATION (MG L^{-1})				
TYPE OF SEPTIC TANK	**MEDIAN**	**AVERAGE**	**STANDARD DEVIATION**	**RANGE**	**NUMBER OF VALUES REPORTED**
Single source domestic	10	12.2	7.9	3-40	49
Multiple source domestic	6.9	7	1.9	5-10	6

6.7 Considerable temporal variation was observed in effluent P concentrations from the six PTPs studied. This is consistent with results from other studies, although these were conducted on more traditional STs. For example, Heistad and Paruch (2006) monitored levels of TP in the effluent from a ST in Norway and found that concentrations ranged between from 2 mg l^{-1} and 11 mg l^{-1} over a 21 month period. Similarly, Gill and others (2009) examined phosphate (PO_4-P) concentrations in the effluent from a standard, two chamber, ST over a 14 month period and found that these ranged between 5 mg l^{-1} and 37 mg l^{-1} over the period of investigation.

6.8 Although it is unclear why P concentrations in the effluent from STs and PTPs vary so dramatically over time, these results raise questions over whether a single effluent sample collected for monitoring purposes adequately represents the longer term situation.

6.9 It should be noted, however, that the above results and discussion are based on effluent P concentrations and not the P load from PTPs and STs. Phosphorus concentrations, alone, do not provide accurate enough information on the amount of P entering the environment as this is affected by the amount of flow through the system, which will be larger in higher capacity systems. In terms of determining impacts on standing waters downstream of these systems, load rather than concentration may be the more important driver of water quality. There is, however, no reason to believe that the flow through a PTP is any different from that through a ST because, in both cases, flow through the system is determined by displacement of the tank contents by inflowing waste.

7 Conclusions

7.1 The main conclusions from this project are presented below.

7.2 The average TP concentration in effluent from the PTPs monitored in this study was 9.7 mg l^{-1}. This value is lower than that from single source STs (12-15 mg l^{-1} TP), but greater than that reported for more comparable multi-source STs (7 mg l^{-1} TP), ie those that process the waste from more than one property. However, only small numbers of results are available for comparison and there was wide variation in the values recorded within and across both types of system.

7.3 Effluent TP concentrations varied considerably over time for any given PTP, which needs to be taken into consideration when trying to understand the effect of any outflows from the systems. So, it is unlikely that the results obtained from a single effluent sample collected for monitoring purposes adequately represents the longer term situation. This highlights the importance of taking uncertainty into account when monitoring effluent discharges for regulatory purposes.

7.4 The average SRP concentration in PTP effluent was found to be about 5.6 mg l^{-1}. This is 49% lower than that determined for single source STs by May and others (2015a). However, when combined with evidence from comparisons with multi source STs, and taking into consideration the variability recorded in effluent quality from individual tanks over time, the results of this study still raise grounds for concern about the potential impact of direct discharges to water from both PTPs and more traditional septic tanks around designated sites.

7.5 Most studies of P pollution from on-site waste water treatment systems focus on determining effluent P concentrations, but P loads are more likely to be important drivers of water quality and environmental impact where the downstream waterbodies are standing waters. Estimating P loads requires rates of flow of effluent to be measured in addition to P concentrations.

7.6 A better understanding of the impact of in-stream dilution on resultant P concentrations in the environment is required. This applies, especially, to how far downstream of an effluent discharge point effects on water quality can still be observed and how the pattern of impact is affected by the mode of delivery, eg via a soakaway or through a direct discharge.

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