Natural England Commissioned Report NECR179

A review of the effectiveness of different on-site wastewater treatment systems and their management to reduce phosphorus pollution

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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 Site of Special Scientific Interest (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 eutrophication risks posed by different types of SSD (eg package treatment plants, septic tanks and cesspits), and options for risk management, a full literature review 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 SSD systems available, highlighting key differences between them, and the relative risks they pose to the environment in terms of eutrophication from Phosphorus.
- Review the options for reducing the phosphorus pollution risk from these systems and their applicability under different environmental conditions.
- Identify the key knowledge gaps in this area highlighting priorities for further research.

The findings contained within this report have allowed Natural England to refine the advice that it provides on the risk of different types of SSDs and their management with respect to potentially vulnerable freshwater SSSIs. It is hoped that the findings will also help steer further applied research in this area within the wider scientific community.

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Further information
This report can be downloaded from the Natural England website: **www.gov.uk/government/organisations/natural-england**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

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Summary

Diffuse water pollution (DWP) is a major cause of SSSI waterbodies not meeting favourable condition and/or water quality objectives set under the EC Water Framework and Habitats Directives. Diffuse water pollution can come from a variety of sources, including agriculture, small un-consented point source discharges, and runoff from roads or urban areas. Natural England estimates that around 166 SSSIs are affected by DWP where pollution reduction plans are being developed for all or part of these sites; 40 of these plans cover Natura 2000 Protected Areas. Many of these DWP plans highlight small domestic discharges (SDDs), as potential sources of nutrients that are causing water quality problems, although often it is not known how significant they are. These include those from septic tanks (STs) and package treatment plants (PTPs).

The most frequently highlighted problem associated with discharges from these systems is phosphorus (P) pollution, which causes eutrophication problems. However, it is often unclear how such problems should be resolved because there is little information on the efficacy of management advice that is currently being given to householders. Such advice includes the regular de-sludging of tanks, the use of P-free detergents, and the replacement of traditional STs with PTPs.

This review assessed the information contained in publicly available literature with a view to enabling Natural England to improve the advice that they give on the correct management of SSDs in relation to reducing their P-related impacts on designated sites. The review found that there was very little knowledge and information available that could be used to develop a more evidence based approach to reducing P discharges from these systems.

Based on the existing knowledge and information reviewed, it was concluded that the most effective options for reducing the levels of P discharged from on-site sewage treatment tanks to the environment are as follows:

1) Reducing P inputs to the tank, eg through the use of P free detergents.
2) Using chemical precipitation to retain P within the tank and incorporate it into the sludge.

It should be noted that the use of P free detergents is becoming increasingly common due to the introduction of recent European legislation (European Union, 2012). It is also important to note that, whilst chemical precipitation is an effective method of retaining P within tanks, issues of personal and environmental safety can be associated with this approach, and at this stage it is not appropriate for widespread use.

In addition to the above, many other approaches to tank management also have the potential to effectively reduce P discharges from these systems. However, at present, there is insufficient data and information available for their level of efficacy to be determined. Other options that are often recommended include frequent de-sludging or replacing traditional STs with PTPs. It is unclear how and to what extent these other options are effective at reducing the P concentration in tank effluent or whether, in practice, these approaches could be making the situation even worse in some situations.

In areas where the water table is high, ie <1.5 m below soil surface, impacts on nearby watercourses can probably be reduced by installing mounded soakaway systems.

This review also identified key gaps in knowledge and recommends that further research be undertaken to answer the following questions:

1) To what extent do P concentrations of ST effluents differ from those of PTPs?

2) How does temporal variation in P output from STs and PTPs (from sub-daily to seasonal) affect the level of uncertainty associated with collecting and analysing a single effluent sample for monitoring/regulatory purposes?

3) How effective are STs and PTPs at breaking down waste if usage is intermittent or seasonal and what are the implications for levels of P in the discharged effluent?

4) Does de-sludging reduce effluent P concentrations?

The results of this research would provide information on the key factors that affect effluent P concentrations from these tanks. This could then be incorporated into advice give to householders on how to reduce P outputs from these systems.

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1 Introduction

1.1 Diffuse water pollution (DWP) is a major cause of SSSI waterbodies not meeting favourable condition and/or water quality objectives set under the EC Water Framework and Habitats Directives. Diffuse water pollution can come from a variety of sources, including agriculture, small un-consented point source discharges, and runoff from roads or urban areas. Natural England estimates that around 166 SSSIs are affected by DWP where pollution reduction plans are being developed for all or part of these sites; 40 of these plans cover Natura 2000 Protected Areas. Many of these plans highlight small domestic discharges (SDDs), as potential sources of nutrients that are causing water quality problems, although currently it is often not known how significant they are. These include those from septic tanks (STs) and package treatment plants (PTPs).

1.2 The most frequently highlighted problem associated with discharges from these systems is phosphorus (P) pollution, which causes eutrophication problems. In general, there is very little regulatory control on P discharges from SDDs. In the US, for example, only 20% of states have regulatory controls in place for such discharges (State Onsite Regulators Alliance National Environmental Services Center, 2012). In the UK, controls are even less common, with the P sensitive catchment of Loch Leven being the most notable exception. Here, the so-called '125% rule' is used to control discharges from SDDs in unsewered areas of the catchment. (Brownlie & others, 2014). In outline, this 'rule' requires developers to reduce P discharges elsewhere within the catchment to mitigate for any additional discharges that are likely to be associated with any new builds that they are proposing.

1.3 Although P discharges from SDDs are not regulated, *per se*, within the UK, in England there is a requirement that systems comply with the new general binding rules for SSDs that were introduced in January 2015 (The Environmental Permitting (England and Wales) (Amendment) (England) Regulations 2014). These include a requirement that they should not cause environmental pollution problems. However, when pollution issues are identified, it is often unclear how these problems should be resolved. In general, the efficacy of advice that is currently being given to householders on how to reduce P pollution of nearby waterbodies from these systems, such as regular de-sludging of tanks, the use of P-free detergents and the replacement of traditional STs with PTPs, has not been tested.

1.4 As stated in the recent reform on SSDs, the Environment Agency is already working with Natural England to tackle impacts on sensitive areas from agriculture and sewage discharges through Diffuse Water Pollution Plans (DWPPs). Where there is evidence of a cumulative impact on sensitive areas and habitats, the Environment Agency will work with Natural England and the catchment partnerships to help identify pollution sources and devise local strategies to reduce pollution in these areas, and so developing our evidence is an important objective.

1.5 For the reasons outlined above, Natural England commissioned this review to enable more scientific evidence to be incorporated into consultations concerning the better management and siting of SSDs, especially in relation to reducing their P-related impacts on designated sites. The review compiled existing knowledge and information on P discharges from these systems and identified key gaps in knowledge that require further research.

2 Methods

2.1 A detailed literature review was undertaken to assess the current evidence base that is available on the effectiveness of different on-site waste water treatment systems in removing P from domestic waste water before it is discharged to the environment. Sources of literature included refereed publications. These were explored through the ‘Web of Science’ gateway (**http://wok.mimas.ac.uk/**) using suitable key words, including various combinations of the following words:

- Sewage
- Effluent
- Phosphorus
- Septic tank
- On-site wastewater treatment plant
- Package treatment plant
- Aerobic treatment unit
- Biodisc systems

2.2 Copies of the relevant publications were obtained through the CEH library and these were supplemented with grey literature that was found on the internet using the Google search engine (**www.google.co.uk/**) and similar keywords. The documents found on the internet included unpublished reports from regulatory bodies, conservation agencies, utility companies and special interest groups, advertising leaflets from supply companies, and *ad hoc* leaflets providing advice to householders in many rural areas.

2.3 The literature review was undertaken against a background of wider issues surrounding P emissions from on-site sewage treatment systems, such as those previously raised by May and others (2010), May and others (2014) and Stutter and others (2014). This report provides initial recommendations on some of the options available for reducing P losses from STs and PTPs to the environment on the basis of existing information. It also identifies key gaps in knowledge that need to be addressed and makes recommendations for further research.

3 Literature review

Commonly used on-site waste water treatment options

3.1 Large numbers of properties in rural areas of the UK, including an estimated 400,000 in England (Defra & EA, 2014) are not connected to mains sewerage systems and rely on on-site treatment systems to manage their domestic waste. Traditionally, these on-site systems were installed where there was no mains sewerage system nearby or where there were technical reasons why a connection could not be made. More recently, however, with the widespread introduction of first time sewerage schemes, the situation is less clear. This is because owners can choose whether to connect to newly installed systems or to retain their on-site system (eg Wessex Water information leaflet).

3.2 Three main types of on-site waste water treatment systems are being used within the UK. These are:

- Septic tanks (STs)
- Package treatment plants (PTPs)
- Cess pits

3.3 Guidance on the installation and use of these systems has been summarised by EA, SEPA and EHSNI (2006).

Septic tanks

3.4 A septic tank (ST) is usually a two- or three-chamber system (Figure 1) that holds sewage for a short period of time, allowing the solids to settle as sludge in the bottom of the tank and the oil and grease to form a scum at the top. Inside the tank, waste is broken down by anaerobic bacterial decomposition to produce a relatively clear liquid effluent that leaves the tank through an outlet pipe (Plate 1). Because the tank is sealed, the level of waste inside of the tank remains constant and the outflow volume equates to, and varies with, the influent volume over time.

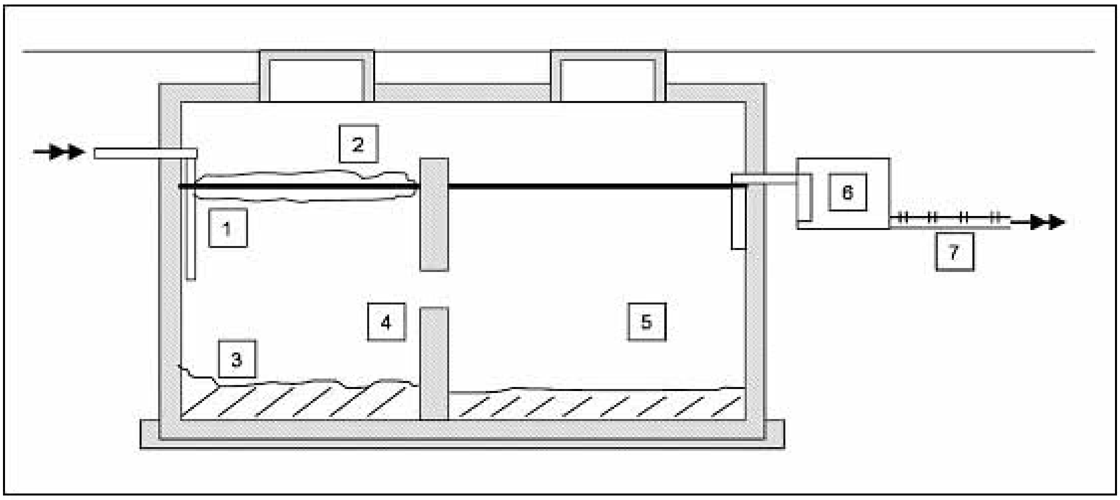


Figure 1 A standard septic tank design

Legend: 1 - inflow; 2 - floating scum; 3 - settled sludge; 4 - connection between chambers; 5 - secondary chamber; 6 - outflow and effluent inspection chamber; 7 - soakaway or drainage system (reproduced from Hilton et al., unpublished).

Plate 1 Effluent from a septic tank discharging into an inspection tank

3.5 Effluent from a ST is not of a suitable quality to discharge directly to a watercourse, because it contains suspended solids, dissolved nitrogen (N) and P, and a range of potentially pathogenic bacteria and viruses. So, it must have additional treatment before it enters a waterbody. Most commonly, the effluent is spread across a soil soakaway or drainage field through a series of perforated distribution pipes; sometimes ST effluent is passed through a package treatment plant, reed bed or gravel filter for further treatment before it is discharged to the environment. In properly functioning systems, these secondary treatments reduce the level of pollutants in the effluent, especially in terms of nutrients and pathogens.

3.6 At present, it is required that septic tanks and their drainage fields are located where they cannot affect surface or ground waters, or cause a nuisance to nearby residential properties. In view of this, The Building Regulations (2002) require all STs to be sited and constructed so that they are not prejudicial to human health and will not contaminate any surface water, ground water, or water supply. In particular, the ST must be located more than 7m from, and preferably downslope of, any habitable building. The drainage field into which it discharges should be:

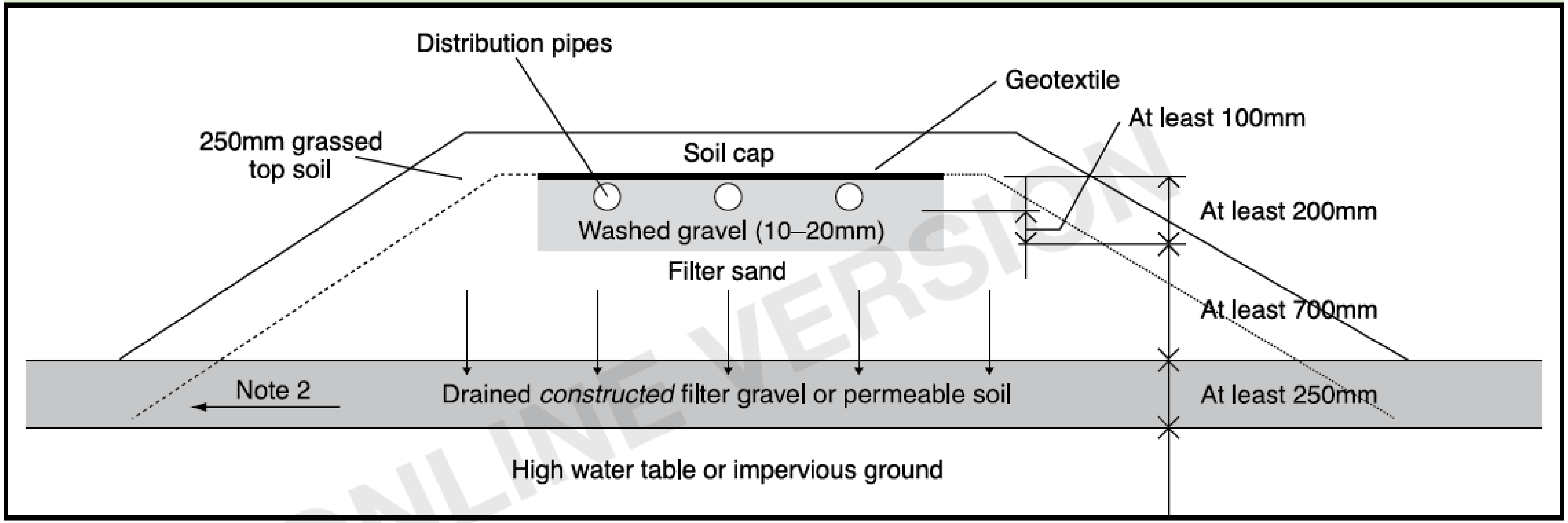
- At least 10m from a watercourse or permeable drain.
- More than 50m from a water supply abstraction point and not within a Zone 1 groundwater protection zone.
- At least 15m from any building and sufficiently far from other systems that the soil soakage capacity is not exceeded.

3.7 Septic tanks must also be positioned so as to ensure aerobic contact between the discharged effluent and the subsoil over a depth of at least 1m (between the lower level of the effluent distribution pipes and the upper level of the water table). In areas where the winter water table is too high to meet this requirement, the Building Regulations (2002) allow a mounded soakaway system, such as that shown in Figure 2, to be installed.

3.8 In addition to the above, the Building Regulations (2002) stipulate the size and design features that a septic tank must have for use in a domestic situation. These can be summarised as follows:

- At least 2,700 litres capacity for up to four users, plus 180 litres for each additional user.
- Water tight.
- Inlet and outlet pipes with access for sampling and inspection.
- Access covers for emptying and cleaning.

3.9 As many older STs were not installed under the regulations outlined above, they fail to meet current building standards. In particular, many are too small, inappropriately sited and badly maintained (Harris & others, 2013; Brownlie & others, 2014; May & others, 2014). The quality of the effluent discharged from a ST is not regulated unless it discharges to an environmentally sensitive area or causes a nuisance to neighbours.



Notes:

1. To provide venting of the filter, the upstream ends of the distribution pipes may be extended vertically above mound level and capped with a cowl or grille.
2. Surface water runoff and uncontaminated seepage from the surrounding soil may be cut off by shallow interceptor drains and diverted away from the mound. There must be no seepage of wastewater to such an interceptor drain.
3. Where the permeable soil is slow draining and overlaid on an impervious layer, the mound filter system should be constructed on a gently sloping site.

Figure 2 Drainage mound for septic tank effluent (*after The Building Regulations, 2002*)

3.10 The Environmental Permitting (England and Wales) Regulations, 2010, currently require all small sewage discharges (eg STs and PTPs) to be registered. However, this has not been implemented yet for existing discharges in England. The regulations also require new discharges to ground within 50m of, or directly to water within 500m of, a designated sensitive area (which includes Special Conservation Areas (SACs), Special Protection Areas (SPAs) RAMSAR sites or Sites of Special Scientific Interest (SSSIs)), to obtain an Environment Agency discharge permit (**www.gov.uk/permits-you-need-for-septic-tanks/print**). In recent months there has been a public consultation on proposals to reform these regulations to simplify the requirements in less sensitive areas. This would involve removing any requirement for registration and record keeping, whilst retaining key measures for preventing pollution. The proposed changes aim to provide a more proportionate and risk based approach to permitting, and they comprise a series of general binding rules that would apply across the whole of England. Although the requirements for permitting of ST discharges in or near to designated sensitive areas would not change, the types of sites classified in this category would be reduced, although they would still include SACs, SPAs, RAMSAR sites and biological SSSIs. As a result of the consultation, there are now plans to introduce this new approach across England in January 2015. It will apply to STs and to PTPs.

Package sewage treatment plants

3.11 Package treatment plants (PTPs), also known as biodisc systems or aerobic treatment units, are similar to septic tanks but contain a rotating biological filter or aeration system that encourages aerobic breakdown of wastes by bacteria. They are often installed as an alternative to STs for on-site treatment of domestic waste. Although PTPs are usually installed as self contained units, they are sometimes installed to provide secondary treatment of ST effluent where an improvement in effluent quality is required.

3.12 Only package treatment plants that have an effluent quality compliant with the European Standard EN 12566-3 (European Committee for Standardisation, 2005) are acceptable to the Environment Agency in England for new installations. This standard requires the system to significantly reduce biochemical oxygen demand (BOD), suspended solids and ammoniacal nitrogen concentrations in the effluent in comparison to the influent waste water before it is discharged from the tank. To gain a compliance certificate, these standards must be maintained under standard test conditions for a 38 week period.

3.13 In general, the effluent from PTPs is perceived to be of much higher quality than that from traditional STs. For this reason, they are often considered suitable for direct discharge to a watercourse if the effluent volume is $\leq 5\ m^3$ per day. However, it should be noted that, although the quality of the effluent from these systems is higher than that from a standard ST, the mandatory tests for certification do not include P content; they only apply to BOD, suspended solids and ammoniacal nitrogen concentrations. This raises questions about the P content of the discharge and its suitability for direct discharge to water.

3.14 Where package treatment plants discharge to a soil soakaway, as described for STs in paragraph 3.3, above. The Building Regulations (2002) provide guidance on the installation of these systems. In summary, they should be sited ≥ 10m from a watercourse or building; they should be tested in accordance with BS 7781 or tested by a ‘notified body’; and, if they require power to operate, they should be able to function adequately without power for up to 6 hours or have an uninterruptable power supply available.

Cess pits

3.15 Cess pits are covered, completely watertight tanks that have no outlet and are used for storing domestic wastewater. They need to be emptied regularly and are only practical as a temporary measure until a more permanent solution can be found. Use of cess pits is discouraged in England and Wales, and not permitted at all in Scotland.

3.16 The Building regulations (2002) require that cess pits are sited at least 7m from, and preferably downslope of, any habitable parts of buildings. In addition, they should have the following design features:

- 18,000 litres capacity for up to two users plus 6,800 litres for each additional user.
- No openings except for the inlet and for ventilation.
- Lockable access covers.
- Access for inspection of the inlet.

3.17 As cess pits need to be emptied regularly, they also require good and safe vehicular access. An 18,000 litre tank serving two domestic users is likely to fill every 6-7 weeks under normal usage. However, as the capacity of a typical emptying tanker is only 9,000 litres, it may need to be emptied more frequently than that.

Effluent P concentrations of septic tanks and package treatment plants

3.18 Of the three on site waste water treatment systems outlined above, only STs and PTPs discharge effluent to the environment and have potential to cause P pollution problems. Cesspools are completely sealed and do not discharge to the environment unless damaged or allowed to overflow.

Septic tanks

3.19 In terms of STs, Lowe et al. (2007) reviewed 150 sources of literature from the US that had been published over the last 35 years to determine the likely effluent P concentrations from these systems. This was followed by a study of 17 field sites to characterise the composition of modern, single, residential septic tanks in more detail (Lowe and others, 2009). In the latter study, a tiered monitoring approach was used, with samples being collected at daily, weekly and monthly intervals.

3.20 During their literature review, Lowe et al. (2007) found that it was difficult to compare published values because of inconsistency in the reported units for P. Most values were reported as total phosphorus (TP), but many were reported for orthophosphate or organic phosphorus. To ensure comparability of results, Lowe et al. (2007) focused their analyses on data reported as TP, only. The results suggested that TP concentrations in ST effluent depended upon the type of system installed, with the lowest values for domestic systems being reported for STs that served multiple households. The authors also highlight the fact that, over the 35 year period being considered, manufacturers had changed the P content of household detergents and concluded that this would be likely to have affected the P concentration of domestic wastewater and effluent over this period.

3.21 The results of the literature review undertaken by Lowe and others (2007), in terms of ST effluent P concentrations, are summarised in Table 1. The values indicate that the average effluent P concentration reported from single source domestic STs in the US was 12.2 mg P l^{-1}, with a range of 3-40 mg P l^{-1}.The corresponding values for multiple source STs were 7 mg P l^{-1} and 5-10 mg P l^{-1}, respectively. Similar values have been reported from the UK and Europe (eg Brix & Arias, 2005 – Denmark [13 ± 6.6 mg P l^{-1}]; May et al., 2014 – UK [15.1 ± 3.5 mg P l^{-1}]).

3.22 The remarkable similarity in effluent P concentrations from these systems across a wide geographical area has led some authors to suggest that chemical reactions within the septic tank, rather than influent P concentrations, may limit the P concentrations in discharged effluent (Zanini & others, 1998; Lombardo, 2006). However, changes in effluent P concentrations achieved through the use of P free detergents (Alhajjar & others, 1990) or through wastewater separation (Brandes, M., 1978) suggest that this is not the case.

Table 1 Descriptive statistics for septic tank effluent total phosphorus concentrations reported in literature from the US (*after Lowe, 2007*)

Type of septic tank	Effluent total phosphorus concentration (mg l^{-1})				
	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

Package treatment plants

3.23 It is generally believed that the P concentration in effluents from PTPs is much lower than that from standard ST systems. For this reason, they are often allowed to discharge directly to a water course (paragraph 3.11). There are very few data available in the published literature on the P content of discharges from these systems. However, the few data that are available suggest that this is not the case. May et al. (2014) sampled a state-of-the-art Klargester Biodisc® tank in England and found the effluent TP concentration to be 12.9 mg P l^{-1}. Similarly, Brownlie et al. (2014) recorded a value of 10 mg P l^{-1} from a package treatment plant in southern Scotland. In addition, monitoring data supplied by the Environment Agency for package treatment plants in Devon, though based on orthophosphate (OP) values rather than TP values, indicated a level of discharge of about 7.7 mg P l^{-1}. This was greater than the 5.5 mg P l^{-1} recorded for OP in effluent discharged by standard STs in the same area.

Phosphorus retention by septic tanks and package treatment plants

3.24 A ST is, primarily, a settlement chamber providing anaerobic conditions that enhance the breakdown of organic and suspended solids in the influent wastewater (Goldstein & Wenk, 1972; Viraraghavan, 1976; Canter & Knox, 1985).However, this environment is, largely, ineffective at reducing the nutrient loading of the wastewater between inflow and outflow. The anaerobic conditions within the tank simply convert most of the influent TP to soluble OP, which is then discharged in the effluent (Bouma, 1979; Wilhelm et al., 1994; Zanini et al., 1998; Beal et al., 2005).

3.25 A secondary treatment system, or PTP, can be installed as an alternative to a ST or to provide subsequent treatment of ST effluent before it is discharged to the soil soakaway. The controlled aerobic environment in these systems accelerates microbial degradation of organic matter. However, most package wastewater treatment systems are not designed to remove P.

3.26 There are very few data available in the literature from which tank P retention rates can be calculated (Lowe, 2007). However, where these values do exist, TP retention rates between inflow and out flow vary widely. This is especially true when average values from a number of tanks are compared rather than those from individual tanks. For example, Lowe and others (2007) found that the median concentration of TP in raw wastewater and ST effluent across a number of systems was 19 mg P l^{-1} and 10 mg P l^{-1}, respectively, and that comparing these values suggested a P removal rate of about 50%. However, the data for raw wastewater was taken from only 8 studies while that for effluent was taken from 49 studies, which may have resulted in unreliable estimates of overall P removal rates Lowe and others (2007). The small amount of data that are available for site specific studies suggest a much lower P retention rate of between 6% and 25% (Brix & Arias, 2005; Gill & others, 2009; Lowe & others, 2009). In general, ST effluent usually contains TP concentrations of 80%–100% of that found in the raw wastewater (Lowe & others, 2007, 2009; McCray & others, 2005; Crites & Tchobanoglous, 1998).

Temporal variation in effluent quality and issues of occasional use

3.27 Both PTPs and STs need a steady flow of sewage to keep the micro-organisms in them alive and to operate effectively. Sites that generate erratic loads (such as holiday accommodation, scout camps, etc.) may need to install a flow balancing system to even out the flow and keep the system working properly (EA, SEPA & EHSI, 2006). There is also evidence from the literature that even the effluent quality from more standard installations varies over time. This evidence is outlined below.

3.28 In terms of the impact of occasional, seasonal or intermittent use on effluent quality, Barscheid and others (1974) compared ST effluent P concentrations from a tank serving a year round trailer park with those from a seasonal, summer use, recreational area. They found that effluent P concentrations from both areas were very similar; suggesting that seasonal use of these systems was having little impact on effluent quality (Table 2). However, the study is not sufficiently detailed to conclude from this that intermittent or seasonal use does not affect effluent quality. This requires further investigation.

Table 2 Effluent P concentrations from septic tanks receiving all year round and seasonal inputs of domestic wastewater (*after Barscheid and others, 1974)*

Wastewater fraction	Effluent P concentration and range (mg P l^{-1})	
	Total phosphorus	**Orthophosphate**
Standard septic tank; trailer park (all year)	7.7 (3.2-10.8) n=9	7.7 (up to 10.8) n=4
Standard septic tank; summer recreation area (June-Sep)	8.2 (2.9-19.5) n=11	7.7 (up to 10.8) n=4

3.29 Gill and others (2009) examined phosphate concentrations in the effluent from a standard, two chamber, ST serving a single household of 6 residents in Ireland over a 14 month period. Samples were collected and analysed at roughly 2-4 week intervals. The results showed that PO_4-P concentrations were highly variable, ranging between 5 mg l^{-1} and 37 mg l^{-1} over the period of investigation (Figure 3). It is unclear why these P concentrations varied so dramatically over time, but the results do raise questions over whether a single effluent sample collected for monitoring purposes, eg when potential pollution problems are being investigated, adequately represents the longer term situation.

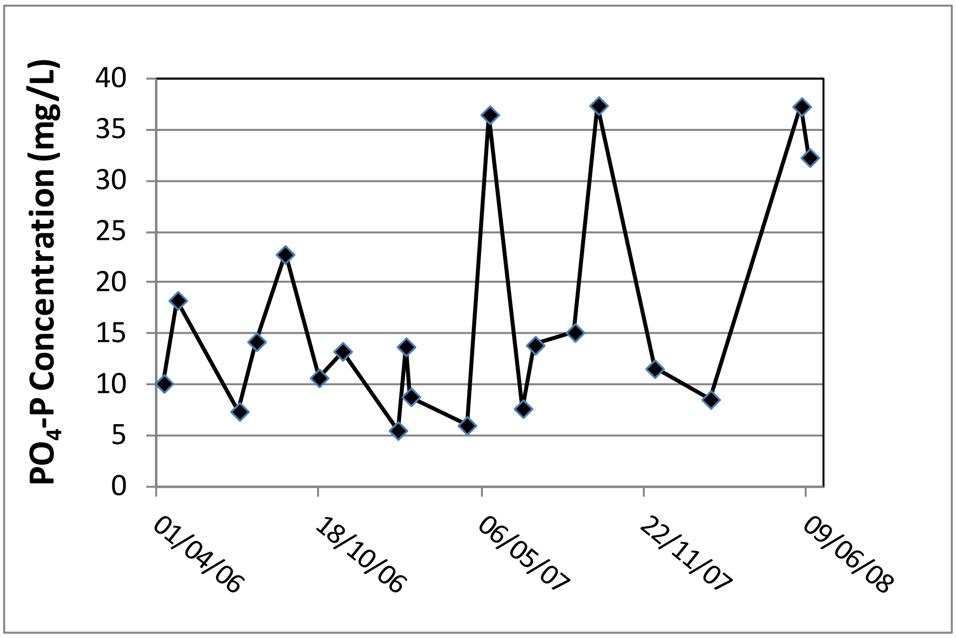


Figure 3 Temporal variation in septic tank effluent PO_4-P concentrations (*Gill, pers. comm.*)

3.30 In a separate study, Heistad and Paruch (2006) monitored TP concentrations in the effluent from a $7m^3$ septic tank that received ordinary domestic wastewater from a house in Norway. The house contained three family flats. The daily hydraulic load to the tank was recorded and values ranged from 450 to 864 litres day^{-1}. The TP concentration in the effluent was measured at 1-3 month intervals over a 21 month period, and values ranging from 2 mg l^{-1} to about 11 mg l^{-1} were recorded. These tended to vary seasonally, with lower values being recorded in winter and higher values in summer (Figure 4). This could suggest that the rate of decomposition of sewage within the tank is affected by seasonal changes in temperature. However, as tanks are usually buried quite deeply in the soil, it might be assumed that they are relatively well insulated from seasonal changes in air temperature and that this is unlikely to be a factor that affects effluent quality.

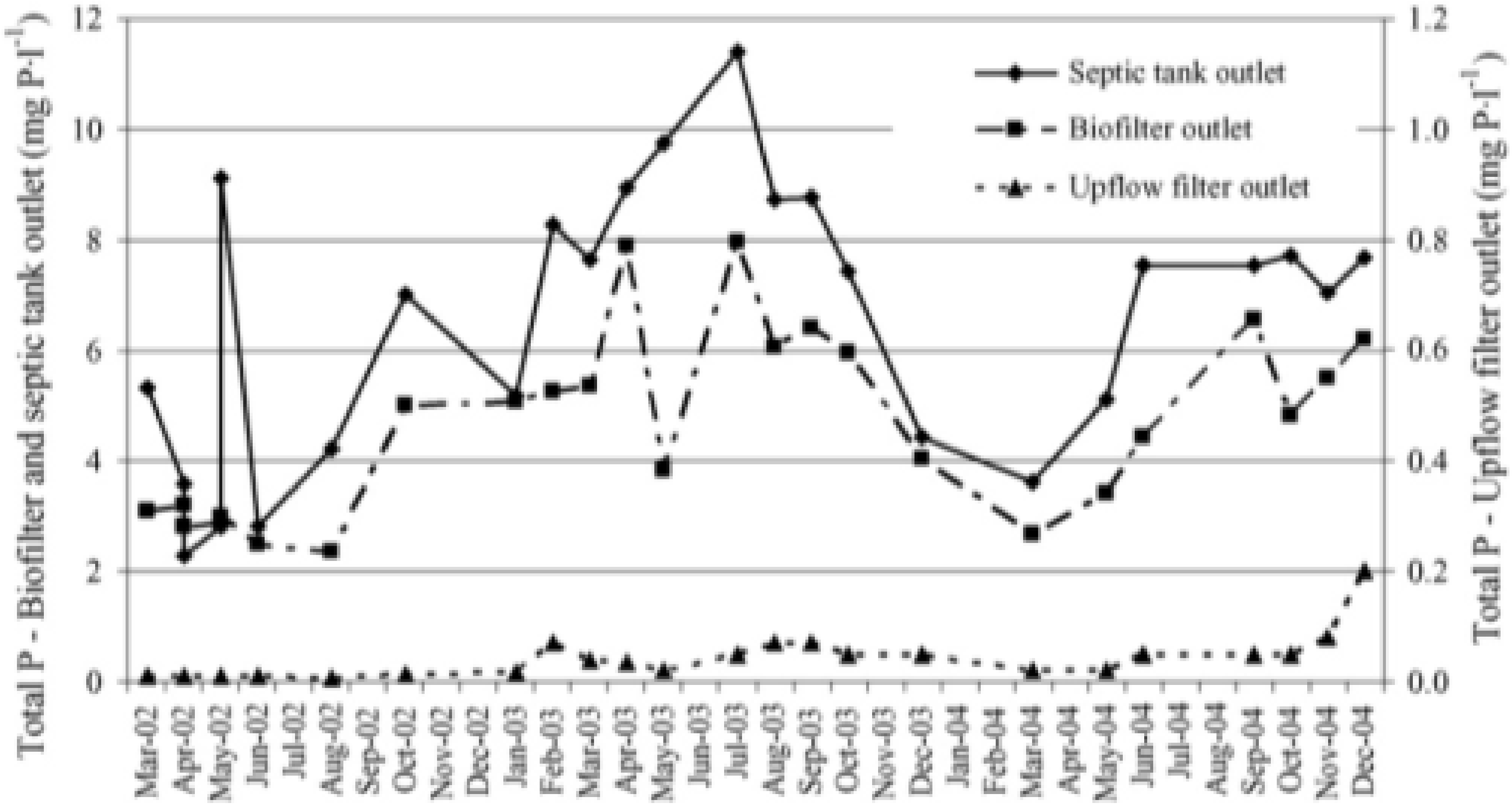


Figure 4 Temporal variation in septic tank effluent TP concentration (*reprinted from Heistad & Paruch, 2006; Copyright 2014 with permission from Elsevier*)

3.31 In contrast to the results of the two studies outlined above, Lowe and others (2009) monitored the P concentrations of the influent wastewater and discharged effluent of 17 individual septic tanks at daily, weekly and seasonal intervals. They found that, although there was considerable variation in the level of P input to the tanks (mainly associated with variations in household activity), the level of P discharged in the effluent was remarkably constant (eg Figure 5). They concluded from the results of their weekly sampling programme that STs equalised not only the flow, but also the chemical composition of the waste.

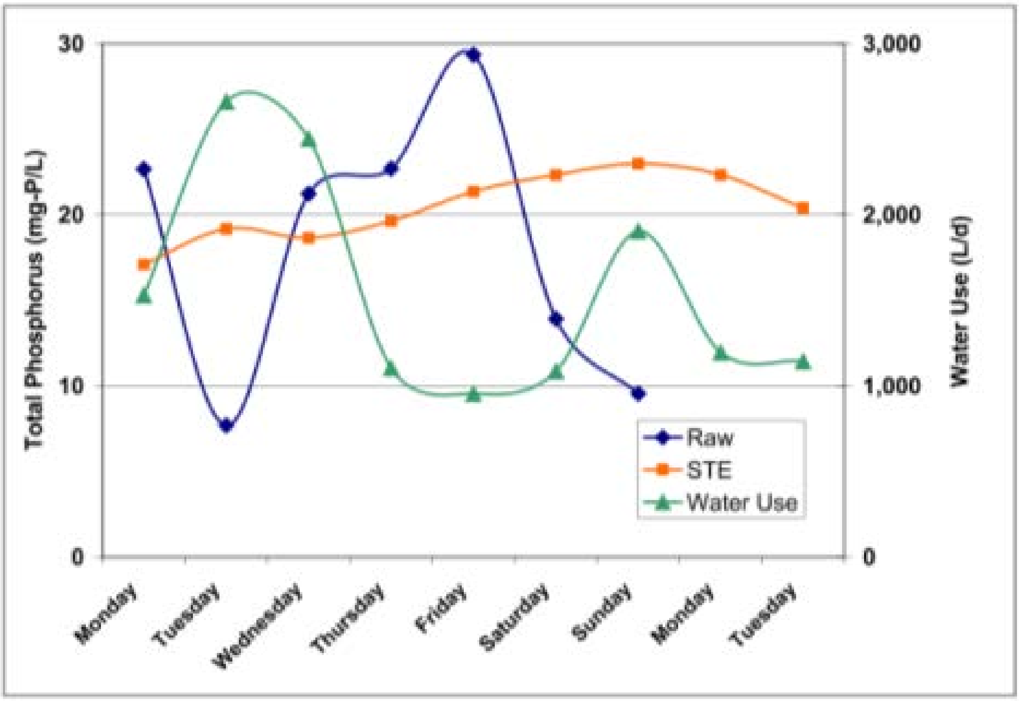


Figure 5 Daily variation in TP concentration of septic tank influent wastewater and discharged effluent over a one week period (*after Lowe & others, 2009; reproduced with permission*)

3.32 A similar result was reported by Whelan and Titamnis (1982) who investigated P concentrations in effluent from 5 two-chambered, concrete septic tanks in Australia. Samples were collected at daily intervals over a 15 day period. The study found that P concentrations in the effluent varied little amongst households and that any observed variation was mostly temporary. Most of the effluent P concentrations recorded in this study were relatively high, ie about 15mg P $^{l-1}$. However, this was probably because the study was undertaken prior to the widespread use of low P detergents.

3.33 In summary, it is unclear from the studies outlined above the extent to which effluent P concentrations vary over time. This requires further investigation if the uncertainty surrounding individual measurements of effluent quality for management and regulatory purposes is to be evaluated.

Mitigation

Use of phosphate free detergents

3.34 Since the 1980s, there have been increasing concerns that phosphates in sewage, especially those from laundry and dishwasher detergents are contributing to eutrophication problems in waters that receive effluent containing domestic waste. Initially, this resulted in a voluntarily reduction in the level of phosphates in detergents by the cleaning products industry. By 2008, the amount of phosphate in raw sewage that was attributable to laundry and dishwasher detergents was estimated to be about 18% and 7%, respectively (Defra, 2008).

3.35 In 2010, the EU announced its intention to ban phosphates in domestic laundry cleaning products with effect from 1 January 2013. In 2012, this resulted in amendment Regulation (EU) No. 259/2012 of Regulation (EC) No. 648/2004, which placed restrictions on the phosphate content of domestic laundry and dishwasher detergents. Limits were set at ≤ 0.5 grams per standard dosage for laundry detergents from 30 June 2013 and ≤ 0.3 grams per standard dosage for dishwasher detergents from January 2017 (European Union, 2012). Regulation (EU) No. 259/2012 was transposed into UK law in May 2013 and, as a result, the amount of phosphate in domestic raw sewage is expected to fall significantly over the next few years.

3.36 As the amount of P discharged from an on-site sewage treatment facility tends to reflect the level of input, increasing use of phosphate free detergents in line with new EU legislation would be expected to reduce P discharges from these systems over time. The effect of using P free detergents on effluent P concentrations from STs was investigated by Alhajjar and others (1990). The study compared the effluent from newly constructed STs serving four volunteer households that were using phosphate based laundry detergents with five that were using P free products. The authors found that the use of P free detergents reduced ST effluent TP levels from an average of 19 mg P l^{-1} to an average of 9 mg P l^{-1} and OP levels from an average of 18 mg P l^{-1} to 8 mg P l^{-1}. The proportion of soluble to particulate P in the effluent also changed, with effluent TP comprising 95% OP if P-based detergents were being used and 88% OP if non-P detergents were being used.

3.37 The results of this review strongly suggest that one way of reducing the discharge of P-laden effluent from STs in the short term is to reduce the level of influent P by encouraging householders to use P-free dishwasher and laundry products. In the longer term, new EU legislation (European Union, 2012) will ensure that the amount of P in these products is reduced over the next few years, with very low values being achieved by 2017.

Wastewater and sewage separation

3.38 Brandes (1978) characterised the effluents from two septic tanks serving a three person household in Ontario, Canada. The tanks processed domestic wastewater that had been collected as grey water (ie from kitchen and bathroom sinks, baths, showers and appliances) separately from wastewater that had been collected as black water (ie from toilets). The effluent from the grey water tank had a TP concentration of 1.4 (0.8 - 3.2) mg P l^{-1}, while that from the black water tank had a TP concentration of 18.6 (16 - 22) mg P l^{-1} (Table 3).

3.39 The results suggest that, although separating grey and black water for treatment purposes may allow partial water reuse, even this is unlikely to reduce the discharge of P to the environment significantly because most of the P is contained in the black water, which has limited potential for re-use. However, because of the influent separation, the detention times of these two tanks varied. That of the grey water tank was about 3 days, similar to that of a 'normal' tank, while that of the black water tank was about 8 days, almost three times longer than that of a 'normal' tank. Brandes (1978) suggests that effluent quality depends on the detention time of the waste water within the tank, but does not comment on whether an increase or decrease on P content would be expected. However, Canter & Knox (1985) suggest that longer detention times and, therefore, more effective breakdown of wastewater may increase the amount of soluble P discharged from the outflow. Soluble P is damaging to the water environment because it is bio-available and may cause eutrophication problems such as algal blooms.

Table 3 Effluent P concentrations from septic tanks receiving different factions of domestic wastewater (*after Brandes, 1978*)

	Effluent P concentration and range (mg P l^{-1})	
Wastewater fraction	**Total phosphorus**	**Orthophosphate**
Grey water only	1.4 (0.8-3.2)	0.17 (0.02-0.26)
Black water only	18.6 (16-22)	15.2 (3.5-21)

Regular de-sludging

3.40 De-sludging of STs and PTPs is often recommended as a way of ensuring that tanks break down waste effectively. It is also assumed that this results in a better quality of effluent. However, Canter and Knox (1985) suggest that any increase in the effectiveness of wastewater breakdown within a tank probably increases, rather than decreases, levels of soluble P in the resultant effluent. If so, regular de-sludging is unlikely to lower P discharges to the environment; it may even increase them.

3.41 There is little information in the literature on the impact of de-sludging on effluent quality from these systems. Although regular de-sludging is widely recommended to householders as a way of reducing pollution from their systems, especially in terms of P discharges, the impact of this process on subsequent effluent P concentrations is unclear. That said, however, it is important to recognise that de-sludging is beneficial to the effective operation of SDD systems in many other ways and, as such, should continue to be encouraged. In particular, it reduces the amount of solids that pass into the soakaway as these may block the soakaway and cause hydraulic failure. There is, however, a need to determine the optimum frequency of de-sludging when these factors are taken into account.

Chemical precipitation

3.42 Chemical precipitation can be used to increase P retention with the sedimentation chamber of a ST or PTP. This has been shown to reduce TP concentrations in the effluent by as much as 85% (Brandes, 1977). The chemically precipitated P is incorporated into the sediment accumulated at the bottom of the tank, which is subsequently removed by de-sludging. Such additives include aluminium sulphate (alum) or sodium aluminate (Long & Nesbitt, 1968). Although chemical precipitation is an effective method of retaining P within these tanks, there may be issues of personal and environmental safety associated with the use of some of these chemicals.

Installation of mounded soakaway systems

3.43 In areas where the water table is high (ie < 1m below the effluent distribution pipes), mounded soakaways are often recommended to replace traditional soakaways (The Building Regulations 2002). The relative effectiveness of mounded systems in removing P from tank effluent, compared to more traditional soakaways has rarely been considered. However, a study by Alhajjar and others (1990) suggests that mounded drainfields are not as effective as conventional drainfields at removing P from tank effluent before it enters groundwater.

3.44 Alhajjar and others (1990) found that P leaching from mounded soakaways could be up to 4.3 times higher than that from a traditional soakaway. That said, however, mounded soakaways can probably reduce the amount of P entering groundwater in areas where the water table is too close to the soil surface. Research suggests that combining this with the use of phosphate free laundry and dishwasher detergents (see paragraphs 3.32 - 3.35, above) will also help reduce P leaching to groundwater.

Initial recommendations on the best option(s) available for reducing P inputs to receiving waters

3.45 The literature reviewed above suggests that the concentration of P in the effluent of STs and PTPs varies according to the way that these tanks are managed. Some of the key features of the variation in effluent P concentrations in relation to different management approaches are summarised in Table 4.

3.46 Based on the existing knowledge and information reviewed above, the most effective options for reducing the levels of P discharged from on-site sewage treatment tanks to the environment are as follows:

1) Reducing P inputs to the tank, eg through the use of P free detergents.
2) Using chemical precipitation to retain P within the tank and incorporate it into the sludge.

3.47 However, it should be noted that chemical precipitation, although it is an effective method of retaining P within these tanks, raises issues of personal and environmental safety associated with the use of these chemicals. Spills may pose a hazard to householders, incorrect dosage may limit effectiveness and disposal of sludge may be more difficult if considered to be contaminated. Also, it is unclear how and to what extent other options that are often recommended, such as frequent de-sludging or replacing traditional STs with PTPs, are effective at reducing the P concentration in tank effluent.

3.48 In areas where the water table is high, ie <1.5 m below soil surface, impacts on nearby watercourses can probably be reduced by installing mounded soakaway systems.

Table 4 Summary of effluent P concentrations from STs in relation to different management practices; average values are given, with ranges in parentheses; n = number of individual observations included

Tank type and management practices	Effluent TP concentration (mg P l^{-1})	Effluent OP concentration (mg P l^{-1})	References
Standard septic tank; P based laundry detergents	19 (17-21) n=4	18 (15-20) n=4	Alhajjar & others (1990)
Standard septic tank; P-free laundry detergents	9 (6.4-16) n=5	7.9 (5.5-11) n=5	Alhajjar & others (1990)
Standard septic tank; trailer park (all year)	7.7 (3.2-10.8) n=9	7.7 (up to 10.8); n=4	Barshied & Elbaroudi (1974)
Standard septic tank; summer recreation area (June-Sep)	8.2 (2.9-19.5) n=11	7.7 (up to 10.8); n=4	Barshied & Elbaroudi (1974)
Standard septic tank; grey water only	1.4 (0.8-3.2) n=1	0.17 (0.02-0.26) n=1	Brandes, M. (1978)
Standard septic tank; black water only	18.6 (16-22) n=1	15.2 (3.5-21) n=1	Brandes, M. (1978)
Standard septic tank	17.2 +/- 7.0 n=10	No data	Brix & Arias (2005)
Standard septic tank; single source	12.2 (3-40) n=49	No data	Lowe & others (2007)
Standard septic tank; multiple source	7 (5-10) n=6	No data	Lowe & others (2007)
Standard septic tank	10.3 (0.2-33.4) n=61	No data	Lowe & others (2009)

Key knowledge gaps

3.49 There is a need for a more evidence based approach to decision making in relation to selecting the best management options for on-site waste water treatment systems. This is particularly true in relation to reducing the flow of P from these systems to SSSI waterbodies. In order to achieve this, the following questions need to be addressed:

1) To what extent do P concentrations of septic tank (ST) effluents differ from those of package treatment plant (PTP)?
2) How does temporal variation in P output from STs and PTPs (from sub-daily to seasonal) affect the level of uncertainty associated with collecting and analysing a single effluent sample for monitoring/regulatory purposes, and how significant is the potential ecological effect of this variability?
3) How effective are STs and PTPs at breaking down waste, if usage is intermittent or seasonal, and what are the main implications for P discharges?
4) Does de-sludging reduce effluent P concentrations?

3.50 In addition to the above, it is also important to determine which is most important, P loads or concentrations, in determining the impact of P discharges from STs and PTPs on the freshwater environment. However, loads, rather than concentrations, are very difficult to determine once the P has been discharged into the soil soakaway. This is because accurate measurements of both P concentrations and flows in the groundwater are required and groundwater flow is very difficult, time consuming and expensive, to measure. So, it is likely to be more cost effective in the short term to focus future research on the factors that affect effluent P concentrations from these tanks and how this information can be used to reduce P outputs through improved tank management.

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