Natural England Commissioned Report NECR171

Development of a risk assessment tool to assess the significance of septic tanks around freshwater SSSIs

Phase 1 – Understanding better the retention of phosphorus in the drainage field

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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 that are not meeting favourable condition and for water bodies that are not meeting good ecological status under the Water Framework Directive. To deliver the objectives of Biodiversity 2020 and the Water Framework Directive there is a need to sufficiently understand and effectively manage these sources of pollution. This is particularly true in relation to phosphorus.

There is a growing body of evidence to suggest that small domestic discharges, such as septic tanks, pose an environmental risk to freshwater habitats in certain situations; however, our ability to systematically and accurately assess this risk on a site by site basis is currently limited by a number of key knowledge gaps. These need to be addressed to enable decisions to be made on how best to protect sensitive SSSIs from phosphorus enrichment. Knowledge gaps include:

- the need to better understand how the lifestyle of a household, and the way that they manage their septic tank affect effluent quality;
- the distance over which phosphorus from these systems travels through the soil, both laterally and vertically; and
- how local environmental conditions affect the likelihood of phosphorus from these sources reaching a nearby water body.

To help address this issue, Natural England, with a contribution from the Broads Authority, commissioned the Centre for Ecology & Hydrology (CEH) in 2013 to investigate:

- The factors affecting the concentrations of phosphorus in discharges from septic tanks to the drainage field.
- The movement of phosphorus in septic tank effluent plumes through the aerated zone of the drainage field, ie within the soil that is above the water table.

The findings contained within this report have allowed Natural England to refine and implement a risk assessment methodology for septic tanks, which was developed through a previous project with CEH (NECR170).

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Further information
This report can be downloaded from the Natural England website: **www.gov.uk/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

There is a growing body of evidence suggesting that small domestic discharges (in practice mainly septic tank systems - STS) pose an environmental risk to freshwater habitats. However, the extent of that risk and its potential impact across the freshwater SSSI series are not well understood. This makes it difficult to make evidence based decisions on where such systems can be located safely in rural areas.

Several knowledge gaps need to be addressed before a more robust evidence based risk assessment tool can be developed for protecting sensitive SSSIs from phosphorus (P) enrichment. These include (1) how the lifestyle of a household and the way that they manage their septic tank can affect effluent quality, (2) the distance over which phosphorus (P) from these systems travels laterally and vertically through the soil profile, and (3) how local environmental conditions affect the likelihood of P from these sources reaching nearby waterbodies.

Diffuse water pollution (DWP) is a major cause of SSSI sites not meeting favourable condition and also not meeting objectives under the Water Framework Directive. Therefore failure to effectively tackle diffuse water pollution presents a significant risk to the delivery of the Biodiversity 2020 and Water Framework Directive requirements. The current project was undertaken to investigate some of the processes outlined above and provide information to underpin the development a ‘family’ of buffer zones to help protect SSSIs from P enrichment associated with rural development. The project was divided into two parts:

1) Factors affecting the discharge of P from the septic tanks to the drainage field.
2) The movement of P in septic tank effluent plumes through the aerated zone of the drainage field, ie within the soil that is above the water table.

It should be noted that the results and conclusions from this study do not apply to situations where STS discharge directly to water, or where there is enhanced connectivity between STS discharges and waterbodies *via* pipes and field drains or through groundwater movement. The results apply to the part of the soakaway that comprises aerated soil that sits above the water table, only.

The average P concentration in effluent discharged from the 11 treatment tanks studied was about 11 mg P/l of soluble reactive P (SRP) and 15 mg/l of total phosphorus (TP). Although a package treatment plant (PTP) had been installed at one of the sites to improve the quality of the effluent discharged, there was no evidence that this had been effective in reducing P concentrations. Discharges from this tank were still high, ie 10.7 mg P/l of SRP and 12.9 mg P/l of TP, and were very similar to those measured in effluent from the older and more traditional tanks. Although no sound conclusions can be drawn from this one example, it is recommended that this issue is investigated further. This is because the current perception that discharges from PTPs are much lower in P content than those from standard septic tanks underpins guidance that allows PTPs to discharge directly into watercourses if installed correctly.

The borehole data showed significant P enrichment of the soils to a depth of just over 1 m below the effluent distribution pipes. The observed reduction in soil P enrichment with depth suggests that much of the P in the effluent that moves vertically through the aerated part of the soil profile is retained by those soils. Although based on a small number of samples from only two sampling points with the same soil type, this strongly suggests that the soils can provide an important function in terms of P retention within these systems. This function is likely to be compromised if the soil becomes waterlogged, as may occur during periods when the water table is high. The results suggest that it may be very important that soil soakaways are situated in areas that provide a significant depth of aerated soil below the effluent distribution pipes. However, this requires further investigation.

In many areas of the UK, orthophosphate is added to water supplies to reduce the levels of lead in drinking water. This study found that tap water at the Norfolk and Oxfordshire study sites had elevated levels of SRP, ranging from 0.9 to 1.1 mg P/l, that were probably attributable to water treatment. Although the number of samples is small, the data tend to suggest a positive relationship between the level of P in tap water in Norfolk and Oxfordshire and that in the effluent from the corresponding septic tanks. This apparent relationship between tap water P and effluent P needs to be explored in more detail given current proposals to reduce levels of lead in drinking water still further as this may lead to the addition of even more orthophosphate.

It is widely believed that the age of a septic tank reduces its effectiveness in treating domestic wastewater, and many older tanks are replaced by newer systems for this reason. This hypothesis was tested in the present study, albeit on only a small number of tanks aged between 2 to 50 years, many of which had never having been emptied, inspected or repaired. The results showed that there was some evidence that older tanks discharge higher levels of P to the environment than more recently installed tanks. However, this was inconclusive because the sample size was too small to separate this effect from other factors that may also exert an influence on P discharge, such as the lifestyle of the household and the level of repair and maintenance of the system. More detailed studies on a larger number of tanks are required to separate the effects of these different drivers, statistically.

Factors that cause incomplete breakdown of particulate matter within a tank, such as infrequent emptying, physical damage, or too low a retention time, can increase the discharge of particulate matter from the tank. This particulate matter may clog the soil soakaway, causing hydraulic failure of the drainage area and increasing the likelihood of P pollution problems. At some of the sites studied, the proportion of particulate P (PP) in the effluent was found to be very high, accounting for up to 86% of the total P discharged. The factors causing high levels of PP to be discharged in the effluents from some tanks but not others could not be determined due to insufficient data. This requires further investigation.

Extracted porewater from the septic tank drainage fields was analysed for SRP and total dissolved P content, while soil samples were analysed for indicators of soil P status (ie Olsen-P concentration (Olsen-P), P sorption index (PSI) and equilibrium phosphorus concentration at zero sorption (EPC_0)). The results suggested that P originating from septic tank discharges may move laterally through the soil profile for a distance of 20-30 m in many of the soil types included in this study. Evidence of this was found in the porewater P values and in the indicators of soil P status measured. This was especially true of TDP concentrations and Olsen-P values, but was also reflected in PSI and EPC_0 values.

The results of this study suggest that the current legislative value of 10 m (The Building Regulations, 2000) for the separation of a septic tank soakaway from a watercourse is probably insufficient to protect that waterbody from being polluted by P discharges, even where the local hydrology of the system does not provide a shortcut for the faster delivery of septic tank discharges to water. So, septic tank systems may need to be located at setback distances of greater than 10 m if sensitive waterbodies are to be protected from P plumes that are moving laterally through the upper layers of the soil. The level of risk seems to depend, primarily, on soil type and soil P characteristics. However, quantifying these relationships sufficiently to inform a risk assessment process has proven difficult within the resource limitations of the current project. It is recommended that the data are investigated further, and in combination with national scale spatial datasets and local knowledge, to inform evidence based decision making at the local scale in relation to permitting local development within SSSI boundaries and mitigating existing problem sites.

Although this study has provided evidence of the potential for P to travel at least 30 m from the septic tank, in general it has shown that this part of the soil soakaway has the capacity to remove most of the P from STS effluent before it enters a waterbody that is at a greater distance. However, it should be noted that this capacity will be reduced if the functioning of this system is compromised by enhanced hydrological connectivity, such as that caused by direct discharge to a waterbody, the installation of local drainage channels and/or a high water table . In addition, a reduction in P retention capacity may also occur if soils become temporarily waterlogged for any reason, such as during local flooding or as a result of hydraulic failure of the soakaway caused by the incorrect repair and maintenance of the system. The information obtained from this study can now be used to improve the methodology for assessing the risks posed by STS on SSSI waterbodies that was originally proposed by May et al. (2010).

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Glossary

DWP	Diffuse water pollution
EPC_0	Equilibrium phosphorus concentration of soil; this is the SRP concentration at which net P adsorption and desorption by soil is zero; as such, it reflects to the SRP concentrations of soil porewater
Olsen-P	Readily available (labile) P within the soil that can exchange with the soil solution relatively rapidly
P	Phosphorus
PP	Particulate phosphorus; the fraction of phosphorus in a sample that is attached to particles
PSI	Phosphorus sorption index; the amount of P adsorbed by the soil relative to the concentration of P left in solution after an addition of 300 mg P/kg; this gives an indication of the relative P sorption capacity of the soil
SRP	Soluble reactive phosphorus; soluble fraction of phosphorus in a sample, mainly consisting of orthophosphate (PO_4)
SSSI	Site of special scientific interest
STS	Septic tank system; this comprises the tank plus the soil soakaway
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

There is now a growing body of evidence suggesting that small domestic discharges (in practice mainly septic tank systems - STS) pose an environmental risk to freshwater habitats in certain situations and under certain conditions (e.g. May and others, 2010; Withers and others, 2011; Withers, 2012; Withers and others, 2013). However, the extent of this risk and its potential impact across the freshwater SSSI series are not well understood. This makes it difficult to make evidence based decisions on where such systems can be located safely in rural areas.

May and others (2010) identified several knowledge gaps that need to be addressed before an evidence based risk assessment tool could be developed for protecting sensitive SSSIs from phosphorus (P) enrichment. These included (1) how the lifestyle of a household and the way that they manage their septic tanks can affect effluent quality, (2) the distance over which P from these systems travels through the soil, and (3) how local environmental conditions affect the likelihood of P from these sources reaching a nearby waterbody. Diffuse water pollution (DWP) is a major cause of SSSI sites not meeting favourable condition and also of not meeting objectives under the Water Framework Directive. Therefore failure to effectively tackle diffuse water pollution presents a significant risk to the delivery of the Biodiversity 2020 and Water Framework Directive targets.

This project was undertaken to investigate some of the processes outlined above and to contribute to the evidence base needed to develop a ‘family’ of buffer zones to help protect SSSIs from any damaging P enrichment associated with rural development. It was intended that, in the longer term, the results would provide a better understanding of how levels of risk vary across sites and help identify where management actions aimed at improving existing installations are likely to be required. It was also intended that the results would contribute to the development of risk assessment criteria that could be used to indicate where future plans for rural development could be damaging to nearby waterbodies.

The specific aims of this project were to:

1) Examine the relationship between STS management and maintenance and the discharge of P to the environment.
2) Investigate how far P discharges from these systems travel through the upper, aerated zone of the soil soakaway.

The study focused on STS that were more than 100 m from a waterbody and at least 2 m above the high water table, because these were less likely to be causing P pollution of waterbodies than those that were less than 100 m from a waterbody and less than 2 m above the high water table. As such, the study focused on P movement through the aerated zone of the soils, ie the part of the system where P uptake from the effluent plume is most likely to occur in a properly functioning system. This approach is in contrast to most other studies, as these have focused on STS that are liklely to be causing a problem. The results of this study will help inform a follow-up desk based study to estimate the relative risk posed by existing STS across the freshwater SSSI series.

It should be noted that the results and conclusions from this study do not apply to situations where STS discharge directly to water, or where there is enhanced connectivity between STS discharges and waterbodies *via* pipes and field drains or through groundwater movement. The results apply to the part of the soakaway that comprises aerated soil that sits above the high water table, only.

The results of this and many other studies have shown that closer attention needs to be paid to the environmental impacts of STS in terms of P pollution delivered to sensitive waterbodies. However, there is still little information on the number and location of STS across many parts of the UK.

In Scotland, a compulsory registration scheme was introduced in 2009 for new properties, properties that are sold, or those that have been identified by the Scottish Environment Protection Agency

(SEPA) as causing pollution problems (**http://www.sepa.org.uk/water/water_regulation/car_application_forms/septic_tank_registration.aspx**). Currently, this registration requires the following information to be collected: location, type of system, and type and size of discharge for all systems, and soil percolation rates and effluent quality for new systems, only. Over time, this will create a full set of STS registrations.

In Wales, STS registration is compulsory for septic tanks serving less than 9 people and package treatment plants serving less than 27 people, or where sewage effluent is being discharged close to a SSSI or a source protection zone for drinking water. The information required from the owner during the registration process includes location, age (ie installation before or after April 2010), system type, discharge type and, for discharge to soakaway only, whether the system is more than 50 m from a borehole used for water supply (**http://www.environment-agency.gov.uk/homeandleisure/132391.aspx**). Almost all STS in Wales have been registered since this became compulsory.

In England, there is no compulsory registration system in place although voluntary registrations are possible. Here, the UK government is planning a consultation on proposals for revising the regulation of STS (including those from septic tanks and package sewage treatment plants) to reduce the burden on households and businesses who rely on them, rather than mains sewerage systems, to manage their waste. Whilst this is happening, STS owners are not required to register, but must still be able to meet the requirements of the exemption and permits are still required for STS that are in a source protection zone 1 and discharging to a soil soakaway, and for new STS that are in or near designated habitat sites as defined in Environment Agency guidance. It is estimated that the location of about 90-95% of systems in England are unknown (May et al., 2010).

In terms of registration fees, Scotland currently charges a registration fee, while Wales and England offer free registration. Only in Scotland, are P discharges from these systems regulated but this is not required in all locations; only where SEPA require it, for example in a designated P-sensitive catchment. In some areas of Scotland, P mitigation forms part of the planning process for new building developments that require on-site sewage treatment facilities.

2 Methods

Sampling and analyses

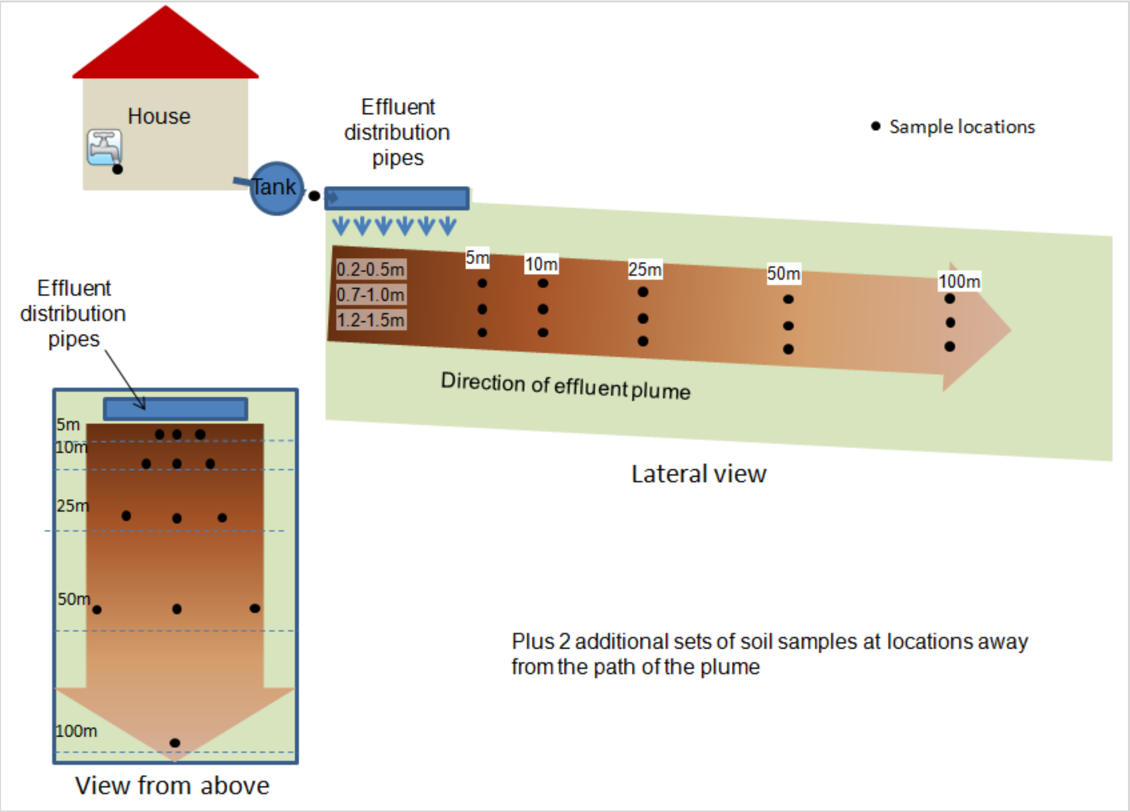
To address the main aims of the project, the study focused on STS that were situated at a distance of more than 100 m from a natural or constructed drainage network and at a height of 2 m or more above the water table. This was to focus on STS where the effectiveness of P uptake in the soil soakaway was less likley to be undermined by enhanced connectivity to a water course or interactions with groundwater.

At each STS site, samples of the following were collected:

- Tap water – to assess the amount of effluent P that was likely to have entered the STS through the domestic water supply.
- STS effluent – to assess the P concentration within the discharge.
- Soil and soil porewater – to investigate the path of P transport through the aerated zone of the soil soakway.

Sample collection

Samples of tap water were collected with a plastic bottle from the kitchen tap of each house visited. Their P content was then determined by analysing for soluble reactive P (SRP) and total dissolved P (TDP), using the methods described below.



Plus 2 additional sets of soil samples at locations away from the path of the plume

Figure 1 Outline sampling strategy for collecting tap water, septic tank effluent, and soil and porewater samples from the soakaway

Samples of septic tank effluent were obtained by sampling the liquor in the final chamber of each tank, close to the outlet pipe. These were secured by dipping a sample bottle into the liquor using a long pole. Access to each tank was gained *via* an existing manhole or inspection cover. Effluent samples were analysed for SRP and TP concentrations. 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 these results as follows:

$$PP = TP - SRP$$

Soil samples from within the soakaway were collected at various and increasing distances from each tank (i.e. approximately 5 m, 10 m, 25 m, 50 m, 100 m), and along the most likely direction of travel of the effluent plume (Figure 1). This direction of travel was determined, initially, from the surface topography using Ordnance Survey® maps. However, minor modifications to the overall sampling regime were necessary at most sites to take account of local conditions and issues relating to access. In addition, at OXON3, sampling was focused on an area below the effluent distribution pipes to investigate downward, rather than horizontal, movement of the effluent plume at this site.

The possible use of an electromagnetic induction (EMI) imaging system to track the path of the effluent plume (Lee and others, 2006) was also investigated. This non-invasive technique has the potential to identify electrical contrasts within the soil that are generated by an effluent plume. However, tests of this technique undertaken in Shropshire at the beginning of the study were inconclusive and the technique was not applied elsewhere. This trial of the technique and the results obtained are summarised in Appendix 1.

As effluent plumes were not easy to locate within the soil matrix using the EMI system, the likely direction of flow was derived from expert opinion taking into account the location of the tank and effluent distribution pipes, the composition of nearby vegetation, the slope of the land and any available local knowledge.

Plate 1 Soil coring with an auger

Soil cores, approximately 0.3 m in length, were collected with a standard auger (Plate 1) at approximately 0.5 m depth intervals, where possible, across the drainage field (Figure 1). These samples were collected to provide information on changing soil P status and porewater P concentrations with depth and distance from the source. In many cases, sampling and subsampling strategies had to be modified to take account of local site conditions, such as soil structure and the depth of the underlying bedrock material. At the Hampshire sites, it was not possible to take samples close to the tanks as these were situated in inaccessible private gardens.

On return to the laboratory, soil samples for determinations of soil P status were air dried at <30^{o}C and then ground to a particle size of less than 2 mm for later analysis (see below). Soil samples for porewater extraction were centrifuged at about 14,000 RPM for 30 minutes and the resultant liquid collected for chemical analysis. However, it should be noted that many soil samples did not contain enough pore water (ie > 2 ml) to allow subsequent analysis.

Chemical analysis of water samples

Porewater samples for determination of total P (TP), total dissolved phosphorus (TDP) and soluble reactive P (SRP) concentrations were processed in the laboratory using standard, internationally recognised, methods such as acid digestion, followed by colorimetry. These analyses were undertaken on whole water samples for TP (Eisenreich and others, 1975) and on filtered samples (0.45 µm membrane filter) for TDP and SRP (Murphy & Riley, 1962).

Samples for TP and SRP determinations were analysed using a Seal AA3 spectrophotometer. The SRP concentration was determined by colorimetry using the molybdenum blue method. A six-point calibration curve was used with a range of 0-1500 µg/l PO_4 and the detection limit was 7.0 µg/l PO_4-P. Samples with a standard known concentration of P were also measured for Quality Assurance/Quality control (QA/QC) purposes.

Samples for TDP determinations were analysed using a Varian Cary 50 Bio spectrophotometer. The samples were digested with acidified potassium persulphate in an autoclave at 121^{o}C. The TDP concentration was then determined by colorimetry using the molybdenum blue method. A ten-point calibration was used with a range of 0-700 µg/l PO_4-P and the detection limit was 7.0 µg/l PO_4-P. Known concentrations were also measured for QA/QC purposes

Chemical analysis of soil samples

Olsen-P is routinely used to estimate the amount of readily available (labile) P within the soil that can exchange relatively rapidly with the soil porewater. Olsen-P was determined by extraction in 0.5M sodium bicarbonate at pH 8.5 according to the method described by Olsen and others (1954). Olsen-P is measured as a concentration and values are reported in mg P/kg of soil. In line with the recommendations of Defra (2010) for agricultural soils, and assuming a soil density close to 1, Olsen-P values from 0-9 are generally considered to indicate P deficiency, 10-15 are low, 16-25 are optimal for crop growth, 26-45 are high, and values greater than 46 are classified as unnecessarily high. In line with the Defra Code of Practice for the Protection of Water (Defra 2009), Olsen-P concentrations above 46 mg/kg are considered to be likely to pose an increased risk of P being transferred to water in land runoff, potentially causing eutrophication.

The equilibrium P concentration of the soil (EPC_0) is the SRP concentration of the porewater at which net P adsorption and desorption by the soil is zero. This value provides an indication of the P concentration of in the soil solution, or porewater (Holford and others, 1974). To determine these values, 1 g of soil was shaken with 20 ml of 0.01M potassium chloride (KCl) containing either no P or 15 mg P/l (equivalent to an addition of 300 mg P/kg) for 16 hours at 20-25^{o}C. The equilibrium P concentration determined after shaking with no added P (EPC_0) provides an estimate of the EPC_o concentrations in the soil solution. These are reported in mg/L and can be compared directly to SRP concentrations travelling in soil leachates that have had a long contact time with the soil matrix. Where soil water that has had very little contact time with the soil, previous work suggests that a target SRP concentration of 0.15 mg/L in runoff equates to an EPC_o concentration of 0.85 mg/L (Withers and Flynn, 2006).

The amount of P adsorbed by the soil relative to the concentration of P left in solution after an addition of 300 mg P/kg is known as the P sorption index (PSI). This gives an estimate of the relative P sorption capacity of the soil (Bache and Williams, 1971). For all determinations, P in solution was measured colorimetrically, following the method of Murphy and Riley (1962). Being a ratio, PSI values have no units. Values >10 indicate that the soils have a sufficiently large capacity to adsorb P that they can maintain a low level of P saturation and low concentrations of P in the soil solution. From previous work (Withers and Flynn, 2006), when PSI values fall below 8, SRP concentrations increases as the percentage P saturation increases. Very low values are indicative of soils with low P sorption capacity.

Site selection

Target areas for sampling STS were selected through discussion with Natural England, the Broads Authority and the steering committee. Sampling sites were located within the following catchments:

1) River Clun, Shropshire
2) River Wylye, Hampshire
3) River Thames, Oxfordshire
4) Broads, Norfolk

These study areas encompassed a range of geographical locations across the English landscape, most of which were within the catchments SSSI waterbodies (Figure 2).

Summary information on the location, major soil types and average annual rainfall within each of these broad geographical areas is shown in Table 1. Average rainfall for each site was calculated from the long term values for rain gauges close to each site, as follows:

- Clun: Gauge 054014 River Severn at Abermule, 1971 – 2000
- Wylye: 043012 River Wylye at Norton Bavant, 1971 – 2000
- Oxfordshire: 039027 River Pang at Pangbourne, 1968 – 2000
- Norfolk: 034019 River Bure at Horstead Mill, 1974 – 2000

Figure 2 Location of study sites

Table 1 Summary information on location, major soil types and average rainfall in each study area

Location	Major soil type	Average rainfall (mm/y)
Clun, Shropshire	Heavy soils; some lighter loams	1293
Wylye, Hampshire	Shallow chalk; greensand; river alluvium	950
Thames, Oxfordshire	Loam over chalk	707
Broads, Norfolk	Muddy sand sediments over shelly crag	667

To obtain sampling sites for the study, the project team contacted more than 200 owners of STS in Shropshire, Hampshire, Oxfordshire, and Norfolk and obtained details of their systems, their locations, their availability and their suitability for the project. Of these, a total of 11 sites were sampled. These are described below.

Obtaining permission to sample STS for this study was, in many cases, very difficult; this limited the number of sites that could be included. Also, it was not possible to replicate sample collection exactly across all sites due to local conditions and access restrictions. In some cases it was not possible to obtain a tap water sample, in others the tank could not be accessed, elsewhere householders were concerned about damage to their gardens and refused access to some parts of the drainage field. A summary of samples that were successfully collected from each site is shown in Table 2.

Field sites were selected to meet the requirements of this project and represented a range system types. The main risk criteria being addressed were those shown in Table 3. So, systems were chosen that were, as far as possible, more than 100 m from a waterbody, more than 2 m above the winter water table and with a drainage field situated on a shallow slope. According to the literature, meeting these criteria should have provided a best case scenario in terms of the likely level of functioning of the STS in relation to factors associated with location. The degree of slope was calculated from the GPS locations and height measurements collected at each soil coring point.

Table 2 Summary of samples collected from each site visited

Location	**Site code**	**Samples collected**		
		Tap	**Tank**	**Soakaway**
Shropshire	CLUN1	Yes	No	Yes
Shropshire	CLUN2	Yes	No	Yes
Shropshire	CLUN3	Yes	Yes	Yes
Hampshire	WYLYE1	No	No	Yes
Hampshire	WYLYE2	No	No	Yes
Oxfordshire	OXON1	No	Yes	Yes
Oxfordshire	OXON2	Yes	Yes	Yes
Oxfordshire	OXON3	No	No	Yes
Broads	BROADS1	Yes	Yes	Yes
Broads	BROADS2	Yes	Yes	Yes
Broads	BROADS3	No	Yes	Yes

Table 3 Factors associated with location that were addressed in this study as having a high likelihood of affecting the risk of STS contaminating nearby waterbodies with P laden effluent (adapted from May and others, 2010)

Attribute	Level of risk			References
	High	Medium	Low	
Soil type	High or low permeability		Medium permeability	Canter & Knox (1985)
Distance to watercourse	< 100 m	100 – 400 m	≥ 400 m	McGarrigle & Champ (1999)
Winter water table height	< 1m	1-2m	> 2m	Canter & Knox (1985)
Slope	≥ 20%	5% - < 20%	< 5%	Canter & Knox (1985)

The sites selected spanned a range of ages, types, design capacities, and levels of management and maintenance. As far as possible, this information was collected from the owners or householders through questionnaires based on those used in previous studies (e.g. Arnscheidt and others, 2007; Campbell and Foy, 2008; Fildes, 2011; Brownlie, pers. comm.). These questionnaires (see Appendix 2) were completed at the time of sampling or shortly afterwards, where possible. However, in some cases, owners were unwilling or unable to supply this information for their sites (Table 4).

Where willing, owners provided information on the following aspects of their STS:

Age and design

1) Age of property
2) Age of septic tank
3) Area of soakaway
4) Design of septic tank and building materials used to construct it
5) Soil percolation rate and date/month tested during installation phase
6) Discharge type
7) Size of household(s) served by the septic tank
8) Size/capacity of the tank
9) Annual water usage (if metered)
10) Presence/absence of connection to roof runoff

Management & maintenance

1) Household diet (i.e. whether or not vegetarian)
2) Type of dishwasher/washing machine detergents
3) Frequency of de-sludging
4) Date of last emptying
5) Frequency of inspection/repair of:
    a. tank
    b. drainage field
6) Tank condition

Table 4 Completion rate for septic tank questionnaires distributed to owners or householders who participated in the study

Sampling date	Location	Site code	Questionnaire completed
29/07/13	Broads	BROADS1	Yes
29/07/13	Broads	BROADS2	Yes
30/7/13	Broads	BROADS3	Yes
8/05/13	Hampshire	WYLYE1	No
8/05/13	Hampshire	WYLYE2	No
01/03/13	Oxfordshire	OXON1	No
01/03/13	Oxfordshire	OXON2	Yes
28/06/13	Oxfordshire	OXON3	Yes
14/02/13	Shropshire	CLUN1	Yes
14/02/13	Shropshire	CLUN2	Yes
14/02/13	Shropshire	CLUN3	Yes

3 Site descriptions

The sites selected for sampling are described in detail, below. Site descriptions are grouped by geographical location at county level. Coring locations are shown for each site. Their pattern of distribution across the drainage field differs slightly from site to site due to practical considerations. In general, however, the labelling of the coring sites is consistent and as follows. The numbers reflect distance from the STS (with ‘1’ being the closest and ‘5’ the furthest away) and the associated letters indicate different coring locations along an arc-shaped horizontal transect at each sampling distance.

Shropshire

CLUN1

This site was sampled on the afternoon of 14th February 2013.

The septic tank, itself, was surrounded by trees (Plate 2: left) and discharged to a soakaway. There was only a slight downhill slope (about 1%) in the drainage field, which was under grass and bordered by a hedge to the east of the property (Plate 2: right). This hedge was parallel to a road that ran in a roughly north-south direction past the site (Figure 3).

The distribution of sampling points for this site is shown in Figure 3. The soils in the drainage field were silty, slightly red in colour and very stony beyond about 0.4 m depth (Plate 3). The bedrock (sandstone) was situated at about 0.5 m and 0.7 m below the surface, so most of the drainage area could be sampled to a depth of 0.2 – 0. 5 m, only. In some locations, sample depths of up to 0.8 m were possible. Most of the samples taken near the septic tank had a maximum depth of about 0.5 m.

Plate 2 Septic tank location (left) and drainage field (right) at site CLUN1

Plate 3 Soil profile within the drainage field at site CLUN1

The septic tank at this site was estimated to be about 45 years old and was constructed of brick. It was not in a good state of repair and presented a health and safety risk to the field team. In particular, the manhole cover was so badly corroded that it could not be lifted. So, no tank samples could be taken at this site. However, it was possible to collect a water sample from the kitchen tap and a full set of soil samples from the drainage field, albeit to a rather shallow depth.

The owner completed and returned a user questionnaire. This indicated that the tank had not been emptied for 6 years and it was unclear whether it had ever been inspected or repaired. Although septic tank safe cleaning products were used by the householder, to some extent, laundry and dishwasher detergents were selected on the basis of cost rather than P content.

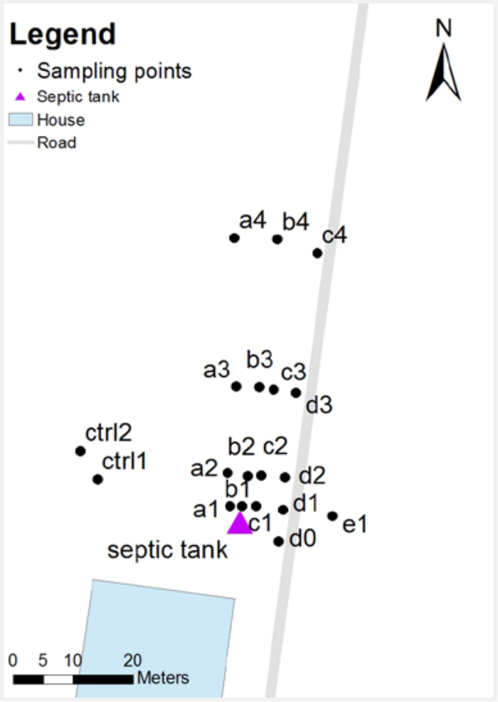


Figure 3 Distribution of sampling points at Site CLUN1

CLUN2

This site was sampled on the morning of 15th February 2013.

The septic tank at this site discharges to a soakaway and both the tank and the seepage pipes, or ‘fingers’, were situated in a clear area that was covered by grass. The tank was constructed of fibre glass and had been installed relatively recently; it was estimated to be about 7 years old. The tank had not been emptied, inspected or repaired since its installation. The owner returned a completed questionnaire. This indicated that septic tank safe cleaning products and ‘eco friendly’ laundry detergents were used at this property. The property did not have a dishwasher.

The septic tank serves holiday accommodation with seasonally varying occupancy and, at times, remains unused for long periods. It was readily accessible (Plate 4, left) but, at the time of sampling, the effluent was covered by a very hard surface crust. Although this was broken using soil augers, the volume of liquid effluent below the crust was small and was grossly contaminated by the solid crust material (Plate 4, right). So, no representative sample of the effluent plume could be collected at this site.

Plate 4 Septic tank access point and sludge collected from the storage tank at CLUN2

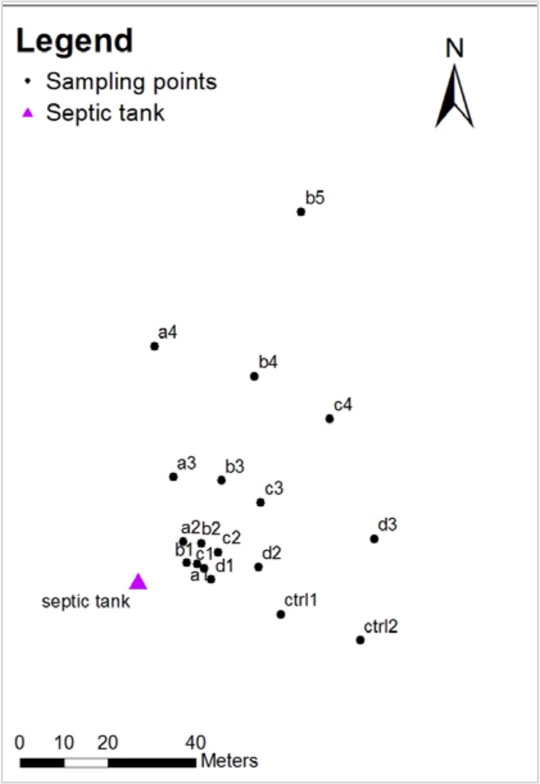


Figure 4 Distribution of sampling points at site CLUN2

The distribution of sampling points across this site is shown in Figure 4. The drainage area sloped fairly steeply (16%) away from seepage area and the soils were silty, but with a less obvious red colour than at CLUN1. The soil was easier to core to about 0.5 m depth than at CLUN1, but it then became quite stony and sampling below about 1.2 m was very difficult in most locations.

CLUN3

Site CLUN3 was sampled on the afternoon of 15 February 2013.

The septic tank at this site was built of concrete and estimated to be about 21 years old. It discharged to a soakaway. The tank and the immediate seepage area around it were on a raised area close to some houses. Further away, the seepage passed under a small road and then down a very steep bank (5 m drop) into a sheep grazing field (Plate 5). Overall, the slope from the tank to the most remote sampling point was estimated to be about 26%. The tank was in a good state of repair and was readily accessible for sampling.

The owner returned a completed questionnaire. This indicated that the tank is emptied and inspected annually. Lowest price, rather than P content, was the main criterion used for selecting laundry and dishwasher detergents, and the household indicated that they used septic tank safe cleaning products.

Plate 5 Septic tank drainage field at CLUN3

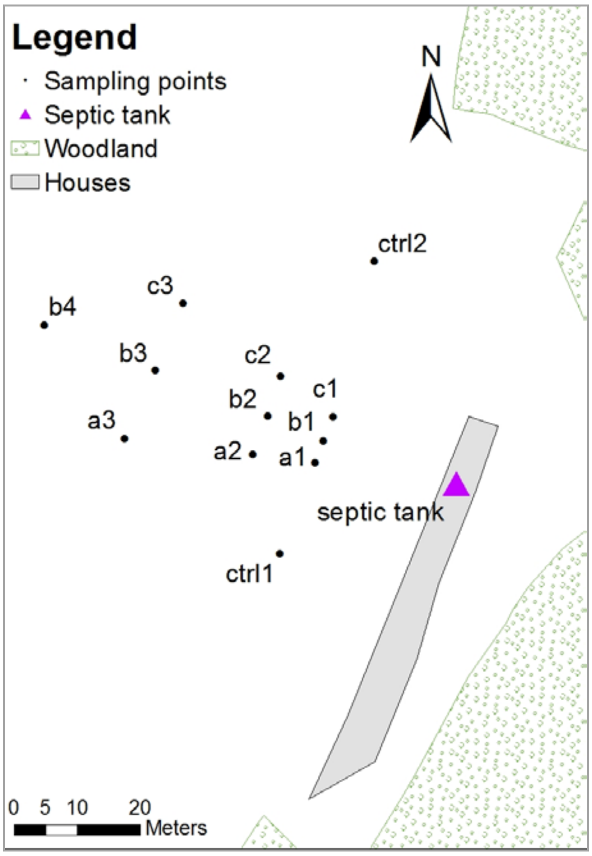


Figure 5 Distribution of sampling points at site CLUN3

The distribution of sampling points for this site is shown in Figure 5. The soil in this area was silty clay with few stones, making sample collection much easier than at the other Shropshire sites. Most locations were sampled to a depth of 150cm. It was noted that a manure heap was situated close to site C1.

Hampshire

WYLYE1 and WYLYE2

The WYLIE1 and WYLYE2 sites were sampled on 8 May 2013 and 9 May 2013, respectively.

These sites were next door to each other and it was determined that any potential discharge plume would probably flow downhill into the field to the rear of the properties, which was used for grazing horses (Plate 6). The sampling team was unable to gain access to the houses or gardens in this area. So, it was not possible to sample the tanks or tap waters, or collect completed questionnaires, at these sites. However, the householders did indicate the approximate position of their septic tanks to the sampling team. These are marked in Plate 6.

Plate 6 Septic tank drainage field at WYLYE1 (red arrow) and WYLYE2 (green arrow)

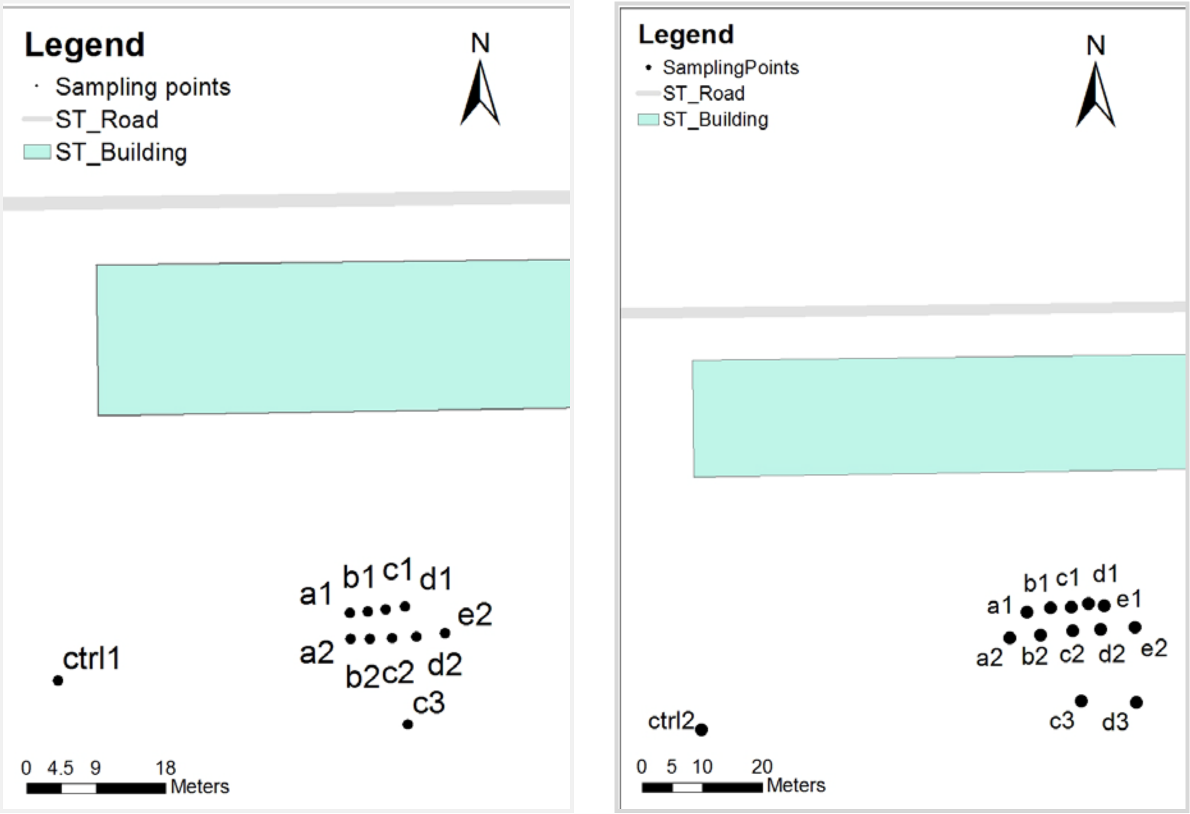


Figure 6 Distribution of sampling points at sites WYLYE1 (left) and WYLYE2 (right)

Due to the problems with access, it was not possible to sample the septic tanks serving these properties or their finger drains. So, the distance between the tanks and the accessible part of the drainage field could not be measured. However, aerial photography of the area suggests that the most northerly row of sampling points was probably about 20 m downslope of the tanks and their effluent distribution pipes. The ground surface sloped (8%) away from the seepage areas.

The drainage area was separated from the tanks and finger drains by a fence. Soil samples were collected in the field close to this fence and then down slope of this area. The distribution of sampling points for this site is shown in Figure 6. The soil was mainly silty loam that was quite stony and difficult to core. Sample depths were mostly a maximum of 1 m, but 1.5 m was possible where the soil was slightly deeper.

Oxfordshire

OXON1

The OXON1 site was sampled on 1 March 2013.

In contrast to the tanks at other sampling sites, the tank at OXON1 was a Klargester Biodisc® system (**http://klargester.com/products/BioDisc-BA-BD.htm**), not a simple septic tank. Klargester Biodisc® systems use a rotating biological contactor to encourage the formation of an active biofilm that improves sludge aeration and, consequently, the efficiency of wastewater treatment in the tank. As this improves effluent quality in line with European legislation (EN-12566) these systems are often permitted to discharge directly to a watercourse. However, it should be noted that this improvement in water quality only applies to biochemical oxygen demand (BOD), suspended solids and ammonium concentrations. Because there is no legal requirement to do so, the quality of the effluent in terms of P discharges is not regulated or tested.

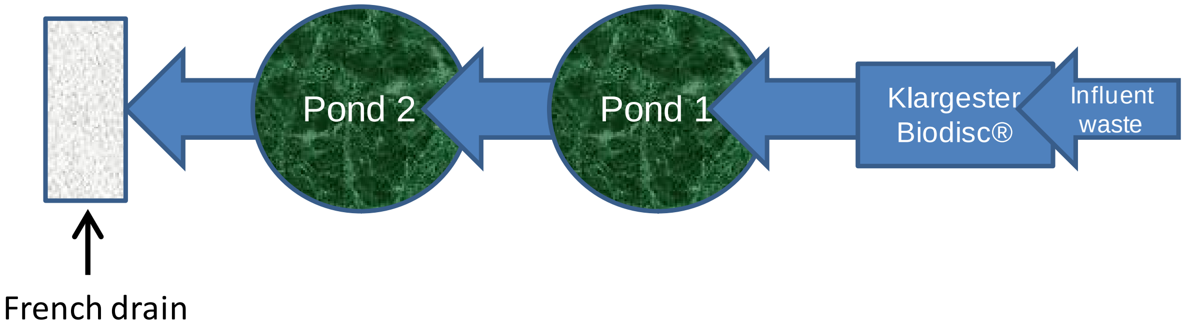


Figure 7 Schematic diagram of the Klargester Biodisc®, ponds and French drain at OXON1

The tank at this site 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. It should be noted that treatment plants of this type do not work well with intermittent loads, such as are likely to be associated with these types of activities. So, the results obtained from this site in the present study should be treated with caution as they may not accurately reflect the situation at other sites where such systems have been installed.

As this was not a domestic dwelling, little information was available on the management and maintenance of this tank. However, project staff was told that the tank had been installed very recently (probably about 2 years ago) and that it was emptied annually. Samples of tap water and septic tank effluent were collected at this site.

It has been suggested that effluent quality from these types of tank can be improved prior to discharge to a drainage field or watercourse by incorporating a reed bed filtration into the system. In line with this recommendation, the installation at this site includes the tank itself and two treatment ponds (e.g. Plate 6). These are lined, to prevent seepage, and connected, in series, by a sealed pipe that delivers treated effluent to a ‘French drain’ (Figure 6). The ‘French drain’ is 1 m wide, 1 m deep and filled with limestone. It discharges to a soil soakaway.

Plate 7 Effluent processing pond at OXON1

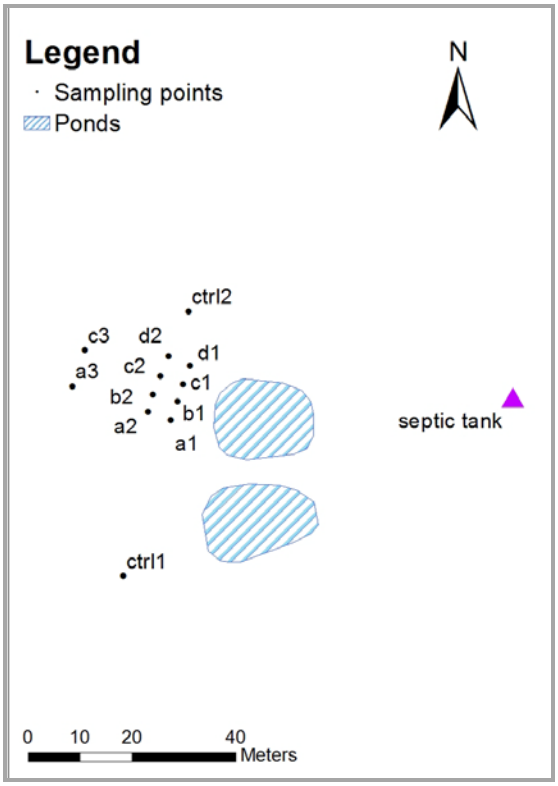


Figure 8 Distribution of sampling points at site OXON1

Soil sampling began where the seepage area started, i.e. just beyond the ‘French drain’, and continued down slope of that point. The distribution of sampling points for this site is shown in Figure 8. One set of samples was taken close to the seepage area, and another set further away. The ground in this area had been disturbed during the construction of a nearby farm track and this was reflected in the soil/material recovered by the auger at some sampling points. Where undisturbed, the soil comprised mainly loam on top of chalk. It was possible to sample down to 1.3 m at most points.

OXON2

The site at OXON2 was sampled on 22 February 2013.

The septic tank at this site was of unknown construction and believed to be about 9 years old. It was shared with neighbouring properties. The tank was readily accessible for sampling and discharged to a soil soakway that was downslope (6%) of the property (Plate 8).

Plate 8 Septic tank drainage field at the OXON2 site

A completed management and maintenance questionnaire was returned for this site. The householder was unable to say how often, if ever, the tank had been emptied, inspected or repaired. Laundry detergent was chosen on the basis of perceived cleaning power and rather than P content and the householder did not use septic tank safe cleaning products.

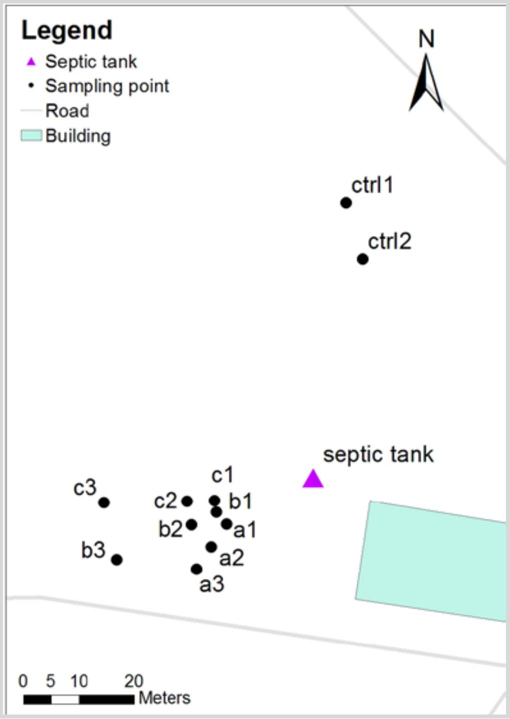


Figure 9 Distribution of sampling points at site OXON2

The distribution of sampling points at this site is shown in Figure 9. The soil comprised mainly loam on top of chalk, with the chalk starting to appear at around 0.7 m depth and the samples becoming entirely chalk beyond 1 m depth. Samples were collected to a depth of 1.5 m at most sampling points.

OXON3

The site at OXON3 was sampled on 28 June 2013 and 15 August 2103.

OXON3 was at an isolated dwelling on the top of a hill, and was surrounded by farm buildings. The septic tank was behind a wall and a pipe carried the effluent under the wall to the finger drains and main seepage area, the location of which was known by the farmer. The ground sloped gradually (6%) away from the finger drains. The position of the effluent distribuion pipes were relatively well known by the farmer, who helped with the positioning of the soil sampling points. The field into which the effluent was discharged was under crops (wheat) at the time of sampling and, therefore, it was not possible to sample using the usual site distribution pattern.

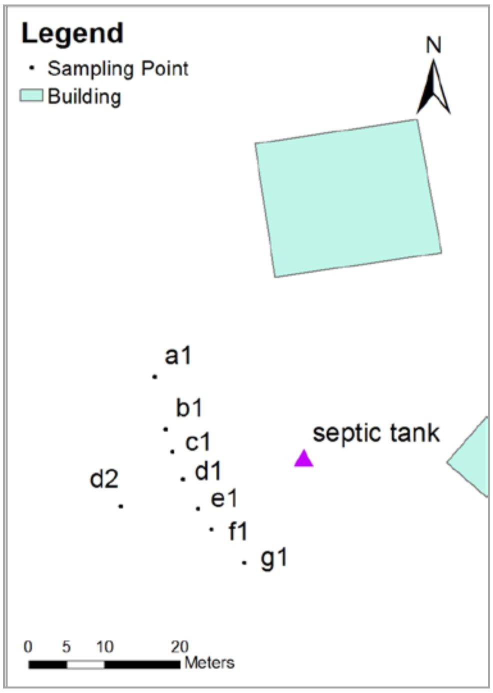


Figure 10 Distribution of sampling points at site OXON3

Plate 9 Septic tank drainage field at the OXON3 site

The drainage field was cultivated (Plate 9), so the surface soil had been recently ploughed to a depth of about 30 cm. However, this is unlikely to have disrupted the path of any effluent from the distribution pipes as these are generally situated at about 50 cm below ground level. The distribution of sampling points for this site is shown in Figure 10. To minimise crop damage, soil samples were taken in an arc shape along a ‘tramline’ that crossed the position of the effluent distribution pipes. Samples C1, D1 and E1 corresponded to the approximate position of the ends of the pipes.

The soil at this site was similar to that at OXON2, i.e. comprising mainly loam on top of chalk, with chalk starting to appear at around 0.7 m depth and consisting entirely of chalk beyond 1 m depth. Sampling down to about 1.5 m was possible with a standard soil auger in most locations and the site was revisited to obtain deeper and more detailed samples from below the distribution pipes 15 August 2103. These were collected with a power auger.

Norfolk

BROADS1

Site BROADS1 was sampled on the morning of 29th July 2013.

The tank at this site was built of brick and estimated to be about 42 years old. It discharged to a soakaway. A completed management and maintenance questionnaire was returned by the householder. This site indicated that the tank was emptied every year, but had probably never been inspected or repaired. The householder chose laundry and dishwasher detergents on the basis of their perceived cleaning power rather than P content, and did not use septic tank safe cleaning products.

Plate 10 Septic tank (left) and drainage field (right) at BROADS1

The tank itself was accessible for sampling (Plate 10: left) and the owner believed that the seepage area (Plate 10: right) could be identified by the patches of nettles growing nearby. It was possible to position the sampling directly over the perceived seepage area. There was no obvious slope to the ground in this area; the elevation data collected suggested that the slope was about 2%.

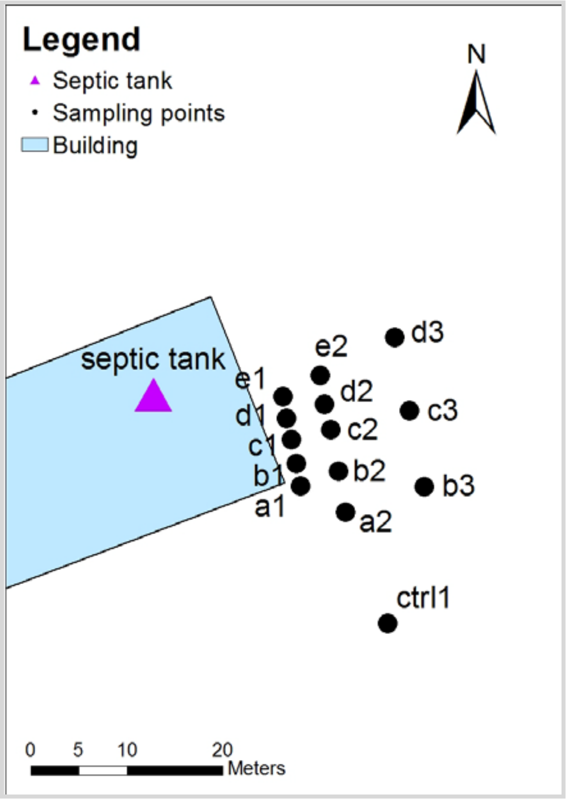


Figure 11 Distribution of sampling points at site BROADS1

The distribution of sampling points for this site is shown in Figure 11. The soils were loamy, with quite a lot of stones distributed throughout. Perhaps due to a recent lack of rainfall, they were also extremely dry and very difficult to auger. Samples were taken down to about 1 m depth at most locations.

BROADS2

Site BROADS2 was sampled on the afternoon of 29 July 2013.

The septic tank at this site was estimated to be about 20 years old and built of concrete. It was readily accessible, but set back in an area of hard standing. The effluent discharged to a soakaway in a nearby field. Because the distribution pipes were in a tree covered area it was not possible to sample very close to them.

The distribution of sampling points for this site is shown in Figure 12. There was no clear slope to the ground in this area. The GPS data collected indicate that the overall slope of the land in the drainage area was about 1%. The sampling field was being used for agricultural purposes, probably to grow sugar beet. It was unclear whether fertiliser additions had been applied to the soils in this field.

As at BROADS1, the soil was loamy, and quite stony throughout. It was extremely dry and very difficult to auger. Most sampling locations (Figure 12) were cored successfully to a depth of about 100 cm.

A completed management and maintenance questionnaire was returned from this site. This indicated that the tank was emptied every 6 years, on average, but had never been inspected or repaired. The householder used septic tank safe cleaning products and chose their laundry and dishwasher detergents on the basis of cleaning ability rather than P content.

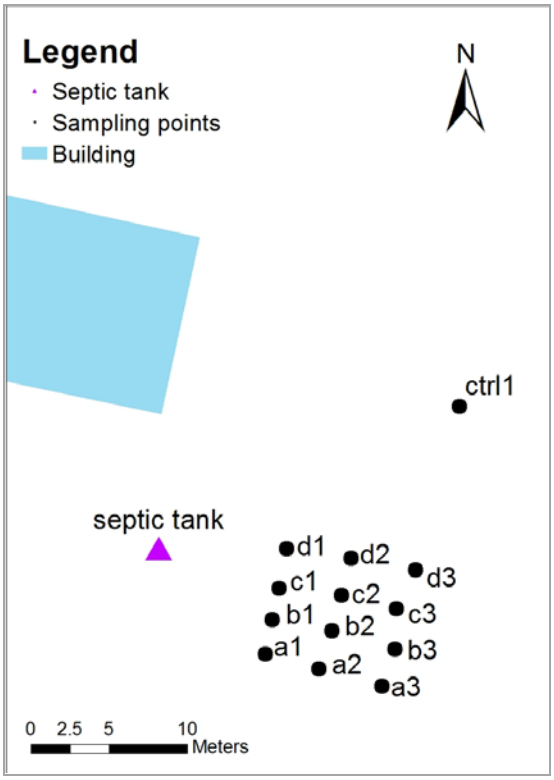


Figure 12 Distribution of sampling points at site BROADS2

BROADS3

The site at BROADS3 was sampled on the morning of 30 July 2013.

The tank was easily accessible and tank samples were collected. However, it was not possible to collect tap water samples at this site. The septic tank at this site is about 50 years old and serves a tenanted property inhabited by two people. The tank is emptied every 5 years and is inspected or repaired every 3 years. No information was available on the lifestyle of the occupants, such as washing machine/dishwasher usage, choice of detergents or use of septic tank safe products.

There was no clearly identifiable area for seepage, making positioning of sampling points very difficult. The area was also bound by a road on one side, and influenced by a hedge line leading into a field of sugar beet on the other (Plate 11). There was a slope (estimated to be about 3%) away from the tank and sampling points were located along this slope.

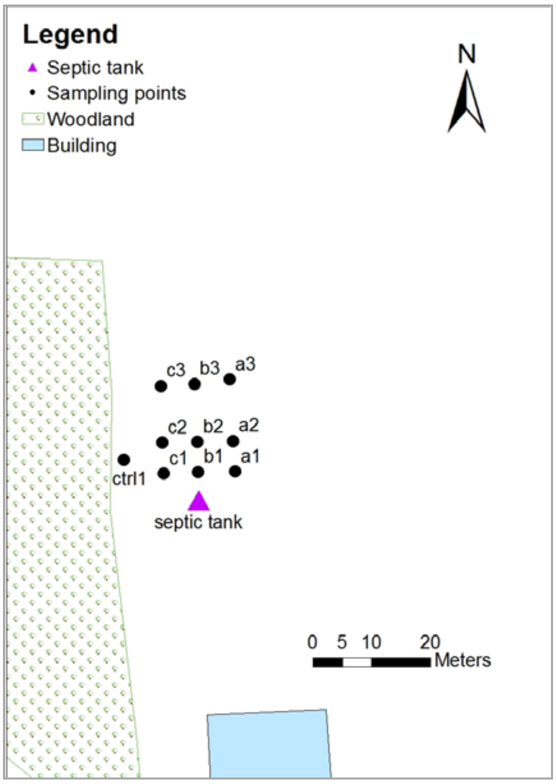


Figure 13 Distribution of sampling points at site BROADS3

Plate 11 Sampling the septic tank drainage field at BROADS3

The distribution of sampling points for this site is shown in Figure 13. As elsewhere in this area, the soil was loamy, quite stony, and very dry. This made it particularly difficult to sample, particularly as the soil was not cohesive enough to stay in the soil augers. Some samples could only be obtained by digging pits through the 0.4 - 0.5 m of very dry surface material before augers could successfully deployed. Most points were samped to a depth of 1 m. A couple of sites had clearly been disturbed by the construction of the road (e.g. C1).

4 Results

Tank effluent quality

Phosphorus concentrations in tank effluent (as defined above) ranged widely from 6.6 and 11.6 mg P/l at OXON2 to 14.5 and 18.4 mg P/l at BROADS1, for SRP and TP, respectively (Table 5). The average value across all tanks for these variables was 11.0 and 15.1 mg P/l, respectively.

It is interesting to note that, although most of the STS sampled were based on traditional septic tanks, that at OXON1 was a Klargester Biodisc® sewage treatment system. It is generally believed that discharges from these systems are lower in P concentration than those from standard septic systems. However, the data collected (Table 5) suggests that this is not always the case. Concentrations of both SRP (10.7 mg P/l) and TP (12.9 mg P/l) in the effluent from the Klargester Biodisc® system were similar to those recorded from the more traditional types of tank.

Table 5 Soluble reactive phosphorus (SRP), particulate phosphorus (PP) and total phosphorus (TP) concentrations in septic tank effluent

Sampling date	Location	Site code	SRP (mg P/l)	PP (mg P/l)	TP (mg P/l)
14/02/2013	Shropshire	CLUN3	11.6	3.4	15.0
29/07/2013	Broads	BROADS1	14.5	4.0	18.4
29/07/2013	Broads	BROADS2	9.4	8.0	17.4
30/07/2013	Broads	BROADS3	13.4	1.7	15.0
01/03/2013	Oxfordshire	OXON1	10.7	2.2	12.9
01/03/2013	Oxfordshire	OXON2	6.6	4.9	11.6
Average across all tanks sampled:			**11.0**	**4.0**	**15.1**

Factors that may affect effluent quality

Orthophosphate additions to tap water

In many areas of the UK, orthophosphate is added to domestic water supplies to reduce plumbosolvency in areas where supplies are still delivered, at least in part, through lead pipework. After treatment, P concentrations in the tap water may be high. Treatment levels vary from region to region and average concentrations as high as 1.9 mg P/l have been reported in some areas (UKWIR, 2012). This is equivalent to about 20% of the P concentration in the effluent of an average septic tank (May & others, 2010).

Soluble reactive phosphorus concentrations in the tap water samples collected ranged from undetectable at CLUN3 to 1.1 mg P l^{-1} at BROADS1 (Table 6). The data suggest that phosphate is probably being added to water supplies in Oxfordshire and the Broads, although the situation for Shropshire is unclear. The lack of P in the tap water at these sites may be due to the fact that phosphates are not added to public water supplies in this area. However, it may also be because the locations sampled have private water supplies. It was not possible to collect tap water samples at the Hampshire sites due to access problems.

Table 6 Soluble reactive phosphorus (SRP) concentrations in tap water

Sampling date	Location	Site code	SRP conc. (mg P/l)
29/07/13	Broads	BROADS1	1.1
29/07/13	Broads	BROADS2	1.1
01/03/13	Oxfordshire	OXON2	0.9
14/02/13	Shropshire	CLUN1	0
14/02/13	Shropshire	CLUN2	0
14/02/13	Shropshire	CLUN3	0
Average across all tap water samples:			**0.5**

The relationship between tap water P concentrations and effluent P concentrations was explored. Although the number of samples was small, there was a tendency for higher P concentrations in tap water to be associated with higher P concentrations in corresponding effluents at sites where tap water P concentrations were high (Figure 14). Although tap water samples were not available at BROADS3 and OXON1, values for these sites were estimated to be the average of BROADS1 and BROADS2 for BROADS3 and the value of OXON2 for OXON1.

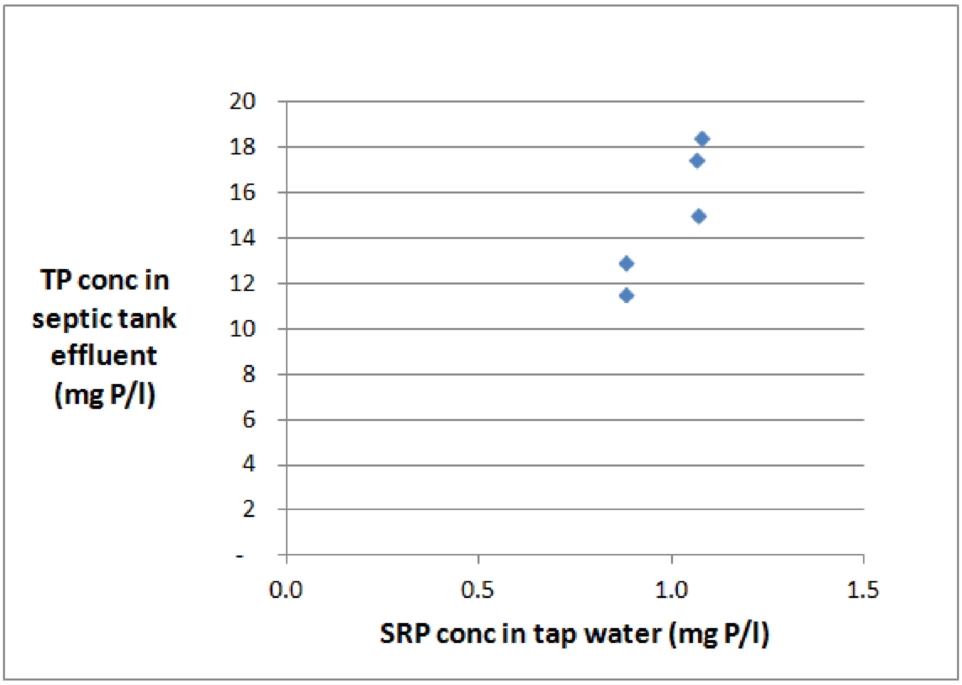


Figure 14 Relationship between soluble reactive phosphorus (SRP) concentrations in tap water and total phosphorus (TP) concentrations in septic tank effluent in areas where orthophosphate is added to tap water

System age and type

Of the nine tanks for which questionnaires were returned, three were less than 10 years old, three were 20-40 years old and three were more than 40 years old (Table 7). The average age of the tanks sampled was 25 years. In general, the oldest tanks were built of brick, the next oldest were of concrete and the newest ones were of fibreglass. The exception was that at the OXON3 site, where the tank was believed to be about 22 years old and constructed from fibre glass.

The average effluent P concentrations for the six STS sampled were 11 mg P/l and 15 mg P/l for SRP and TP, respectively. Although it is difficult to generalise from the widely varying results obtained from such a small number of sites, there was a slight tendency for the TP concentration of the effluent in older systems to be higher than that in newer systems (Figure 15). The exception was the tank at OXON3, which the householder believed to be fibre glass and about 22 years old. Its fibre glass construction suggests that it may, in fact, be newer than this.

Table 7 Construction material, discharge type and estimated age of STS systems sampled in this study, where known

Sampling date	Location	Site code	System type	Discharge type	System age
14/02/13	Shropshire	CLUN1	Brick	Soakaway	45 years
14/02/13	Shropshire	CLUN2	Fibre glass	Soakaway	7 years
14/02/13	Shropshire	CLUN3	Concrete	Soakaway	21 years
01/03/13	Oxfordshire	OXON1	Klargester	Pond/soakaway	2 years
01/03/13	Oxfordshire	OXON2	Unknown	Soakaway	9 years
28/6/13	Oxfordshire	OXON3	Fibre glass	Soakaway	22 years
29/07/13	Broads	BROADS1	Brick	Soakaway	42 years
29/07/13	Broads	BROADS2	Concrete	Soakaway	20 years
30/07/13	Broads	BROADS3	Brick	Soakaway	50 years

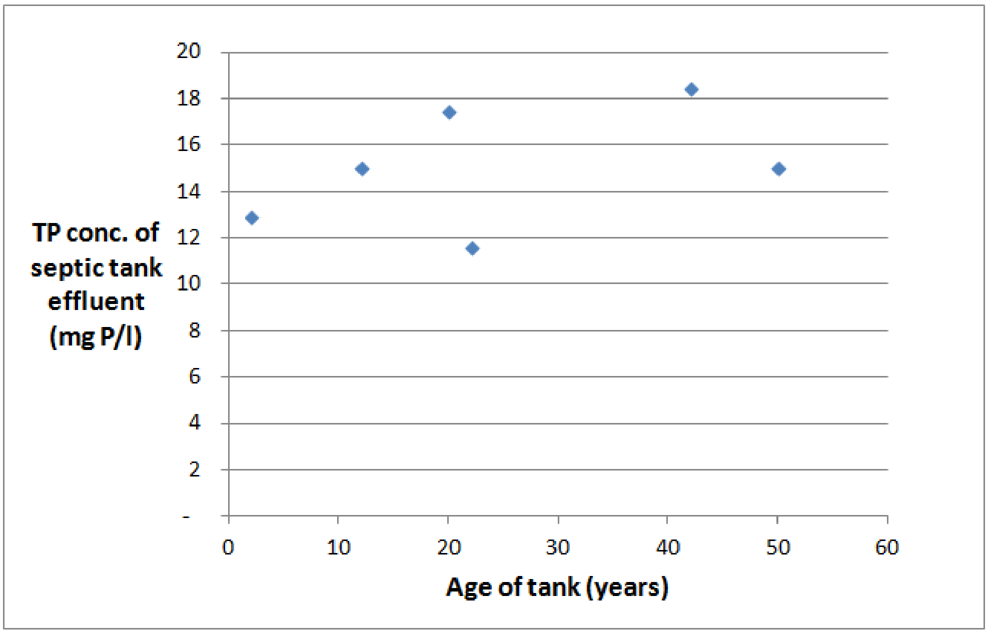


Figure 15 Relationship between total phosphorus (TP) concentrations in tank effluent and estimated age of tank

Particulate phosphorus (PP) in the effluent, calculated as the difference between TP and SRP, results from the incomplete breakdown of particulate matter that enters the tank in wastewater. This particulate matter, if discharged, can clog soakaways causing hydraulic failure and increases in P pollution problems. The relationship between PP concentration and age of tank was explored. It was found that PP concentrations in the tank effluents sampled ranged widely from 13% of TP at BROADS3 to 86% of TP at BROADS2. There appeared to be no relationship between the percentage of PP in the effluent and the age or type of tank (Figure 15).

Levels of management and maintenance

Results from the questionnaires (Table 8) indicated that few tanks were emptied every two years or less. However, most householders were aware of, and often using, septic safe cleaning products. Most dishwasher and laundry products were chosen on the basis of their price and cleaning ability, rather than their P content. However, overall, there were insufficient data to link levels of management and maintenance to the concentration of P in the tank effluents. So, no firm conclusions could be drawn from these data.

Table 8 Levels of management and maintenance of the septic tanks sampled

Sampling date	Location	Site code	Frequency of emptying	Frequency of inspection or repair	Use of septic safe products
14/02/13	Shropshire	CLUN1	Never	Never	Yes
14/02/13	Shropshire	CLUN2	Never	Never	Yes
14/02/13	Shropshire	CLUN3	Annually	Annually	Yes
01/03/13	Oxfordshire	OXON1	Annually	Annually	Unknown
01/03/13	Oxfordshire	OXON2	Never	Unknown	No
28/06/13	Oxfordshire	OXON3	Every 5 years	Every 5 years	No
29/07/13	Broads	BROADS1	Annually	Never	No
29/07/13	Broads	BROADS2	Every 6 years	Never	Yes
30/07/13	Broads	BROADS3	Every 3 years	Every 5 years	Unknown

Factors that may affect P transport through the drainage field

Site specific factors associated with location affect the likelihood of STS contaminating nearby waterbodies with P laden effluent. The most important of these have been identified as distance to a waterbody, water table depth, slope of the terrain within which the soakaway is situated, and soil P sorption characteristics (May and others, 2010). However, the relative importance of these characteristics is unclear.

To exclude at least some of these risk factors from the study, sites were chosen in areas with a low water table and at a distance of at least 100 m from a waterbody. This enabled the project to investigate the potential impact of slope and soil characteristics on plume development and P transport within the soil, especially within the upper soil layers above the water table. It also enabled the project to focus on systems that were more likely to be functioning correctly, rather than those that were already contaminating waterbodies. This is in contrast to most other studies, which have mainly focused on failing systems.

Slope

According to the criteria proposed by May and other (2010) (see Table 3), 10% of the soakaways sampled were found to be on slopes that posed a high risk of polluting nearby waterbodies, 54% were on slopes that posed a medium risk, and 36% were on slopes that posed a low risk (Table 9).

Table 9 Site specific characteristics of the STS soakaways sampled

Location	Site code	Drainage field soil type	Distance to waterbody (m)	Winter water table depth (m)	Slope of terrain
Shropshire	CLUN1	Silty with slight red colour; very stony; bedrock 0.5-0.7m depth.	> 100m	> 2m	1%
Shropshire	CLUN2	Silty; less red than at CLUN1; stony at depths below 50cm; bedrock about 120cm.	> 100m	> 2m	16%
Shropshire	CLUN3	Silty; few stones; sampled to about 1.5 m depth.	> 100m	> 2m	27%
Hampshire	WYLYE1	Silty loamy; quite stony.	> 100m	> 2m	8%
Hampshire	WYLYE2	Silty loamy; quite stony.	> 100m	> 2m	8%
Oxfordshire	OXON1	Loamy soil over chalk at 0.5 - 0.7 m.	> 100m	> 2m	5%
Oxfordshire	OXON2	Loamy soil over chalk at 0.5 - 0.7 m.	> 100m	> 2m	6%
Oxfordshire	OXON3	Loamy soil over chalk at 0.5 - 0.7 m.	> 100m	> 2m	6%
Broads	BROADS1	Loamy soil with stones.	> 100m	> 2m	2%
Broads	BROADS2	Loamy soil with stones.	> 100m	> 2m	1%
Broads	BROADS3	Loamy soil with stones.	> 100m	> 2m	3%

Soil and porewater P characteristics of each site

CLUN1

Soil samples were collected from the area that appeared to be downslope of the septic tank discharge point at Site CLUN1. The weather had been very wet prior to sampling, but it was impossible to extract sufficient porewater from the samples for chemical analysis in 19 of the 24 samples collected. Most of the drier samples were from depths of greater than 80cm, apart from at the Control 2 site where no liquid could be extracted from a sample collected from 0.2 – 0.5 m depth. The values reported are the highest levels recorded in each depth profile.

Concentrations of SRP within the porewater samples (Figure 16: lower panel, left) were very low at most sampling points, with values below the limit of detection (7µg/l PO_4-P) in 12 of the samples analysed. In the remaining 7 samples, values ranged between 10 and 74 µg/l PO_4-P, with concentrations at D1 (74 µg/l PO_4-P) and Control 1 (60 µg/l PO_4-P) being much higher than the others. The high value recorded at Site D1 was probably due to an accumulation of discharge from the septic tank in that area. However, this value was very local and SRP values were low at other sites in that area. It is unclear why the SRP value recorded at Control 1 was so high, as this area did not receive septic tank effluent or any other source of P.

Concentrations of TDP within the porewater samples (Figure 16: lower panel, right) were higher than those for SRP, ranging from 9.2 µg P/l at A1 to 225 µg P/l at D1. Relatively high values of TDP (145 µg P/l and 106 µg P/l) were recorded in the area around site D1, ie at sites D2 and D0. This suggests the possible movement of TDP, which is likely to have resulted from the biological processing of SRP from the tank effluent at this location.

Olsen-P values estimate the amount of soil P that is readily available, or ‘labile’, within the soil. Along with other measures of soil P characteristics, such as P sorption index (PSI) and EPC_0, it is a measure of the level of eutrophication of the soil and surrounding porewaters. The Olsen-P values of the soil samples collected at CLUN1 (Figure 16: upper panel, left) ranged from 1 to 32 mg/kg, with the highest values being recorded closer to the septic tank outlet and along a transect that seemed to follow the expected direction of effluent flow, given the local topography. The values recorded were not atypical of fields under agricultural production although, in this case, the field was under grass and appeared to be used for animal grazing.

PSI values ranged from 15 to 38, with lower values tending to measured at sites with higher Olsen-P values along the likely path of the plume (Figure 16: upper panel, centre). Values recorded for EPC_0 varied between 0 and 0.15 mg/l and tended to be highest around the septic tank and immediately surrounding drainage area (Figure 16: upper panel, right). Overall, the data suggest that STS effluent was probably causing P contamination of the surrounding soils over a distance of about 20 m from the tank at this site.

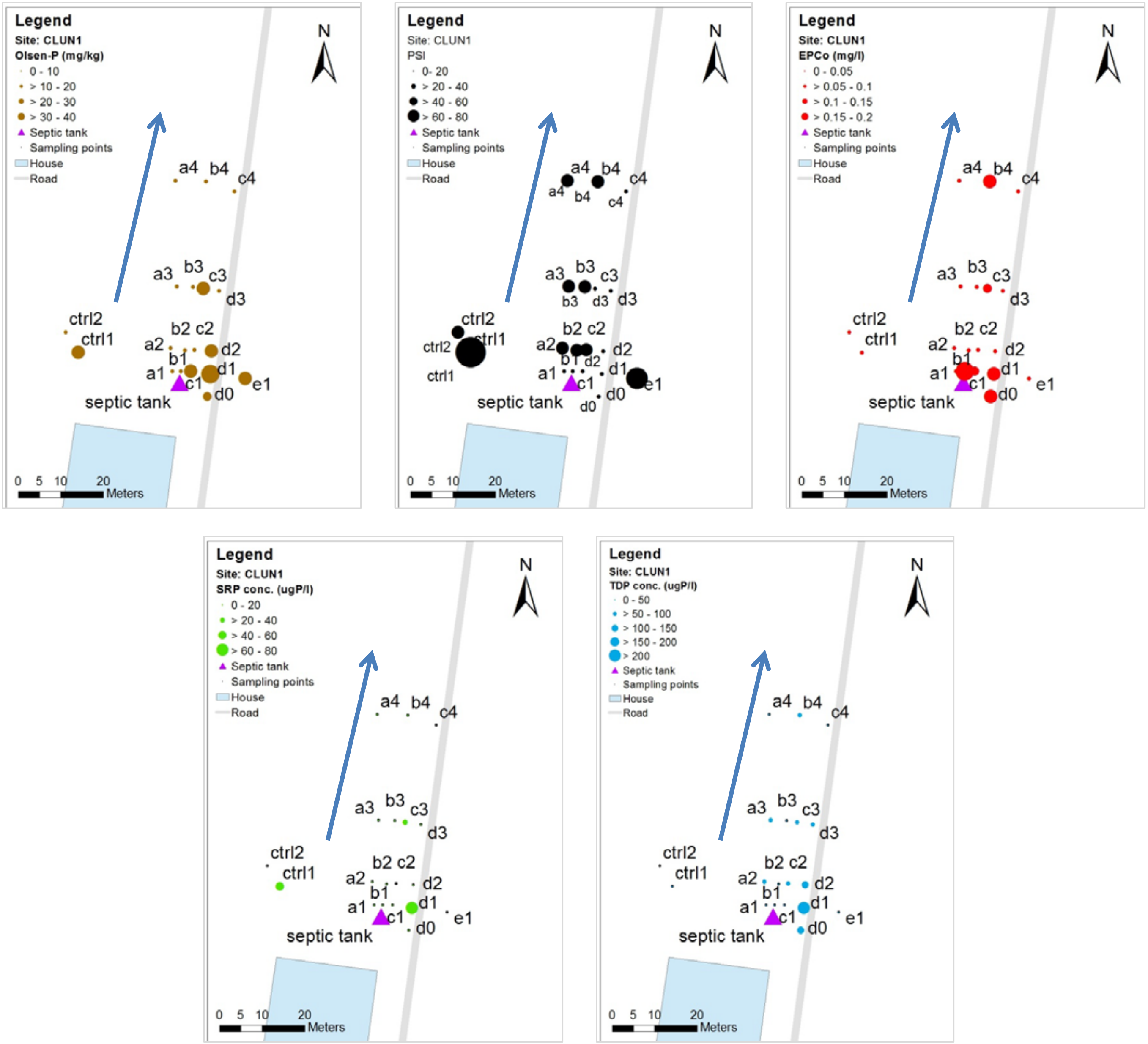


Figure 16 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the CLUN1 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

CLUN2

Soil samples were collected from what appeared to be the main drainage area for the septic tank at this site. This was based on local knowledge. The weather had been very wet prior to sampling, and it was possible to extract sufficient porewater from the samples for chemical analysis in 23 out of 26 cases. The drier samples were from depths greater than 70 cm. The values reported are the highest levels recorded in each depth profile.

Concentrations of SRP within the porewater samples (Figure 17: lower panel, left) were below the limit of detection (ie < 7µg/l PO_4-P) at all CLUN2 sampling points. So, no conclusions could be drawn from these data, except that the septic tank appeared to be having no impact on SRP levels in the surrounding soils.

Concentrations of TDP within the porewater samples (Figure 17: lower panel, right) were also relatively low compared to those recorded at CLUN1. Values mainly ranged between 2.6 and 46 µg P/l, although one exceptionally high value of 250 µg P/l was recorded at A4. This was an isolated value on the edge of the likely path of the plume and did not appear to be derived from septic tank effluent.

Although it was noted during the EMI survey that sites D2 and D3 were highly conductive and might have high levels of contaminants in the soil porewater, there was no evidence to suggest that this might be related to septic tank effluent. Indeed, all soil and porewater P levels in this area were very low.

The Olsen-P values for the soil samples collected at CLUN2 (Figure 17: upper panel, left) ranged from 2 to 11 mg/kg, with the higher values being recorded closer to the septic tank outlet than elsewhere. Evidence of slightly elevated Olsen-P values were observed for up to 20 m from the tank compared to background levels but, overall, the levels of soil available P recorded in this area were very low.

PSI values ranged from 18 to 71, the highest values (> 60) being recorded at sites A1 and A3 (Figure 17: upper panel, centre). Corresponding values for EPC_0 were generally very low, and varied between 0 and 0.015 mg/l. They also tended to be highest along the likely path of the septic tank plume at sites A1, B1, B2 and C3.

Overall, the data suggest a very slight eutrophication of the soils along the likely path of the effluent plume for a distance of up to 20 m. The level of eutrophication recorded was very low, probably reflecting the fact that this tank is relatively new (< 7 years old) and serves a holiday rental property that is not in constant use and, therefore, likely to discharge only small amounts of P. Because the pattern of usage is likely to be different from a normally occupied house, for example holidaymakers may wash less laundry than other house occupants, the source apportionment of P in the influent waste may also be different.

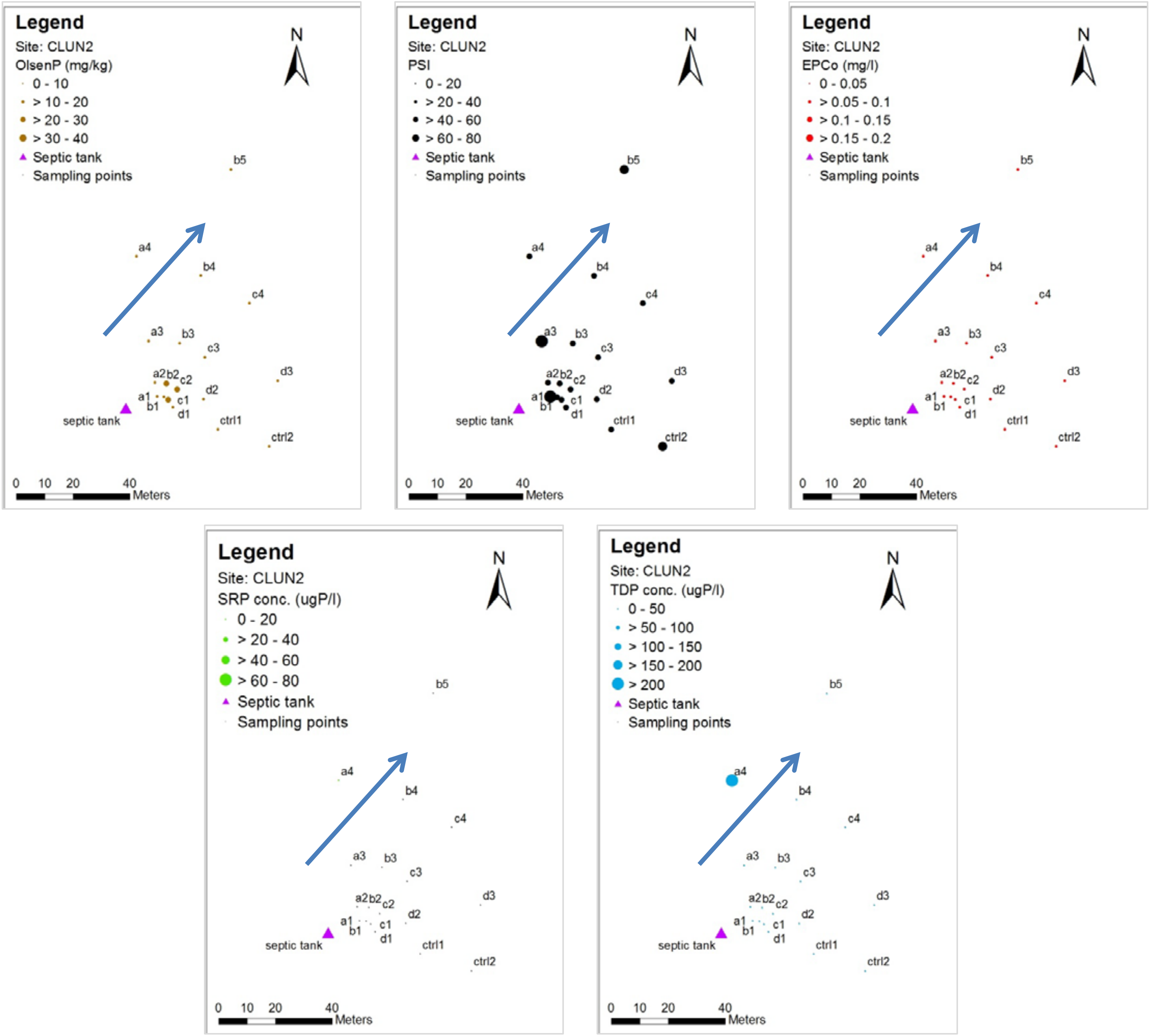


Figure 17 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the CLUN2 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

CLUN3

At CLUN3, soil samples were collected from an area that, according to local knowledge, the septic tank discharged effluent into. This was downslope of the septic tank discharge point and on the other side of a small road. The weather had been very wet prior to sampling, so it was possible to extract sufficient porewater for analysis from all of the samples collected. The values reported are the highest levels recorded in each depth profile.

Concentrations of SRP within the porewater samples (Figure 18: lower panel, left) were very low at most sampling points, with values being below the limit of detection (7µg/l PO_4-P) in 24 of the 26 samples collected. In the remaining two samples, values of 15-16 µg/l PO_4-P were recorded; these were at sites Control 1 and Control 2.

Concentrations of TDP within the porewater samples (Figure 18: lower panel, right) were higher than those for SRP, ranging mainly between 9.6 µg P/l (Site B1) and 46 µg P/l (Site C1). Two very high values (331 µg P/l) were, however, also recorded at Sites C2 and C3. These may have been contaminated by a manure heap that was located upslope of these sites, close to Site C1. There was no evidence of elevated TDP concentrations along the likely path of the septic tank effluent plume.

The Olsen-P values of the soil samples collected at CLUN3 (Figure 18: upper panel, left) ranged from 0 at Site C2 to 6 mg/kg at Site Control 1. These are exceptionally low values in comparison to values recorded in other areas. PSI values ranged from 10 at site B1 to 24 at Site B3 (Figure 18: upper panel, centre). Values recorded for EPC_0 varied between 0 and 0.027 mg/kg (Figure 18: upper panel, right). In contrast to the results from CLUN1 and CLUN2, there was no evidence of soil eutrophication or elevation of porewater P by STS effluent at this site, even though the STS had been in place for more than 20 years. This suggested that the field survey may not have correctly located the path of the effluent plume at this site.

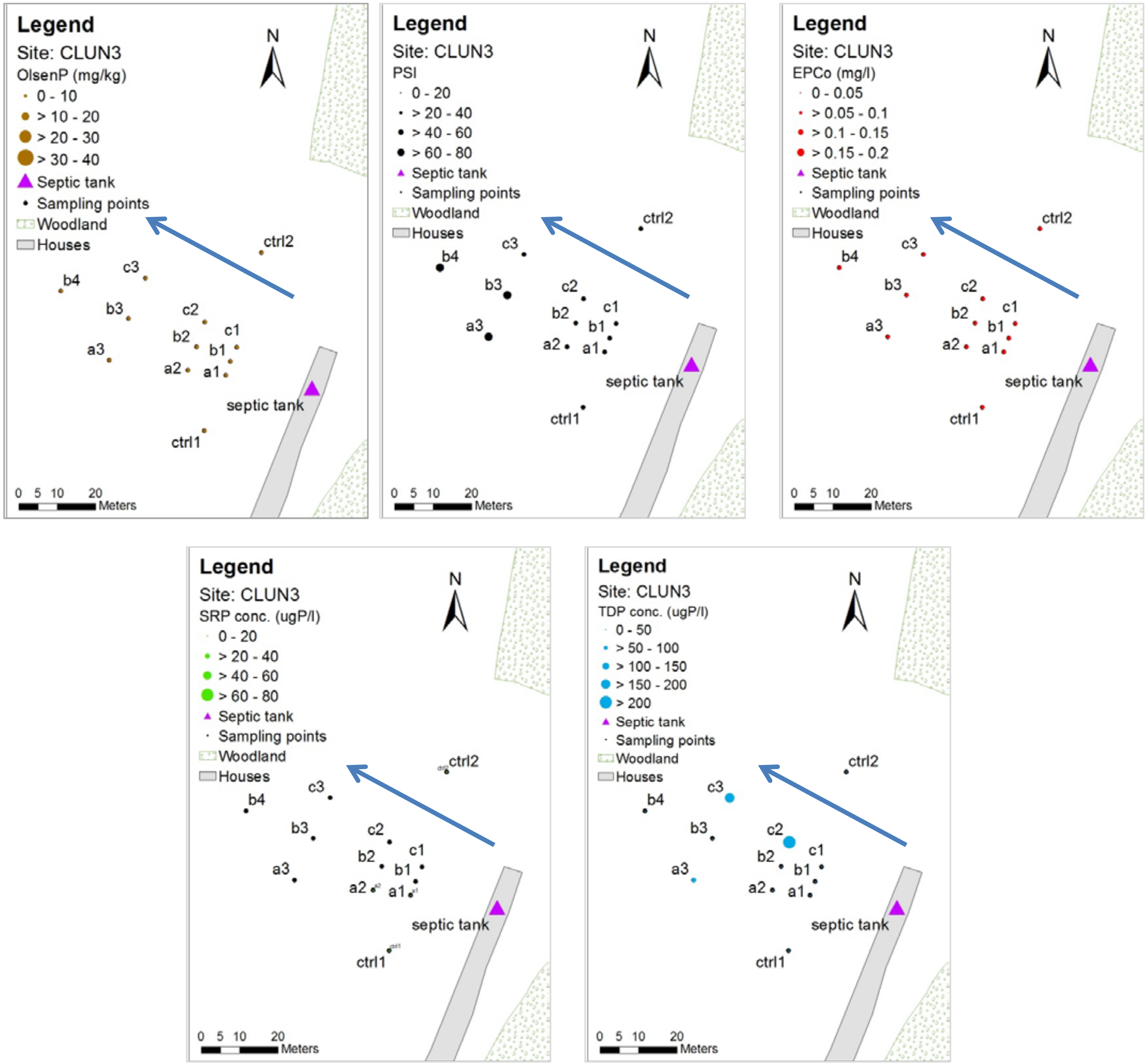


Figure 18 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the CLUN3 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

WYLYE1

At WYLYE1, soil samples were collected from the area that appeared to be downslope of the septic tank discharge point at this site. However, the sampling team did not have access to the area immediately around the septic tank as this was garden, vegetable plots and patios, not open fields as at other sites. For this reason, sampling commenced at the boundary fence and continued down slope of that point. The weather had been fairly wet prior to sampling, but this is a well drained area on chalk so the soils were relatively dry. It was only possible to extract sufficient porewater for analysis from 8 of the 26 samples collected. The drier samples were mostly from the greater sampling depths (70-100 cm), although some were from the shallower 0.2 - 0.5 m depth range. The values reported are the highest levels recorded in each depth profile.

Concentrations of SRP within the porewater samples (Figure 19: lower panel, left) were generally high, with values ranging from 40 µg P/l at the control site to 950 µg P/l at Site D1. Concentrations at Sites B1 (855 µg P/l), D1 (950 µg P/l) and E1 (510 µg P/l) were much higher than at the other sampling points. The high values recorded at these sites seemed to reflect some sort of P discharge from the garden of the house that was upslope of this point. Due to access problems, it was not possible to confirm that this was caused by seepage of septic tank effluent. However, it seems highly likely. If so this P-laden seepage may have travelled about 20 m from the tank.

Concentrations of TDP within the porewater samples (Figure 19: lower panel, right) were higher than those for SRP, ranging from 142 µg P/l at E2 to 1184 µg P/l at D1. These high values were also aligned along the boundary fence, downslope of the garden of the house. Again, it cannot be proven, but it is highly likely that these high levels of dissolved P in the porewater were the result of septic tank seepage.

The Olsen-P values of the soil samples collected at WYLYE1 (Figure 19: upper panel, left) ranged from 0 mg/kg at B1 to 29 mg/kg at D1, with the highest values being recorded close to the boundary fence and in the path of the suspected septic tank plume. This reflected the pattern observed for porewater P. PSI values ranged from 4.6 at C1 to 8.6 at A2, with low values being recorded at all sampling points (Figure 19: upper panel, centre). Values recorded for EPC_0 varied between 0.03 mg/l at B2, E2 and Control 1, and 0.4 mg/l at B1 and D1 (Figure 19: upper panel, right). Again, the data suggest that STS effluent was probably causing eutrophication of the soils for a distance of about 20 m from the tank at this site. However, this cannot be confirmed.

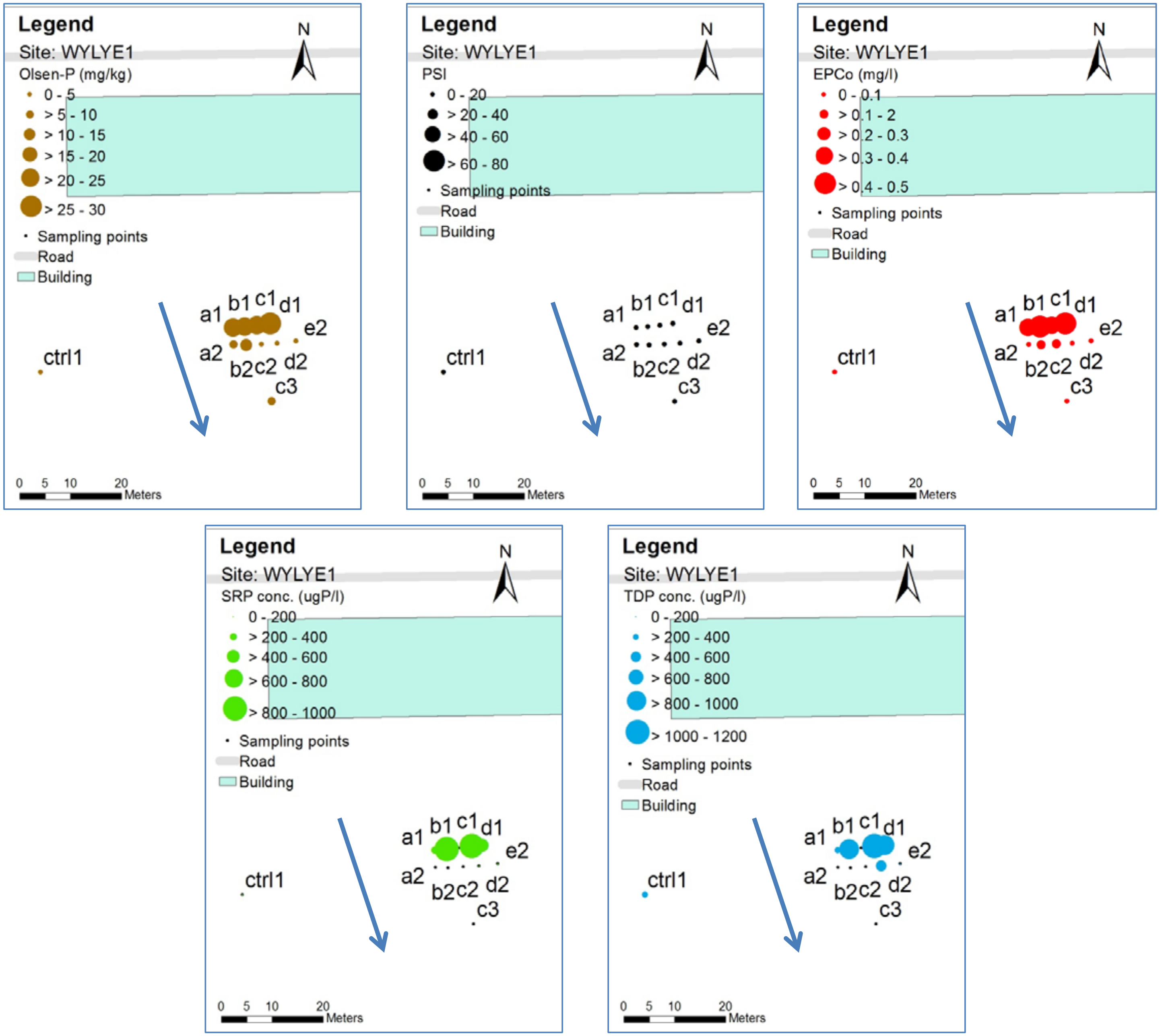


Figure 19 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the WYLYE1 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

WYLYE2

At WYLYE2, soil samples were collected from the area that appeared to be downslope of the septic tank discharge point at this site. However, again, the sampling team did not have access to the area immediately around the septic tank as this was made up of garden, vegetable plots and patios, not open fields as at other sites. As with WYLYE1, sampling commenced at the boundary fence and continued downslope of that point. The weather had been fairly wet prior to sampling, but this is a well drained area on chalk, so the soils were relatively dry. It was only possible to extract sufficient porewater for analysis from 11 of the 24 samples collected. The drier samples were collected over the entire depth range at this site. The values reported are the highest levels recorded in each depth profile.

Concentrations of SRP within the porewater samples at WYLYE2 (Figure 20: lower panel, left) were fairly high, with values ranging from 20 µg P/l at Control 2 and A1 to 444 µg P/l at E5. These higher values seemed to reflect some sort of P discharge from the garden of the house that was upslope of the sampling points, because values measured further down the slope were lower. However, due to access problems, it was not possible to confirm that this was caused by the seepage from a septic tank. However, it is highly likely that this is the case and, if so, P-laden seepage may have travelled about 20 m from its source.

Concentrations of TDP within the porewater samples (Figure 20: lower panel, right) showed a similar pattern of distribution to those for SRP but were generally higher, ranging from 122 µg P/l at Control 1 to 682 µg P/l at E5. Again, these values seemed to indicate some sort of P-laden seepage from the garden that was located up slope of the sampling points. This was the most likely location of the septic tank.

The Olsen-P values of the soil samples collected at WYLYE2 (Figure 20: upper panel, left) ranged from 0 to 2 mg/kg at B1 and D1, respectively, with the highest values being recorded closer to the boundary fence between the garden of the upslope property and the field in which the samples were collected. PSI values were very low, ranging from 4.6 at C1 to 9 at A2 (Figure 20: upper panel, centre). Values recorded for EPC_0 varied between 0.03 and 0.4 mg/l and tended to be highest along the boundary fence (Figure 20: upper panel, right), as was the case for Olsen-P. Overall, the data suggested that STS effluent was probably causing eutrophication of the soils for a distance of about 20 m downslope of the tank at this site, but this could not be confirmed due to access problems.

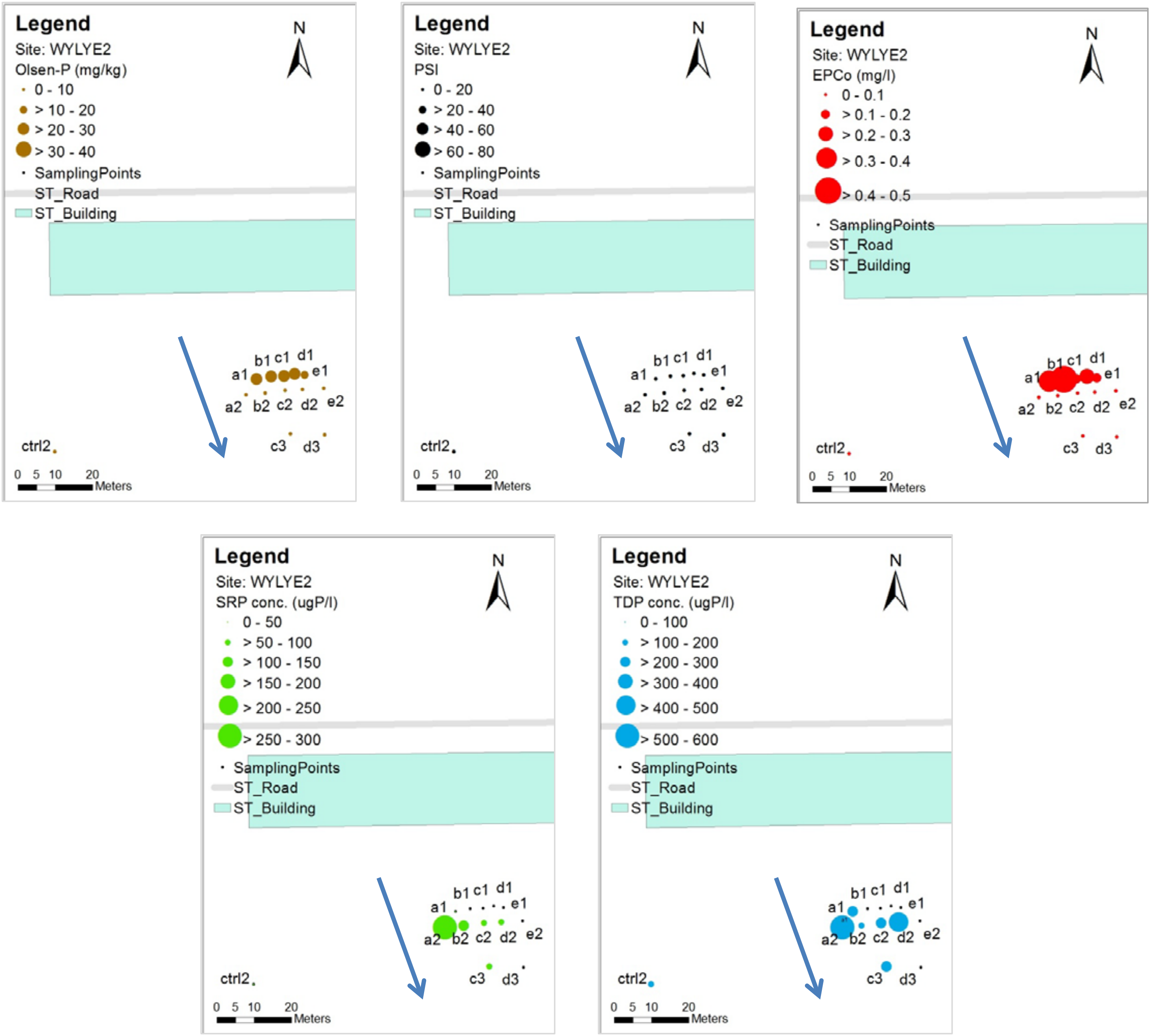


Figure 20 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the WYLYE2 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

OXON1

The tank at site OXON1 was not a standard STS, but a Klargester Biodisc® system (see page 17). The effluent from this system drained into a series of two ponds and a ‘French drain’ before being discharged to a soil soakaway. The aim of installing this enhanced sewage treatment system was to improve effluent quality before it was discharged into the environment. However, as noted above, these systems are only required to comply with discharge regulations in relation to BOD, suspended solids and ammonia to gain EN-12566 accreditation. There is no requirement for these systems to discharge lower levels of P than any other on-site sewage treatment systems, such as standard septic tanks. The values reported are the highest levels recorded in each depth profile.

Soil samples were collected just below the ‘French drain’, as this was the final treatment point in the system. This was beyond the two ponds that had been installed to provide additional treatment of the tank effluent before it was discharged to soakaway. Most of the 26 samples collected were sufficiently wet for porewater to be extracted for analysis. However, this was not possible with 9 of the samples. These were mainly from the deeper cores (120-150cm).

Concentrations of SRP within the porewater samples (Figure 21: lower panel, left) ranged between 8 µg P/l at Control 2 to 352 µg P/l at Control 1. The very high P value at Control 2 compared to Control 1, suggested that Control 2 was probably not suitable for use as a control. In general, values were higher at A1 (215 µg P/l) and B1 (256 µg P/l), close to the final treatment pond, than at sampling points further down the slope. The SRP concentration in the final treatment pond was measured; this was 2,760 µg P/l.

Concentrations of TDP within the porewater samples (Figure 21: lower panel, right) were higher than those for SRP, ranging from 73.2 µg P/l at B2 to 660 µg P/l at Control 1. Relatively high values of TDP (145 µg P/l and 106 µg P/l) were recorded at A1 and B1, just down slope of the second treatment pond. This, and the high SRP values mentioned above, suggests that the pond is discharging effluent with a relatively high P content to the soakaway. However, this P content (2.8 mg P/l) is much lower than the raw effluent from most septic tanks (about 11 mg P/l, see above). Further data collected in this area suggest that high porewater P concentrations of about 60-70 µg P/l SRP and 100-200 µg P/l TDP persist for at least 20 m downslope of the effluent discharge point.

The Olsen-P values of the soil samples collected at OXON1 (Figure 21: upper panel, left) ranged from 1 mg/kg at 3A to 68 mg/kg at Control 1. The highest values were recorded further downslope than those of SRP and TDP samples, suggesting soil uptake of P from porewater in this area. PSI values ranged from 9.2 at D2 to 10.9 at 3a, with values being very similar across the whole area (Figure 21: upper panel, centre). Values recorded for EPC_0 varied between 0 mg/l at C3 and 0.31 mg/l at D2, with a tendency for values to increase downslope (Figure 21: upper panel, right). Overall, the results suggest that the effluent from treatment pond 2 was lower in P content than that from a standard septic tank, but was still causing eutrophication of soils downslope for a distance of at least 10 m.

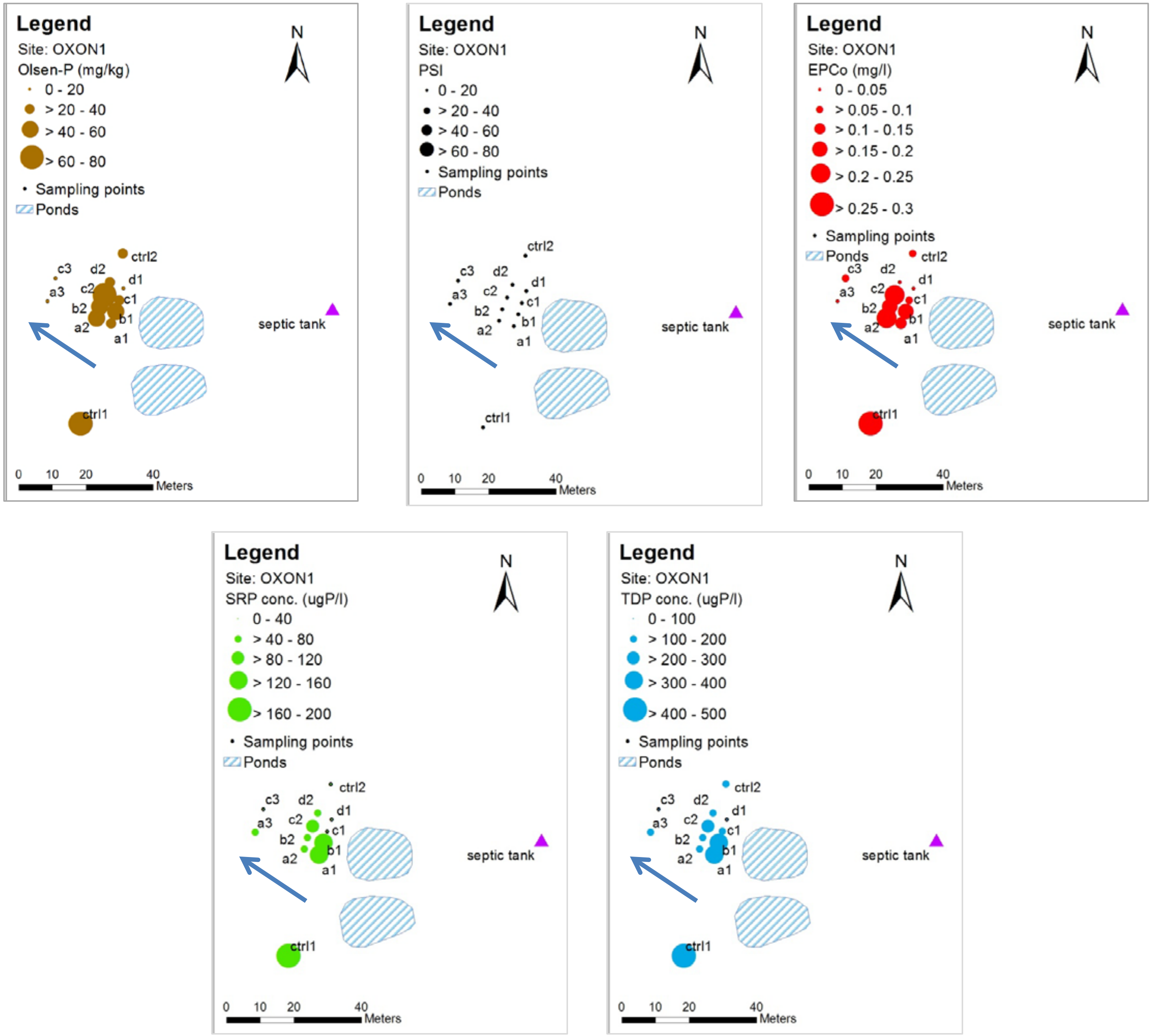


Figure 21 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the OXON1 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

OXON2

At OXON2, soil samples were collected from what appeared to be the drainage area for the septic tank. Porewater was successfully extracted from the samples for chemical analysis in 27 of the 32 samples collected. Most of the drier samples were from depths of greater than 120cm. The values reported are the highest levels recorded in each depth profile.

Concentrations of SRP within the porewater samples (Figure 22: lower panel, left) were mostly close to or below the limit of detection (7µg/l PO_4-P), apart from that at site A3, which was 172 µg P/l. The reason for this was unclear but, given its position, it seems unlikely to be linked to a septic tank effluent plume.

Concentrations of TDP within the porewater samples (Figure 22: lower panel, right) were higher than those for SRP, ranging from 11.2 µg P/l at Control 1 to 216 µg P/l at A3. Again, the reason for the high value at A3 is unclear, but it is unlikely to be related to a septic tank effluent plume.

The Olsen-P values of the soil samples collected at OXON2 (Figure 22: upper panel, left) ranged from 1 mg/kg at A1 and Control 2 to 63 mg/kg at A3. PSI values ranged from 4 at A3 to 11 at B2 and C2 (Figure 22: upper panel, centre). Values recorded for EPC_0 varied between 0.01 mg/l at A2 and 0.25 mg/l at A3 (Figure 22: upper panel, right). Overall, the data suggested that STS effluent may have been causing some eutrophication of the soils near sites B1, B2 and C2 although, as described above, this is unlikely to be the cause of the greater eutrophication of soils recorded at A3. If the elevation in soil P levels observed at B1, B2 and C2 is due to septic tank discharges, this suggests that soil eutrophication has occurred to a distance of at least 20 m from the tank at OXON2.

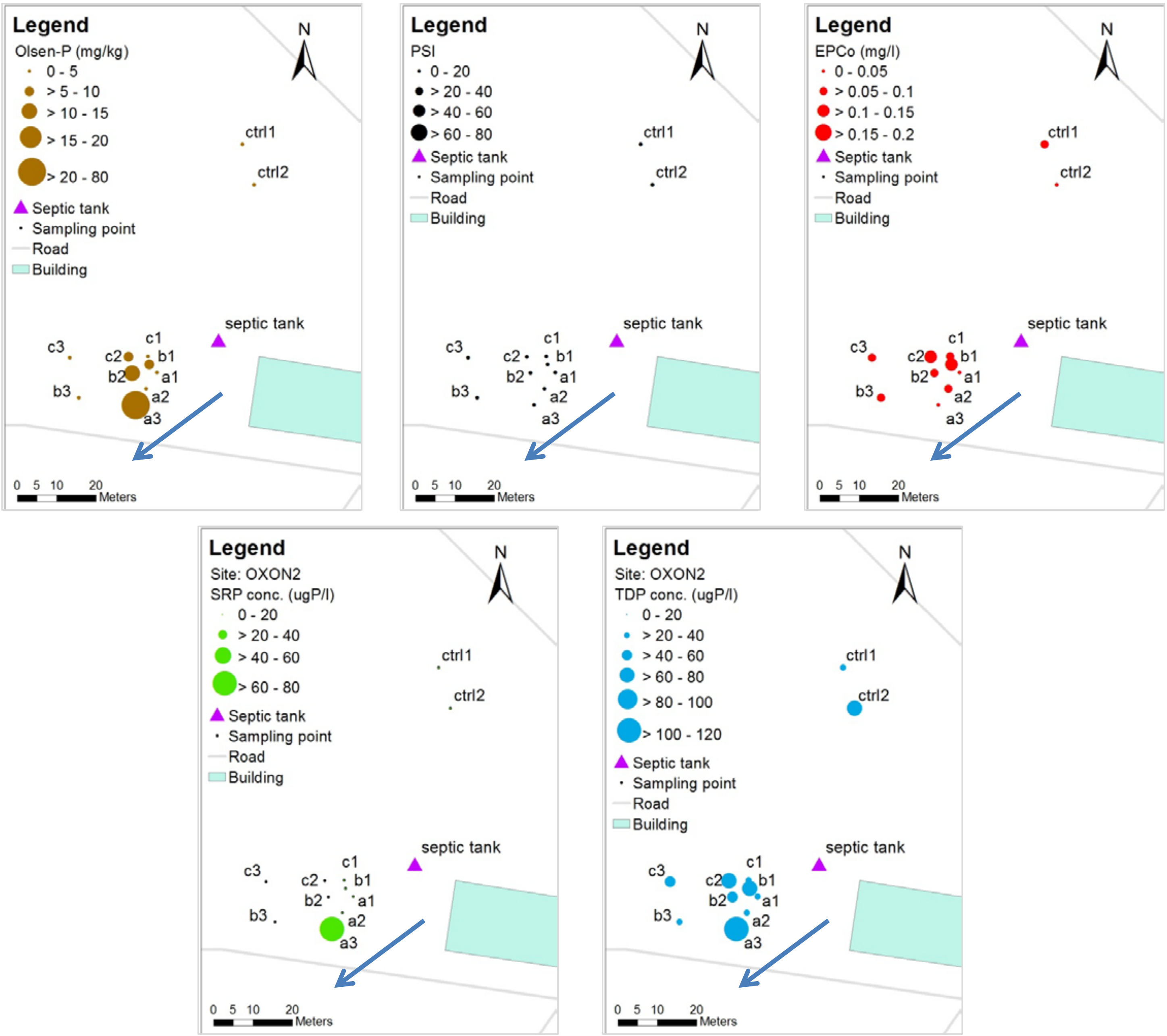


Figure 22 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the OXON2 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

OXON3

Soil samples were collected from an arc around the septic tank drainage area at site OXON3 due to lack of access to the wider drainage field. Porewater was successfully extracted from the samples for chemical analysis in 10 of the 19 samples collected. Samples that were too dry for porewater to be extracted were collected from all depths. The values reported are the highest levels recorded in each depth profile.

In addition, more detailed, depth sampling was undertaken at two ‘borehole’ coring sites within the area of the distribution pipes. This was to investigate the hypothesis that, in contrast to the original assumptions of the project, the effluent plume may be travelling vertically through the soil soakaway with little or no horizontal flow away from the system. This was investigated because it was one possible explanation for the original sampling regime collecting rather limited evidence of effluent plumes within the sites already sampled.

Concentrations of SRP within the porewater samples collected from around the septic tank (Figure 24: lower panel, left) were very high at most of the sample collection points, ranging from 105 to 720 µg P/l. This suggested that there was a strong source of soluble P in the area that, given its location, was probably due to the discharge of septic tank effluent into the soakaway. These high values were recorded more than 15 m from the tank itself, but within a few metres of the effluent distribution pipes. This is the only septic tank in the entire survey where high SRP values were recorded. At most locations, where sampling was usually a little further from the tank and distribution pipes, SRP values were below the limit of detection.

The Olsen-P values of the soil samples collected at OXON3 (Figure 24: upper panel, left) ranged from 8 mg/kg at D1 to 168 mg/kg at F1. The latter value is well above that normally found in agricultural fields. PSI values ranged from 2 at B1 to 12 at G1 (Figure 24: upper panel, centre). Values recorded for EPC_0 varied between 0.01 mg/l at G1 and 1.1 mg/l at A1 (Figure 24: upper panel, right). Overall, the data suggested that STS effluent may have been causing some eutrophication of the soils in the area, especially at sites A1, B1 and F1. This suggests that soil eutrophication has occurred to a distance of 15-20 m from the tank at OXON3.

The boreholes at OXON3 showed significant P enrichment of the soils to a depth of at least 1 m below the soil surface. This was more pronounced at site BH1 than BH2, but the pattern of decreasing concentration with depth is fairly consistent across the two boreholes (Figure 23). As these boreholes were situated amongst the effluent distribution pipes, these depth distribution curves illustrate the way in which P in the effluent travels through the soil immediately below them. In general, most of the P is removed from the plume by soil uptake within the first metre of soil below the distribution pipes. The reason for the single, very high Olsen-P level at almost 2 m depth at site BH2 is unclear.

There is a very strong relationship between Olsen-P and EPC_o (ie P in the soil solution) at OXON3. The degree of enrichment in the drain field below the distribution pipes is, however, much higher than those measured in the survey sites, with Olsen-P values being much higher in the borehole samples. This indicates a much higher uptake of P in the soils immediately below the pipes than further away from the tank. Overall, the area around this septic tank is highly contaminated with P.

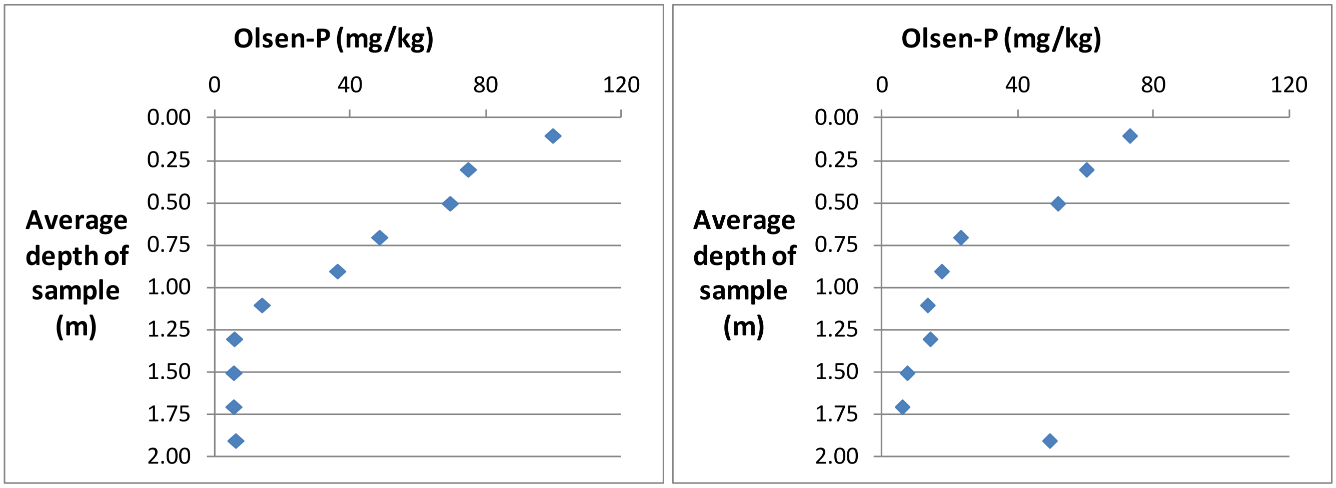


Figure 23 Change in Olsen-P values with depth at two borehole sites situated among the effluent distribution pipes at OXON3

While the results suggest that the major pathway for effluent flow is downward rather than horizontally at this site, it is difficult to extrapolate results from this single site to septic tanks in other geographical areas. This is because the soil type in this location may have been a significant factor in determining the major flow pathway.

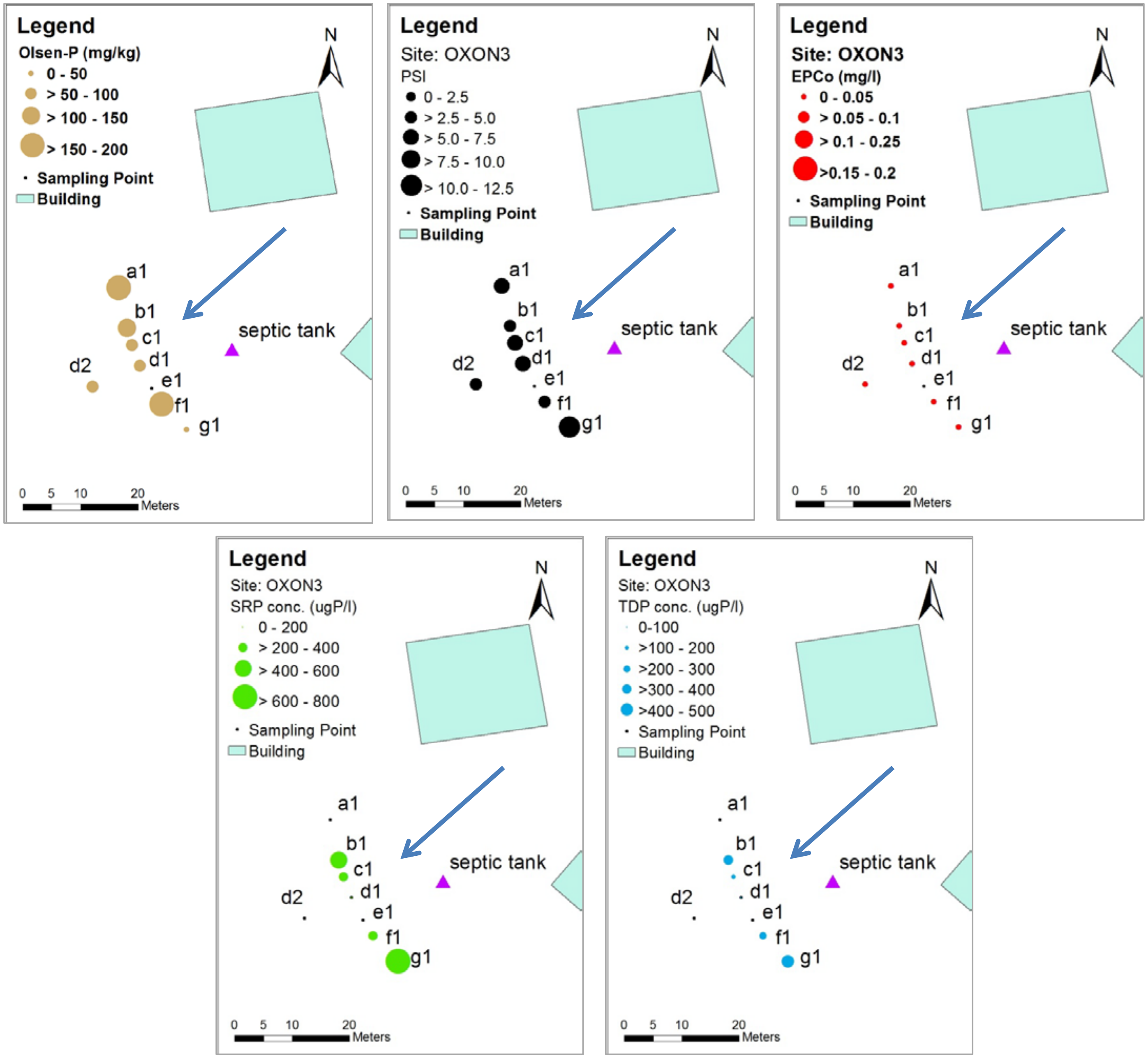


Figure 24 Spatial distribution of maximum soil (upper panel) and porewater (lower panel) P values across the drainage area at the OXON3 site. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

BROADS1

At BROADS1, soil samples were collected from what appeared to be the main drainage area for septic tank discharges point at this site. The weather had been very dry prior to sampling, and it was not possible to extract sufficient porewater from any of the samples for analysis. So, concentrations of SRP and TDP within the porewater samples could not be determined at this site. The values reported are the highest levels recorded in each depth profile.

The soil P analysis showed that BROADS1 is a very P-rich site where even the soil samples from the controls have high values (Olsen-P 62 mg/kg; EPC_0 0.8 mg/l). In general Olsen-P concentrations ranged from 34 mg/kg to 74 mg/kg, with an average value of 54 mg/kg, but did not decrease greatly with depth or change markedly across the site (Figure 26). This suggests a considerable amount of P enrichment of the subsoils and high levels of P contamination in this area. There was a close relationship between EPC_0 and Olsen-P values at this site (Figure 25).

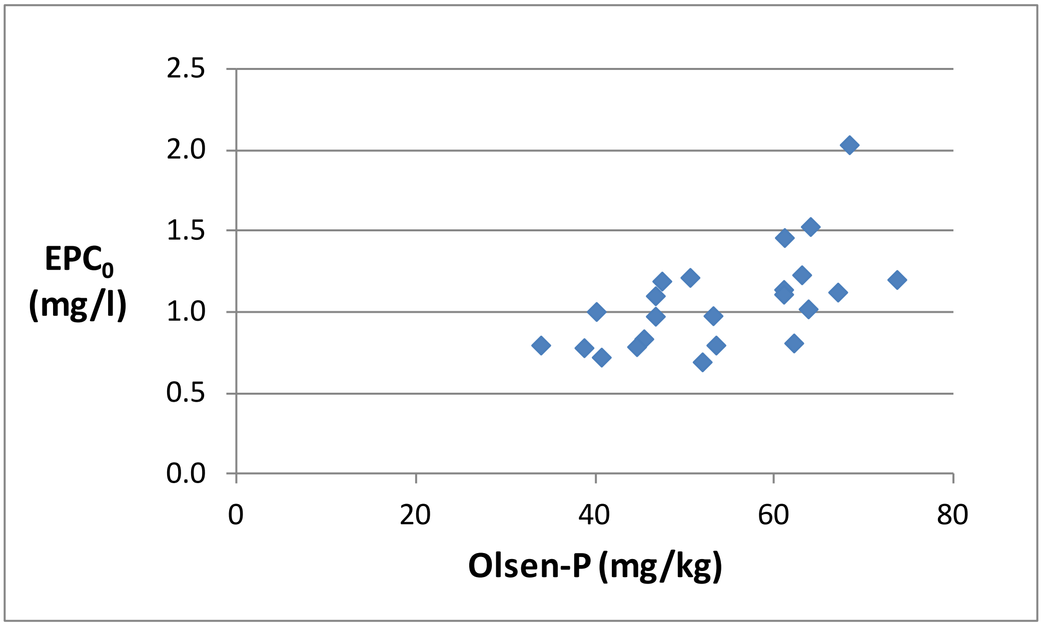


Figure 25 Relationship between EPC_0 and Olsen-P values at BROADS1

The PSI values were extremely low, ranging from 0 to 1.8, with an average of 0.8. In contrast, solution P concentrations (EPC_0 values) were very high (0.7 to 2 mg/l, with an average of 0.7 mg/l). This suggests very organic, enriched, soils in this area. However, the field teams reported predominantly sandy loam soils in this area from visual inspection of the core samples. There were no clear trends in soil P values across the site. All were fairly high (PSI: 0.5 – 1.1; Olsen-P: 45 – 67 mg/kg; EPC0: 0.8 – 2 mg/l) at 0.2 - 0.5 m depth. Although the soils at this site appeared to be highly contaminated with P compared to the other non-Broads sites sampled in this study, the high levels of Olsen-P recorded at this site are not uncommon for agricultural fields this area (Outram, *pers comm*., University of East Anglia).

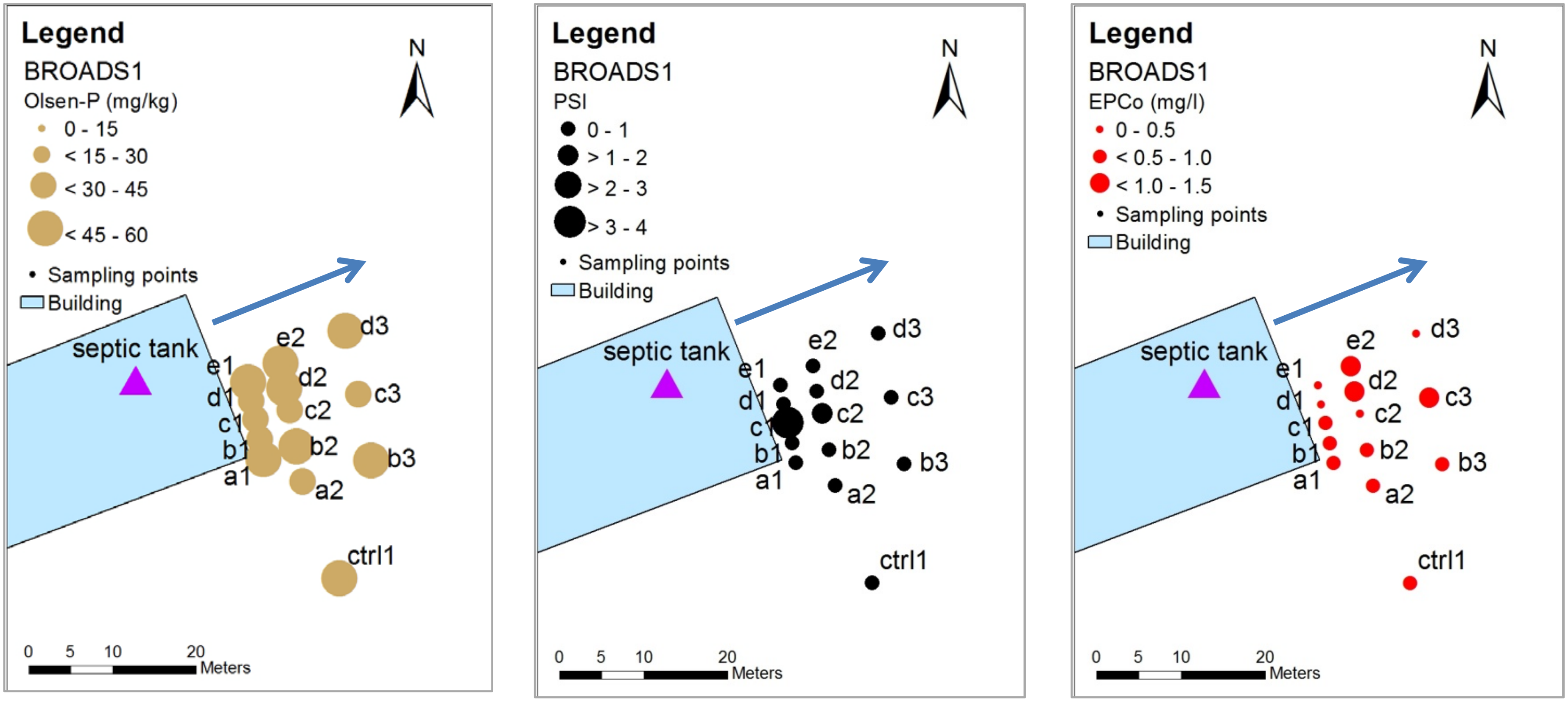


Figure 26 Spatial distribution of maximum soil P values across the drainage area at the BROADS1 site; the soils were too dry for porewater values to be determined. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013.

BROADS2

Soil samples at BROADS2 were collected from what appeared to be the main drainage area for septic tank discharges at this site. The weather had been very dry prior to sampling, so it was not possible to extract sufficient porewater from any of the samples for analysis. As a result, concentrations of SRP and TDP within the porewater samples could not be determined at BROADS2. The values reported are the highest levels recorded in each depth profile.

The soil P analyses showed that the BROADS2 site had very low PSI values ranging from 0 to 3.5, with a mean of 0.6. As with BROADS1, these values suggested organic, possibly peaty, soils but the sampling team reported very sandy, loamy soils from visual inspection of the core samples. Olsen-P values ranged from 6 to 56 mg/kg across the site, with a mean of 35 mg/kg. The corresponding EPC_0 values were 0, 2.5 and 0.7 mg/l, respectively. As at BROADS1, there was a fairly strong (and essentially similar) relationship between EPC_0 and Olsen-P values at Olsen-P concentrations above about 35 mg/l (Figure 27).

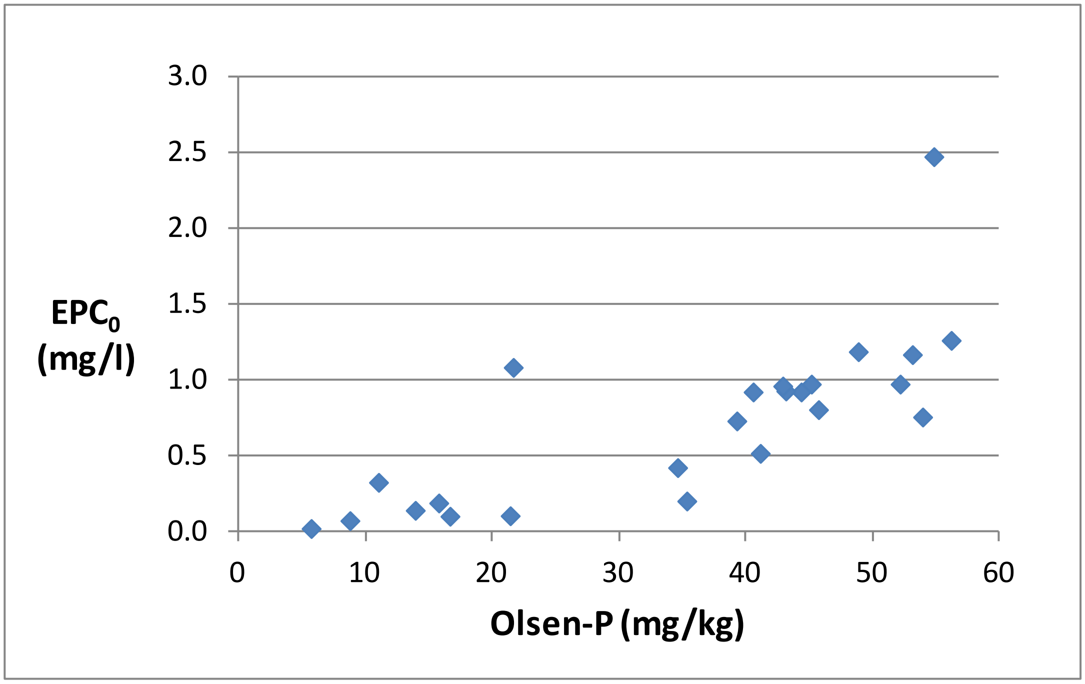


Figure 27 Relationship between EPC_0 and Olsen-P values at BROADS2

The control sample was already high in P (PSI: 0.9; Olsen-P: 46 mg/kg; EPC_0: 0.81 mg/l) and there did not appear to be any evidence of an increase in P status across the sampling transects (Figure 28). The high levels of Olsen-P recorded at this site are not uncommon for agricultural fields this area (Outram, *pers comm*., University of East Anglia). There was, however, a clear decrease in soil P values with increasing depth at some sampling points (e.g. B1, D2, D3). In general, high levels of P were evident to a depth of 1m.

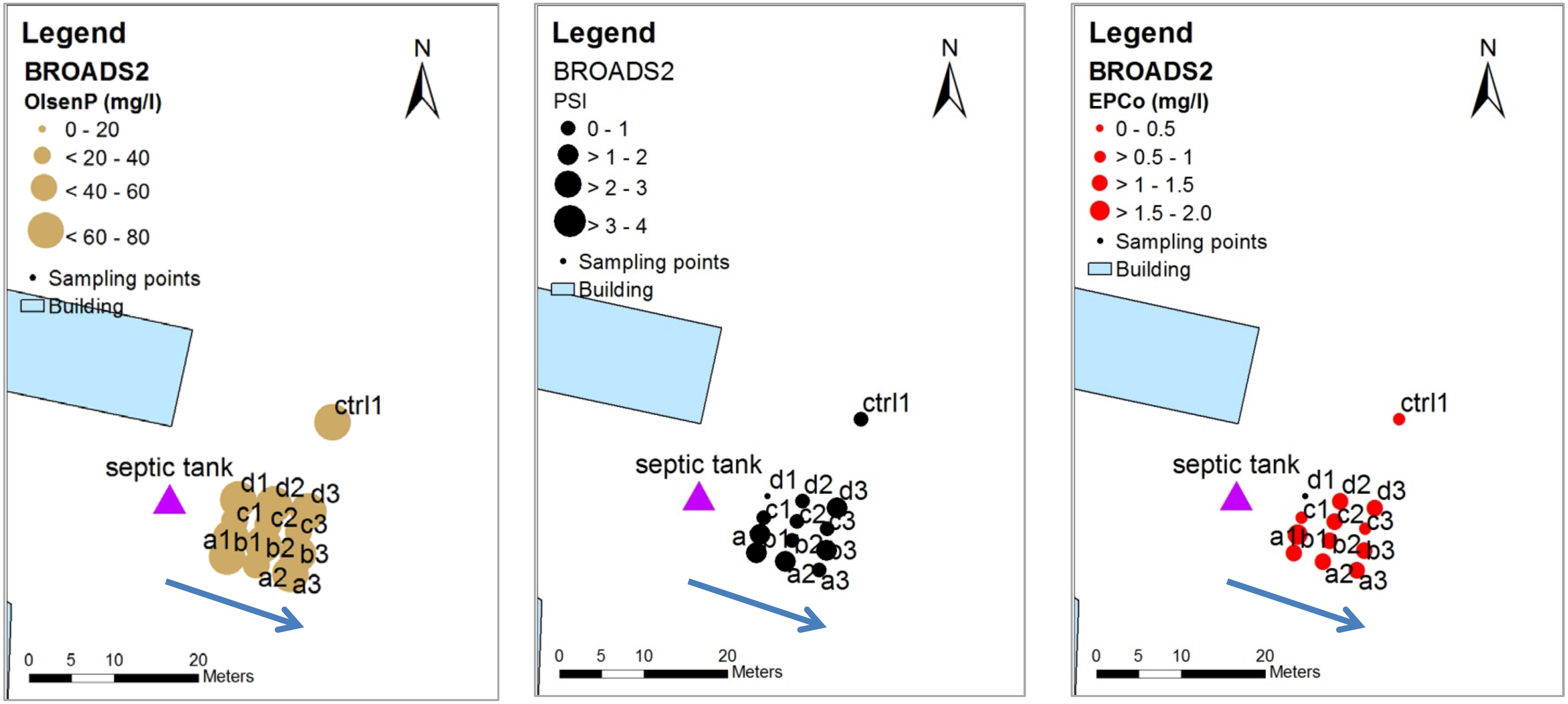


Figure 28 Spatial distribution of maximum soil P values across the drainage area at the BROADS2 site; the soils were too dry for porewater values to be determined. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013.

BROADS3

Soil samples at BROADS3 were collected from what appeared to be the main septic tank drainage area at this site. The weather had been very dry for several weeks before sampling was undertaken, and it was not possible to extract sufficient porewater from any of the samples for chemical analysis. So, concentrations of SRP and TDP within the porewater samples could not be determined at this site.

Soil P analyses showed that the BROADS3 site had very low PSI values ranging from 0 to 4.3 with a mean of 1.5. As with BROADS1 and BROADS2, these values again suggested organic, probably peaty, soils; this contrasts with the sampling team report of very sandy, loamy soils from visual inspection of the core samples.

Olsen-P values ranged from 2 to 29 mg/kg across the site, with a mean of 9 mg/kg. The corresponding EPC_0 values were 0, 1.0 and 0.25 mg/l, respectively. The control sites at BROADS3 were low in P (PSI: 2.3-3.7; Olsen-P: 3-8 mg/kg; EPC_0: 0 mg/l) and the 0.2-0.5 m depth samples showed some enrichment. This is reflected in an increase in solution P. As at BROADS1 and BROADS2, there was a fairly strong (and essentially similar) relationship between EPC_0 and Olsen-P values at this site, although soil P concentrations were generally lower at BROADS3 than at the other two Broads sites (Figure 29). Overall, there was a clear decrease in soil P levels with increasing depth.

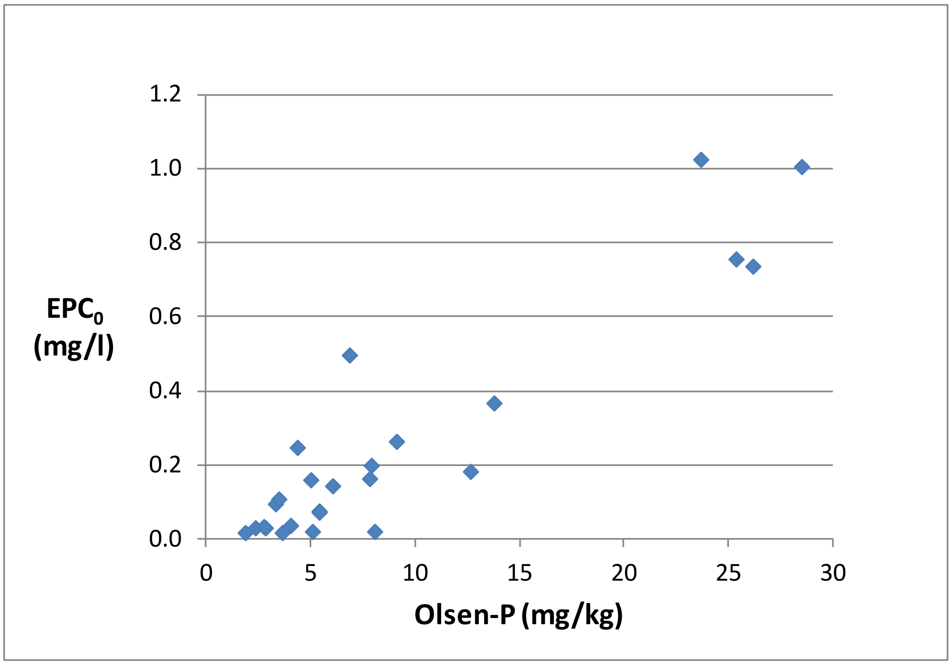


Figure 29 Relationship between EPC_0 and Olsen-P values at BROADS3

There is some evidence that the effluent plume travels *via* A1, A2, A3/B3 but sampling ceased before soil P concentrations had returned to background levels (Figure 30). This suggests a travel distance of at least 20 m. So, at BROADS3, P appears to move further in the soil than at many of the other sites visited. This may reflect the fact that this septic tank receives roof runoff, which will cause the contents of the septic tank to be flushed out of the system when it rains, and when soils are likely to be saturated with water.

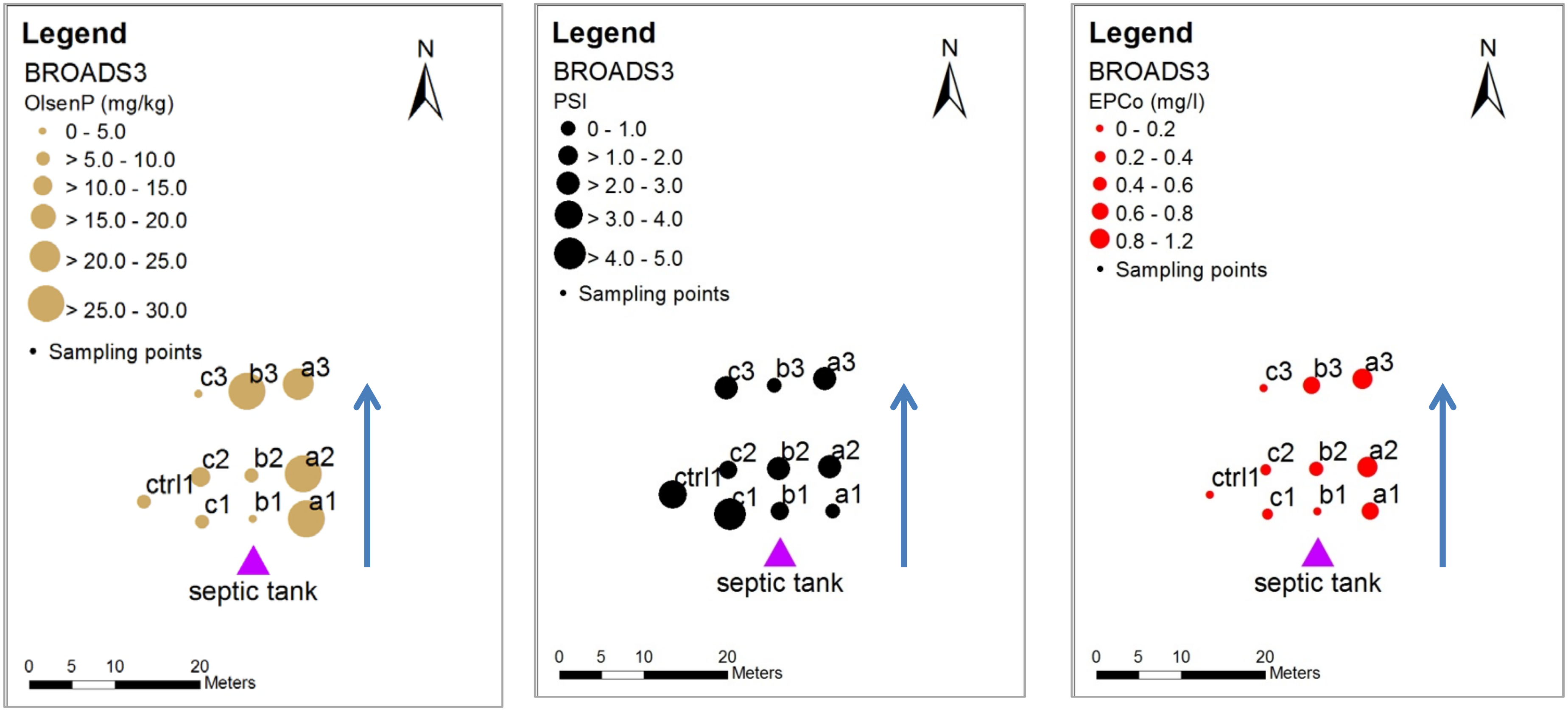


Figure 30 Spatial distribution of maximum soil P values across the drainage area at the BROADS3 site; the soils were too dry for porewater values to be determined. Blue arrow indicates likely direction of plume development. Contains Ordnance Survey data © Crown copyright and database right 2013

Overview of soil and porewater P results

A range of soil available P (Olsen-P) values were obtained at most of the sites visited (Table 10). Values of less than nine indicate a P deficiency in the soil, while values in the range 16-25 are considered optimal for crop growth, and those above 46 are considered high.

Table 10 Range of Olsen-P, P sorption index (PSI) and equilibrium P concentration (EPC_0) values obtained at each site sampled

Location	Site code	Olsen-P (mg/kg)	PSI (ratio)	EPC_0 (mg/l)
Shropshire	CLUN1	0-32	14-77	0-0.2
Shropshire	CLUN2	2-11	18-71	0-0.015
Shropshire	CLUN3	0-5	10-24	0-0.03
Hampshire	WYLYE1	0-29	5-9	0.02-0.4
Hampshire	WYLYE2	5-30	1-12	0.01-0.5
Oxfordshire	OXON1	1-68	9-11	0-0.31
Oxfordshire	OXON2	1-63	4-11	0.01-0.25
Oxfordshire	OXON3	8-168	2-12	0.01-1.1
Norfolk	BROADS1	34-74	1-2	0.7-2.0
Norfolk	BROADS2	2-28	0-4	0-1.03
Norfolk	BROADS3	6-56	0-4	0-2.47

Control samples at the CLUN and WYLYE sites, and at OXON2, were all very low in Olsen-P, with the exception of one control sample at CLUN3. The control samples at OXON1 were high and may not have been suitable for use as control sites. At the CLUN2 and CLUN3 sites, there was no evidence of any increase in soil available P in the soakaway. At CLUN2, this was probably because the septic tank was relatively new and only used occasionally. At CLUN3, the sampling regime probably missed the plume altogether as no soil enrichment was recorded anywhere within the area sampled. In contrast, at CLUN1, the two WYLYE sites, the OXON sites and the BROADS sites there seemed to be clear evidence of P enrichment.

The extent to which P enrichment from STS occurred at OXON1 is difficult to judge based on the control samples, but samples along transect 3 at this site all showed deficient P status. Using transect 3 as the control, then the data suggest that this site was also enriched. Where P enrichment occurred it was almost always greatest within the 0.2-0.5 m depth sampling zone and concentrations decreased with depth.

Larger concentrations of inorganic P in the soil solution were obtained at the OXON and WYLYE sites compared to the CLUN sites, relative to Olsen-P concentrations. This probably reflects the more calcareous nature of the soil at OXON and WYLYE. Phosphorus does not bind as strongly in soils that are dominated by calcium (Ca) as it does in soils dominated by iron (Fe) and aluminium (Al) oxides. This is reflected in the much lower PSI values (Table 10).

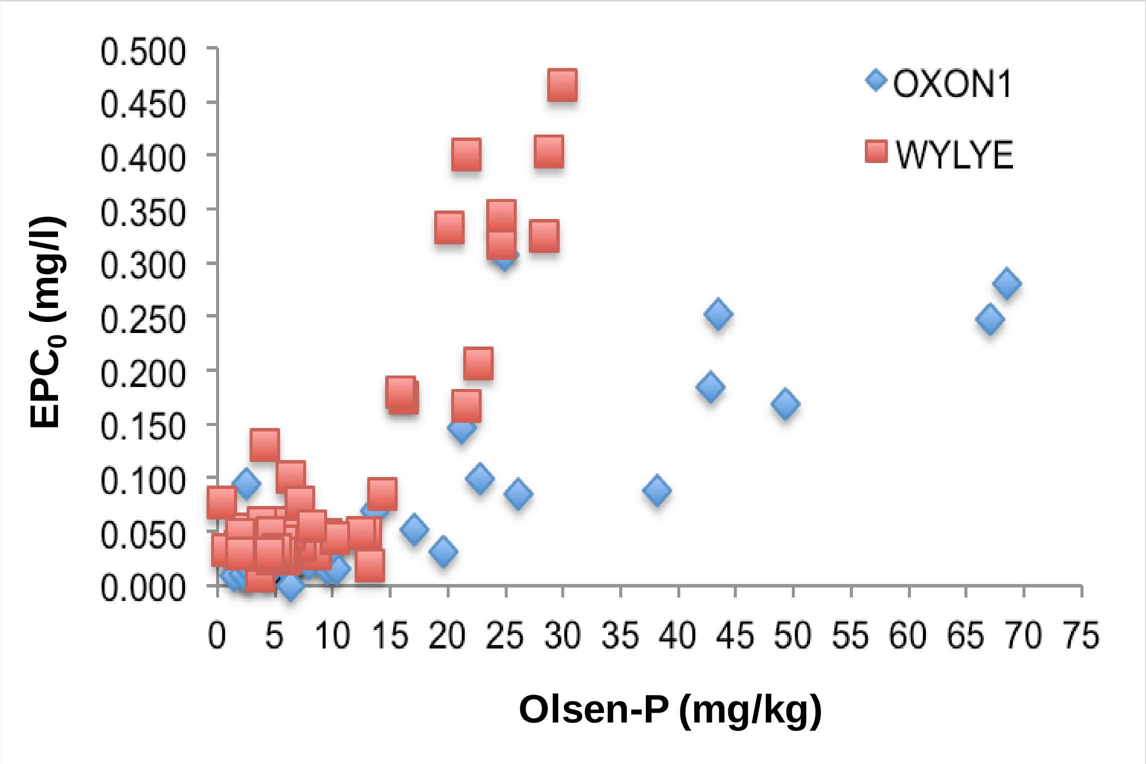


Figure 31 The relationship between equilibrium P concentrations in the soil solution (EPC$_0$) and soil available P (Olsen-P) at sites at WYLYE and OXON1

Solution P concentrations (EPC$_0$) tended to increase as Olsen-P increased across all sites, and high solution P concentrations were obtained when PSI values were less than *ca*. 12. These results are consistent with previous work. At sites where there was no enrichment in Olsen-P, there was also no increase in EPC$_0$. At the WYLYE and OXON2 sites, EPC$_0$ increased markedly once Olsen-P concentrations were above 10-15 mg/kg (Figure 31). However, the rate at which solution P concentrations increased varied between the WYLYE and OXON2 sites. This reflects differences in the P binding capacities of their soils, which were lower at the WYLYE sites. This was also reflected in their PSI values. At CLUN1, solution P concentrations were not linked to Olsen-P concentrations and appeared to be highly variable. The reason for this is unclear.

The spatial distribution of the soil P and solution P concentrations at CLUN1, the WYLYE sites and the OXON sites suggest greatest enrichment nearer the septic tank outlet with elevated concentrations still evident up to 20-30 m away. This appears to be a consistent pattern across these sites, although the distance between the septic tank and the sampling sites varied.

5 Discussion

The specific aims of this project were to examine the relationship between STS management and maintenance and the discharge of P to the environment and to investigate how far P discharges from these systems travel through the upper, aerated zone of the soil soakaway. The study focused on STS that were more than 100 m from a waterbody and at least 2 m above the high water table, because these were less likely to be causing P pollution of waterbodies than those that were less than 100 m from a waterbody and less than 2 m above the high water table. The results of this study, discussed below, will help inform a follow-up desk based study to estimate the relative risk posed by existing STS across the freshwater SSSI series.

The study focused on P movement through the aerated zone of the soils, ie the part of the system where P uptake from the effluent plume is most likely to occur in a properly functioning system. This approach is in contrast to other studies, as these have focused on STS that are likely to be causing a problem. So, there are no results from other studies with which those from the current study can be compared.

A total of 11 septic tanks and their drainage areas were sampled during the course of this study. More than 50 samples were collected from each site and each was analysed for five different chemical determinands. Information of the lifestyle of the household, and on the servicing and maintenance of each tank, was collected by questionnaire.

The P concentrations in the effluents of the on-site sewage treatment systems studied were remarkably similar across all types of system, including the package treatment plant (PTP) sampled at OXON1. The average P concentrations in effluent discharged from the standard septic tanks studied was about 11 mg P/l of soluble reactive P (SRP) and 15 mg/l of total phosphorus (TP) and the equivalent values from the PTP were 10.7 mg P/l of SRP and 12.9 mg P/l of TP. There was no evidence that this PTP was any more effective at retaining P than a standard septic tank. Although this result is specific to one particular installation, a similar result was also recorded by Brownlie et al. (2013), while working in the catchment of Loch Leven, Scotland. This raises concern about current guidance on small discharges, which allows PTPs to discharge directly to water. This advice is based on tests that show that PTP effluent is less polluting than septic tank effluent. However, these tests are based on the ammonium and suspended solids content of the discharge, and its biological oxygen demand, only, not its P content, as this is not a regulatory requirement. Although results based on the very small number of systems sampled in this study are inconclusive, and cannot be extrapolated to all septic tanks and PTPs, they do raise concerns about the level of P emissions from PTPs in comparison to standard septic tanks and strongly suggest that this should be investigated further in terms the level of P mitigation offered by these systems. If septic tanks that discharge to soakaways are replaced by PTPs that have permission to discharge directly to water, but discharge a similar amount of P, eutrophication problems may be exacerbated rather than improved by such an ‘upgrade’.

The borehole data from the OXON3 site showed significant P enrichment of the soils to a depth of just over 1 m below the effluent distribution pipes. The observed reduction in soil P enrichment with depth suggests that much of the P in the effluent that moves vertically through the aerated part of the soil profile is retained by those soils. Although based on a small number of samples from only two sampling points with the same soil type, this strongly suggests that the soils can provide an important function in terms of P retention within these systems. This function is likely to be compromised if the soil becomes waterlogged, as may occur during periods when the water table is high. The results suggest that it may be very important that soil soakaways are situated in areas that provide a significant depth of aerated soil below the effluent distribution pipes. However, this requires further investigation.

In many areas of the UK, orthophosphate is added to water supplies to reduce the levels of lead in drinking water. Levels of treatment vary from region to region, but average concentrations may be as high as 1.9 mg P/l in some areas (UKWIR, 2012). The present study found that tap water at the Norfolk and Oxfordshire sites contained relatively high levels of SRP, ranging from 0.9 to 1.1 mg P/l. These values were compared with the P content of corresponding tank effluents, and it was found that there may be a positive relationship between the two. Although these results are based on a low number of samples, the apparent relationship between tap water and effluent P concentrations is sufficiently strong to warrant further investigation. This is especially true in the light of current proposals to reduce levels of lead in drinking water still further, as this will require even higher additions of orthophosphate to domestic water supplies.

It is widely believed that the greater the age of a septic tank the less effective it is in processing domestic wastewater effectively. Indeed, many older tanks are often replaced by newer systems for this reason. This hypothesis was tested in the present study, albeit on a small number of tanks aged between 2 to 50 years, many of which had never having been emptied, inspected or repaired. The results showed that there was some evidence of older tanks discharging higher levels of P to the environment than more recently installed tanks. However, this was inconclusive because the sample size was too small to separate this effect from that of other factors that may also exert an influence, such as the lifestyle of the household and the level of repair and maintenance of the system. More detailed studies on a larger number of tanks are required to provide sufficient data to separate these effects, statistically.

Factors that cause incomplete breakdown of particulate matter within a tank, such as infrequent emptying, physical damage, or too low a retention time, may increase the discharge of particulate matter from the tank. This particulate matter may clog the soil soakaway, causing hydraulic failure of the drainage area and increasing the likelihood of P pollution problems. At some of the sites studied, the proportion of particulate P (PP) in the effluent was found to be very high, accounting for up to 86% of the total amount of P discharged. The factors causing high levels of PP to be discharged in the effluents from some tanks but not others could not be determined due to insufficient data.

Extracted pore water was analysed for SRP and total dissolved P content, while soil samples were analysed for indicators of soil P status (ie Olsen-P concentration (Olsen-P), P sorption index (PSI) and equilibrium phosphorus concentration at zero sorption (EPC_0). The results suggested that P originating from septic tank discharges can move laterally through the soil profile for a distance of 20-30 m in most of the soil types included in this study. Evidence of this was found in the porewater P values and the indicators of soil P status measured. This was especially true of TDP concentrations and Olsen-P values, but was also reflected in PSI and EPC_0 values.

The results of this study suggest that the current legislative value of 10 m for the separation of a septic tank soakaway from a watercourse (The Building Regulations, 2000) is probably insufficient to protect that waterbody from P pollution from this source, even where the local hydrology does not provide a shortcut for the delivery of septic tank discharges to water. So, septic tank systems may need to be located at setback distances of greater than 10 m to protect sensitive waterbodies from P plumes that are moving laterally through the upper layers of the soil. However, the level of risk seems to depend, primarily, on soil type and soil P characteristics. Quantifying these relationships sufficiently to inform a risk assessment process has proven difficult within the resource limitations of the current project. It is recommended that the data are investigated further, and in combination with national scale spatial datasets and local knowledge, to inform evidence based decision making in relation to local development within SSSI boundaries and mitigation of existing problem sites. The main pathways for delivery of septic tank effluent to water, ground water movement and enhanced hydrological conductivity due to pipes and drains still remain an important issue, but did not form part of the current study. The results only apply to P transport through the aerated soil zone, above the water table.

The results show that, although P from STS may still be transported through the aerated part of the soil towards nearby waterbodies (ie those < 30 m away), in general this part of the soakaway system does remove P from STS effluent effectively unless it is compromised by enhanced hydrological connectivity such as that caused by direct discharge to a waterbody, local drainage channels or a high water table. If these soils become waterlogged for any reason, however, they will fail to provide this function effectively. These factors can now be incorporated into the planned assessment of risks posed by STS on SSSI waterbodies.

6 Recommendations for further work

The results of this study provide an indication of the relative importance of some of the factors associated with the management and maintenance of STS, and with their location, that affect the risk that they pose to nearby SSSI waterbodies in terms of P pollution.

Some of the results were inconclusive due to small sample sizes and it is recommended that these are followed up in subsequent work. Questions that still need to be addressed in terms of mitigating the impacts of existing systems on SSSIs, and informing the safe installation of new systems, include:

1) Is the effluent quality from package treatment plants higher, in terms of P content, than that from standard septic tanks?
2) What is the effect of de-sludging on the P concentrations in the effluent that is discharged by septic tanks?
3) Does the P content of tap water affect the level of P in septic tank effluent and how will this be affected by proposals to lower lead concentrations in drinking water by adding more orthophosphate?
4) Is the age of the tank a key factor in determining the quality of the effluent?

The study has also shown that the aerated soil zone within 20-30 m of a septic tank provides an important function in terms of removing P from a septic tank plume before it enters a receiving waterbody. By implication, this suggests that enhanced hydrological connectivity to a waterbody, which short circuits this process, is probably one of the main factors that causes pollution of SSSIs by these systems. This knowledge should now be incorporated in a new or updated risk assessment protocol, such as that proposed by May et al. (2010).

It was not possible to examine the depth profiles collected from each soakaway in any detail within the resources of the current project. So, only the maximum porewater and soil P values are reported for each core. A more detailed analysis of the three dimensional nature of the data collected, including the relationships between porewater and soil P values, is recommended.

The electro-magnetic imaging technique requires further development, especially in relation to the environmental conditions under which it can operate effectively, before it is sufficiently well developed for operational use.

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Appendix 1 Plume tracking

Background

The path of the effluent plume through the drainage field needs to be determined as accurately as possible in order to track and quantify the fate of P from STS within the wider environment. The possible use of an electromagnetic induction (EMI) imaging system (Lee et al., 2006) was investigated for use within the project. This non-invasive technique, which does not disturb the soil, is still under development, but has the potential to identify electrical contrasts within the soil that are generated by effluent plumes. However, it should be noted that the method is susceptible to interference from metallic infrastructure close to the area being surveyed and may only be applicable to septic tanks in open fields.

Plume tracking

To explore the possible effectiveness of EMI in tracking effluent plumes through the soil, data collected from a farm site in Wales during the summer of 2011 was re-examined. The image from that study, shown below, indicates the presence of various effluent plumes as indicated by the areas shaded in yellow (Figure A). The first, labelled (1), is probably the result of outwash from nearby sheep sheds. That shown in the area (2) is less clearly defined but was believed to indicate the likely path (arrowed) of an effluent plume from a septic tank located within the area circled in red.

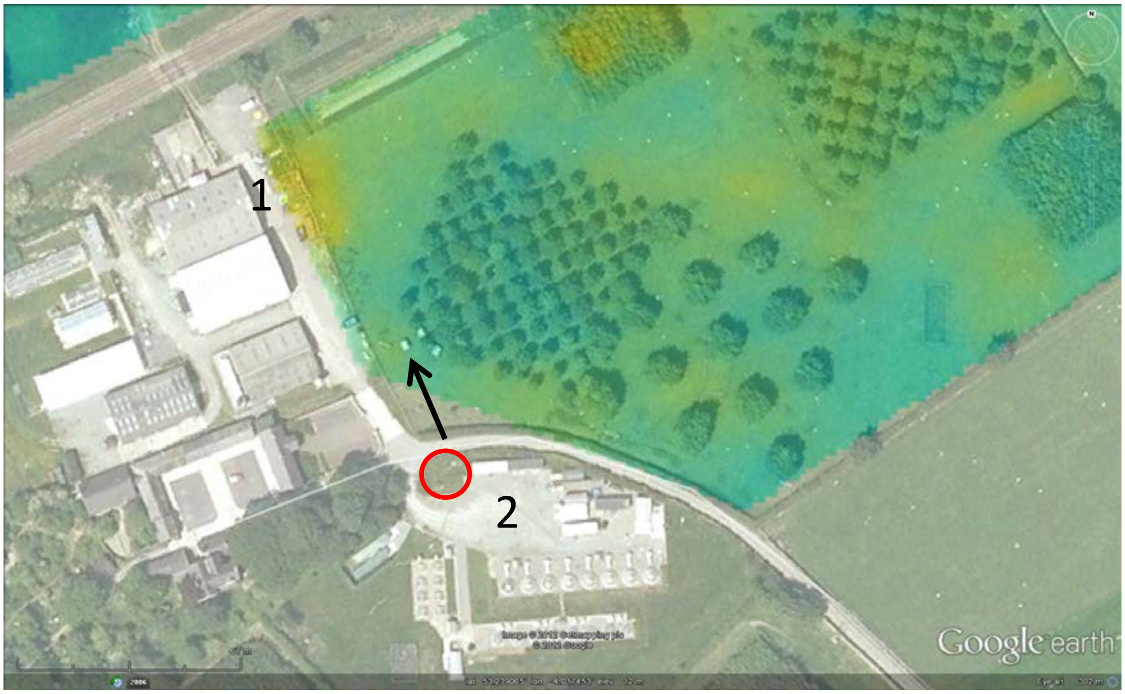

Figure A Areas of high electrical conductivity (yellow shading), probably effluent plumes, identified using EMI tracing on a farm in Wales; the position of the septic tank (red circle) and the likely path of the effluent plume (arrow) are indicated

The signal from the sheep sheds plume differs in intensity from that thought to be associated with the septic tank (Figure A). This suggests that EMI can pick up the more saline outwash from manure effectively, but may be less reliable for tracking STS effluent plumes.

Before fieldwork for the current study began, the area around the septic tank at the Welsh farm site was resurveyed in more detail to see if the path of the apparent effluent plume could be identified more accurately. However, the results were inconclusive. On this occasion, the main plume seemed to be travelling in a different direction, ie under a gravelled car park (Figure B; see arrow) rather than through the nearby field as had been expected from the previous results. This apparent change in direction may have been due to the much wetter soil conditions under which the more recent (winter) survey was undertaken, and may suggest that effluent plumes do not always follow the same path under different hydrological conditions. A lot of interference in the signal was observed at this site. This seemed to be due, mainly, to metal in the fences and gates.

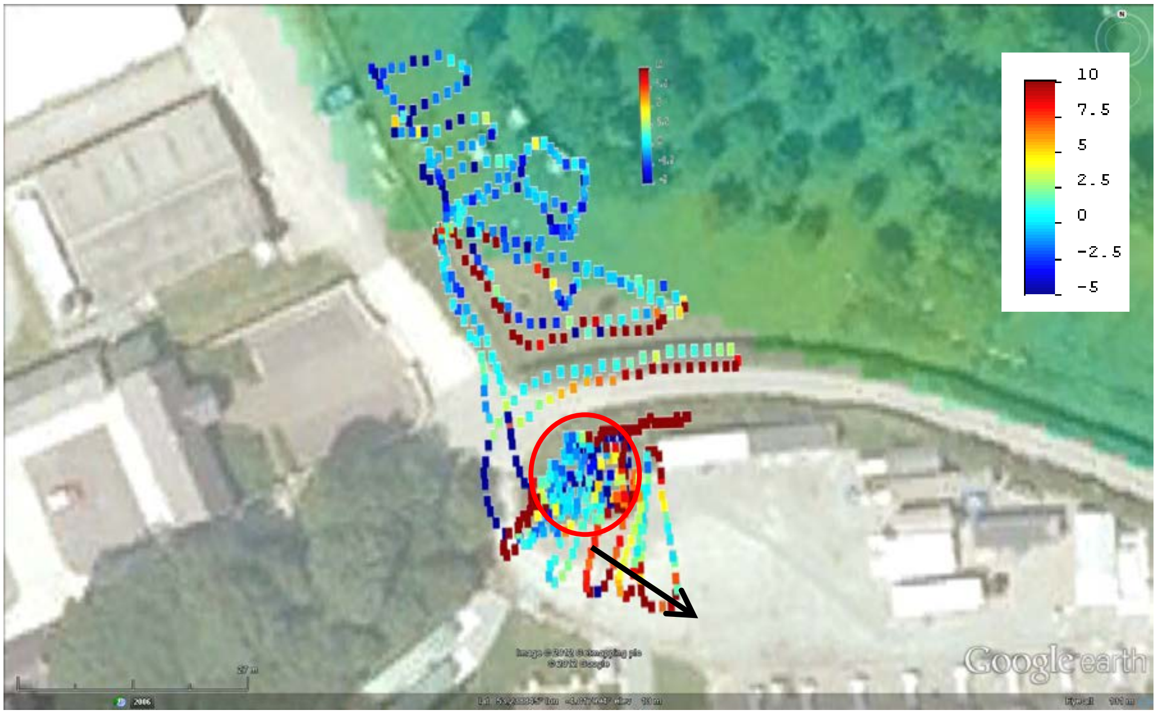

Figure B More detailed data from a re-survey of the farm site in Wales showing the position of the septic tank (red circle) and the likely path of the effluent plume (arrow); levels of electrical conductivity (shown in arbitrary units) range from low (blue) to high (red)

On the basis of the inconclusive results outlined above, and the lack of soil porewater and chemistry results to validate the plume tracking results, EMI surveying tested in more detail at the first three survey sites visited in the current study, ie CLUN1, CLUN2 and CLUN3.

CLUN1

The potential effectiveness of EMI in tracing the plume from the tank was tested at CLUN1. Although no evidence of plume was detected at depths of 0-0.5 m below the soil surface (Figure C; upper panel), the results provided possible evidence of a plume travelling at a depth of 0.8 - 1.30 m along a culvert at the side of the road (Figure C; lower panel). However, the soil P status and porewater P results failed to confirm that this signal was generated by a septic tank plume and it seems more likely that the EMI was detecting road runoff or a buried electrical cable, instead. There was no evidence of a plume travelling into the field across the road, even though this was slightly downhill of the tank.

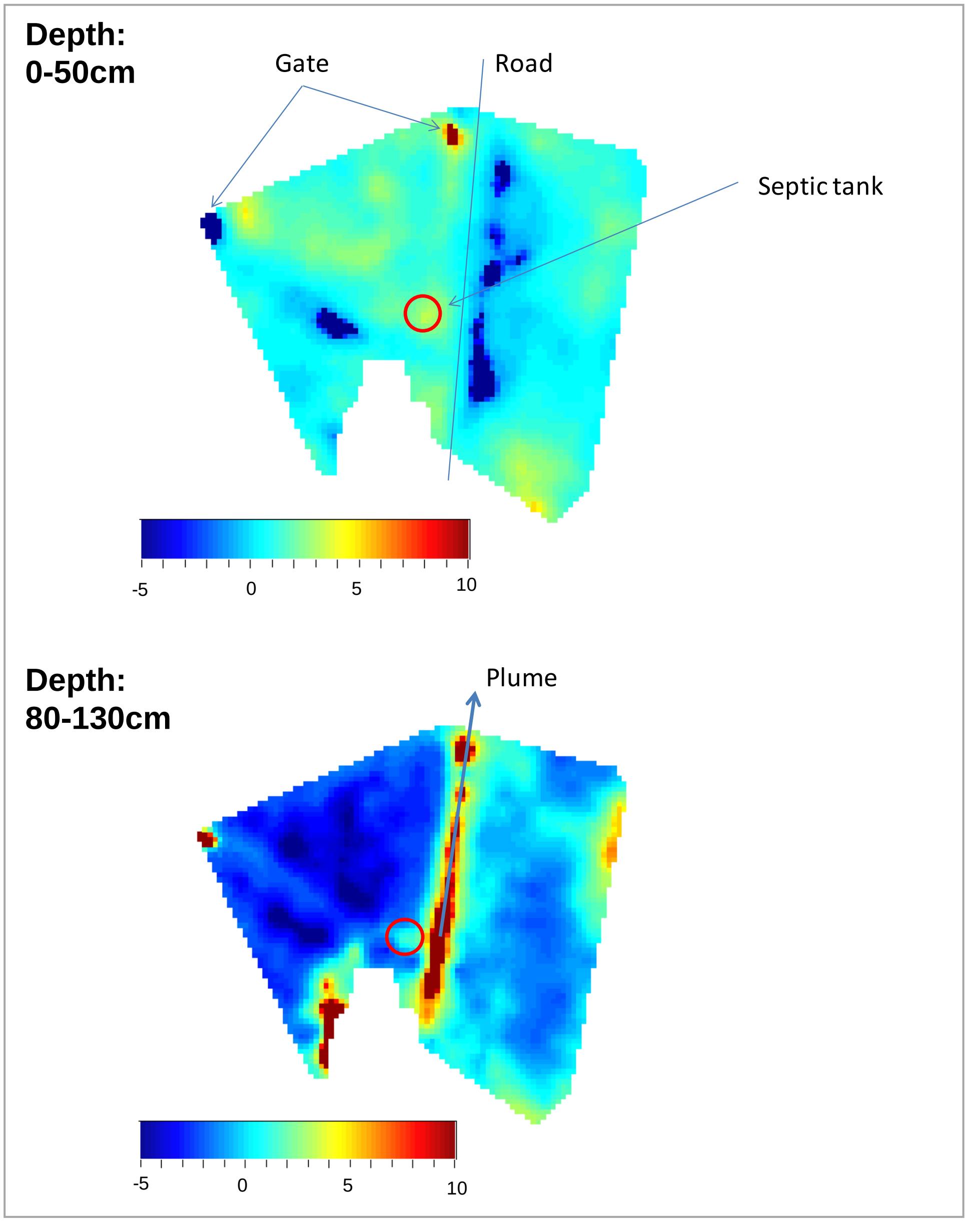

Figure C Electromagnetic image (EMI) of the drainage field at Site CLUN1 indicating the possible path of the plume from the septic tank. Levels of electrical conductivity (shown in arbitrary units) range from low (blue) to high (red)

CLUN2

EMI surveying was also undertaken at site CLUN2. This did not show a distinct plume at this site, although a couple of conductive hotspots were identified (Figure D).

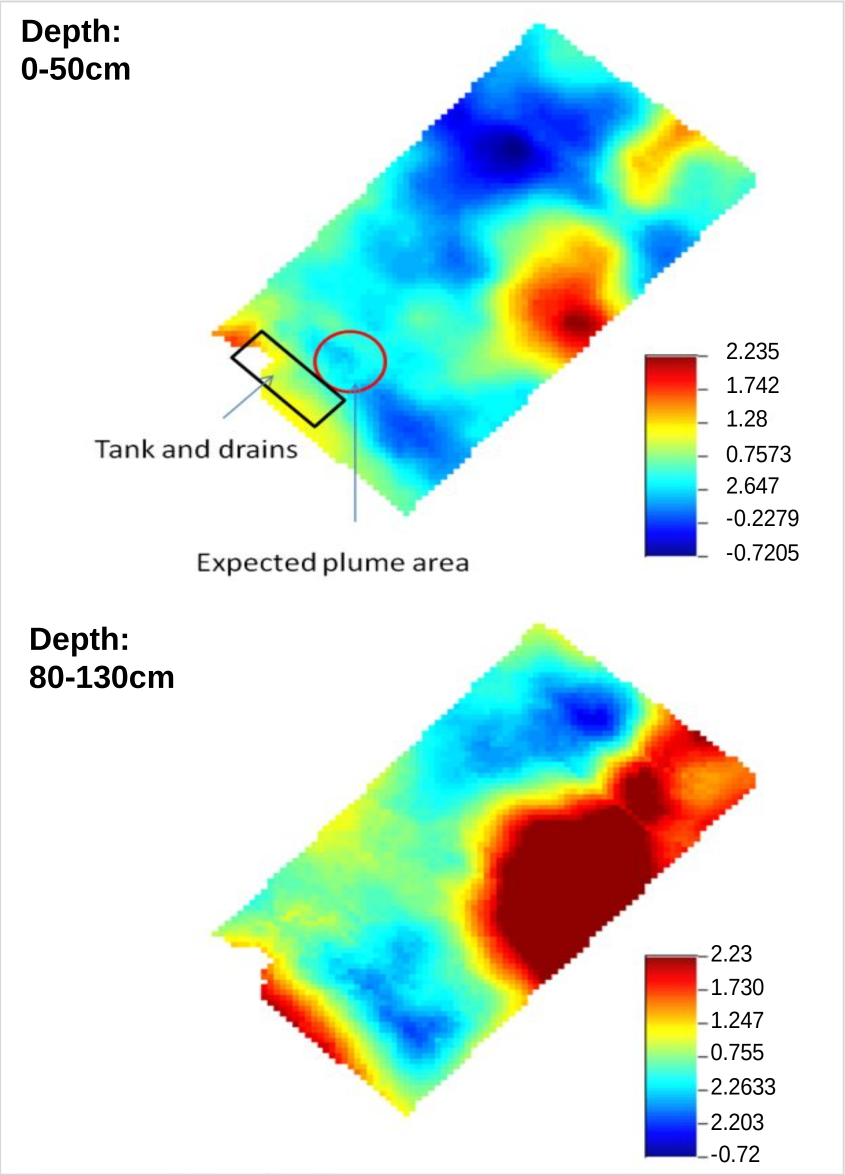

Figure D Electromagnetic image (EMI) of the drainage field indicating the possible path of the plume from the septic tank at site CLUN2. Levels of electrical conductivity (shown in arbitrary units) range from low (blue) to high (red)

In terms of soil and porewater samples, most were collected to a depth of about 100 cm, although, in some cases, depths of up to 1.5 m were achieved. Additional samples were taken to support the EMI imaging test at this site, especially D2 and D3 which were located within the two ‘hotspots’ identified. The soil P status and porewater P concentrations were not elevated above background levels at these points and no obvious explanation could be found for the high electrical conductivity recorded in these areas.

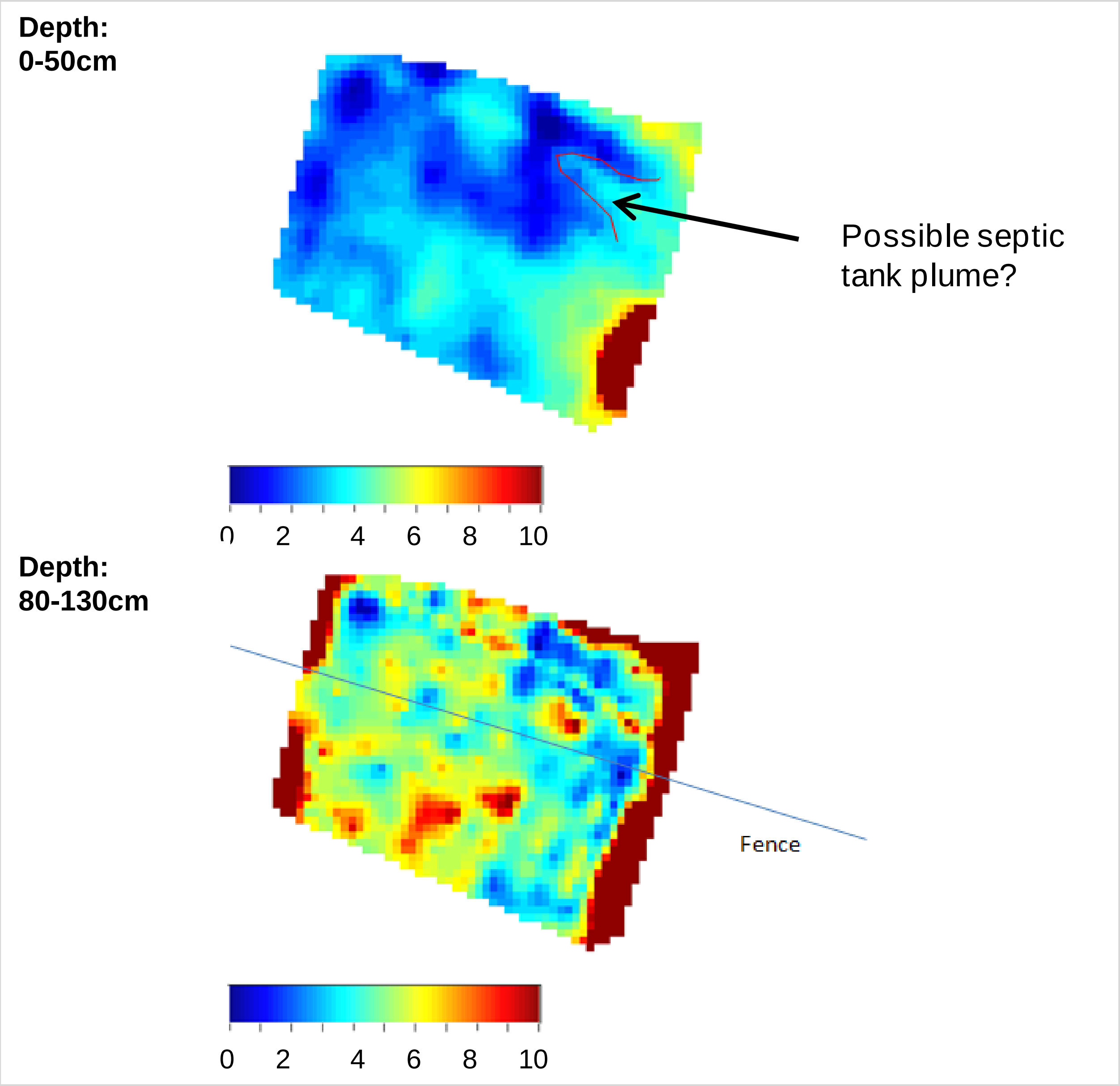

Figure E Electromagnetic image of the drainage field indicating the possible path of the plume from the septic tank at site CLUN3. Levels of electrical conductivity (shown in arbitrary units) range from low (blue) to high (red)

The potential effectiveness of EMI in tracing the plume from the tank was also tested at CLUN3. The results (Figure E) suggested a plume in the top 0.5 m of the soil (Figure E; upper panel) that, in the central (most noticeable) section, seemed to extend 30 m down slope. Further away from the tank, readings returned to background levels. The measured soil and porewater P levels at the site, however, failed to provide any evidence that this signal was generated by a septic tank plume.

Conclusions

Several conductive hotspots were recorded by the EMI imaging survey within the likely area of the septic tank plumes at these sites. However, as these could not be validated by the soil P status or porewater P concentration data collected, the usefulness of this technique for operational use (in its present state of development, at least) remained unproven. So, no EMI surveys were undertaken at the remaining sites.

Our results are in contrast to those reported by Lee and others (2006), who conducted a more detailed and focused study of this technique than was possible in the present study. These authors concluded that the technique looked very promising for tracking septic tank plumes in soil drainage fields. One reason for this is that they were able to exploit the contrast between dry summer soil and wet plumes from septic tanks. The work undertaken for this research was limited to winter when minimal contrast in soil wetness and is expected. A full test of the EMI method might be achieved by returning to sites when the soil is dry to determine if a contrast difference can be observed, or using a site to conduct a summer flush/tracer test to determine at what point the plume becomes most visible to the electromagnetic signal. Lee and others (2006) recorded a plume within about 10-15 m of the effluent distribution pipes in the system that they studied, but only when the soil had a low background moisture content and high plume moisture content.

As a result of our study, it is recommended that further testing of the technique, and of the environmental conditions under which it can operate successfully, are needed before the technique will be sufficiently well developed for operational use.

Appendix 2 User questionnaire

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ADDRESS DATE

Dear NAME,

On behalf of Natural England and the Broads Authority, the Centre for Ecology & Hydrology and Bangor University are conducting a study to look at how good soil soakaways are at removing phosphorus, a plant nutrient, from septic tank effluent. The overall aim of the project is to determine safe setback distances for septic tank systems from waterbodies (rivers and lakes) that have a high conservation value. Waterbodies may be badly affected by nutrient impacts, such as algal blooms, if polluted by these sorts of discharges.

We are contacting you because you have kindly offered to allow us to sample your septic tank and take some soil samples from your soakaway system as part of this study. The amount of phosphorus that enters a soakaway from a septic tank is affected by many local factors such as the age of the tank, how often it is emptied and the 'lifestyle' of the household that uses it. So, to help us understand our results better, we would be grateful if would also be willing to complete a short questionnaire for us. The 'lifestyle' questions will not be too intrusive – they just include things that affect the phosphorus content of the effluent, such as whether you have a dishwasher or washing machine, whether the household is predominantly vegetarian, and which household cleaning products you prefer to use.
All of the information that you provide will be kept confidential. However, if there is a question that you would prefer not to answer for any reason, you are welcome to leave it blank.

In compliance with the requirements of the data protection act, we would ask you to note that:

- We will use your information on water usage and lifestyle to estimate the amount of phosphorus that enters your septic tank in waste water from your kitchen, bathroom and domestic appliances.
- We will use information from our field survey to look at the amount of phosphorus in the effluent from your septic tank and how this changes as the effluent plume travels through the soil soakaway.
- We will use information on the age, construction and history of your septic tank to determine whether these factors affect the quality of the effluent and the distance that it travels.
- We will report the summary findings from our project in terms of general advice on:
    - safe setback distances from sensitive waterbodies for new septic tank systems, and
    - the extent to which the risks from existing systems can be reduced through small changes in lifestyle, such as the use of phosphate-free household products.
- We will not identify any specific households in our reports or disclose personal details to anyone outside of the project team. However, if you would like to receive individual results from your own septic tank system, we would be pleased to provide these, on request, at the end of the project.

We would be grateful if you could return the completed questionnaire to our survey team when they are on site to collect samples.

Thank you very much for your valuable support for our project. It is very much appreciated.

Yours sincerely,

Dr Linda May
Project leader

Please tell us about your house and your septic tank system.

If you do not know the answer to the question please put a '?'

If you would prefer not to answer a question, just leave it blank.

1) Roughly how old is your house? ....years

2) How long have you lived there for? ....years

3) How old is your septic tank? ....years

4) What is the area of your soakaway? *(if known)* **approximately ....ft/m by ....ft/m**

5) What is your septic tank made of?

(Please tick whichever applies)

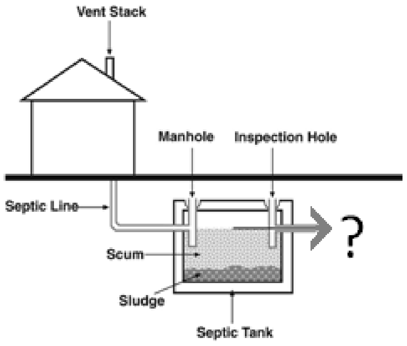
- ☐ **Fibre glass/plastic**
- ☐ **Concrete**
- ☐ **Brick**
- ☐ **Other** (please specify) **……………………………..**
- ☐ **Unsure**

6) If you have replaced your septic tank, how long ago was this? ....years

7) For a recent installation, what was result from the percolation rate test and the date that the soil was tested? .... secs/mm on ..../..../…….

8) Do you know where the output from your septic tank drains to?

- ☐ **Direct to a river, stream or ditch**
- ☐ **Soakaway**
- ☐ **Reed bed**
- ☐ **Other**
- ☐ **Unsure**



9) Is your septic tank shared with neighbouring properties?

Yes ☐ (If yes, how many? …………)   No ☐

10) Has your septic tank ever let you down by failing to work properly, becoming blocked or over flowing? **Yes ☐ (How many times?…………)** **No ☐**

11) Have you ever had your septic tank emptied? **Yes ☐ No ☐**

12) If yes:

a. How often is it emptied? **Approx. every ....years**

b. How long ago was it last emptied? **.........years**

13) Has your septic tank or related pipework got any cracks or leaks that you know of?

Yes ☐ No ☐

14) How often is your septic tank system inspected or repaired?
Approx. every ....years

15) Does your septic tank receive rainwater from your house roof? **Yes ☐ No ☐ Don't know ☐**

16) What is the size/volume of your septic tank? **..........**

17) What is the size of the household(s) connected to it now? **..........people**

18) What is the size of any household(s) connected to it previously (if known)? *(Please give approximate dates, if you can).*

.... people for …….. years/between …..…. and …..….

.... people for …….. years/between …..…. and …..….

…..…...people for …….. years/between …..…. and …..….

In the next part of the questionnaire, we would like to collect some information on the sources of waste water that go into your septic tank and the types of detergents that you use in your household.

19) Roughly, how many times per week do you use your dishwasher? ....

20) Roughly how many times per week do you use your washing machine? ....

21) Roughly, how many times per week is the shower used? ....

22) Roughly, how many baths are run per week? ....

23) If you have a water meter, what is your annual water usage? ....

24) If you have a dishwasher, what is most important to you when choosing detergent for it? *(tick multiple boxes if required)*

- ☐ **Lowest price**
- ☐ **Cleans the best**
- ☐ **Eco friendly**
- ☐ **Low in phosphorus**
- ☐ **Other** *(please explain)* ……………………………..

25) Which brand(s) of dishwasher detergent do you use?

…………………………………………………………………

26) If you have a washing machine, what is the most important to you when choosing detergent for it? *(tick multiple boxes if required)*

- ☐ **Lowest price**
- ☐ **Cleans the best**
- ☐ **Eco friendly**
- ☐ **Low in phosphorus**
- ☐ **Other** (please explain) ……………………………..

27) Which brand(s) of laundry detergent do you use?

……………………………..……………………………..

28) Do you use household cleaning products that are safe for using with a septic tank?

Yes ☐ **No** ☐ **Didn't know they existed** ☐

Finally, we would like to ask a couple of questions about your lifestyle.

29) How many people live in your house? ……….

30) How many of your household are vegetarian? ……….

31) Do you tip food waste down your sink? **Yes** ☐ **No** ☐

Thank you for completing our questionnaire. The information that you have provided will be very useful in helping us interpret the results from our study.

If you would like to find out more about our research project and how your responses have contributed, please provide us with an email address or other contact details, below, and we will send you a copy of the conclusions from our report.

Email Address:

Contact info:

Alternatively, if you have any further questions about our survey, please email us at **lmay@ceh.ac.uk**.

***COMMENTS**: If you would like to leave any comments please do so in the box below. We look forward to reading them.*