Report

Dudley, Bernard; May, Linda. 2007 *Estimating the phosphorus load to waterbodies from septic tanks.* Centre for Ecology and Hydrology, 45pp. (CEH Project Number: C03273, C01352)

Estimating the phosphorus load to waterbodies from septic tanks

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Report to the Scottish Environment Protection Agency and Scottish Natural Heritage

10 July 2007

Centre for Ecology and Hydrology Project nos: C03273 and C01352

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Executive Summary

Septic tanks are widely used across the UK for the disposal of household waste in rural areas. Sewage is a rich source of phosphorus (P) and one of the functions of these systems is to remove much of this P from waste water before it reaches groundwater or surface waters. This is necessary because increased P inputs to waterbodies encourages algal growth and degrades water quality.

In recent years, much effort has been invested in reducing the output of P from large point sources, such as waste water treatment works (WWTWs). This has led to the assumption that agriculture is now the main source of P entering waterbodies in rural catchments. However, there is mounting evidence that this is not the case. Small point sources of P in these areas, such as septics tanks, may also be important sources of P.

Very little is known about how effective septic tank systems are at removing P from sewage effluent, and how much P they release to surface waters. It is important that this is now quantified so that it can be placed into context in relation to other sources of P in rural areas, such as agriculture. This information is essential to help us manage our water resources better and to enable us to meet the requirements of the Water Framework Directive.

In theory, septic tanks systems can effectively remove the majority of P from household waste if they are sited, maintained and used properly. The extent of P removal is dependant upon many inter-related factors. These include soil grain size and chemical composition, proximity to the water table, proximity to surface water, capacity of the system in relation to the number of people using it, chemical composition of the sewage that is received by the system, and the frequency at which the tank is emptied of sludge. Also, the effective functioning of the tank itself is dependent upon several interconnected components that are responsible for capturing solids and breaking down organic materials. Failure of any one of these components will reduce the extent to which P is retained by the system.

To date, most estimates of the contribution of P from septic tanks to water bodies have used a simple export coefficient approach applied at the catchment, regional or national scale. This is a very general method that takes no account of local variation in P removal due to the influence of factors such as soil type, hydrology, and the location, age and level of maintenance of the system itself, all of which may have a significant impact on P transfer from septic tanks to waterbodies. It also tends to assume that all tanks are properly maintained and functioning correctly, which is often not the case. In order to assess the contribution of septic tank systems to P loads to water more accurately, more information is needed on these factors and their impact on P mobility.

The availability of the additional information necessary for improving these calculations was investigated through a case study of the Loch Leven catchment. This revealed that little is known about the age, size, location, method of discharge or level of maintenance of septic tanks in this area. A study by SNH strongly suggests that about 750 properties within the catchment are served by private sewage treatment facilities such as septic tanks. Of these, less than 10 per cent are registered with the SEPA and the data that exist on these are insufficient for estimating their P load to the loch. A similar situation is believed to exist across the UK.

Literature studies suggest that the P load to waterbodies from properly located and efficiently functioning septic tanks should be very small. However, there is strong anecdotal evidence that a large number of septic tanks across the Loch Leven catchment are not working effectively. This is because many are not de-sludged regularly, some are being used beyond their original design capacity and others discharge directly to a watercourse. A review of SEPA monitoring data for this catchment supported this view. The data showed that the P concentration of many of the septic tank effluents monitored was very high at the location of the outflow. No data exist on the P content of the effluent beyond this point.

It is recommended that a detailed study of P losses from septic tanks across the catchment should be undertaken. This study should include:

- Determination of the number, location and type of septic tanks
- Estimation of the P load to surface waterbodies from these systems
- Assessment of P losses to groundwater

In conclusion, this review suggests that septic tank systems are probably a significant and underestimated source of P inputs to waterbodies in rural catchments across the UK. It is, therefore, highly recommended that research is undertaken to quantify the parameters needed to estimate these P inputs more accurately. In particular, effort should be focused on identifying the factors that most influence P losses to waterbodies from these systems to enable effective management of the problem.

Contents

1 The need for assessment of nutrient loads to waterbodies from septic tanks and private sewage treatment works

The 1991 Urban Waste Water Treatment Directive (UWWTD) was implemented by European Union (EU) member states in 1998. This set the level to which sewage must be treated before being discharged into a waterbody in a sensitive area. As a result, many of the larger waste water treatment works across the UK were upgraded, reducing their phosphorus (P) output by about 80 per cent (e.g. Bowes *et al*., 2005). Since then, attention has turned to the controlling the remaining main sources of P, most of which were assumed to be related to agricultural runoff.

Recent evidence suggests that this assumption may be false. Jarvie *et al.* (2006) found strong evidence that P-laden effluent from point sources still posed a greater risk to UK rivers in relation to eutrophication problems than P from diffuse agricultural sources. This was found to be true even in rural areas where it was once thought that small point discharges of P, such as those from septic tanks and small private sewage treatment works (STWs), would have little impact on P concentrations in the receiving waters. It is now recognised that, although individually small, these sources may account for a significant proportion of the P load to a waterbody when considered collectively and at the catchment scale.

In the past, many P loading studies have highlighted the potential importance of loads from small sources of P. Some have simply noted them as important and worthy of attention (e.g. Babtie Group, 2001; Spey Catchment Steering Group, 2003), while others have attempted to quantify them on the basis of incomplete and unreliable information (Table 1.1; Section 3). In order to comply with the EU Water Framework Directive (EU, 2000), it is now essential for environmental organisations, such as the Scottish Environment Protection Agency (SEPA) and Scottish Natural Heritage (SNH), to obtain a good understanding of the impact of P losses from these sources on water quality in rural areas. This report reviews our current level of knowledge in relation to this and highlights gaps and uncertainties in the available data and methodologies.

Table 1.1 The estimated P load to waterbodies from septic tanks within their catchments.

Waterbody	**Estimated P load to waterbody from septic tanks** (tonnes y^{-1})	**Proportion of external P load to waterbody attributable to septic tanks** (%)	**Reference**
Bassenthwaite Lake	2.3	18.0	May *et al*. (1996)
Loch Earn	0.07	1.2	Weller (2000)
Loch Flemington	0.02	17.5	May *et al*. (2001)
Loch Leane	1.5	12.0	KMM & Pettit (2000)
Loch Leven	1.5	10.0	Frost (1996)
Loch Ussie	0.03	22.0	May and Gunn (2000)
Lough Erne	**-**	12.0	Foy (*pers. comm.*)
Lough Neagh	56.0	14.0	Foy (*pers. comm.*)
Llyn Tegid	4.6	3	Milliband *et al*. (2002)
Black Beck	0.25	40 - 76	Hall (2001)
Lough Conn	1.58	5	McGarrigle & Champ (1999)
Lough Derg	25.8	12	KMM (2001)
River Liffey	1	3	MCOS (2002)
River Suir	-	7	MCOS (2002)
River Boyne	5.6	8	MCOS (2002)
All standing waters in Northern Ireland	118	5	Smith *et al*. (2005)
All waterbodies in Northern Ireland	130	8.5	SNIFFER (2006b)
All waterbodies in Scotland	142	2.6	SNIFFER (2006b)

2 The function of septic tank systems

There are many methods of sewage treatment used by rural populations in Scotland. These are summarised in Table 2.1. Although there are a small number of private sewage treatment works (or package treatment plants), most sewage treatment facilities in rural areas are based on septic tanks.

Table 2.1 Rural sewage treatment systems in use in Scotland.

Type of system	Discharges to:
Septic tank	Soakaway
Septic tank	Watercourse
Septic tank	Watercourse *via* field drain
Septic tank	Mound ‘soakaway’
Septic tank + iron dosing	Soakaway or watercourse in P sensitive catchment
Septic tank + reedbed	Soakaway or watercourse in P sensitive catchment
Package treatment plant	Soakaway or watercourse in P sensitive catchment
Package treatment plant + reedbed	Soakaway or watercourse in P sensitive catchment

Septic tank systems are a means of disposal of liquid wastes (generally domestic) when connection to a sewered network and municipal sewage treatment works is not practicable. Their design is intended to maximise the removal of solids, pathogens and other pollutants. Although most modern septic tanks are bulb-shaped fibre-glass units, those associated with many older properties are box shaped structures built from brick or concrete. In many cases, the latter are under-sized for modern patterns of water use that include frequent bathing and the use of domestic appliances such as washing machines and dishwashers.

All septic tanks have effluent discharges in Scotland, because closed cess pits with no outlet are illegal here. In general, most of these discharges connect to a soakaway system, although some go directly to a watercourse and others tap into field drain systems.

Discharges to a watercourse are much less commonly used now than in the past, although new ones do still occur (e.g. the relatively recently installed septic tanks on Castle Island and at Vane Farm visitor centre in the Loch Leven catchment).

This Section outlines the function of a septic tank. For more detailed information, the authors particularly recommend the excellent review by Beal (2005). All of the literature reviewed below appears to be in agreement that septic tank systems are an effective means of processing household foul waste (sewage), *providing that they are functioning properly*. However, it is important to understand what comprises 'proper' functioning in order to know how it can go wrong.

2.1 Septic tank design

A standard septic tank is designed to maximise the removal of solid wastes from household sewage and has two connecting chambers to achieve this (Figure 2.1). Household effluent is delivered to the first chamber, below the surface of the liquid. This subsurface delivery prevents the escape of gases back through the plumbing and reduces the likelihood of blockage. In this primary chamber, heavy solids – known as sludge – settle to the bottom and lighter solids – known as scum – float to the surface. The connection between the two chambers, similar to the inflow, is situated below the surface of the liquid to prevent the movement of scum from the first chamber into the second. Further sludge deposition takes place in the second chamber. Where the effluent flows from the septic tank into the soakaway, an inspection chamber allows examination of the effluent.

The current use and design of septic tanks in the UK is specified by British Standard EN 12566-1:2000. Modern septic tanks tend to be spherical in design but, essentially, they have the same characteristics as described above. The new shape has allowed the use of new plastic and composite materials instead of the bricks and concrete that were used previously to construct these tanks.

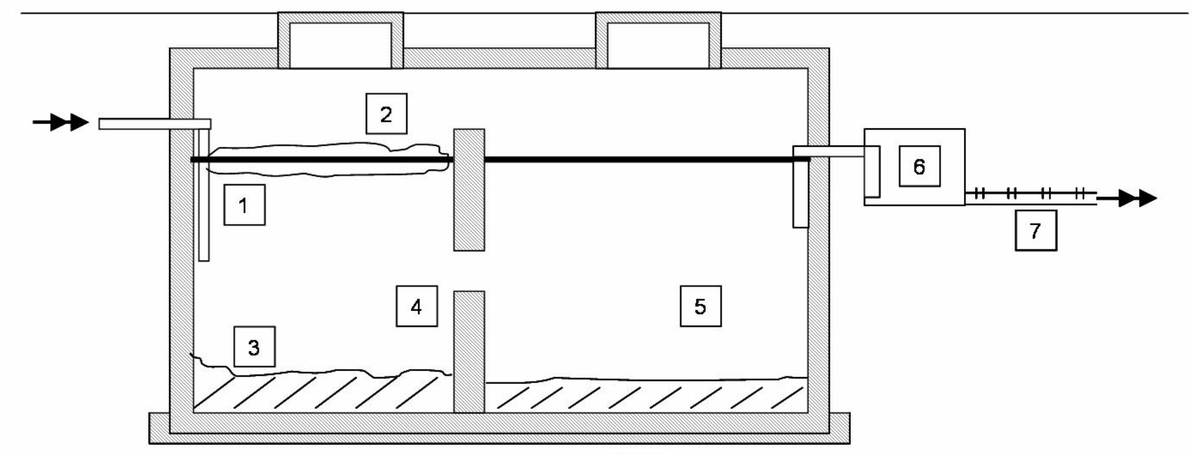

Figure 2.1. A standard septic tank design. 1- inflow to primary chamber, 2 - floating scum layer, 3 - settled sludge layer, 4 - connection between chambers, 5 - secondary chamber, 6 outflow and effluent inspection chamber, 7 - soakaway system (reproduced from Hilton *et al*., unpublished).

A normal septic tank provides only a basic level of treatment (primary treatment). Where discharge is direct to a watercourse, and there is limited dilution in the receiving water, secondary treatment may be required. This may be in the form of any of a number proprietory package plants or a passive treatment system such as a reed bed. The relative merits of these systems are unclear and a comparison of their effectiveness needs to be undertaken to inform policy positions in respect of new development and authorisations under the Water Environment and Water Services (Scotland) Act 2003. However, most septic tanks discharges are to soakaway, the structure and function of which is described below.

2.2 Soakaway design

Soakaways, also known as infiltration systems, are designed to disperse the effluent from the tank into the surrounding soil. They generally consist of a network of perforated pipes arranged in such a way as to allow liquids to disperse under gravity (Figure 2.2). The design of a soakaway is dependent upon the characteristics of the surrounding soil and the position of the water table. In many situations, their use is not allowed at all (Scottish Building Standards Agency, 2007). Within the UK, a percolation test is used to determine whether a particular site is suitable for a soakaway and what its general design should be. The percolation test consists of a standard amount of water being poured into a standard sized hole dug into the soil. The change in water level within the hole is then timed and percolation is measured as unit time per unit change in water level, generally expressed as s mm^{-1} (Scottish Building Standards Agency, 2007). A measure of between 15 s mm^{-1} and 100 s mm^{-1} is described as a 'normal percolation rate' and, if achieved, a soakaway system may be installed if there is sufficient height between the soakaway and the underlying water table.

If the infiltration rate is greater than 100 s mm^{-1}, then alternative methods of effluent disposal must be used. These include reed beds, constructed wetlands or proprietary filtration systems such as that shown in Figure 2.3 (also see Mara, 2004). For 'very slow percolation rates' (> 140 s mm^{-1}), mound filter systems are recommended. A mound filter is a constructed, layered, mound, built on top of the existing ground level, which allows for the effluent to be filtered (Figure 2.4). These systems are only permissible for a single dwelling.

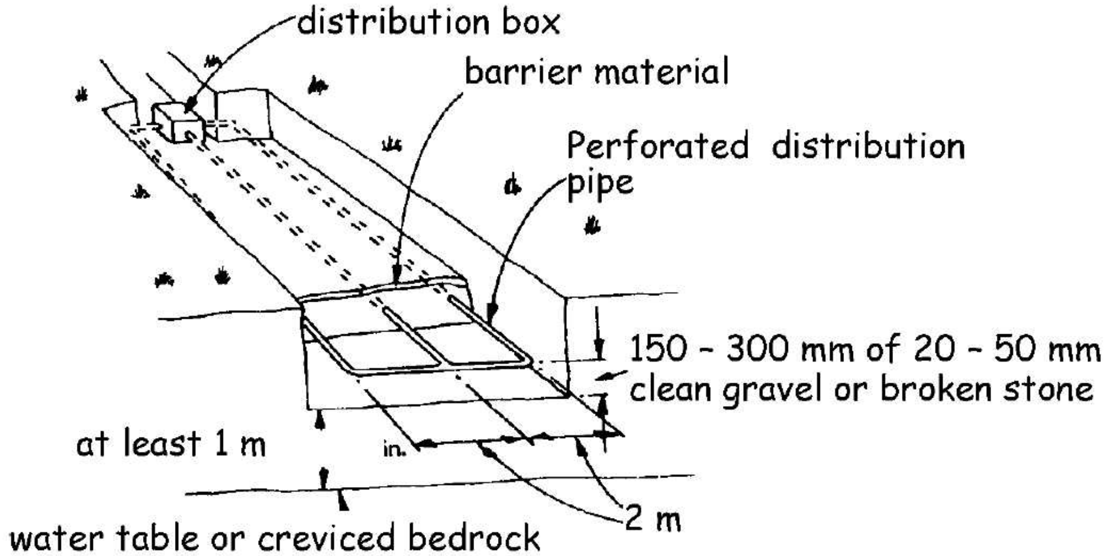

Figure 2.2. Diagram of a section of a wastewater infiltration system (soakaway). Reproduced from Scottish Building Standards Agency (2007)**.**

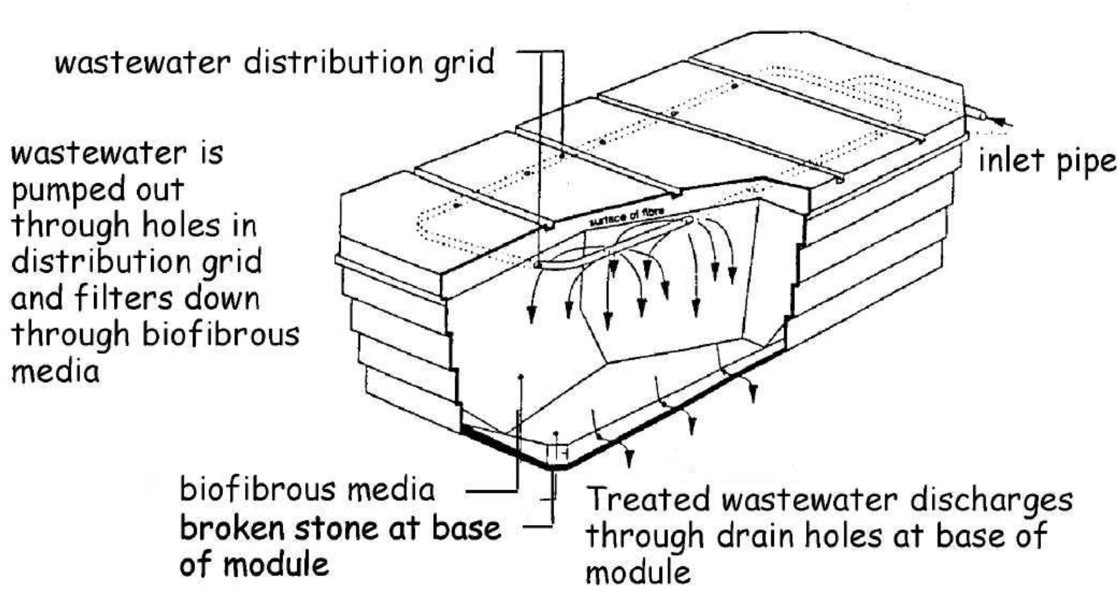

Figure 2.3. Design of a proprietary infiltration system (Scottish Building Standards Agency, 2007).

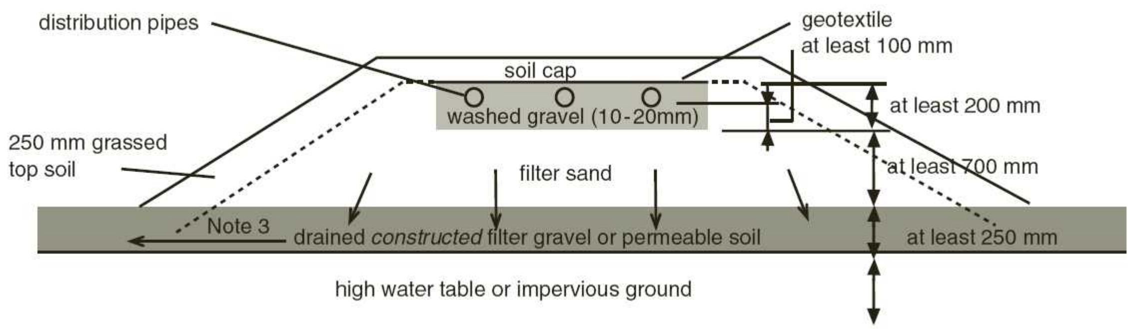

Figure 2.4. Design of a mound filter system (Scottish Building Standards Agency, 2005).

2.3 Biological processes

As well as the physical processes of sedimentation and flotation of solids inside septic tanks, and the dispersal of liquids by soakaways, there are biological processes taking place within septic tank systems that alter the composition of the raw sewage. These processes occur both in the septic tank itself, and in the soil immediately and adjacent to the conducting pipes within the soakaway, known as the 'biomat' zone (Beal *et al*., 2005). This soil biomat zone is self-generating and is initiated by a clogging of pores in the soil, mostly by anaerobic bacteria. Clogging usually occurs within a few months of installation and first use of the septic tank system, resulting in a reduction in infiltration of effluent to the surrounding soil (Beal *et al*., 2005). Clogging results in the formation of a biologically active bacterial mat that intercepts and alters the septic tank effluent. Within this mat, much organic matter is digested by bacteria. This results in the production of methane and carbon dioxide gases, and various dissolved compounds. These include inorganic forms of the nutrients that are most responsible for eutrophication in water bodies, such as ammonium, nitrate and phosphate. Soluble nitrogen and phosphorus may also be immobilised within the biomat, by incorporation into biomass (Beal *et al*., 2005). However, this effect seems to be minimal in comparison with the amounts of these compounds that pass through the biomat and into the soil (van Cuyk *et al*., 2001). The mat also performs a physical role. It increases the retention of particles, including bacteria and viruses, by altering the effective pore size within the soil mat (Vaughn *et al*., 1983).

The biomat zone, also known as the saturated zone, is anaerobic due to the increased biological activity and associated consumption of oxygen. In a well designed septic tank system, the soil below and adjacent to the biomat zone remains aerobic. This area is also known as the unsaturated zone. The absence of an unsaturated zone indicates a system that has been poorly designed, or that is being used beyond its intended capacity (Beal *et al*., 2005).

2.4 Adsorption and precipitation

Adsorption and precipitation are two chemical processes that are said to account for most of the P retention in septic tank systems (Beal *et al*., 2005; Harman *et al*., 1996; Robertson & Harman, 1999). Adsorption is the process of adherence of soluble compounds to insoluble particles. In septic tank systems, this process is most important in the unsaturated zone beyond the biomat, where the chemical environment is oxidising rather than reducing. Adsorption of orthophosphate from septic tank systems to neighbouring soil has been shown to be reversible (Robertson & Harman, 1999). This means that large amounts of P held in the soil may be released to sub-surface water under certain conditions. This could happen as a result of changes in water table height, increases in acidity, or reduced oxygen availability.

Precipitation of orthophosphate ions occurs when they combine with other ions to form an insoluble compound. In tertiary-level sewage treatment, this process is used to strip P from effluent water and is often termed 'dosing' or 'stripping'. Ions that co-precipitate with phosphate include ferric and ferrous iron (Fe^{2+} and Fe^{3+}) (Robertson, 2000) and compounds of aluminium (Huang *et al*., 2007) or magnesium (Parent *et al*., 2007). This process also occurs in soils where such ions are present naturally and it can also occur inside the septic tank, if these ions are present in the water supply.

It is generally claimed that soakaways are responsible for the adsorption of phosphate to the surrounding soil, but there is very little information available about the capacity of soils to adsorb nutrients indefinitely, or the impact of poor maintenance of septic tank systems on the ability of soakaways to remove soluble phosphate (see Beal *et al*., 2005 for review). It is likely that septic tank systems progressively lose the ability to remove these soluble nutrients. If so, they will change from a nutrient sink to a nutrient source over time (Beal *et al*., 2005).

2.5 Hydraulic failure

Hydraulic failure occurs when infiltration rates through the biomat are greater than the loading rate of effluent into the soakaway system (Beal *et al.*, 2005). This results in effluent discharging onto the soil surface. This situation is more common in older or poorly designed septic tank systems, or in those that are used at a capacity beyond that originally planned. The latter situation is likely to be associated with the use of clothes and dish washing machines to replace manual cleaning, or an increase in the number of people using a septic tank system. Hydraulic failure may also result from overdevelopment of the biomat, which reduces infiltration, or changes in the height of the water table.

2.6 When things go wrong

A septic tank system consists of multiple elements connected in series. In a properly functioning septic tank system, solids are settled in the tank itself and these solids undergo anaerobic digestion by bacteria. Much P is retained in these solids. Liquid passing out of the tank into the soakaway is still rich in organic materials, both dissolved and particulate, which are then further digested in the biomat zone. Bacteria and viruses are also largely intercepted in the biomat zone. Liquid passing through the biomat zone into the unsaturated zone contains high concentrations of inorganic nutrients, especially orthophosphate and nitrate. Phosphate, and to a lesser extent nitrate, are adsorbed to soil in the unsaturated zone. If any of these elements fails, then the system no longer performs as expected.

One of the most frequently recorded causes of reduced efficiency in septic tank systems is failure to periodically empty tanks of accumulated sludge, often brought about as a result of a lack of awareness of the maintenance requirements of these systems by users (e.g. DCMP, 2006). A properly functioning septic tank retains 48% - 57% of the inflow P in the sludge that accumulates within the tank (Gold, 2006). If this is not removed periodically, the effective volume of the tank becomes limited and the residence time of the effluent is reduced. This reduces the amount of processing that the effluent receives. As a result, an increased load of undigested P-laden material, which would otherwise have been deposited as solids in the tank, may reach the biomat zone. In addition, solids are likely to pass out of the tank and into the soakaway causing the biomat to become blocked, potentially resulting in hydraulic failure. The recommended frequency for removal of septic tank sludge is once every 12 to 24 months (Scottish Water, 2005). The current cost of this service is about £124 per household and £186 per business for tanks up to 9 m^3 in volume plus £25 per additional m^3 of capacity for larger larger tanks (Scottish Water, 2006). It should be noted, however, that care should be taken in the disposal of phosphorus-laden sludge from septic tanks. This is because the sudden introduction of tankered sludge may overload a small WWTW which may cause pollution problems elsewhere in the catchment or, sometimes, in another catchment (Wood & Gibson, 1974).

When hydraulic failure occurs, septic tank effluent bypasses the soakaway system and flows directly to surface waters, generally a ditch or stream. In this scenario, both undigested organic matter (including bacteria and viruses) and large amounts of inorganic nutrients enter the water body directly, without being processed by the saturated and unsaturated zones of the soakaway. A common response to hydraulic failure by the users of septic tanks, has been to simply excavate a ditch from the soakaway to the nearest watercourse (Philip Jordan, *pers. comm.*, regarding septic tank system in Northern Ireland), thereby by-passing the soakaway completely.

Hydraulic failure can also occur if a septic tank is poorly situated, for instance in an area where the water table is close to the surface. In this case, even if hydraulic failure does not occur, the presence of a sub-surface body of water can result in the absence of an unsaturated zone. If so, minimal adsorption of inorganic nutrients occurs and nutrients are transported by the sub-surface waters. Other examples of poor locations for septic tanks includes sites that are too close to a drainage channels (resulting in a reduced unsaturated zone) or sites that are on impermeable soils (resulting in hydraulic failure).

It can be seen from these examples that the P load to water bodies from septic tanks will be determined not only by the number of people using septic tank systems within the catchment, but also on many other influential factors such as soil characteristics, the level and flow of sub-surface water bodies and, perhaps most importantly, where the septic tank systems are situated and how they are maintained.

3 Existing methods for assessing the phosphorus load to waterbodies from septic tanks

The amount of phosphorus (P) produced in human excreta is in the region of 1.6 - 1.7 g per person, per day (Schouw *et al*., 2002). For a population of 10,000 people, this equates to a P output of about 6 t y^{-1}. This figure does not, however, represent the total amount of P contained in household waste, because the total figure also includes significant contributions of P from other sources, such as household detergents.

Estimating the proportion of the P load to a waterbody that can be attributed to septic tanks within a catchment is not an easy task. This Section describes the main method that has been used to date (an export coefficient approach) and some of its many variants. Gaps and uncertainties in the available data are highlighted. In addition, some more novel methods that might prove useful for nutrient source apportionment within catchments are described at the end of this Section. The methods reviewed are summarised and discussed in relation to their relative strengths and limitations.

3.1 Export coefficient methods

Export coefficient methods assume a constant (or coefficient) load of P from a particular source over time. This is expressed as an amount of P per unit of source (e.g. person, household or septic tank), per unit time, e.g. grammes *per capita* per year. The amount of P entering receiving waters from each source is estimated by multiplying the export coefficient by the number of source units. This method is equivalent to that commonly employed when estimating nutrient loads from diffuse sources except that, in the latter case, the coefficient is expressed in terms of area of land drained rather than number of people or septic tanks, e.g. 0.2 kg P ha^{-1} yr^{-1} for felled forest (Anonymous).

Although the concept of using export coefficients for estimating P losses from septic tanks is common and widespread, the method of calculating the individual coefficients varies considerably between studies. These are reviewed below. One of the main limitations on the way in which these coefficients are estimated is, generally, the quality of the available data and the scale of the study.

3.1.1 Using the correlation between water-body nutrient concentrations and population

A crude method of estimating export coefficients for septic tank discharges at the national scale was used in a study that aimed to estimate all inputs of P to standing waters across Northern Ireland (Smith *et al*., 2005). The coefficient was determined by linear regression and represented the ratio of the *per capita* discharge of soluble reactive P (SRP) from urban STWs to that from septic tanks within the Lough Neagh catchment (Smith, 1977). This value was 0.58. The method assumed that the only non-constant source of SRP in catchments across Northern Ireland was the human population, and that all P from sewage related sources was exported as SRP. It also assumed, like all export coefficient methods, a constant export coefficient across the entire study area. Using an export coefficient of 0.44 kg P $person^{-1}$ yr^{-1}, the authors calculated a total annual load of 118 tonnes of P from septic tanks to standing waters in Northern Ireland as a whole (Smith *et al*., 2005). This equated to about 5 per cent of the estimated P inputs to standing waters from Northern Ireland, and about 12 per cent of that attributable to sewage effluent.

Although useful at the national level, this method would be of limited use at the site specific level. This is because individual septic tanks and small STWs vary in their construction, location, level of maintenance, method of discharge and, consequently, their P loss to nearby waterbodies. The method also provides no resolution of the location of 'hot-spots', although if the populations of sub-catchments could be quantified, then the more significant areas of P from human sources could be estimated.

3.1.2 The use of literature values

Many studies rely on the published literature for their export coefficient values (e.g. Carvalho *et al*, 2005, May & Gunn, 2000; Hall, 2001; May *et al*., 2001; SNIFFER, 2006a). This is probably due to a lack of resources needed to estimate values on a site specific basis. However, this approach should be used with care, as export coefficients may be specific to the conditions under which they were determined. Variables that may alter the value of the export coefficient locally include:

- the extent to which septic tanks discharge directly to watercourses (Patrick, 1988)
- the efficiency of soakaway systems in adsorbing P; this depends on environmental factors such as soil type (Ptacek, 1998) and level of P saturation (Robertson,

1995), distance to the nearest watercourse (Chen, 1988; Robertson, 1995; Woods, 1993) and level of waterlogging of the surrounding soil (Patrick, 1988)

- the extent to which septic tanks are maintained, especially whether or not they are de-sludged regularly; a study of 24 septic tanks in the Lough Leane catchment found that 88 per cent of them were full of sludge to the outlet and not functioning efficiently (KMM, 2004)
- the nature of the household sewage; this will reflect lifestyle factors, such as the extent to which phosphorus-rich detergents are used (Alhajjar, 1989, 1990[1]; Harper, 1992)
- the timing of the production of sewage; many properties that use septic tanks are used as holiday homes, so the septic tanks will only be used seasonally (Harper, 1992)

3.1.3 Quantifying human sources

As mentioned above, an export coefficient is a measure of the amount of P output by a particular source, per unit of source and per unit of time. While the quantification of time is fairly simple, estimating human sources of P within a catchment is often more challenging. Ideally, the location of each septic tank or private STW, the amount and composition of any effluent from them, and the amount of nutrient that is exported to any nearby water-body needs to be known. In practice, these values are likely to have to be derived from other sources of data that have been collected for other purposes and which correspond to different geographical categories. These are rarely compatible in terms of their scale or geographical coverage. For example, the geographical boundaries of water-body catchments rarely coincide with those of political areas such as electorates, parishes, counties, regions or countries, which are the main source of information about people and their properties. As a consequence, it is always necessary to find ways of combining these data to estimate either the number of dwellings, or the number of people, that use septic tanks or small, private, STWs in a particular catchment. Some of the methods used are outlined below.

The first example is the GIS-based method developed by May *et al*. (1999). This was originally applied to the catchment of Bassenthwaite Lake and later to that of Black Beck

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[1] It should be noted, however, that Alhajjar *et al*. (1989, 1990) also found that the use of phosphate free detergents resulted in a doubling of nitrate leaching to groundwaters.

(Hall, 2001). The method involved subtracting the number and location of dwellings that paid sewerage connection charges from the total number of dwellings in the area. Postcodes were used to approximately locate dwellings served by septic systems, so that individual people and their properties could not be identified. In this study, it was assumed that each septic tank served three people and an export coefficient was used to calculate total load from septic tanks across the catchment. The export coefficients used ranged from 0.365 to 0.7 kg P capita^{-1} y^{-1}. The postcode approach also provided some spatial information, enabling septic tank locations to be mapped (Figure 3.1; May *et al.*, 1996). It should be noted, however, that this particular approach may require modification for further use within the UK, as a consequence of the more recent introduction of the Data Protection Act (1998). A simplified version of this method was later used by SNIFFER (2006a) to estimate the number and location of septic tanks across Scotland at the catchment, or river basin scale.

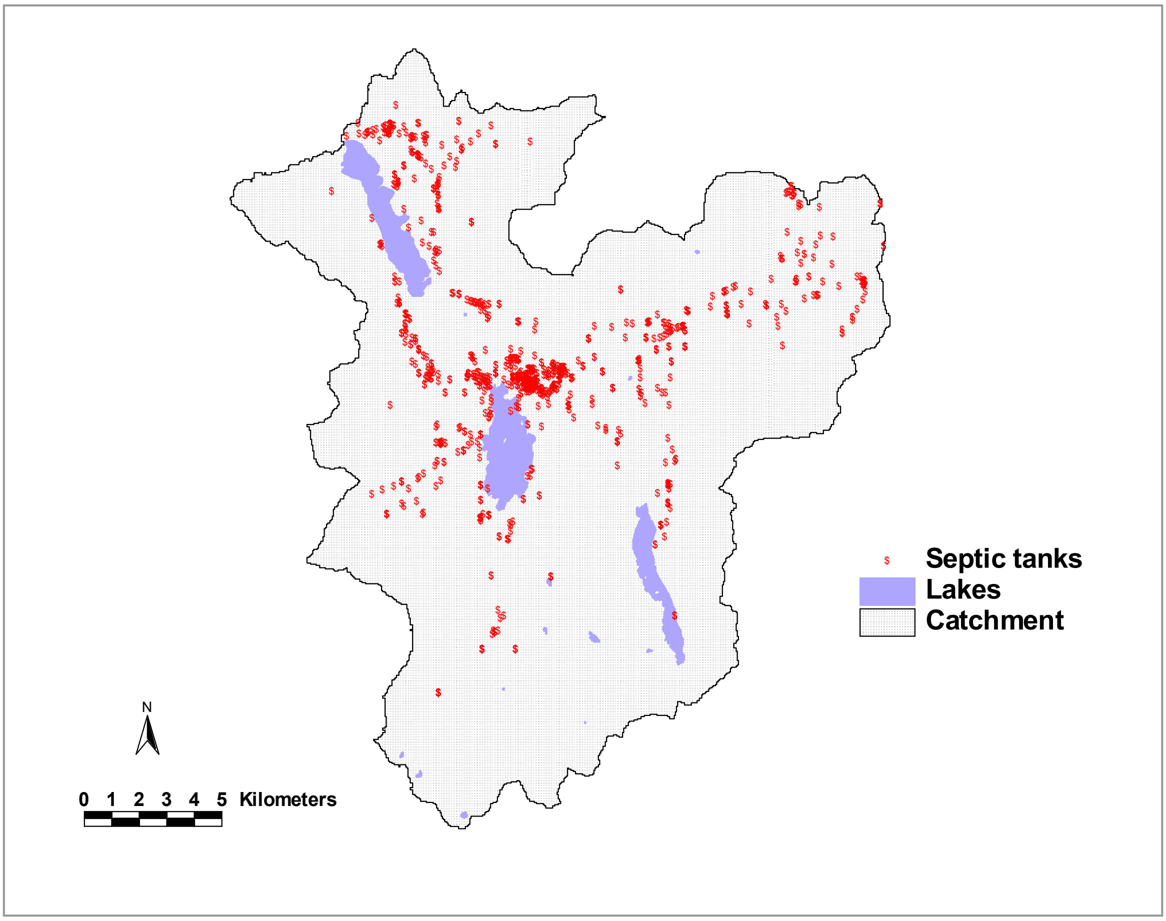

Figure 3.1 Estimated location of septic tanks within in the catchment of Bassenthwaite Lake (after May *et al.*, 1996).

A second example was used by May and Gunn (2000), May *et al*. (2001) and Weller (2000). This employed a more labour intensive, map-based method of estimating the number of rural households within the catchments of Lochs Ussie, Flemington and Earn, respectively, in order to estimate the P load to these water bodies from septic tanks. Individual dwellings were identified by eye from a 1:50 000 scale Ordnance Survey Landranger map. These figures were then used to estimate the likely P load from this source using an estimated household size of 2 persons and a *per capita* P export coefficient of 0.7 kg yr^{-1}, as suggested by (Harper, 1992). More recently, a GIS-based method based on this procedure, but using readily available digital map data, has been described by Hilton *et al*., unpublished.

A third example is described by Hilton *et al*., unpublished. This involves using sewer system network diagrams to derive the area of a catchment served by the public sewer system. The method assumes that premises that are outside the sewered area are connected to private sewage treatment systems, such as septic tanks. However, this method is difficult to use because the utilitycompanies are often unwilling to disclose the necessary information about the location of their sewer networks because of its commercial value and security implications.

3.2 Direct measurement

Discharges from septic tanks and other small sources of P to nearby water courses have rarely been measured or documented. Most of the information that suggests that these sources are important comes from anecdotal evidence (see Section 1). However, the CEH does hold a small amount of data that give some indication of the magnitude of the output from such sources. The data also highlight strong evidence that exceptionally high discharges from these sources may be associated with high discharge/rainfall events.

The first example is from an inflow to Bassenthwaite Lake, in Cumbria, which was monitored during 1993 (Figure 3.2). In this study, orthophosphate (OP), which is equivalent to soluble reactive phosphorus (SRP), was measured. On most occasions, the OP load in this stream was very low, falling within the range 0.03 – 0.3 kg d^{-1} and with a mean daily value of 0.12 kg. Corresponding OP concentrations ranged from 40 - 150 µg l^{-1}, with a mean value of 90 µg l^{-1}. However, OP loads in this stream were found to increase markedly during two high flow events in May and August 1993. These values rose to 3.7 kg d^{-1} and 5.9 kg d^{-1}, respectively. These exceptionally high loads corresponded to very high in-stream concentrations of 429 μg l^{-1} in May and 773 μg l^{-1} in August. The stream drains a small area of farmland and passes very close to farm buildings just above the monitoring site. This farm was, almost certainly, the source of these high OP events, although it is unclear whether these were associated with a septic tank, alone, or whether several sources of P were involved.

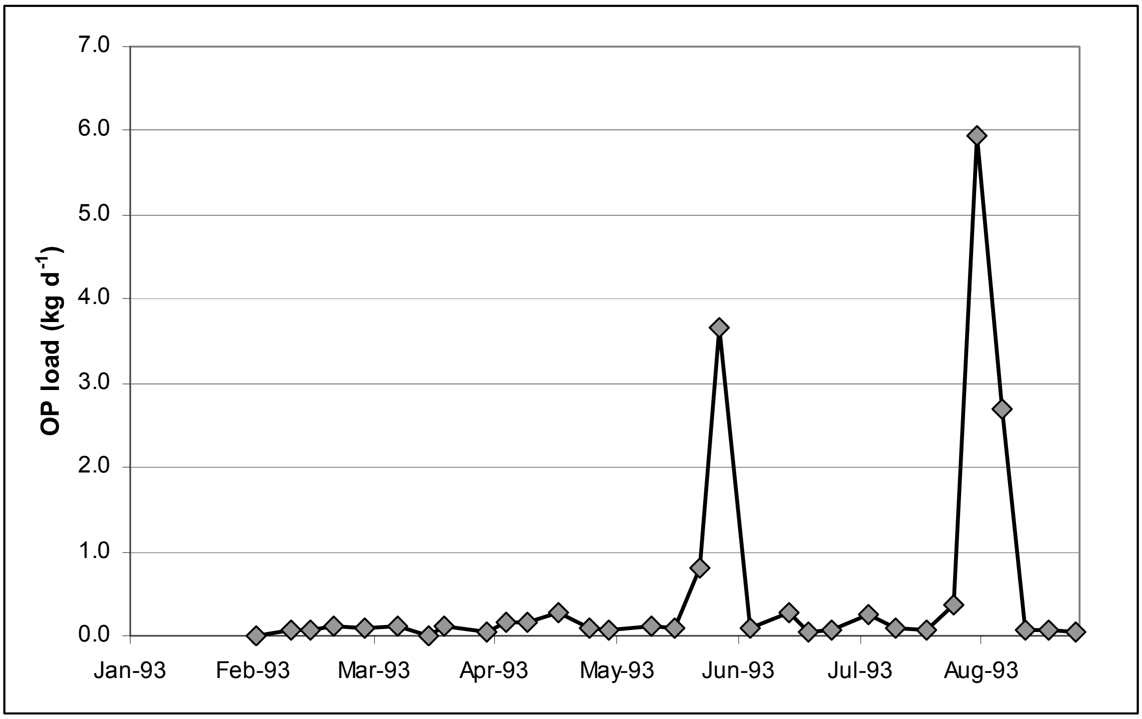

Figure 3.2 Orthophosphate (OP) concentrations in a small inflow to Bassenthwaite Lake.

The second example is from a small feeder stream to Loweswater, Cumbria (Figure 3), where OP concentrations were monitored during 2004/2005. Although annual mean OP concentrations in most of the inflows to the lake were low (i.e. <10 μg l^{-1}), one stream had a much higher OP concentration than the others (i.e. 24 μg l^{-1}). This stream was found to be receiving effluent from a faulty septic tank. When combined with flow values, the mean daily OP load from this tank over the whole year was estimated to be approximately 8 g d^{-1} or 2.9 kg y^{-1}. However, during a storm event in December 2004, a single daily value of 122 g (equivalent to 4% of the annual load) was recorded which, again, highlights the importance of rainfall driven discharge events in relation to these sources.

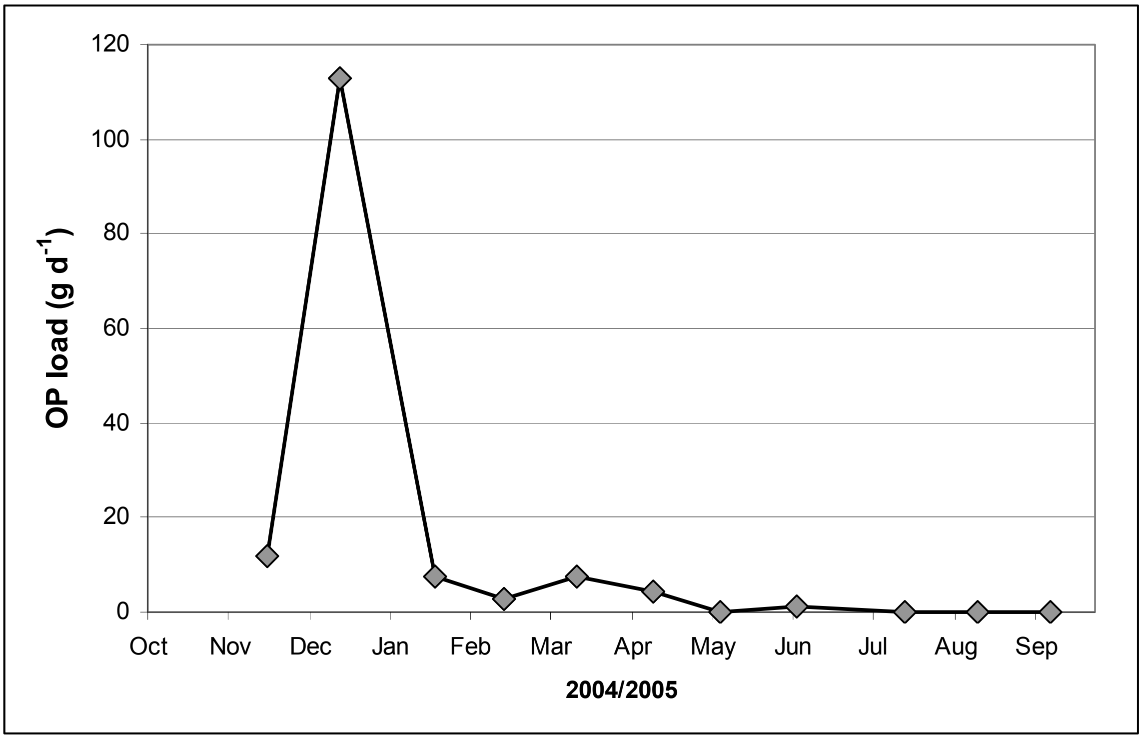

Figure 3.3 Orthophosphate (OP) concentrations in a small inflow to Loweswater.

3.3 Using tracers to estimate the proportion of phosphorus in a water course that emanates from septic tanks

Measuring the amount of P in receiving waters that emanates from septic tanks is very difficult to achieve given that there are many other potential sources of P in rural catchments. In the past, some studies have used tracers to help estimate the proportion of P in drainage waters that originates from a sewage-related sources; the use of some of these tracers is outlined below. However, most of these studies have used these techniques to trace effluent from large STWs. It is unclear how applicable these techniques will be in rural catchments where most sewage-related sources are septic tanks, which may discharge to soakaways.

3.3.1 Boron

Boron is found in more or less constant concentrations in effluent from STWs and septic tanks and can be used as a tracer of human sources of nutrients (Jarvie *et al.*, 2006; Neal *et al.*, 2005). Studies in the south of England have demonstrated a linear relationship between soluble reactive phosphorus (SRP) and boron concentrations, although they found that the SRP:B ratio was lower in streams than it was in STW effluent. The SRP:B ratio in secondarily-treated sewage effluent was found to be 9.46 (Neal *et al*., 2005). It was inferred that this difference in SRP:B ratios was evidence, firstly, that there were no other significant sources of SRP into those particular streams and, secondly, that there was a significant amount of in-stream processing of the SRP once it had entered the streams. This work appears to provide a very promising and fairly easy to use indicator for use at the catchment and sub-catchment scale.

It should be noted, however, that the papers of Neal and Jarvie quoted above refer to rivers in southern UK, which drain catchments with a very different geology to those of Scotland. Geology and soil type will influence how much of the SRP that leaves a septic tank arrives in a nearby watercourse. It will also influence the nature of the sediment in the watercourse which will, in turn, affect biological and non-biological in-stream processing. Also, the SRP:B ratio that they determined was for effluent that directly entered a water course and it is unclear whether this, or any other, constant ratio could be applied to effluent that discharges *via* a soakaway. To maintain this ratio, the rate of adsorption of boron by the soil would need to be the same as that for SRP. This is unlikely to be the case.

3.3.2 Caffeine

Caffeine is one of the most widely consumed substances, with an annual average consumption worldwide of 70 mg capita^{-1} d^{-1} (James, 1991). Because a large proportion of the caffeine consumed passes through the body unchanged (Arnaud, 1993), and a lot of tea and coffee are disposed of down household drains (Seiler *et al*., 1999), significant quantities of this substance are found in household wastes and effluent from sewage treatment facilities. So, its presence in surface waterbodies (Buszka *et al*., 1994, Barber *et al*., 1995) and groundwaters (Albaiges *et al*., 1986), sometimes in appreciable concentrations as far as 10 km downstream of the original source (Worgan, *pers. comm.*), indicates contamination from domestic sewage. Such contamination has already been linked to discharges from septic tanks (Seiler *et al*., 1999), suggesting that caffeine may be a good tracer of discharges from this source in rural catchments.

3.3.3 Fluorescence

Another promising method of estimating the proportion of the P in a water course that emanates from septic tanks and private STWs is the use of fluorescence as an indicator of animal faecal waste (Baker, 2002; Baker *et al*., 2004). This method uses the fluorescent properties of certain organic compounds that are found in animal waste and human sewage. Fluorescence occurs when a molecule that absorbs light of a particular wavelength, emits light of a different (longer) wavelength. In the method of Baker (2002 and 2004), the results of fluorescence analysis of surface waters are expressed as a matrix of excitation and emission wavelengths. Within this matrix, five characteristic peaks were found to be associated with compounds that occur in farm manure and human sewage. The results of these studies suggest that this method may be able to differentiate between human and farm animal sources of P-laden waste (Baker, 2002).

Fluorescence spectroscopy is a rapid method that can be adapted for field analysis (Baker *et al*., 2004), but it does require dedicated equipment. If the analysis is performed in a laboratory, analyses must be undertaken within 24 hours of sample collection (Naden, *pers. comm*.).

3.3.4 Sterols

In rivers and estuaries, the ratio of different types of sterols in sediments can be used as a marker to differentiate between human (omnivore) and ruminant (herbivore) faecal contamination (Arnscheidt *et al.*, 2007). This is achieved by analysing the sediments according to the method of Leeming *et al*. (1996, 1998) and then calculating the ratio of coprastanol : coprastanol + 24-ethylcoprastinol. A ratio higher than 75 per cent indicates faecal contamination from human sources, alone, whereas a ratio below 30 per cent shows that the source of the contamination is herbivores, alone. If the ratio is less than 75 per cent and greater than 30 per cent, there is a 2.5 per cent decrease in human contamination and a 2.5 per cent increase in herbivore contamination for every 1 per cent decrease in the sterol ratio. The application of this methodology to rivers and streams in rural areas could provide a way of differentiating between P from human sources (i.e. septic tanks) and P from ruminants (i.e. agricultural sources).

3.3.5 Other tracers

In a study in the USA (Steffy & Kilham, 2004), the ratio between the two stable isotopes of nitrogen, ^{15}N and ^{14}N, was shown to be an indicator of the presence of septic tank effluent. In catchments where the human population were served by septic tanks, the $\delta^{15}N$ ratio (the ratio between the relative concentrations of ^{15}N and ^{14}N in a sample and their 'natural' relative concentrations in the atmosphere) in stream biota was up to 10‰ higher than in catchments where the population was connected to a mains sewerage system. This method shows some promise for tracing nitrogen but, unless it can be demonstrated that septic tank and soil retention of P is similar to that of nitrogen, then the method will be of limited use for tracing P from septic tanks. Unfortunately, as P has only one stable isotope, this type of method cannot be used directly for P.

It may be possible to trace septic tank effluents through the presence of pharmaceutical or recreational drugs in surface waters. These compounds have been shown to be present in measurable concentrations in freshwaters that have anthropogenic impacts (Hua *et al*., 2006), but it is not known whether this approach has been applied to tracing septic tank effluent. Even if it could be applied to septic tank discharges, it is likely that this method would suffer from the same disadvantage as the previous method, i.e. that it cannot be safely assumed that the transport through and retention by soils of these compounds would be similar to that of phosphorus. Robertson *et al*. (1998) showed that phosphate migration through soils is 20 – 100 times slower than that of other soluble contaminants, such as nitrogen.

Chemicals that are not normally present in septic tank effluent may also be used as tracers if added to the effluent. One of these is sulphur hexafluoride (SF_6), which has been used to trace the speed and direction of groundwater flow and its associated nutrient loads in the Florida Keys (Dillon *et al*., 1999). Using this type of approach enables maximal control over the tracer itself. The particular chemical used can be selected to be either inert and conservative (meaning that it will not interact with its environment), as is the case with SF_6, or to behave in a similar way to the nutrient under examination. The amount and timing of the tracer chemical can be controlled, allowing assessment of the hydrology and accurate discrimination of the source of the water being examined. It must be remembered, though, that adding any chemical to natural waters may be subject to gaining the necessary permission.

4 Estimating of the amount of the phosphorus load to Loch Leven that can be attributed to septic tanks – a case study

4.1 Introduction

Following major concerns about deteriorating water quality at Loch Leven, a detailed phosphorus (P) loading study was carried out by the Centre for Ecology and Hydrology (CEH) during 1985 (Bailey-Watts & Kirika, 1987). The study showed that the annual P input to the loch at that time was about 20 tonnes. In the years that followed, the P load to the loch from large point sources, such as industrial sources and sewage treatment works, was reduced in an attempt to improve water quality. A repeat survey in 1995 found that the annual P load to the loch had fallen to about 8 tonnes, less than half of the 1985 level (Bailey-Watts & Kirika, 1999). The initial findings of a further survey carried out in 2005 suggested an annual P load of about 7 tonnes (Defew, *pers. comm.*)

Now that the P inputs from larger point sources have been addressed, attention is now focusing on P inputs from other sources in rural areas. In the past, these have been attributed mainly to agricultural sources. However, more recently, it has been recognised that part of this 'diffuse' P load is associated with discharges of sewage effluent from the many properties across the catchment that are outside the areas served by mains sewerage systems (Figure 4.1). These are connected to small sewage treatment facilities such as septic tanks and private treatment works.

The size of this contribution from septic tanks is unknown, although Frost (1996) suggested that septic tanks may have been contributing about 1.5 tonnes y^{-1} of P to the loch in 1985. The author derived this figure from rural population figures, estimated to be about 1100 people, and from the assumed likely fate of P entering septic tanks. It was assumed that, if a septic tank discharged to a soakaway, much of the P would be retained in the soil. However, Frost (1996) also notes that at least 50% of the soils within the Loch Leven catchment are unsuited to soakaway construction and that, even where suited, many of the older installations probably discharge directly to water courses (Frost, 1996).

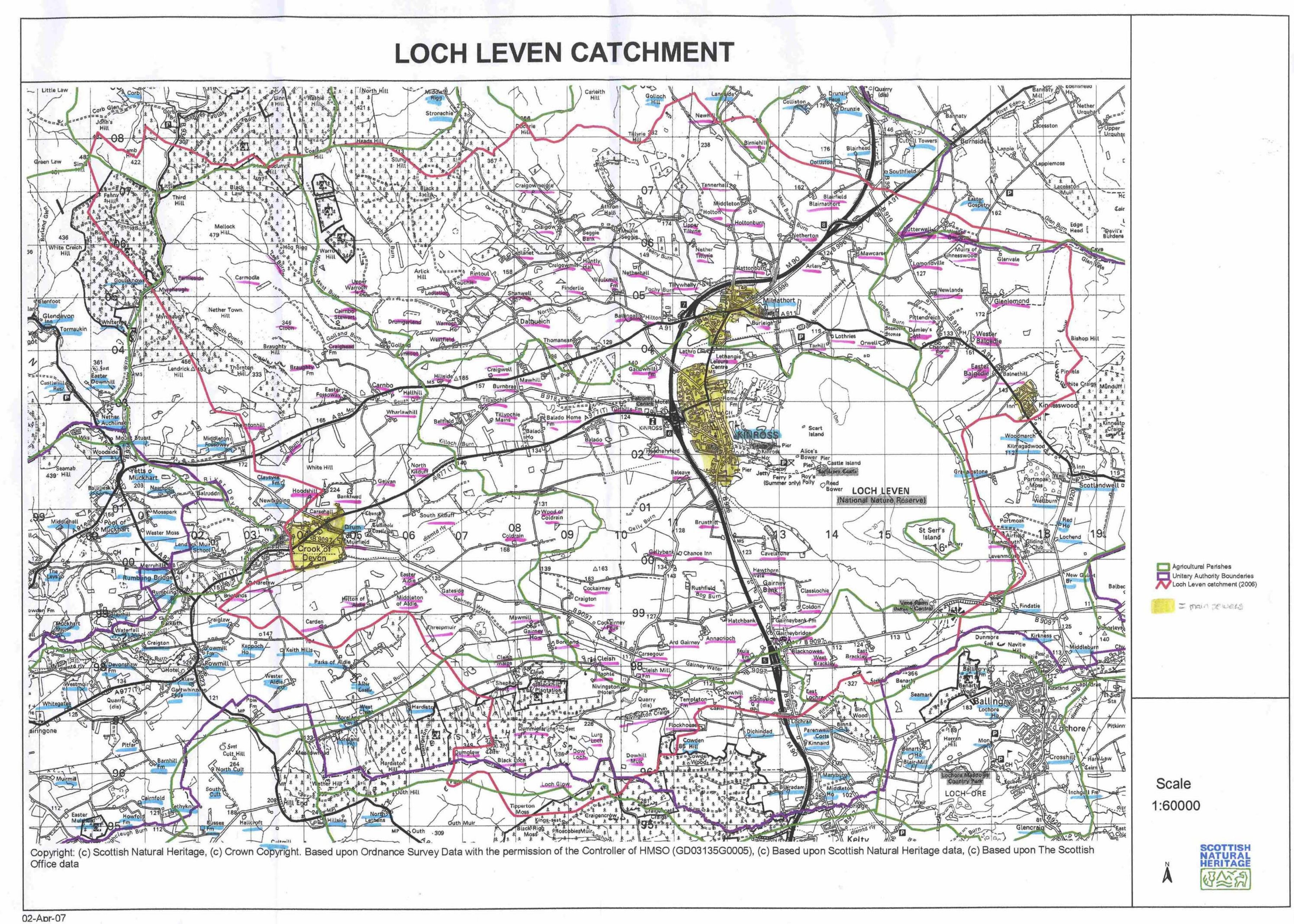

Figure 4.1 Map of Loch Leven catchment showing areas connected to mains sewerage system.

The study outlined above illustrates how difficult it is to estimate nutrient loads from septic tanks within a catchment without adequate information. In the case cited, the key 'unknowns' were:

- the number, size and location of septic tanks within the catchment
- the mode of discharge (i.e. directly into a watercourse or *via* a soakaway)
- the condition and level of maintenance of individual septic tanks
- likely P concentrations in the effluent

All of these are important factors in determining the actual P input to waterbodies from septic tanks. A similar situation exists for small, private STWs, the number of which is increasing due to a recent increase in development pressures within the catchment.

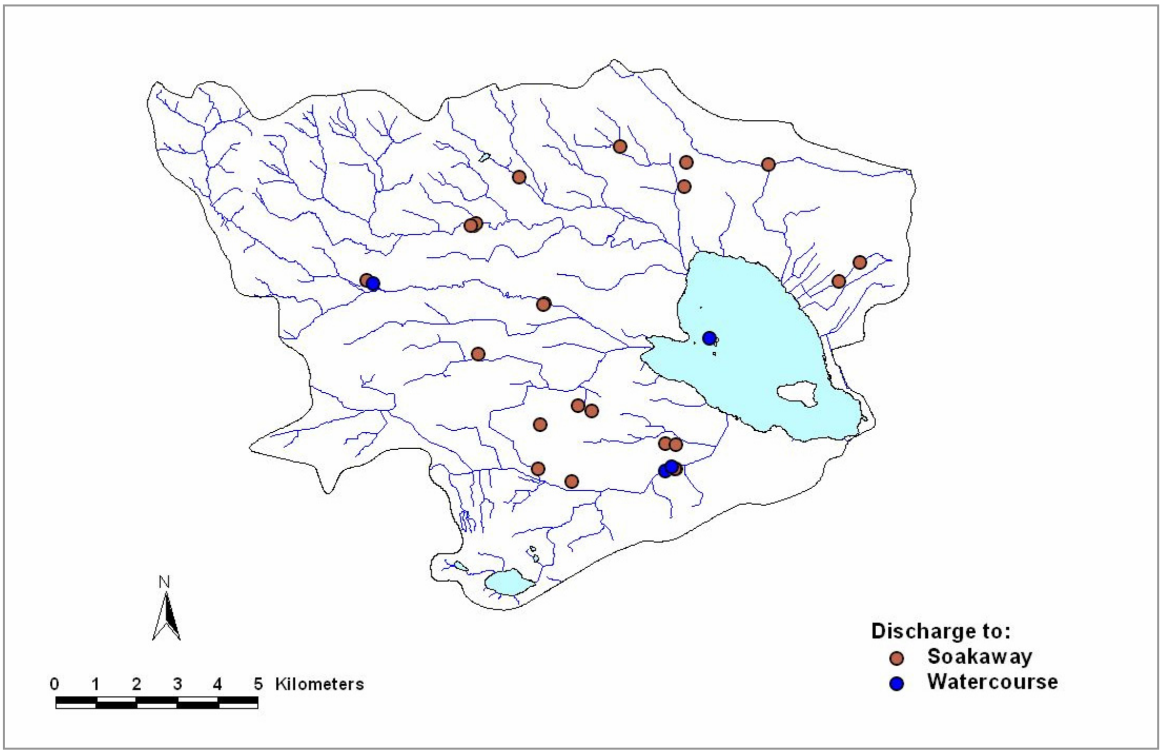

Figure 4.2 Location of consented discharges within the catchment showing whether discharge is to soakaway or direct to watercourse.

4.2 Analysis of existing data

The SEPA provided information on septic tanks and other small sewage sources within the catchment that were registered in their discharge consent and monitoring databases. The data from the consent register comprise information on approximately 29 installations serving about 70 properties. These include 18 septic tanks and 6 private STWs. Although the majority of these systems discharge to soakaway, 17 per cent discharge directly to a watercourse (Figure 4.2). Sizes, in terms of number of people served, range from 4 to 57 person equivalents (PE) per installation (Figure 4.3).

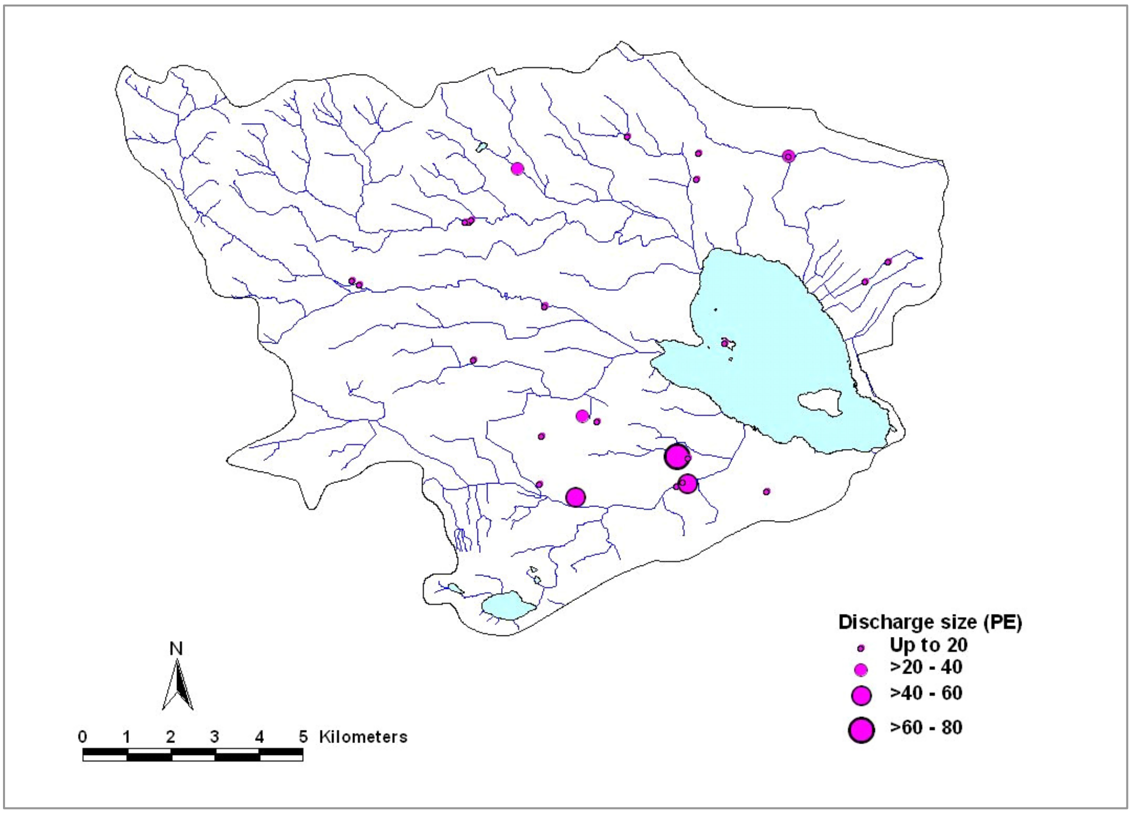

Figure 4.3 Location of consented discharges within the catchment showing size in terms of population equivalent (PE).

The SNH recently estimated the total number of premises within the catchment that are served by septic tanks and private STWs, using a method similar to that described by May *et al*. (1999). They found that approximately 650 households and 23 businesses were not connected to the mains sewerage network (Reed, *pers. comm.*). This suggests that the SEPA database contains only about 10 per cent of the properties connected to septic tanks and private STWs within the catchment. As registration and discharge consent is a relatively recent requirement for private sewage treatment facilities, it is likely that most of these are modern installations that are working correctly.

The monitoring data provided by SEPA comprised nutrient concentrations in the effluent from two large septic tanks, three small STWs and a biodisc system. These data are summarised and reviewed here and in Table 4.1. Although the datasets included several measurements of suspended solids, pH, conductivity, BOD and ammonia concentrations, in some cases over a 13 year period, the early data did not cover total organic nitrogen or orthophosphate concentrations. So, there are only a few, recent values for these parameters. The limited data that do exist show that P concentrations in the effluents from these septic tank systems ranged from 7.7 mg l^{-1} to 13.2 mg l^{-1}. On every sampling occasion, the recorded values significantly exceeded the generally accepted effluent concentration standard of 2 mg P l^{-1} (a value that is, itself, at least 100 times higher than the annual average concentration in Loch Leven). However, in general, the data from these tanks, which serve an estimated 96 people, showed fairly consistent orthophosphate concentrations of about 10 mg P l^{-1} for most of the time. If it is estimated that each person contributes 150 l of water to these systems each day (Mara, 2004), then these concentrations equate to an output from these two systems together of about 50 kg P y^{-1}, corresponding to a *per capita* discharge of about 0.5 kg y^{-1}. This value is similar to the *per capita* P export coefficients that have been used by other authors for these systems (see Section 3.1) and has been used in the context of Loch Leven in Section 4.4, below.

The concentrations of orthophosphate measured in the effluents from private STWs were, generally, more variable than those obtained from the septic tank systems. The P concentrations measured in the effluent from one of these systems ranged from 0.05 mg l^{-1} to 12.9 mg l^{-1}. This suggests that, although these plants have the potential to remove P from sewage, they are not functioning in a consistent way. Of all of the systems monitored by SEPA, the biodisc appeared to discharge the most consistently low concentrations of orthophosphate, ranging from 3 mg l^{-1} to 4.6 mg l^{-1}.

4.3 Field survey data

During the course of this project, several water samples were taken from a site close to a roadside culvert that was purported to be carrying effluent from a septic tank that served several houses near the West Bank Burn at Middleton. Samples were collected on 2 April 2007, at two sites - the culvert itself and the ditch into which it drained. The latter was sampled several hundred metres ‘downstream’ of the culvert discharge point.

Table 4.1 Concentrations of orthophosphate (OP) measured in the effluent from three small sewage treatment works (STW), two septic tanks and a biodisc system (data provide by SEPA)**.**

Site	OP concentration in effluent ($mg\ l^{-1}$)	
	Mean	Range
STW 1	10.77	8.54-12.55
STW 2	5.12	0-13.5
STW 3	2.43	0.7-5.9
Septic tank 1	11.28	9.5-13.2
Septic tank 2	8.95	7.7-10.1
Biodisc	3.26	2.3-4.6

Two replicate samples were taken from each site. The samples were analysed for soluble reactive phosphorus (SRP, equivalent to orthophosphate) and total P (TP), using the molybdate/antimony method and persulphate digestion for TP (Mackereth *et al*., 1989). All replicate concentrations were within 10% of the mean value for each site. Discharge was estimated using a bucket and a stopwatch, and should be considered correct within ±30%. Sampling was conducted at 11.05 am (ditch) and 11.25 am (culvert). The results are summarised below and in Table 4.2.

The estimated TP load of the drainage water at the culvert site was 3.8 g P d^{-1}. This equates to an annual load of about 1.4 kg, if it is assumed that these spot measurements can be extrapolated to annual values. However, these initial results must be treated with caution. Firstly, the measured concentrations are much lower than those recorded for septic tank effluents by SEPA and, secondly, the level of discharge does not seem to be consistent with that which would be expected for effluent from a small number of houses. A discharge rate of 10 l min^{-1} is equivalent to 14,400 l d^{-1}, which is a level of discharge that might be expected from a population of about 70 people (using the *per capita* sewage flow per day value given by Mara, 2004). It is likely then, that the culvert carries water from another source that dilutes the septic tank effluent, or that the septic tank itself also receives water from another source, such as roof runoff.

Figure 4.1 Discharge from the roadside culvert that near Middleton, which was sampled on 2 April 2007.

The contribution of discharge water from roof runoff can be estimated if it is assumed that an average house has a roof area of about 60 m^2 (Ragab, *pers. comm.*) and that the percentage of rainfall captured by that roof is about 75% (Ragab *et al.*, 2003). The estimated discharge of roof drainage water into a septic tank in an area such as this, which has an average annual rainfall of about 1000 mm (Sargent & Ledger, 1992), would be about 45 m^3 *per* household *per* year. If the tank receives roof runoff and the properties connected have an average occupancy of three people each, this would suggest that this septic tank serves about 25 properties. In reality, this small cluster of properties is much smaller than this. So, some of the drainage water must, at least in part, be coming from another, unknown source. This uncertainty makes it difficult to determine the P load in this effluent that is attributable to the septic tank, alone.

Table 4.2 Concentrations and estimated loads of SRP and TP from two sites that drain into the Greens Burn catchment, near Kinross.

Site	NGR	Flow ($l\ min^{-1}$)	SRP conc. ($\mu g\ P\ l^{-1}$)	TP conc. ($\mu g\ P\ l^{-1}$)	SRP Load ($g\ P\ d^{-1}$)	TP load ($g\ P\ d^{-1}$)
Culvert	NO124067	10	267	331	3.8	4.8
Ditch	NO126066	30	114	139	4.9	6.0

The culvert empties into a roadside ditch that carries runoff from other sources. The water in the ditch beyond the discharge point comprises approximately 33% water from the culvert and 66% water from another source, such as runoff from farmland. To achieve a final SRP concentration of 114 $\mu g\ P\ l^{-1}$ SRP in the ditch (Table 4.2) with this dilution factor, the background SRP concentration upstream of the culvert would be about 37 $\mu g\ P\ l^{-1}$.

4.4 Catchment scale evaluation

The number and location of most septic systems within a catchment is unknown because the Control of Pollution Act 1974 (CoPA) did not require sewage discharges to soakaway to be consented by the SEPA (SEPA, 2006). Although the more recently introduced Controlled Activity Regulations 2005 (CAR) now require all small sewage treatment systems (i.e. those serving less than 15 people) to be registered with the SEPA in future, retrospective registration will only occur when a property is sold. So, it will be many years before detailed information becomes available at the national scale.

In the meantime, estimating the proportion of the annual P load to the loch that is attributable to septic tanks requires the number and location of these systems to be derived from readily available data. This process has been carried out for the Loch Leven catchment by the SNH, who have used a method similar to that described by May *et al.* (1999). SNH found that there were approximately 650 households and 23 businesses (Reed, *pers. comm.*) within the catchment that were connected to either septic tanks or to private STWs.

If it is assumed that each household equates to approximately three person equivalents (PE), that each business equates to approximately 10 PE, and that the P export from a well managed septic tank is about 0.5 kg P $capita^{-1}$ y^{-1} (see Section 4.2, above), then the annual export of P from all septic tanks within the catchment is likely to be about 1000 kg P y^{-1} (i.e. about 14 % of the annual load to the loch). However, it is unclear how much of this discharge will eventually reach the loch. This depends upon – amongst other things (see Section 2.6) – on the mode of discharge of the effluent (i.e. *via* soakaway or direct to waterbody), the distance to the nearest watercourse and the hydrological connectivity of the catchment.

The impact of these factors on P transport is not well understood. Many studies have shown that, if septic tanks discharge to soakaway, a high proportion of the P in the effluent is removed in the first 30 - 100 centimetres of soil that it passes through (Jones & Lee, 1979; Harman *et al*., 1996; Robertson & Harman, 1999; Sawnhey & Starr, 1977; Zanini *et al*., 1998). However, because initial concentrations are so high, the remaining P in the effluent plume 50 – 100 m from the original source can still be high enough to pollute receiving waterbodies. Wieskel & Howes (1992) estimated that only about 0.3% of the original phosphate content of the effluent (i.e. about 0.03 mg l^{-1}, using SEPA data for the Loch Leven catchment – see Table 4.2) would reach a waterbody 100 m from a septic source. A similar result was obtained by Chen (1988), who measured P concentrations at distances of 40 m and 100 m from a septic tank and found P concentrations of 0.1 mg l^{-1} and 0.04 mg l^{-1} in the effluent plume, respectively. More research, including a structured field sampling programme, is needed to determine how much of P exported by septic tanks actually reaches the loch in the case of Loch Leven.

5 Proposal for future work

This Section presents an outline proposal for future work aimed at better quantifying the contribution of septic tank effluent to the P load to Loch Leven. The proposal is sub-divided into three parts that address each of the main issues:

- Determining the number, location and type of septic tanks
- Estimating the P load to surface waterbodies from septic tanks
- Assessing P losses to groundwater from septic tanks

5.1 Determining the number, location and type of septic tanks

The number of properties served by septic tanks within the Loch Leven catchment has been estimated by the SNH using a method similar to that published by May *et al*. (1999). The study concluded that there were approximately 650 households and 23 businesses not connected to the mains sewerage network (Reed, *pers. comm*.). As the addresses of these properties are known, their location within the catchment can be determined from their postcodes using the method described by May *et al*. (1999).

The type of septic tank at each location cannot be determined easily from available data. So, a questionnaire-based survey would need to be carried out to determine this and other factors that affect P transport, such as frequency of de-sludging, distance from a watercourse and method of discharge (i.e. soakaway or direct to watercourse). Survey-based approaches have been used successfully by other studies to obtain this type of information (e.g. Patrick, 1988; KMM & Pettit, 2000; Arnscheidt *et al*., 2007). Once compiled, the information can be used to evaluate the risk of pollution occurring from each septic tank or group of tanks, as demonstrated by Arnscheidt *et al*. (2007).

5.2 Estimating the P load to surface waterbodies from septic tanks

The amount of P in a stream that is attributable to effluent from septic tank(s) can be determined by measuring flows and P concentrations upstream and downstream of a known tank location and subtracting upstream loads from downstream loads. In theory, sampling at multiple points upstream and downstream of the point source would ensure that background levels of P from land use sources could be separated from those associated with the point source (see Figure 3.1). However, this method would need to be tested across various sites to determine its ability to provide the necessary information. If proven effective, this approach could be used to investigate the impact of factors such as (i) distance from watercourse, (ii) age and management of the septic tank system, (iii) soil type, (iv) number of people using the system, etc., on P losses from septic tanks to surface waters. This would not, however, detect any contributions to groundwater (see below).

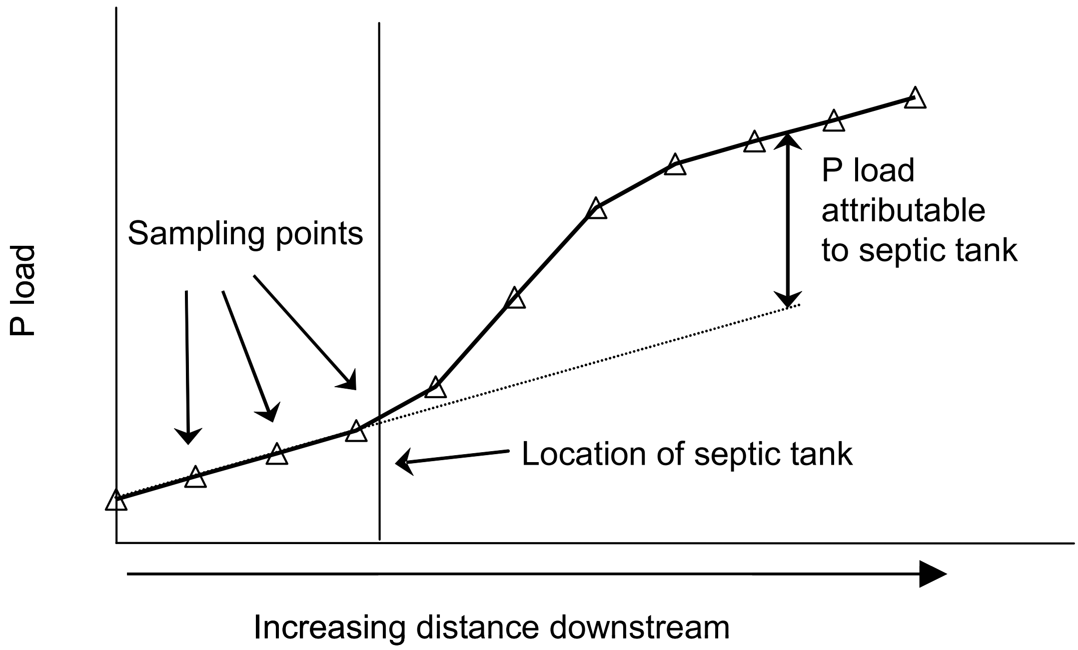

Figure 5.1 Idealised model showing increase in P load downstream from a septic tank or other point source of P.

5.3 Assessing P losses to groundwater from septic tanks

Assessing septic tank contamination of groundwaters requires groundwater to be sampled and analysed for P content. Sampling is usually achieved by sinking boreholes and installing soil water collection devices such as lysimeters. These comprise a porous ceramic cup and sample collection tube which draws water from the soil when a vacuum is applied. The water sample is then extracted from the collection tube and analysed in the laboratory.

Installing a system of lysimeters at the catchment scale would be very impractical and prohibitively expensive. An alternative method of collecting groundwater that should be considered for a survey at this scale is the collection and analysis of water samples from the many wells and springs that already exist in this area (Figure 5.2). Some of these are already monitored by the SEPA and British Geological Survey (BGS) or are consented abstraction sites (Figure 5.3). Where water samples are found to contain high levels of P, additional analyses could be undertaken to determine whether this is likely to be related to contamination from domestic effluent. These analyses would test for the presence of tracers, such as boron, caffeine or sterols (see Section 3.3), that are likely to have a human origin. It is unclear, however, whether these tracers are suitable for identifying sewage contamination of soil water and groundwater. This would need to be investigated before the method could be applied.

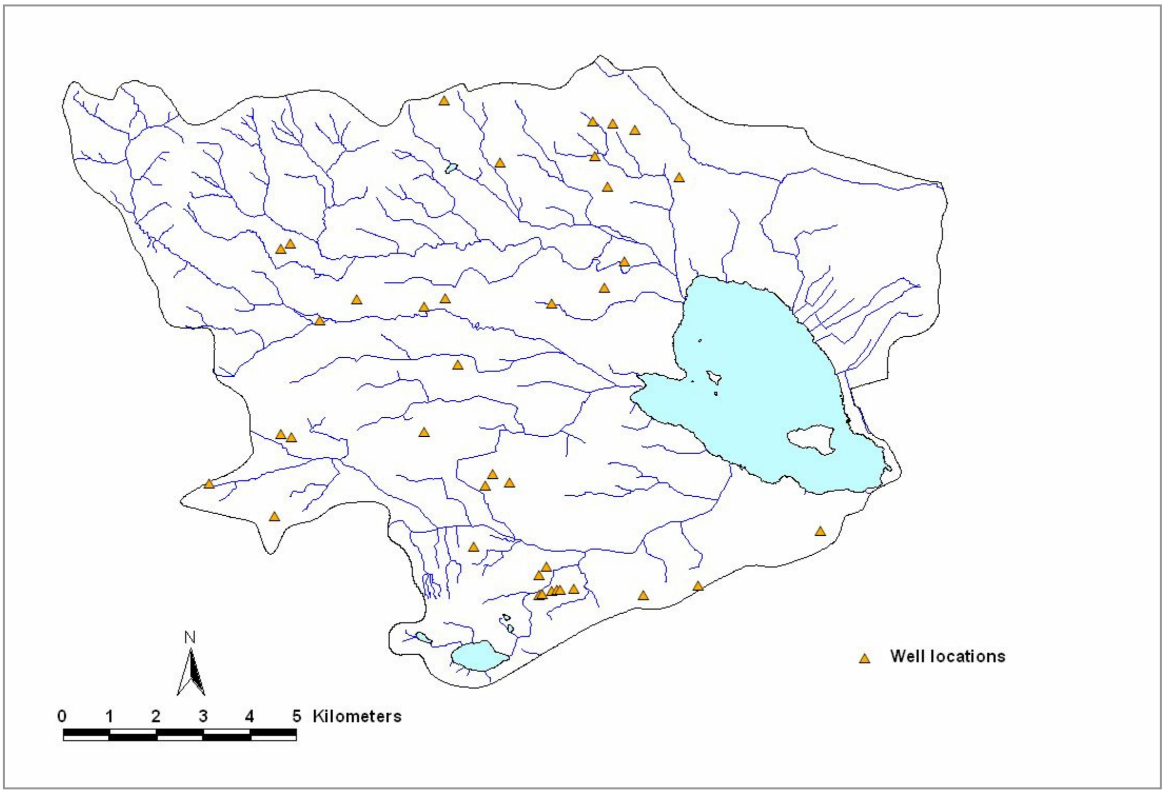

Figure 5.2 Map of the Loch Leven catchment showing the locations of wells, as determined from an Ordnance Survey 1:25,000 Pathfinder Series map.

Although impractical at the catchment level, a series of lysimeters could be installed at a range of different depths and distances from a small number of septic tanks that drain to soakaway. This would provide a vertical and horizontal profile of P concentrations in the soil water that would allow the contaminant plume to be tracked as it passes through the surrounding soil. The rate and distance of travel would provide general information on the likely transport of P to the loch or nearest watercourse from any given septic tank location.

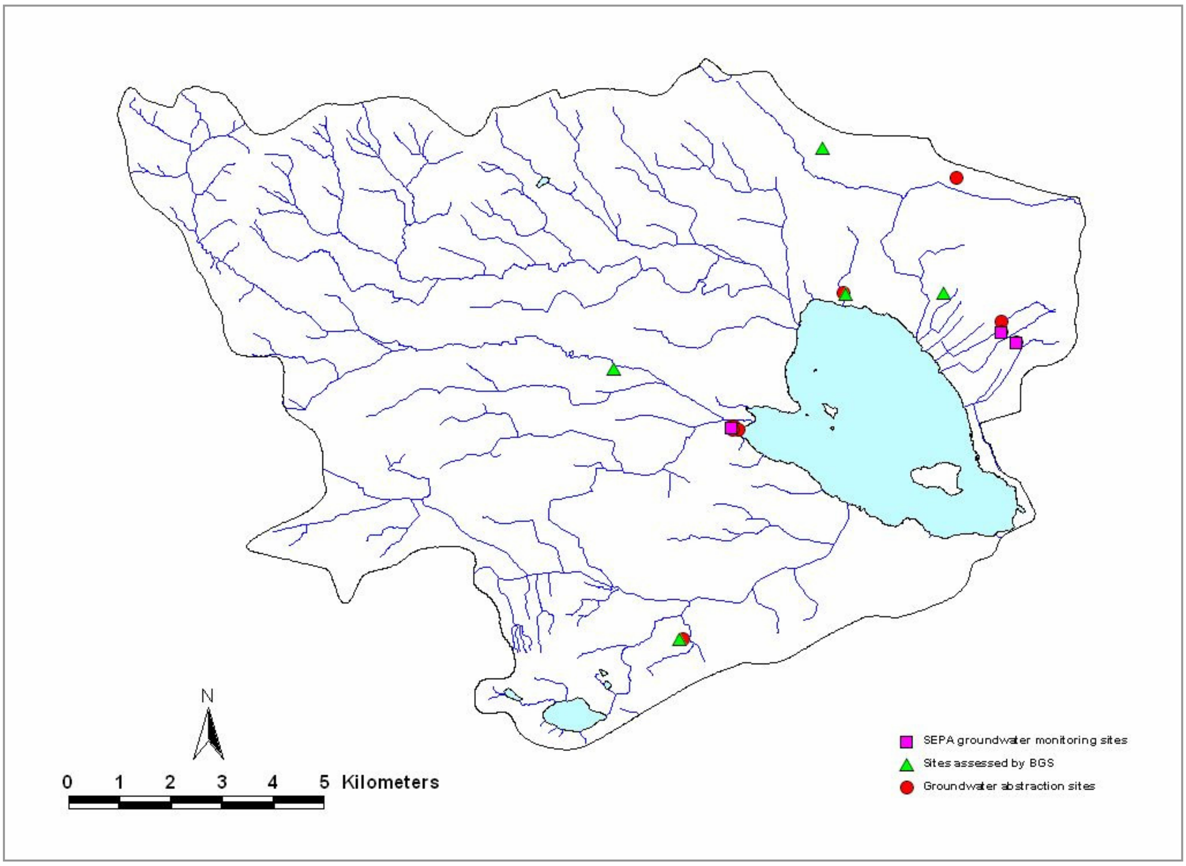

Figure 5.3. Groundwater sites within the Loch Leven catchment that are monitored by the SEPA and British Geological Survey (BGS) or are consented abstraction sites.

5.4 Summary of proposed study

The proposed study would:

1. Locate septic tanks within the catchment.
2. Survey all households connected to septic systems to determine size, type, number of people connected, seasonality of discharge, frequency of de-sludging, distance

from watercourse, type of discharge; use this information to evaluate the risk of pollution from each source or group of sources.

3. Monitor P levels in drainage waters upstream and downstream of known septic tanks locations for different types/sizes of tanks and different modes of discharge.

4. Survey P levels in readily accessible groundwater supplies, such as existing wells or springs.

5. Monitor the transport of P through the soil profile at a small number of locations close to septic tanks that discharge to soakaway.

6. Determine a generally applicable approach to the desk based assessment of P loads to lochs from septic tanks that can be applied across Scotland; this would include an assessment of the key factors that would need to be determined on a site specific basis and those that can be derived from more general national datasets.

6 Acknowledgements

We are grateful to everyone who contributed to data and ideas to this study, especially the following: Brian D'Arcy (SEPA), Deborah Ballantyne (SEPA), Mike Bowes (CEH), Paul Butler (SEPA), Tony Edwards, Helen Jarvie (CEH), Eleanor Jennings (Trinity College Dublin), Phil Jordan (University of Ulster), Colin Neal (CEH), Trevor Page (EA/Univ Lancaster), Denise Reed (SNH) Brian Reynolds (CEH) and Nick Robins (BGS).

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