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Title: Assessment of a novel development policy for the control of phosphorus losses from private sewage systems to the Loch Leven catchment, Scotland, UK.

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ABSTRACT

Legislation to control nutrient enrichment of inland waters has been developed and implemented across local, regional and international scales. In the EU, measures must be identified to ensure that all inland water bodies meet ecological guidelines as set by the Water Framework Directive (WFD) by 2015 or 2027. However increasing demand for rural development, associated with projected population increase, confound existing nutrient management approaches. Here we assess the efficacy of a rural development policy that was designed to ensure that the private sewage systems (PSS) of new developments do not increase the phosphorus (P) load to the environment within a lake catchment. In outline this policy involves mitigating 125% of their calculated P output of a development by modifying an existing, third party PSS. The assumption that PSS discharge a hierarchal reduction in P output with increasing treatment level (i.e. primary treatment (10 mg l^{-1}) > secondary treatment (5 mg l^{-1}) > tertiary treatment (2 mg l^{-1})) lies at the core of this policy. This study assesses the effectiveness of the policy instrument in achieving a reduction in nutrient discharge from PSS to the catchment. To do this, seven PSS (four with primary, one with secondary and two with tertiary treatment) were monitored over a four month period to provide a range of P discharge concentrations across treatment types. These data were used to assess the potential impact of future rural development on P losses to the catchment using the expected, and the hypothetical, population increase rate of 1.3% yr^{-1} over a 90 year projection. No significant differences in TP discharge concentration were observed among PSS or treatment levels of PSS sampled. To ensure this policy meets its aim, improvement in technology and management of PSS along with alternative mitigation measures are required.

1. Introduction

The estimated annual total phosphorus (TP) load to British rivers is 41.6 kt yr^{-1}. Households contribute 25.3 kt yr^{-1} (68.7%) of this, with 21.1 kt yr^{-1} being soluble reactive phosphorus (SRP), the most bioavailable form of phosphorus (P) in aquatic ecosystems (White and Hammond, 2006). Improved nutrient management practices associated with municipal waste water treatment works and agriculture in recent decades have led to reductions in nutrient concentrations in receiving waters, a precursor to effective ecosystem management (Jeppesen et al., 2007). However, in many cases, ecological recovery lags behind chemical recovery (Jarvie et al., 2006; Jarvie et al., 2013). This is probably a result of legacy P release from bed sediments (Spears et al., 2011; Verdonschot et al., 2012) or insufficient reduction of P inputs from external sources.

It has been suggested that there are about 1.5 million private sewage systems (PSS) within the UK. Recent studies suggest that 80% of these are working inefficiently, potentially causing significant P pollution of freshwater bodies in rural Britain (Selyf-Consultancy, 2002; Kirk et al., 2003). A significant issue in monitoring P discharges from PSS is the lack of data on their location and state of repair (May et al., 2010). Under the revised Groundwater Directive (Directive 2006/118/EC), discharges from PSS are no longer exempt from groundwater protection legislation. To reflect this, regulations introduced in 2010 outlined a need for registration of PSS in England and Wales and environmental permits for those located in areas vulnerable to groundwater pollution (Bennett, 2011).

In England there is still debate over legislation surrounding PSS and their registration, and environmental permits for PSS are not compulsory. In contrast, in Wales, registration of PSS is legally required. In Scotland, under The Water

Environment (Controlled Activities) (Scotland) Regulations 2011, owners are obliged to register their PSS with the Scottish Environment Protection Agency (SEPA), although this is only legally imposed if the property is to be sold.

In catchment scale TP export calculations, PSS are rarely accounted for separately (Wood et al., 2005; White and Hammond, 2006) and, if they are, they are represented by simplified export coefficients (Smith et al., 2005). These approaches may underestimate the impacts of PSS and have limited use at a site specific level (May and Dudley, 2007). Limited evidence of PSS impacts on waterbody P concentrations exist in the literature. High frequency river sampling in a 5 km^2 Irish rural sub-catchment within the Lough Neagh basin that had no obvious industrial or municipal point sources identified a chronic TP base-flow transfer of c. 0.25 to 0.50 mg l^{-1} that was characteristic of pollution from PSS (Jordan et al., 2007). Arnscheidt et al. (2007) reported a correlation between in stream TP concentrations and indicators of faecal and grey water from PSS during low-flow conditions in three Irish rural catchments. Spot sampling conducted in English rivers downstream of PSS have indicated increases of up to 700% in TP concentrations, with impacted concentrations of 0.4 mg l^{-1} being reported (May et al., 2010). The impact of PSS on P concentrations in receiving waters is expected to increase in rural catchments under low-flow conditions when dilution levels are reduced (Foy et al., 2003; May et al., 2010; Macintosh et al., 2011). Evidence suggests that, in some catchments, PSS may contribute significantly to the net P loading of their drainage waters, driving the need for legislation to address such potential impacts.

In east Scotland, UK, a novel planning policy has been put in place to address the potential increase in P discharges to the Loch Leven catchment from new developments with PSS. Under the Town and Country Planning (Scotland) Act 1997; as amended by the Planning etc. (Scotland) Act 2006 (amended in 2009) (Scottish Government, 2009), councils and national park authorities must construct a Development Plan (DP) to manage building development. The Loch Leven Catchment is covered by the TAYplan Strategic Development Plan (TAYplan, 2012), which provides guidance for an area of 8,112 km^2 with over half a million inhabitants. Local planning authorities must convert these broad DPs into a more detailed local development plan (LDP) that details land use policies and proposals for their area (Figure 1, upper panel). DPs and LDPs may also accept supplementary guidance. For example, the Kinross Area Local Plan (2004) adopts the principles of the the Loch Leven Catchment Management Plan (1999) (LLCMP) for the control of pollution to Loch Leven (Figure 1).

The Kinross Area Local Plan (2004) contains novel rural policies that aim to ensure that new developments do not increase P loading to the Loch Leven catchment. The policies are aimed at individuals proposing any form of rural development within the catchment that require a PSS (policy 10). It states that the future P output from the PSS must be estimated (policy 11) and that measures to mitigate the estimated output to the catchment by 125% must be proposed (policy 12). This should be achieved by upgrading third party primary treatment PSS to systems with secondary or tertiary treatment (Loch Leven Special Protection Area and Ramsar Site, 2011). In the following text, these policies are, collectively, termed ‘the 125% rule’. The 125% rule assumes that PSS with secondary treatment (i.e. wetlands, reed beds and mechanical treatment plants) or tertiary treatment (i.e. sand filters, drum filters, membrane systems or chemical dosing) will produce lower TP discharge concentrations than PSS with primary treatment (single septic tank treatment, only) (SEPA, 2011), thereby reducing the P discharge to the environment. The efficacy of this new legislation relies on the accuracy of the desk based TP load estimation for proposed PSS and requires validation in the context of potential benefits or threats to the net TP load to the Loch.

In order to better understand the effectiveness of the 125% rule, we quantified potential uncertainty using the current desk based calculation procedure and compared it to actual measured TP concentrations from seven PSS within the Loch Leven catchment. The potential change in P output from projected developments over the next 90 years was forecast using both of these approaches. The results are compared and discussed in relation to potential policy appraisal.

2. Methods

2.1. Site description

Loch Leven is a large shallow lake (mean depth 3.9m; surface area 13.3 km^2) with a surface water catchment of 145 km^2 that is dominated (80%) by agriculture (LLCMP, 1999). Due to its high conservation value, both nationally and internationally, it is recognised as a Special Site of Scientific Interest (SSSI), a Special Protected Area (SPA) (UK9004111), a RAMSAR site (UK13033) and is part of the Natura 2000 network.

Loch Leven has a long and well-documented history of nutrient pollution, catchment management and recovery (May and Spears, 2012a, 2012b; May et al., 2012).

Catchment management in the 1980s to 1990s resulted in a significant (c. 60%) reduction in P inputs to the loch. This was mainly due to reductions in P loads from waste water treatment works, industrial point sources, and improvements in agricultural practices leading to reduced diffuse P loadings from diffuse sources (May et al., 2012). This led to significant ecological improvements (Dudley et al., 2012), although ecological responses were delayed as a result of sediment P release within the loch (Spears et al., 2011). Central to the success of the improvements in water quality at Loch Leven has been the LLCMP (1999), which was based on empirical relationships between P concentrations in the lake and water quality indicators. The estimated amount of P entering the loch in 2005 was 7.69, 3.57, 2.68 and 4.11 tonnes of TP, total soluble phosphorus (TSP), SRP and particulate phosphorus (PP), respectively (Defew, 2008). The long term monitoring program at Loch Leven (> 45 years) has been facilitated by an almost unique cooperation between researchers, policy makers and stakeholders and makes it an internationally important research site (May and Spears, 2012a).

2.2. Implementation of the '125% rule'

The 125% rule assessment calculations use pre-defined TP discharge concentrations of 10.00 mg l^{-1}, 5.00 mg l^{-1} and 2.00 mg l^{-1}, for PSS with primary, secondary and tertiary treatment, respectively (Loch Leven Special Protection Area and Ramsar Site, 2011; SEPA, 2011), a people equivalence (P.E.) value based on the number of bedrooms (n) (P.E. = n + 2) and an estimated per capita waste water production rate of 180 l day^{-1} (British Water: Flows and Loads 3., 2009). Phosphorus output (mg l^{-1}) is calculated by multiplying the P.E. by the estimated water usage (l) and the TP discharge concentration according to the treatment type (Figure 1, lower panel).

A case study for rural development in the Loch Leven catchment using these recommended guidelines is presented in Figure 1. All available mitigation options are first identified and potential TP load ‘savings’ estimated. Such ‘savings’ must be greater than 125% of the estimated TP load from the proposed development. Therefore the number of bedrooms allowed in the proposed development is reliant on how much the net TP can be reduced. In this case study, the mitigation scheme proposes an upgrade to the PSS of a five bedroom house with secondary treatment, resulting in an estimated reduction in TP discharge to the catchment of 6.30 g P day^{-1}. This figure must equate to 125% of the PSS TP load from the proposed development. Therefore, to meet the requirements of the 125% rule, the proposed development must produce $<$ 5.04 g P day^{-1}.

In this way, mitigation options provide guidance on the scale of proposed developments. In keeping with the ‘TP budget,’ development of a three bedroom house (P.E. = 5 people) with secondary treatment, discharging an estimated 4.5 g P day^{-1} would be allowed. If accurate, this development and associated mitigation activities would reduce the TP load to the catchment by 0.54 g P day^{-1}.

2.3. Septic tank sampling methods

To explore the uncertainty of the assumptions for P effluent concentrations of PSS with different treatment levels, discharges from seven PSS within the Loch Leven catchment were analysed for TP, SRP and total soluble phosphorus (TSP) content over a 5 month period. From these data, particulate phosphorus (PP=TP-TSP) and soluble un-reactive phosphorus (SURP=TSP-SRP) were calculated. A particularly challenging and constraining feature of this experimental design was locating suitable PSS that could be sampled easily and regularly; those chosen represent systems with primary, secondary and tertiary treatment. Four primary systems were selected to represent systems eligible for modification under mitigation scenarios; two constructed from concrete tanks (PSS 1 and 2) and two from fibreglass tanks (PSS 3 and 4). One tank with secondary treatment (mechanical mixing) (PSS 5) and two with tertiary treatments, one injected daily with 5ml of concentrated iron chloride to bind orthophosphate (PSS 6) and one fitted with an aeration system and filter system using Bauxsol^{TM} pellets (containing Al and Fe compounds) to bind P (PSS 7), were sampled. Samples were collected between October 2011 and February 2012. Restricted access to some sites, lead to less frequent sampling with PSS 3 and 4 sampled eight times; PSS 1, 2, and 6 sampled seven times and PSS 5 and 7 sampled five times.

Samples were collected in 250 ml sample bottles previously cleaned with 10% hydrochloric acid and rinsed thoroughly with distilled water. Samples were taken from the last or only settling tank of each PSS, accessed by opening their hatch and lowering a sample tube attached to a rod to 60 cm below the surface to avoid collection of surface scum. Concentrations reported here are ‘in tank’ concentrations; as these are closed systems it is considered that the samples taken closely resemble P concentrations of actual discharging liquor. Discharge pipes from the final tanks of all PSS were buried underground making them inaccessible for sample collection.

Samples for SRP and TSP analyses were filtered through a Whatman® GF/F filter paper then stored with unfiltered samples for TP analysis at 4°C in darkness, overnight. All samples were analysed within 48 hours of collection. TP and TSP samples were digested using potassium persulfate ($K_2S_2O_8$) acid hydrolysis digestion based on methods by Eisenreich et al. (1975). Samples were then analysed for orthophosphate-P according to the methods of Murphy and Riley (1962).

2.4. Statistical analysis

Data were analysed using the statistical software R version 2.51.1 (R-CORE-TEAM, 2012). Linear models were used to test for significant differences in TP, SRP and SURP effluent concentrations of individual PSS and between treatment types. To account for the residual spread of the data within the categories of PSS and treatment type, the generalised least squares (‘gls’) function within the ‘nlme’ package (Pinheiro et al., 2012) of R was used. To test for significant differences in SRP:TP and SURP:TP concentration ratios between PSS and between treatments, data were transformed with the ‘arcsin’ square root transformation to meet linear model assumptions prior to analysis.

2.5. Modelled scenarios and uncertainty analysis

Uncertainty analysis of the modelled TP discharge concentration from PSS using the 125% rule assessment procedure was conducted. The following analysis is based on the assumption that all P discharged from PSS represents an increase in the P load to the Loch Leven *catchment*, and is therefore *potentially* delivered to Loch Leven. In this study, no significant difference in TP concentration between treatments was observed, therefore all samples irrespective of treatment type were combined to give a median TP concentration (9.28 mg l^{-1}). The net TP load from PSS to the catchment was calculated using assumed (i.e. by the 125% rule) TP discharge concentrations for those with primary, secondary and tertiary treatment as well as the median TP concentration of all ‘in tank’ samples collected in this survey. A projected population increase of PSS users within the Loch Leven catchment allowed comparison of the increase in net P discharge from PSS to the catchment using each modelled scenario between 2010 and 2100.

2.6. Population projections

The number of properties not connected to mains sewerage in the Loch Leven catchment in 2001 was estimated to be 654. This figure was compiled by the Scottish Environment Protection Agency (SEPA), Scottish Natural Heritage (SNH), Perth and Kinross Council (PKC) and Scottish Water using ordinance survey data to count the number of properties located in postcode areas not served by mains sewerage. Assuming that these properties are served by PSS, and using 2.22 as the average number of people per household (2010 estimate in The National Records of Scotland, 2012), 1452 people are served by PSS. Population growth within the Perth and Kinross area is projected to be 1.28% per annum between 2010 and 2035 (National Records of Scotland, 2012); assuming that growth in PSS users occurs at the same rate, an estimated 5114 people will be served by PSS in 2100. This figure is used to demonstrate the scale of uncertainty in predicting phosphorus discharge from PSS in line with potential population increases.

3.0 Results

3.1. Loch Leven catchment private sewage system survey

Total phosphorus concentrations of all samples taken from PSS with primary treatment (PSS 1 to 4) ranged from 4.45 to 18.01 mg l^{-1} with a median 9.06 mg l^{-1}. The median TP discharge concentration of individual PSS ranged from 6.19 to 12.81 mg l^{-1}. Soluble reactive phosphorus concentrations in all samples taken from PSS with primary treatment ranged from 0.32 to 10.56 mg l^{-1}, with a median of 4.83 mg l^{-1}. The SRP median concentration of individual PSS ranged from 1.83 to 8.82 mg l^{-1}. For SURP, concentrations of all samples taken from PSS with primary treatment ranged 0.04 to 6.14 mg l^{-1} with a median of 0.67 mg l^{-1}, whilst the median SURP discharge concentration of individual PSS ranged from 0.12 to 0.94 mg l^{-1} (Figure 2).

Total phosphorus concentrations from all samples taken from the PSS with secondary treatment (PSS 5) ranged from 5.79 to 14.43 mg l^{-1}, with a median concentration of 11.86 mg l^{-1} (as only one PSS with secondary treatment was accessible in this trial no range of median concentrations could be calculated). SRP concentrations ranged from 2.26 to 11.91 mg l^{-1} with a median concentration of 8.82 mg l^{-1}, whilst SURP concentrations ranged from 0.41 to 1.44 mg l^{-1} with a median of 0.86 mg l^{-1} (Figure 2).

Total phosphorus concentrations of all samples taken from PSS with tertiary treatment (PSS 6 and 7) ranged from 1.91 to 14.44 mg l^{-1}, with a median concentration of 9.31 mg l^{-1}. The median concentration of PSS 6 and 7 was 10.57 mg l^{-1} and 8.26 mg l^{-1}, respectively. The SRP concentration of all samples taken from PSS with tertiary treatment ranged from 1.42 to 10.60 mg l^{-1}, with a median average of 5.54 mg l^{-1}. The median SRP discharge concentration of PSS 6 and 7 was 7.28 and 3.76 mg l^{-1}, respectively. Soluble unreactive phosphorus concentration of all samples taken from PSS with tertiary treatment ranged from 0.10 to 1.71 mg l^{-1} with a median of 0.36 mg l^{-1}. The median SURP concentration of PSS 6 and 7 was 0.29 and 0.44, respectively (Figure 2).

No significant difference was observed in TP concentrations (linear model, $F_{(6,40)} =$ 1.36 P = 0.25, n = 47) or SURP concentrations (linear model, $F_{(6,40)} =$ 1.80 P = 0.12, n = 47) among PSS, although SRP concentrations were significantly different (linear model, $F_{(6,40)} = 12.91$, $P = < 0.001$, $n = 47$). No significant differences were observed in TP (linear model, $F_{(2,44)} = 0.27$, $p = 0.76$, $n = 47$), SRP (linear model, $F_{(2,44)} = 0.99$, $p = 0.38$, $n = 47$) or SURP concentrations (liner model $F_{(2,44)} = 2.11$, $P = 0.13$ $n = 47$, respectively) among treatment types (Figure 2).

The ratio of SRP:TP was significantly different among individual PSS (Figure 8; linear model $F_{(6,40)} = 6.20$, $p = <0.001$, $n = 47$), but not among treatments (linear model, $F_{(2,44)} = 0.98$, $p = 0.38$, $n = 47$). The median SRP contribution to TP was 68.48% (from a range of 2.36 to 91.32%). The ratio of SURP:TP did not show significant differences among individual PSS (linear model $F_{(6,40)} = 1.74$, $p = 0.14$, $n = 47$), or treatments (linear model, $F_{(2,44)} = 1.57$, $p = 0.22$, $n = 47$). The median SURP contribution to TP was 7.24% (from a range of 0.25 to 47.53%) (Figure 3).

3.2. Uncertainty analysis of the '125% rule' with future population growth

Using the assessment methods outlined by the 125% rule, if the 3486 extra people served by PSS between 2010 and 2100 are connected to PSS with primary, secondary or tertiary treatment an additional TP discharge to the catchment of 3.36, 1.68 or 0.67 t TP yr^{-1} is expected, respectively (Figure 10). Using the average median TP discharge concentration from PSS sampled an increase of 3.12 t TP yr^{-1} is estimated, with a range of 1.78 to 4.94 t TP yr^{-1} (based on the 5th and 95th percentile) (Figure 4).

4. Discussion

4.1. Variation in P concentrations in PSS

No significant difference in TP concentration was observed between PSS or between treatment types of PSS in this study. The median TP concentration of all samples (9.28 mg l^{-1}) most closely resembled concentrations expected from PSS with primary treatment (10mg l^{-1}) under the 125% rule assumptions (Loch Leven Special Protection Area and Ramsar Site, 2011; SEPA, 2011). These results indicate that secondary and tertiary treatments do not significantly reduce TP concentration in the sampled tanks, suggesting that the assumptions used in the 125% rule may not reflect reality.

Phosphorus reduction is not required for the E.U. Standard for PSS (E.U. Standard (EN12566-1-7:2000). Gill et al. (2009) states that package treatment plants (septic tanks with secondary or tertiary treatment) are not specifically designed to remove P. It has been reported that the aerobic environment provided by secondary treatment aeration can cause c. 15% reduction in PSS effluent P via assimilation, precipitation and adsorption (Metcalf and Eddy, 2003). In this study, reductions were not observed and this would not be enough to accommodate the TP reduction assumed in the 125% rule from upgrading from primary to secondary treatments. Gill (2009) reported similar (12%) reduction in SRP through biological assimilation under secondary treatment and, although SRP concentration did vary significantly between PSS sampled in this study, this was not significantly related to treatment type. Human domestic behaviour such as detergent choice (sodium tri-polyphosphate (STPP) is a common source of SRP from detergent), water usage and maintenance regime of PSS (i.e. desludging interval) may account for this observed variation.

Quantifying the impacts of human behaviour on SRP discharge concentration may identify options that can be used to reduce P discharge concentration.

The ratio of SRP:TP varied significantly between PSS but not among treatment levels, with no significant difference being observed in SURP:TP ratio between PSS or treatment. In samples analysed, a median of 68.48% of TP was present in the form of SRP whilst 7.24% was present as SURP. Bouma (1979) reported studies that found more than 85% of TP in septic tanks was SRP whilst Whelan and Titamnis (1982) found 93-100% of TP was SRP. Although delivery from PSS may be relatively small (in comparison to other sources), PSS have the potential to cause persistent inputs (Arnscheidt et al., 2007), raising concern that, during low flow summer months when dilution capacity is reduced and ecological sensitivity is greatest, such SRP delivery could promote eutrophication (Macintosh et al., 2011). It is unclear whether high domestic SRP input or in-tank biological conversion of organic P to SRP is responsible for this SRP dominance. What is evident is that treatment aimed at reducing TP discharge concentration will be most effective if designed to target SRP. Flocculation of soluble P compounds by adding alum to primary settling tanks in PSS can reduce SRP in septic tank effluent by 96% (Brandes, 1977). This could provide SRP reductions that meet the required P reduction targets outlined in the 125% rule, but difficulty in creating flocculant in ‘real life’ systems (i.e. pH can affect flocculation (Reitzel et al., 2009)) and the implications that aluminium delivery has for the environment may make safe and effective application challenging.

4.2. Relative contribution of PSS to catchment P load

Variation in the transport of P from PSS can be attributed to site characteristics such as the chemical adsorption capacity and physical texture of draining soils, hydrology, soil microbiology and the slope and distance to proximal water courses (Rea and Upchurch, 1980; Harper, 1992; Beal et al., 2005). Currently site characteristics are not specifically considered in the 125% rule, although building regulations deem that new PSS must be 10m from a water course, with soakaways constructed in free draining soils (H.M. Government, 2000). Much of the soil in the Loch Leven catchment is not suited to soakaway construction and many older installations discharge directly to a water course (Frost, 1996). In older soakaways, long term P laden discharge can fully saturate soils, over riding their P buffering capacity (Heathwaite et al., 2006). Improvement and management of soil adsorption systems (i.e. soakaways) may yield a greater percentage reduction of PSS P from delivery to the Loch. However, evidence of irreversible sorption has been questioned in a long term monitoring site, suggesting that P in groundwater may not be permanently immobilised (Robertson, 2008). Such considerations should be included in policies aimed at reducing P delivery from PSS.

4.3 Implications for local policy development and implementation

The 125% rule invokes ‘The Precautionary Principle’ (Commission of the European Communities, 2000; European Union, 2010) allowing rapid preventative decision-taking in the face of possible threat to the environment where scientific data does not allow full risk assessment, and carries a ‘polluter must pay’ policy. The use of a ‘125%’ reduction offers a buffer against a net increase of P to the catchment from development where data are lacking, acknowledging uncertainty in estimation of

PSS P load. At the core of the assessment procedure is the assumption that P output from PSS decreases with increasing treatment level. Whilst the 125% rule is conceptually strong, the PSS sampled here do not display any significant reduction with increasing treatment level, albeit we are considering a small population of tanks. A larger number of PSS need to be sampled and a better understanding of P processing within PSS is required to reveal whether such policy instruments can cause nutrient loss reduction.

Using the 125% rule assumptions and substituting the median effluent TP concentration of PSS sampled (9.28mg l^{-1}), to offset 125% of the P from the 3486 extra people predicted to be connected to PSS by 2100, developers would be required to mitigate 2.19 t TP yr^{-1}. Currently this must come from improvement to third party PSS. This exceeds the current estimate of 0.99 t TP delivered annually to the catchment from PSS, capping mitigation potential. If increasing treatment level does not make suitable reductions, future developments will need to rely on improved technology and management of PSS (to significantly reduce TP), reduction of domestic P loading and/or alternative mitigation measures such as change in land use (Abell, 2011) or removal of PSS systems into municipal waste water treatment works.

The 125% rule aims to ensure that new developments do not increase P load to the catchment (Loch Leven Special Protection Area and Ramsar Site, 2011). Although Wakida and Lerner (2002) observed greater transfers of nitrates as a result of soil disruption during housing construction (65 kg ha^{-1}) than ploughing temporary grassland (50 kg ha^{-1}) (Cameron and Wild, 1984), little or no research has addressed equivalent P losses (Lubliner, 2007). Other potential P sources associated with development (non-PSS associated) may also need to be assessed, such as garden fertiliser, car washing detergents and domestic livestock waste.

To improve the efficacy of this policy further information is required:

- high frequency monitoring of PSS at all stages of effluent treatment to ascertain process P reduction profiles (i.e. primary septic tank, after secondary and tertiary treatment, soakaway etc.),
- site specific risk analysis of proposed and existing PSS,
- identification and quantification of domestic behaviours that reduce P load to PSS,
- quantification of alternative mitigation options, and
- regular policy auditing based on monitoring data.

To aid monitoring, future installation and retrofitting of PSS should incorporate easily accessible sample collection points at each stage of treatment.

4.4. Implications for wider policy development and implementation

In terms of wider policy development there is a well recognised lack of information surrounding PSS, such as number, location, age, condition, efficiency, maintenance and frequency of desludging of PSS, downstream processing of P in soils, hydrological variation and proximity of watercourses at a site level, and the impacts of human domestic behaviour on P loading (Harper, 1992; Withers et al., 2012). Without such information, estimation of the relative contribution PSS make to catchment TP loads will suffer potential inaccuracies whilst policy aiming to reduce such contributions may misrepresent the problem and the solution. Where data are limited and problems are complex, normal planning and policy making processes may not be equipped to offer timely intervention. Reducing P output with expensive engineering solutions (treating the effects of the problem) may be less effective than reducing domestic P inputs to PSS in the first place (reducing the causes of the problem). Detergent P forms between 9% and 50% of P in wastewater (Morse et al., 1993). Sale of detergents with more than 0.5% P is banned in sixteen states in the U.S. due to the risks they pose to freshwaters (Lusk et al., 2011), resulting in a reduction of P in wastewaters by 40-50% (U.S. Environmental Protection Agency, 2002). In June 2013, similar bans in the E.U. will prohibit sale of consumer laundry detergents that provide ≥ 0.5 g P per standard dosage and bans on sale of dishwasher detergents with ≥ 0.3 g P per standard dosage in 2017; (European Commission, 2011). Use of low P detergents and reductions in the volume of detergents used will reduce P entering PSS, in the UK this could potentially offer a < 28% reduction of wastewater P (Comber et al., 2012) and is a positive step towards reducing our human P footprint.

To make significant reductions in TP discharge concentration from PSS (as required by policies such as the 125% rule), a holistic approach covering user inputs, PSS outputs and downstream processing is required. With a better understanding of the risks PSS pose to the environment, pioneering policies such as the 125% rule can be developed using more quantitative approaches to provide a vehicle to support new sustainable rural development.

5. Conclusions

- The range of TP, SURP and PP in all seven PSS sampled were 1.91 to 18.01 mg l^{-1}, 0.04 to 6.14 mg l^{-1} and 0.23 to 16.13 mg l^{-1}, respectively.
- No significant differences in TP concentration between PSS with primary, secondary or tertiary treatment were observed in the PSS sampled in this study.
- Our results indicate that PSS treatment type may not be an accurate indicator of TP discharge.
- Policy changes should be made to encourage efficient and routine monitoring of all PSS.
- The importance of human domestic behaviour and tank treatment type and design should be combined to assess the drivers of variability in the quantity and quality of P discharged from PSS.

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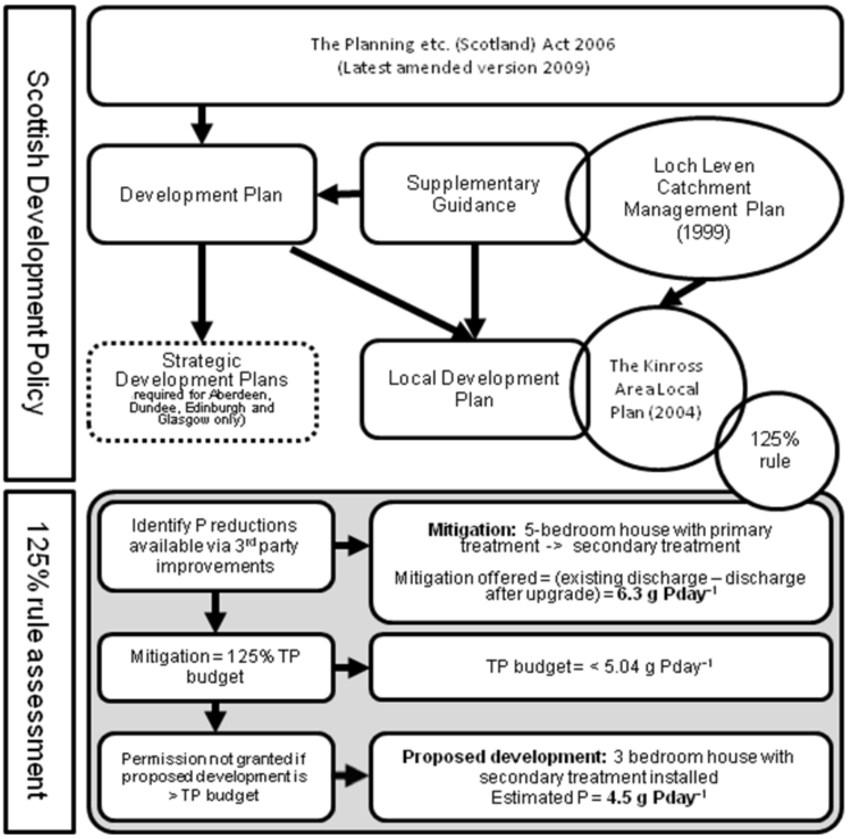
FIGURE LEGENDS

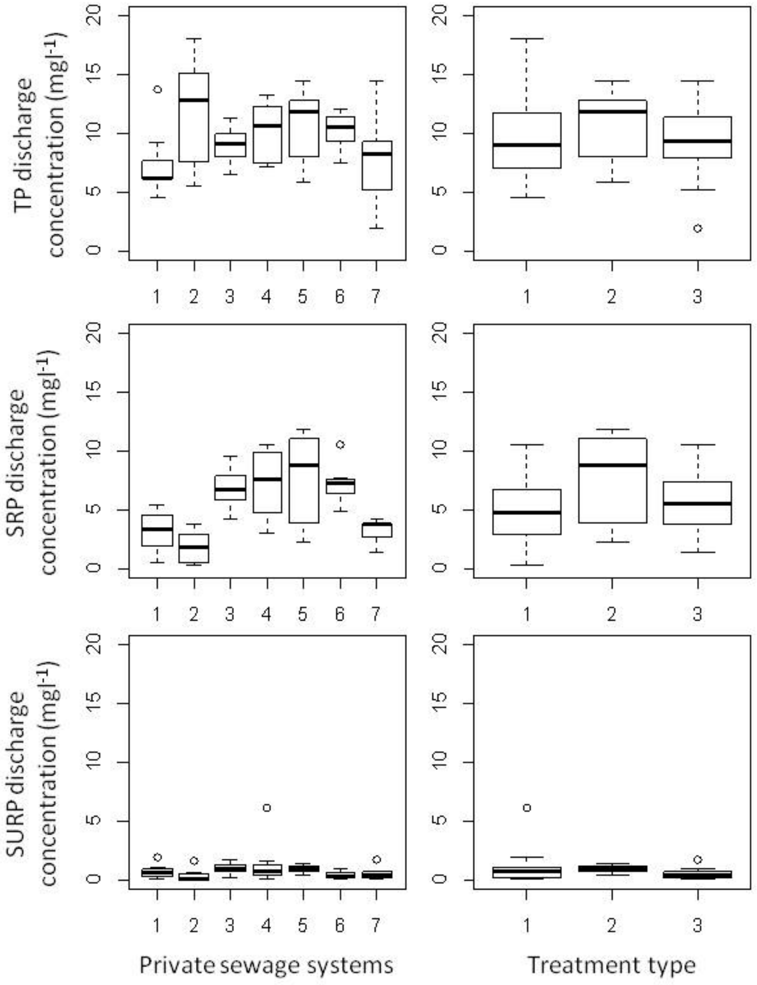
Figure 1. Figure showing the current structure of planning and development legislation in Scotland, including the 125% rule. The assessment calculation of the “125 rule” for a case study example is also shown (with assumptions used).

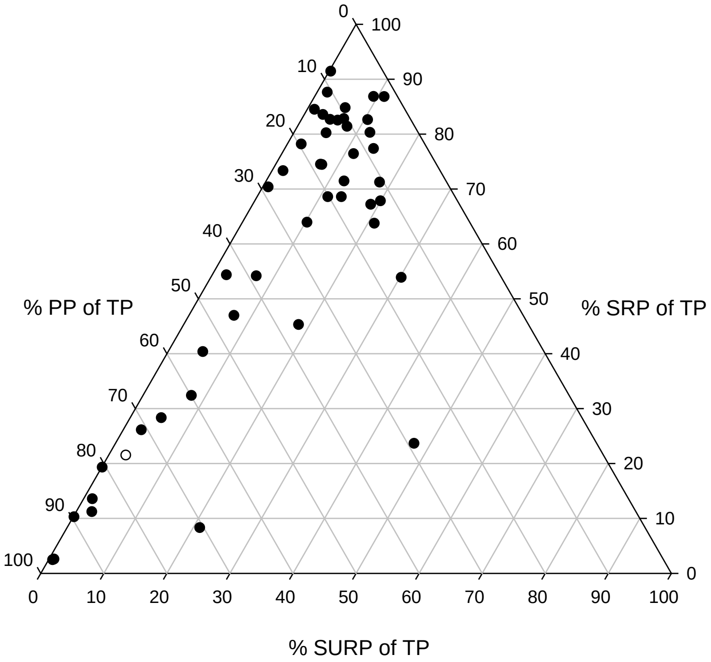
Figure 2. Boxplots showing TP (top panel), SRP (middle panel) and SURP (bottom panel) discharge concentrations (mg l^{-1}) between individual PSS and between primary, secondary and tertiary treatments of 7 PSS within the Loch Leven Catchment

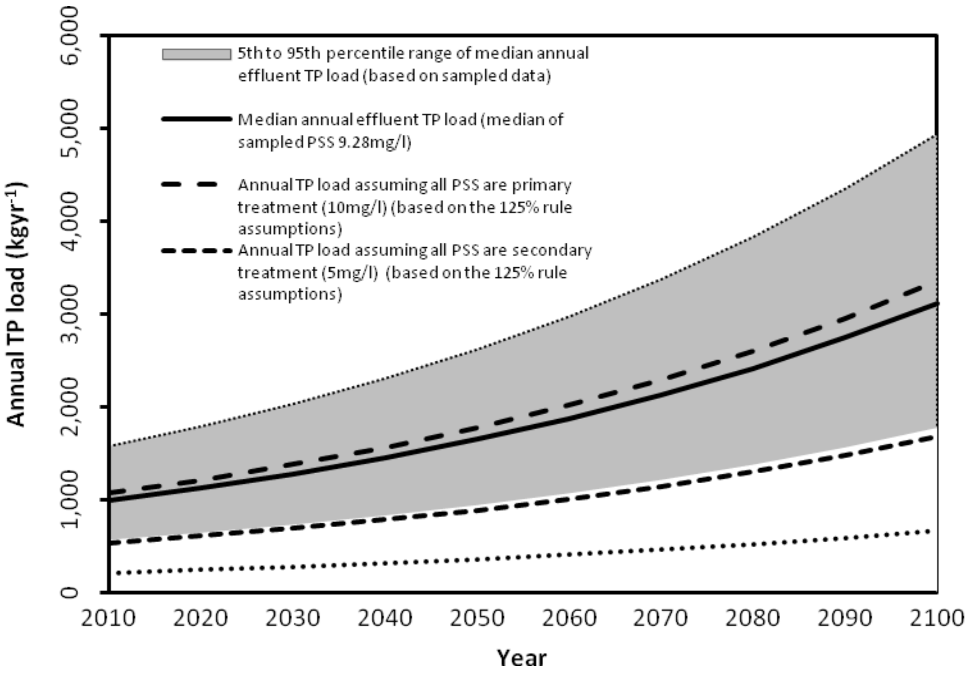
Figure 3. Ternary plot showing the proportion of SRP, SURP and PP found in all samples taken from 7 PSS in the Loch Leven catchment during this study

Figure 4. Graph showing additional TP load from septic tanks to the Loch Leven catchment under the projected population increase until 2100


Scottish Development Policy
The Planning etc. (Scotland) Act 2006
(Latest amended version 2009)
Development Plan
Supplementary Guidance
Loch Leven Catchment Management Plan (1999)
Strategic Development Plans
required for Aberdeen, Dundee, Edinburgh and Glasgow only)
Local Development Plan
The Kinross Area Local Plan (2004)
125% rule
125% rule assessment
Identify P reductions available via 3rd party improvements
Mitigation: 5-bedroom house with primary treatment -> secondary treatment
Mitigation offered = (existing discharge – discharge after upgrade) = 6.3 g Pday-1
Mitigation = 125% TP budget
TP budget = < 5.04 g Pday-1
Permission not granted if proposed development is > TP budget
Proposed development: 3 bedroom house with secondary treatment installed
Estimated P = 4.5 g Pday-1


TP discharge concentration (mgl-1)
SRP discharge concentration (mgl-1)
SURP discharge concentration (mgl-1)
0
5
10
15
20
1
2
3
4
5
6
7
Private sewage systems
Treatment type


% PP of TP
% SRP of TP
% SURP of TP
0
10
20
30
40
50
60
70
80
90
100


5th to 95th percentile range of median annual effluent TP load (based on sampled data)
Median annual effluent TP load (median of sampled PSS 9.28mg/l)
Annual TP load assuming all PSS are primary treatment (10mg/l) (based on the 125% rule assumptions)
Annual TP load assuming all PSS are secondary treatment (5mg/l) (based on the 125% rule assumptions)
Annual TP load (kgyr-1)
0
1,000
2,000
3,000
4,000
5,000
6,000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year