

Article (refereed) - postprint

Brownlie, Will; May, Linda; McDonald, Claire; Roaf, Susan; Spears, Bryan M.. 2014. **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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1 **Title: Assessment of a novel development policy for the control of phosphorus**
2 **losses from private sewage systems to the Loch Leven catchment, Scotland,**
3 **UK.**

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24 Keywords: rural; development; eutrophication; septic tank; policy; phosphorus;

25 nutrient management.

26 **ABSTRACT**

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

51 **1. Introduction**

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

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

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

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

79 In catchment scale TP export calculations, PSS are rarely accounted for separately
80 (Wood et al., 2005; White and Hammond, 2006) and, if they are, they are
81 represented by simplified export coefficients (Smith et al., 2005). These approaches
82 may underestimate the impacts of PSS and have limited use at a site specific level
83 (May and Dudley, 2007). Limited evidence of PSS impacts on waterbody P
84 concentrations exist in the literature. High frequency river sampling in a 5 km² Irish
85 rural sub-catchment within the Lough Neagh basin that had no obvious industrial or
86 municipal point sources identified a chronic TP base-flow transfer of c. 0.25 to 0.50
87 mg l⁻¹ that was characteristic of pollution from PSS (Jordan et al., 2007). Arnscheidt
88 et al. (2007) reported a correlation between in stream TP concentrations and
89 indicators of faecal and grey water from PSS during low-flow conditions in three Irish
90 rural catchments. Spot sampling conducted in English rivers downstream of PSS
91 have indicated increases of up to 700% in TP concentrations, with impacted
92 concentrations of 0.4 mg l⁻¹ being reported (May et al., 2010). The impact of PSS on
93 P concentrations in receiving waters is expected to increase in rural catchments
94 under low-flow conditions when dilution levels are reduced (Foy et al., 2003; May et
95 al., 2010; Macintosh et al., 2011). Evidence suggests that, in some catchments, PSS
96 may contribute significantly to the net P loading of their drainage waters, driving the
97 need for legislation to address such potential impacts.

98

99 In east Scotland, UK, a novel planning policy has been put in place to address the
100 potential increase in P discharges to the Loch Leven catchment from new

101 developments with PSS. Under the Town and Country Planning (Scotland) Act 1997;
102 as amended by the Planning etc. (Scotland) Act 2006 (amended in 2009) (Scottish
103 Government, 2009), councils and national park authorities must construct a
104 Development Plan (DP) to manage building development. The Loch Leven
105 Catchment is covered by the TAYplan Strategic Development Plan (TAYplan, 2012),
106 which provides guidance for an area of 8,112 km² with over half a million inhabitants.
107 Local planning authorities must convert these broad DPs into a more detailed local
108 development plan (LDP) that details land use policies and proposals for their area
109 (Figure 1, upper panel). DPs and LDPs may also accept supplementary guidance.
110 For example, the Kinross Area Local Plan (2004) adopts the principles of the the
111 Loch Leven Catchment Management Plan (1999) (LLCMP) for the control of
112 pollution to Loch Leven (Figure 1).

113

114 The Kinross Area Local Plan (2004) contains novel rural policies that aim to ensure
115 that new developments do not increase P loading to the Loch Leven catchment. The
116 policies are aimed at individuals proposing any form of rural development within the
117 catchment that require a PSS (policy 10). It states that the future P output from the
118 PSS must be estimated (policy 11) and that measures to mitigate the estimated
119 output to the catchment by 125% must be proposed (policy 12). This should be
120 achieved by upgrading third party primary treatment PSS to systems with secondary
121 or tertiary treatment (Loch Leven Special Protection Area and Ramsar Site, 2011).
122 In the following text, these policies are, collectively, termed 'the 125% rule'. The
123 125% rule assumes that PSS with secondary treatment (i.e. wetlands, reed beds and
124 mechanical treatment plants) or tertiary treatment (i.e. sand filters, drum filters,
125 membrane systems or chemical dosing) will produce lower TP discharge

126 concentrations than PSS with primary treatment (single septic tank treatment, only)
127 (SEPA, 2011), thereby reducing the P discharge to the environment. The efficacy of
128 this new legislation relies on the accuracy of the desk based TP load estimation for
129 proposed PSS and requires validation in the context of potential benefits or threats to
130 the net TP load to the Loch.

131

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

138

139 **2. Methods**

140 *2.1. Site description*

141 Loch Leven is a large shallow lake (mean depth 3.9m; surface area 13.3 km²) with a
142 surface water catchment of 145 km² that is dominated (80%) by agriculture (LLCMP,
143 1999). Due to its high conservation value, both nationally and internationally, it is
144 recognised as a Special Site of Scientific Interest (SSSI), a Special Protected Area
145 (SPA) (UK9004111), a RAMSAR site (UK13033) and is part of the Natura 2000
146 network.

147

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

150 Catchment management in the 1980s to 1990s resulted in a significant (c. 60%)
151 reduction in P inputs to the loch. This was mainly due to reductions in P loads from
152 waste water treatment works, industrial point sources, and improvements in
153 agricultural practices leading to reduced diffuse P loadings from diffuse sources
154 (May et al., 2012). This led to significant ecological improvements (Dudley et al.,
155 2012), although ecological responses were delayed as a result of sediment P
156 release within the loch (Spears et al., 2011). Central to the success of the
157 improvements in water quality at Loch Leven has been the LLCMP (1999), which
158 was based on empirical relationships between P concentrations in the lake and
159 water quality indicators. The estimated amount of P entering the loch in 2005 was
160 7.69, 3.57, 2.68 and 4.11 tonnes of TP, total soluble phosphorus (TSP), SRP and
161 particulate phosphorus (PP), respectively (Defew, 2008). The long term monitoring
162 program at Loch Leven (> 45 years) has been facilitated by an almost unique
163 cooperation between researchers, policy makers and stakeholders and makes it an
164 internationally important research site (May and Spears, 2012a).

165

166 *2.2. Implementation of the '125% rule'*

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

174 and the TP discharge concentration according to the treatment type (Figure 1, lower
175 panel).

176

177 A case study for rural development in the Loch Leven catchment using these
178 recommended guidelines is presented in Figure 1. All available mitigation options are
179 first identified and potential TP load 'savings' estimated. Such 'savings' must be
180 greater than 125% of the estimated TP load from the proposed development.

181 Therefore the number of bedrooms allowed in the proposed development is reliant
182 on how much the net TP can be reduced. In this case study, the mitigation scheme
183 proposes an upgrade to the PSS of a five bedroom house with secondary treatment,
184 resulting in an estimated reduction in TP discharge to the catchment of 6.30 g P day⁻¹.
185 This figure must equate to 125% of the PSS TP load from the proposed
186 development. Therefore, to meet the requirements of the 125% rule, the proposed
187 development must produce < 5.04 g P day⁻¹.

188

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

194

195 *2.3. Septic tank sampling methods*

196 To explore the uncertainty of the assumptions for P effluent concentrations of PSS
197 with different treatment levels, discharges from seven PSS within the Loch Leven
198 catchment were analysed for TP, SRP and total soluble phosphorus (TSP) content

199 over a 5 month period. From these data, particulate phosphorus (PP=TP-TSP) and
200 soluble un-reactive phosphorus (SURP=TSP-SRP) were calculated. A particularly
201 challenging and constraining feature of this experimental design was locating
202 suitable PSS that could be sampled easily and regularly; those chosen represent
203 systems with primary, secondary and tertiary treatment. Four primary systems were
204 selected to represent systems eligible for modification under mitigation scenarios;
205 two constructed from concrete tanks (PSS 1 and 2) and two from fibreglass tanks
206 (PSS 3 and 4). One tank with secondary treatment (mechanical mixing) (PSS 5) and
207 two with tertiary treatments, one injected daily with 5ml of concentrated iron chloride
208 to bind orthophosphate (PSS 6) and one fitted with an aeration system and filter
209 system using BauxsolTM pellets (containing Al and Fe compounds) to bind P (PSS 7),
210 were sampled. Samples were collected between October 2011 and February 2012.
211 Restricted access to some sites, lead to less frequent sampling with PSS 3 and 4
212 sampled eight times; PSS 1, 2, and 6 sampled seven times and PSS 5 and 7
213 sampled five times.

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

223

224 Samples for SRP and TSP analyses were filtered through a Whatman® GF/F filter
225 paper then stored with unfiltered samples for TP analysis at 4°C in darkness,
226 overnight. All samples were analysed within 48 hours of collection. TP and TSP
227 samples were digested using potassium persulfate ($K_2S_2O_8$) acid hydrolysis
228 digestion based on methods by Eisenreich et al. (1975). Samples were then
229 analysed for orthophosphate-P according to the methods of Murphy and Riley
230 (1962).

231

232 *2.4. Statistical analysis*

233 Data were analysed using the statistical software R version 2.51.1 (R-CORE-TEAM,
234 2012). Linear models were used to test for significant differences in TP, SRP and
235 SURP effluent concentrations of individual PSS and between treatment types. To
236 account for the residual spread of the data within the categories of PSS and
237 treatment type, the generalised least squares ('gls') function within the 'nlme'
238 package (Pinheiro et al., 2012) of R was used. To test for significant differences in
239 SRP:TP and SURP:TP concentration ratios between PSS and between treatments,
240 data were transformed with the 'arcsin' square root transformation to meet linear
241 model assumptions prior to analysis.

242

243 *2.5. Modelled scenarios and uncertainty analysis*

244 Uncertainty analysis of the modelled TP discharge concentration from PSS using the
245 125% rule assessment procedure was conducted. The following analysis is based on
246 the assumption that all P discharged from PSS represents an increase in the P load
247 to the Loch Leven *catchment*, and is therefore *potentially* delivered to Loch Leven.
248 In this study, no significant difference in TP concentration between treatments was

249 observed, therefore all samples irrespective of treatment type were combined to give
250 a median TP concentration (9.28 mg l⁻¹). The net TP load from PSS to the catchment
251 was calculated using assumed (i.e. by the 125% rule) TP discharge concentrations
252 for those with primary, secondary and tertiary treatment as well as the median TP
253 concentration of all 'in tank' samples collected in this survey. A projected population
254 increase of PSS users within the Loch Leven catchment allowed comparison of the
255 increase in net P discharge from PSS to the catchment using each modelled
256 scenario between 2010 and 2100.
257

258 *2.6. Population projections*

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

272

273 **3.0 Results**

274 *3.1. Loch Leven catchment private sewage system survey*

275 Total phosphorus concentrations of all samples taken from PSS with primary
276 treatment (PSS 1 to 4) ranged from 4.45 to 18.01 mg l⁻¹ with a median 9.06 mg l⁻¹.
277 The median TP discharge concentration of individual PSS ranged from 6.19 to 12.81
278 mg l⁻¹. Soluble reactive phosphorus concentrations in all samples taken from PSS
279 with primary treatment ranged from 0.32 to 10.56 mg l⁻¹, with a median of 4.83 mg l⁻¹.
280 The SRP median concentration of individual PSS ranged from 1.83 to 8.82 mg l⁻¹.
281 For SURP, concentrations of all samples taken from PSS with primary treatment

282 ranged 0.04 to 6.14 mg l⁻¹ with a median of 0.67 mg l⁻¹, whilst the median SURP
283 discharge concentration of individual PSS ranged from 0.12 to 0.94 mg l⁻¹ (Figure 2).

284

285 Total phosphorus concentrations from all samples taken from the PSS with
286 secondary treatment (PSS 5) ranged from 5.79 to 14.43 mg l⁻¹, with a median
287 concentration of 11.86 mg l⁻¹ (as only one PSS with secondary treatment was
288 accessible in this trial no range of median concentrations could be calculated). SRP
289 concentrations ranged from 2.26 to 11.91 mg l⁻¹ with a median concentration of 8.82
290 mg l⁻¹, whilst SURP concentrations ranged from 0.41 to 1.44 mg l⁻¹ with a median of
291 0.86 mg l⁻¹ (Figure 2).

292

293 Total phosphorus concentrations of all samples taken from PSS with tertiary
294 treatment (PSS 6 and 7) ranged from 1.91 to 14.44 mg l⁻¹, with a median
295 concentration of 9.31 mg l⁻¹. The median concentration of PSS 6 and 7 was 10.57
296 mg l⁻¹ and 8.26 mg l⁻¹, respectively. The SRP concentration of all samples taken from
297 PSS with tertiary treatment ranged from 1.42 to 10.60 mg l⁻¹, with a median average
298 of 5.54 mg l⁻¹. The median SRP discharge concentration of PSS 6 and 7 was 7.28
299 and 3.76 mg l⁻¹, respectively. Soluble unreactive phosphorus concentration of all
300 samples taken from PSS with tertiary treatment ranged from 0.10 to 1.71 mg l⁻¹ with
301 a median of 0.36 mg l⁻¹. The median SURP concentration of PSS 6 and 7 was 0.29
302 and 0.44, respectively (Figure 2).

303

304 No significant difference was observed in TP concentrations (linear model, $F_{(6,40)} =$
305 1.36 $P = 0.25$, $n = 47$) or SURP concentrations (linear model, $F_{(6,40)} = 1.80$ $P = 0.12$,
306 $n = 47$) among PSS, although SRP concentrations were significantly different (linear

307 model, $F_{(6,40)} = 12.91$, $P = < 0.001$, $n = 47$). No significant differences were
308 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 (linear model $F_{(2,44)} = 2.11$, P
309 $= 0.13$ $n = 47$, respectively) among treatment types (Figure 2).

311

312 The ratio of SRP:TP was significantly different among individual PSS (Figure 8;
313 linear model $F_{(6,40)} = 6.20$, $p = <0.001$, $n = 47$), but not among treatments (linear
314 model, $F_{(2,44)} = 0.98$, $p = 0.38$, $n = 47$). The median SRP contribution to TP was
315 68.48% (from a range of 2.36 to 91.32%). The ratio of SURP:TP did not show
316 significant differences among individual PSS (linear model $F_{(6,40)} = 1.74$, $p = 0.14$, n
317 $= 47$), or treatments (linear model, $F_{(2,44)} = 1.57$, $p = 0.22$, $n = 47$). The median
318 SURP contribution to TP was 7.24% (from a range of 0.25 to 47.53%) (Figure 3).

319

320 *3.2. Uncertainty analysis of the '125% rule' with future population growth*

321 Using the assessment methods outlined by the 125% rule, if the 3486 extra people
322 served by PSS between 2010 and 2100 are connected to PSS with primary,
323 secondary or tertiary treatment an additional TP discharge to the catchment of 3.36,
324 1.68 or 0.67 t TP yr⁻¹ is expected, respectively (Figure 10). Using the average
325 median TP discharge concentration from PSS sampled an increase of 3.12 t TP yr⁻¹
326 is estimated, with a range of 1.78 to 4.94 t TP yr⁻¹ (based on the 5th and 95th
327 percentile) (Figure 4).

328

329 **4. Discussion**

330 *4.1. Variation in P concentrations in PSS*

331 No significant difference in TP concentration was observed between PSS or between
332 treatment types of PSS in this study. The median TP concentration of all samples
333 (9.28 mg l⁻¹) most closely resembled concentrations expected from PSS with primary
334 treatment (10mg l⁻¹) under the 125% rule assumptions (Loch Leven Special
335 Protection Area and Ramsar Site, 2011; SEPA, 2011). These results indicate that
336 secondary and tertiary treatments do not significantly reduce TP concentration in the
337 sampled tanks, suggesting that the assumptions used in the 125% rule may not
338 reflect reality.

339

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

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

356

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

377

378 *4.2. Relative contribution of PSS to catchment P load*

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

395

396 *4.3 Implications for local policy development and implementation*

397 The 125% rule invokes 'The Precautionary Principle' (Commission of the European
398 Communities, 2000; European Union, 2010) allowing rapid preventative decision-
399 taking in the face of possible threat to the environment where scientific data does not
400 allow full risk assessment, and carries a 'polluter must pay' policy. The use of a
401 '125%' reduction offers a buffer against a net increase of P to the catchment from
402 development where data are lacking, acknowledging uncertainty in estimation of

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

410

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

422

423 The 125% rule aims to ensure that new developments do not increase P load to the
424 catchment (Loch Leven Special Protection Area and Ramsar Site, 2011). Although
425 Wakida and Lerner (2002) observed greater transfers of nitrates as a result of soil
426 disruption during housing construction (65 kg ha^{-1}) than ploughing temporary
427 grassland (50 kg ha^{-1}) (Cameron and Wild, 1984), little or no research has

428 addressed equivalent P losses (Lubliner, 2007). Other potential P sources
429 associated with development (non-PSS associated) may also need to be assessed,
430 such as garden fertiliser, car washing detergents and domestic livestock waste.

431

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

433

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

442

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

445

446 *4.4. Implications for wider policy development and implementation*

447 In terms of wider policy development there is a well recognised lack of information
448 surrounding PSS, such as number, location, age, condition, efficiency, maintenance
449 and frequency of desludging of PSS, downstream processing of P in soils,
450 hydrological variation and proximity of watercourses at a site level, and the impacts
451 of human domestic behaviour on P loading (Harper, 1992; Withers et al., 2012).

452 Without such information, estimation of the relative contribution PSS make to

453 catchment TP loads will suffer potential inaccuracies whilst policy aiming to reduce
454 such contributions may misrepresent the problem and the solution. Where data are
455 limited and problems are complex, normal planning and policy making processes
456 may not be equipped to offer timely intervention. Reducing P output with expensive
457 engineering solutions (treating the effects of the problem) may be less effective than
458 reducing domestic P inputs to PSS in the first place (reducing the causes of the
459 problem). Detergent P forms between 9% and 50% of P in wastewater (Morse et al.,
460 1993). Sale of detergents with more than 0.5% P is banned in sixteen states in the
461 U.S. due to the risks they pose to freshwaters (Lusk et al., 2011), resulting in a
462 reduction of P in wastewaters by 40-50% (U.S. Environmental Protection Agency,
463 2002). In June 2013, similar bans in the E.U. will prohibit sale of consumer laundry
464 detergents that provide ≥ 0.5 g P per standard dosage and bans on sale of
465 dishwasher detergents with ≥ 0.3 g P per standard dosage in 2017; (European
466 Commission, 2011). Use of low P detergents and reductions in the volume of
467 detergents used will reduce P entering PSS, in the UK this could potentially offer a <
468 28% reduction of wastewater P (Comber et al., 2012) and is a positive step towards
469 reducing our human P footprint.

470

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

477

478 **5. Conclusions**

479

- 480 • The range of TP, SURP and PP in all seven PSS sampled were 1.91 to 18.01
481 mg l⁻¹, 0.04 to 6.14 mg l⁻¹ and 0.23 to 16.13 mg l⁻¹, respectively.
- 482 • No significant differences in TP concentration between PSS with primary,
483 secondary or tertiary treatment were observed in the PSS sampled in this
484 study.
- 485 • Our results indicate that PSS treatment type may not be an accurate indicator
486 of TP discharge.
- 487 • Policy changes should be made to encourage efficient and routine monitoring
488 of all PSS.
- 489 • The importance of human domestic behaviour and tank treatment type and
490 design should be combined to assess the drivers of variability in the quantity
491 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







