Overview of Source Load Apportionment Model (SLAM)

Merged Final Report

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Contents

1 Background

This report will describe EPA's Source Load Apportionment Mode (SLAM) in broad terms and summarise how it has been used for catchment modelling in NI. The SLAM itself is essentially a GIS framework for estimating point source and diffuse nutrients loads and therefore carry out source load apportionment. It is not a "model" in the conventional sense of a dynamic model where the user sets up scenarios that simulate several years of observed data. It only provides a single estimate based on the different source loads that are provided by the user. The SLAM framework was tested under NI conditions in the CatchmentCARE project. To date only the Phosphorus (P) component of the model (termed the Catchment Characteristic Tool (CCT)) CCT-P has been implemented on the cross-border Blackwater and Arney catchments, and is the focus of this report. It should be noted that the EPA have included nitrogen (N) in the SLAM for use in their CCT-N component.

A full description of the SLAM methodology is summarised in "Report 3" of the EPA Pathways Project (Packham et al., 2014) and EPA Report 249 on "Catchment Management Support Tools" (Mockler & Bruen, 2018). More information can also be found in Deakin et al. 2016; Mockler et al. 2016; Mockler et al. 2017) and a more detailed technical report is also available from CatchmentCARE project archive.

The model structure is shown below in Fig. 1

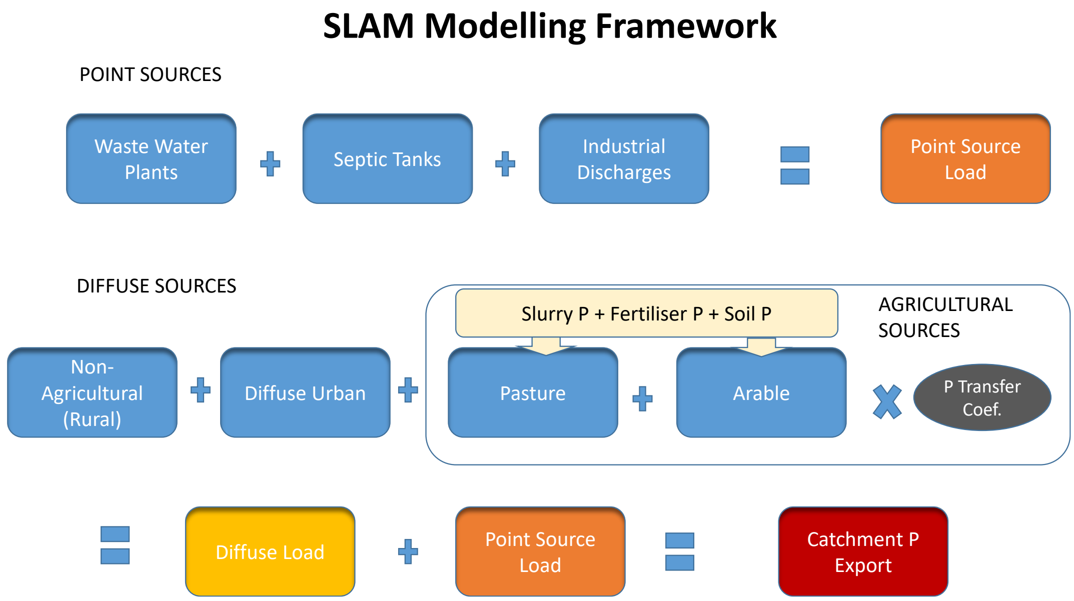


Figure 1 Diagram of SLAM framework

1.1. CCT and SLAM

In terms of the history, the Catchment Characterisation Tool (CCT) (Packham et al., 2014) was incorporated into the diffuse Nitrogen (N) and Phosphorus (P) model component of the SLAM framework with a few minor modifications (Deakin et al. 2016, Mockler et al. 2016. Mockler & Bruen, 2018). The CCT was developed first under the Pathways Project (2007-2013), originally as a GIS-based risk assessment tool to identify CSAs in catchments (Packham et al, 2014). The part of the CCT used here is the algorithm to calculate N and P loadings for diffuse agricultural and non-agricultural land uses.

The following sections will describe SLAM (the model described by Mockler & Bruen (2018)) and work through the different components of the loads (focussing on P). As of writing the CCT module within SLAM is undergoing a further revision and upgrade on the EPA/UCD Diffuse Tools Project (http://cwrr.ucd.ie/diffusetools-project/) with the objectives of (i) developing a field-scale risk assessment tool that can map critical source areas for mobilisation and delivery of P into watercourses at a much finer spatial resolution (5 m or less), (Thomas et al., 2020, 2016) (ii) producing a SLAM v3 with an updated diffuse N loading model (based on the *Ncycle IRL* model for grassland and using equations from *NLEAP* for arable, which were used in SLAM v2) and a diffuse P loading model based on existing Pathways factors from the current PIP (Phosphorus Impact Potential) maps (Mockler *pers. comm,* 2020).

The SANICOSE (Source Apportionment of Nutrients in Irish Catchments for On-Site Effluent) model (Gill & Mockler, 2016) is a septic tank risk assessment tool developed by the EPA under a research contract involving a research data set collected from different septic tank systems and contains three pathways for transfer of nutrients from the septic tanks to watercourses and groundwater. It forms one of the point source modules of the SLAM. A more detailed description of the SANICOSE model can be found in Gill and Mockler (2016), which is summarised in Mockler and Bruen (2018).

2 Overview of the SLAM

The SLAM is constructed around a GIS framework which requires several data layers, the most important of which relate to land use (e.g. CORINE or CEH Land Cover), soil types (AFBI), spatially distributed agricultural input loads, and the locations of any point sources in the catchment (Table 1). These feed into different sub-models that relate land use (diffuse loads) or point sources to the N and P output loads accounting for any natural attenuation or treatment to remove N and P. The structure is extremely flexible so that more or less detail on a particular load or flow pathway can be included as required. These output loads are calculated for a pre-defined area in space, e.g. a subcatchment; then they can then be converted into nutrient concentrations and assigned to a number of different flow pathways. In this report, the model is applied at the Water Management Unit (WMU) (or sub-catchment) scale (i.e. 10-50 km^2), with the input data aggregated up to this scale (i.e. the dominant soil types were identified across each sub-catchment). This was done for all data except for land use where it was important to retain the breakdown of percentages of different land use in each sub-catchment in the model, as there are quite significant differences in nutrient loads from different land uses (Table 2).

A version of SLAM using 25 x 25m gridded data has been evaluated in a sub-catchment of the Blackwater and this provides more detailed maps of local “hotspots” of high P loads in the sub-catchments. Hence, the gridded SLAM results show the user where combinations of soils and land uses are locally having an impact on P loading rates. The EPA have also used a GIS – based approach when using SLAM to evaluate diffuse loads in the Irish catchments, e.g. Mattock which is similar to this. The equations and methods used in the gridded version are identical to the sub-catchment version described below.

3 Diffuse Sources Component: Loads

3.1 SLAM Calculations of diffuse P loading: Agricultural Land

SLAM uses a set of equations to calculate a diffuse nutrient loading for two different agricultural land uses (pasture and arable), the example shown here is for P but N is modelled in a similar way. In SLAM, the available agricultural P load is first calculated, which is the sum of the input loads of soil, slurry and chemical fertiliser P if these data are available, this originates from the CCT (Packham et al., 2016).

$$AgPLoad(LU) = slurryP \times f(LU) + (SoilP(LU) + FertP(LU)) \times Area(LU) \qquad (1)$$

Where *LU* is either arable or grassland, *slurryP* is the sub-catchment slurry P load, *f(LU)* the areal fraction of the land use, *SoilP* the mean Olsen P and *FertP* the annual mean fertiliser P application rate (kg P/ha) for the land use (Values shown in Table 1 below). It is calculated using Eq. (1) for each of the two diffuse agricultural land uses (arable and grassland) and the two loads are added together to calculate the total load from within the sub-catchment.

SLAM calculates the diffuse P exported from the *AgPLoad* using a "Soil Transfer Factor" (*STF*) and then partitions this load into a near-surface and a groundwater load, then the P load exported to the watercourse from each flow pathway is calculated using "reduction factors" α and β (Eq. 2). Further explain is given on these factors in section 3.2 below.

The resulting equation for diffuse P load *DiffAgri* is shown below (2)

$$DiffAgri = AgPLoad \times STF \times [(1-BFI) \times \alpha) + (BFI \times \beta)] \quad (2)$$

Where α and β are P transport coefficients, *STF* is the Soil Transfer Factor and *BFI* is the Base Flow Index (described below).

The input data layers required, to make the P load calculations in (1) and (2) are shown in Table 1 below. Two options are shown, one spatially varying using NI spatial data, and one using non-varying values (i.e. a single value for each sub-catchment).

The data layers and values used by the EPA (Mockler and Bruen, 2018) are also shown. These options give the user some flexibility in their approach to modelling nutrient loads. It can be tailored to data availability, for example if fertiliser and slurry P data are not available for a particular region then the EPA's maximum application rate data can be used instead. However, the drawbacks with using the EPA method are that (i) when looking at mitigation scenarios there are only two P loads to manipulate in order to reduce the overall loads in the catchments (i.e. Soil P and combined Slurry + Fertiliser P); and (ii) the values are defined for two land uses only and cannot be varied in space across a subcatchment.

Table 1 Data Sources for SLAM Model from EPA and NI

P Source Load	EPA Data Layers	Non-varying (NI) Data	Spatial Data (NI)	Source
Slurry P	Maximum P Application rate assigned by crop type or grassland intensity. Typically Arable - 25 kg/ha	Same values used as EPA data.	Data derived from NI Farm Census data can be used relating to livestock numbers. Some	Mockler and Bruen, (2018) NI Census from 2011

	Grass - 21 kg/ha		caveats on how this is distributed to townlands.	
Soil P	Index 3 Morgan's P values used, As Olsen P : Arable - 29.7 mg/kg Grass - 25.3 mg/kg	1. Same values used as EPA data. *or* 2. Mean (e.g. EAA) value can be used (26.5 mg/kg)	Data from EAA scheme can be used, or any Olsen soil test P data for the catchment	Mockler and Bruen, (2018) AFBI data
Fertiliser P	EPA method includes this in the maximum P application rate.	Mean NI values used: Arable: 17 kgP ha[1] Grassland:4 kgP ha[1] *or* combine with slurry P	Not available so data in "*Non-varying*" column used	Mockler and Bruen, (2018) AFBI data (relating to historical fertiliser usage)[1]

[1] from Bailey and Frost (2015)

Spatial data can be provided down to 25 x 25m grid resolution or aggregated to WMU (sub-catchment) scale (see above). A hybrid approach was used in the model application to the Blackwater and Arney catchments, where the land use percentages in each sub-catchment were retained so that the SLAM model calculated the diffuse P load from each land use in it, and summed these up to obtain the total P load, rather than just from the dominant land use (which would always have been pasture in all of the 50+ Blackwater sub-catchments).

Nitrogen application rates for different land use relating to fertiliser N applications are also available in Mockler and Bruen (2018). The EPA SLAM used a single value representing the maximum application rate that includes the combined N input load from slurry and fertiliser which varies by crop type (e.g. grassland and winter wheat) which was then fed into a N leaching model to calculate the available N that will form the load that is routed through the SLAM, using reduction factors for each flow pathway similar to those used for P (see 3.2 below). Different N leaching models were specified for pasture and arable land uses to further complicate matters.

3.2 Soils Related data

The following parameters introduced in Eq. 2 above relate to the soil properties in the catchment and are taken from EPA sources (Mockler and Bruen, 2018) unless modified for NI as described below.

i) P transport coefficients α and β: These parameters control the partitioning of P fluxes between the near surface and groundwater flow pathways respectively. Parameter α is a parameter that can be increased or decreased depending on how well drained or not the soils are, and is the most sensitive parameter as it controls the amount of P transported in near surface flow pathway. Its value varies by soil texture, i.e. how well drained the soil is. Parameter β varies according to the depth to bedrock except in peat soils and where the bedrock is karstic.

ii) Baseflow Index (*BFI)* is also available from the NI HOST soil classification, with a higher *BFI* meaning that more P is potentially transported by the groundwater flow pathway than the near surface flow pathway and vice-versa with a low value.

iii) The soil transport factor (*STF*) was assigned an value of 0.01 by EPA. However, no rationale for the use of the value is provided in EPA Report 249 (Mockler and Bruen, 2018), but the explanation was given as "*The factors of 1% of total P and 1% of soil P were settled on following the literature review and any steering committee debates*." (Mockler, *pers comm*, 2019). For the Blackwater simulations this value was found to be too low so an increased value of 0.067 was used instead based on a test application of SLAM on the Upper Bann sub-catchments, this modification effectively increased the total diffuse P load by nearly seven times.

A similar approach would be used in SLAM for N, however additional parameters relating to how N is leached through the soil need to be supplied for the model, which are based on subsoil permeability, and there is also the potential to attenuate nitrate in the groundwater flow pathway and remove it through denitrification with a bedrock attenuation coefficient (Ref *Section 6* in Mockler and Bruen (2018)). These have not yet been investigated or validated for NI conditions as (currently) a separate leaching model is required for pasture (e.g *Ncycle IRL*).

3.3. SLAM Calculations of diffuse P loading: Non-Agricultural Land

For the non-agricultural part of the catchment SLAM uses a simpler export coefficient method, where the load of N and P is calculated by multiplying the area of a particular land use by the export coefficient. For NI, the values of the coefficients for different land uses were obtained from earlier studies including work by Jordan (1997) and Jordan et al. (2000) (for P) and are shown below in Table 2:

Table 2 Breakdown of Export Coefficients Used for Non-Agricultural Land

Name of Land Use	**CEH LU 2015**	**CORINE Land Use**	**SLAM (LU)**	**Export Coeff. (kg N /ha/year)**	**Export Coeff. (kg P /ha/year)**
Broadleaf Forest	1	311,313[2]	1	5.42	0.33
Coniferous Forest	2	312	1	5.42	0.33
Grassland, heather, rough grazing etc. (non-agricultural)	5-7, 9-12	412	6	2	0.2
Marsh, Fen	8	411	5	2	0.325
Freshwater (i.e. Lakes)	14	512	7	9.4	0.5
Urban	20	111[3]	8	5	1.4
Suburban	21	112[3]	9	5	0.86
Forest (transitional)[1]	N/A	324	2	3.71	0.57

[1] This is a CORINE land use that EPA classified as having a higher P export than broadleaf or coniferous forest. There is no CEH LU2015 equivalent for the UK.

[2] This is classed in CORINE as “mixed” forest. There is no CEH LU2015 equivalent for the UK.

[3] There are additional urban land uses in CORINE but only the most dominant ones that correspond to CEH LU2015 land cover types found in the Blackwater are shown here for clarity.

The retention of P by lakes over 50 ha in area in a sub-catchment is also simulated by the SLAM model using a simple relationship that assumes that a fixed fraction of the annual P load from the sub-catchment containing the lake is retained each year, where L_{point} and $L_{diffuse}$ are the point and diffuse loads respectively.

$$L_{out} = (L_{point} + L_{Diffuse}) \times (1 - LAKE). \quad (3)$$

LAKE= estimated nutrient lake retention factor (0.24 for P) from a study of the Lee catchment.

The export coefficient values for “Freshwater” in Table 2 therefore represent atmospheric deposition rates only and do not account for any mobilisation of nutrients within the lake itself.

3.4 Point Source Load Component

Point sources are divided into four categories in SLAM and simple equations used to calculate the total point source load by multiplying the loading of P by a population figure. The methods also account for retention or removal by processes in the treatment plant or tank:

- Urban and Rural WWTP
- Septic tanks (both NIEA consented (i.e. licenced to discharge directly into watercourses under permitted constraints) and non-consented)
- Industrial Point sources (currently not included in the NI model).
- Untreated sewerage, this would include storm water overflows/CSOs (not included in the UK Blackwater or Arney models).

The point source component that has been tested in NI is much simpler than the module incorporated in EPA's SLAM framework mostly due to data availability for the CatchmentCARE project.

If consented annual N and P loads are not available for the WWTPs, as is the case in the CatchmentCARE project for the NI Blackwater, then a method based on the loading of N and P per capita is used to calculate the total point loads. The population connected to the WWTPs (Pop_{Sew}) in the catchment was obtained from NIEA, as a "PE" (Population Equivalent) which includes the loading of any industrial wastewater discharges routed through the plants for treatment. The population in a 1km radius buffer zone surrounding each plant was also estimated using the 2011 Census data and GIS. This method allows the population not connected to the mains sewer to be estimated which is required for the septic tank loading to be calculated (see below).

The values used for the per capita P export is open to modification depending on data availability, as is the WWTP's removal efficiency which depends on the level of tertiary treatment used at the plant. The figures taken from Mockler and Bruen (2018) are:

P_{sew} (Sewered P load) =0.73 kg TP/capita/year (source: *the international guidance value reported in OSPAR (2004) cited in* Mockler and Bruen (2018)). Earlier studies in NI reported the annual P loads of large WWTPs discharging into Lough Neagh (Foy et al., 1995) however these were calculated from actual (measured) discharge volumes multiplied by the (measured or assumed) TP concentration in wastewater.

WWTP treated P removal efficiency (WRE) (= 62%), this states that 62% of the P loading can be removed by the tertiary treatment at the plant. Mockler and Bruen (2018) cautioned that these figures are under review (as of publication of the Pathways report). For smaller WWTPs (i.e. only providing primary and secondary treatment), Foy et al. (2003) used a removal efficiency of only 10% which was probably appropriate for older primary treatment works.

The above data are used to calculate the WWTP point source load L_{sew}:

$$L_{sew} = P_{sew} \times (1 - WRE/100) \times Pop_{Sew} \quad (3)$$

Using the census data the remaining population not connected to wastewater treatment plants can be calculated (Pop_{Sep}). This gives the population in the catchment connected to septic systems. The census will also give us the number of households in the catchment (an assumption on typical household size needs to be made to convert from the total population to the number of connected households on septic systems N_{hsep}). For P, for example the following values are used to calculate the point source loads from septic tanks (L_{sep}), also taken from Mockler and Bruen (2018), who obtained the mean values from the SANICOSE model (Gill and Mockler, 2016).

P_{dwel} (Dwelling P load) =1.9 kg P/household/year

$$L_{sep} = P_{dwel} \times (1 - SRE/100) \times N_{hsep} \quad (4)$$

Septic tank P retention (SRE) = 95%, this suggests that 95% of the P loading either remains in the tank or is removed by tanker without discharging to watercourses either as a licenced or unlicensed discharge (including leaks). This value was obtained from an average of the SANICOSE model results for Irish catchments (Gill and Mockler, 2016). It is open to adjustment for local conditions or to be included in a sensitivity analysis. An earlier study in NI (Foy at al., 2003) referred to a “connectivity factor” of 58% which was based on the ratio of rural to urban per capita SRP and suggested that just under half of the human P loading was retained by the septic systems in use in the late 1990s with 58% discharging into watercourses. Multiplying their per capita P loading by this factor would give a corresponding dwelling P load (assuming 4 persons per dwelling) of approximately 1.7 kg P/household/year.

3.5 Summary

In summary, it can be seen that there is scope to make the SLAM framework more or less complicated depending on the input data available to the user, particularly the spatial data layers (GIS). The framework has the advantage of using data sets that should be readily available for an entire catchment or region allowing a large scale assessment of nutrient loads from both point and diffuse loads to be rapidly made. The SLAM equations could be programmed into ARC-GIS or other modelling frameworks (e.g. R). A single annual load (split into diffuse and point source fractions) is outputted for each sub-catchment or WMU which has an associated uncertainty that should be at least considered if not quantified.

A certain amount of manipulation of the input data is required to simplify more complex classification schemes (e.g. different data on soil types) into those needed for the modelling where the number of classes is much smaller (e.g. freely drained or waterlogged). It would also be useful to run multiple scenarios with different input parameters or loads, for example to examine differences between artificially drained and undrained agricultural soils and different P removal efficiencies from WWTPs and septic tank retention rates.

4 Application to the Blackwater Catchment

Results from the baseline SLAM run on the Blackwater catchment are shown below:

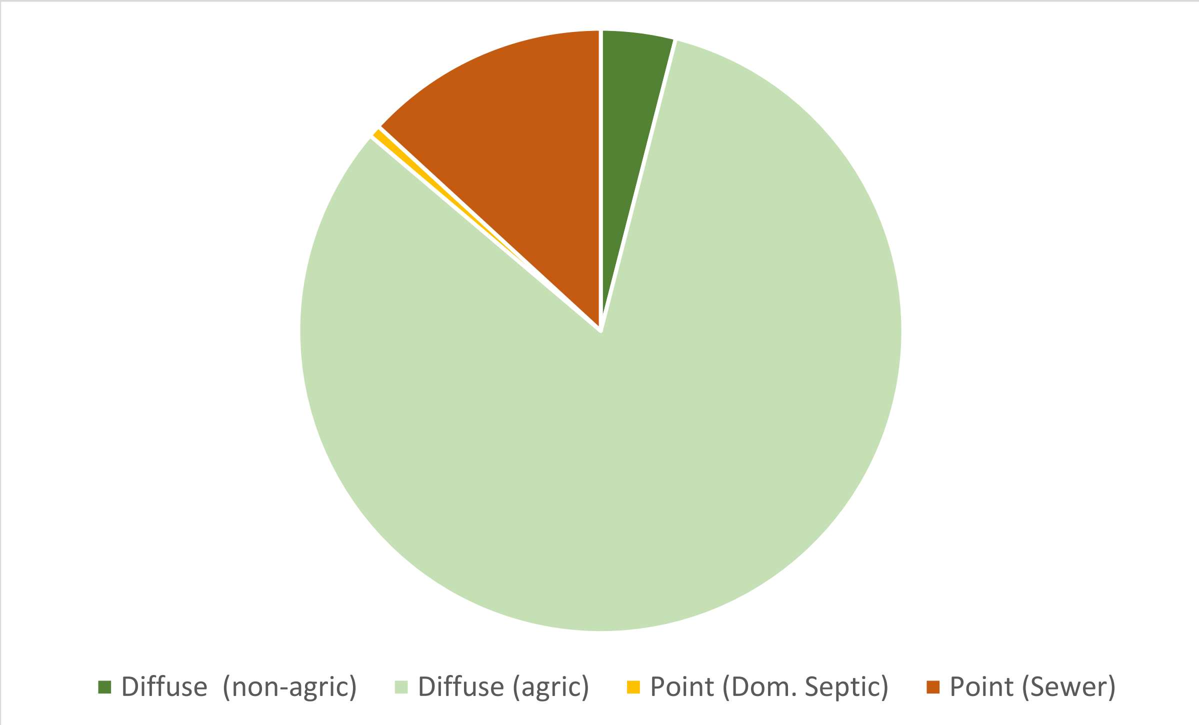


Figure 2. Breakdown of Point and Diffuse sources in Blackwater (NI part) catchment

Figure 2 above shows the percentage of different sources of P loading broken down into diffuse and non-diffuse (point) sources, for the UK portion of the Blackwater catchment, and then into non-agricultural and agricultural diffuse sources, and domestic septic and sewered point sources. This type of chart comes from the SLAM modelling output. The Blackwater (in NI) is clearly dominated by diffuse agricultural (improved grassland) as the largest source of P, in total diffuse sources comprised 82% of the total P loading. The total P loading (load into watercourses) was almost 117 T/year of which point sources contributed 20.3 T/year, non-agricultural diffuse P loads were not significant.

Secondly, the user can generate spatial maps, for example Figure. 3 shows the TP load in kg P/year from the same SLAM model run on the Blackwater catchment (the combined point and diffuse load). The mean diffuse P load across the 982.6 km^2 catchment was 1.28 kg P/ha/year. Values obtained from the EPA from their SLAM model runs for the southern part of the Blackwater indicated a similar proportion of point and diffuse P loads, the total P loading from the ROI part of the catchment was 44.2 T/year from 302.3 km^2.

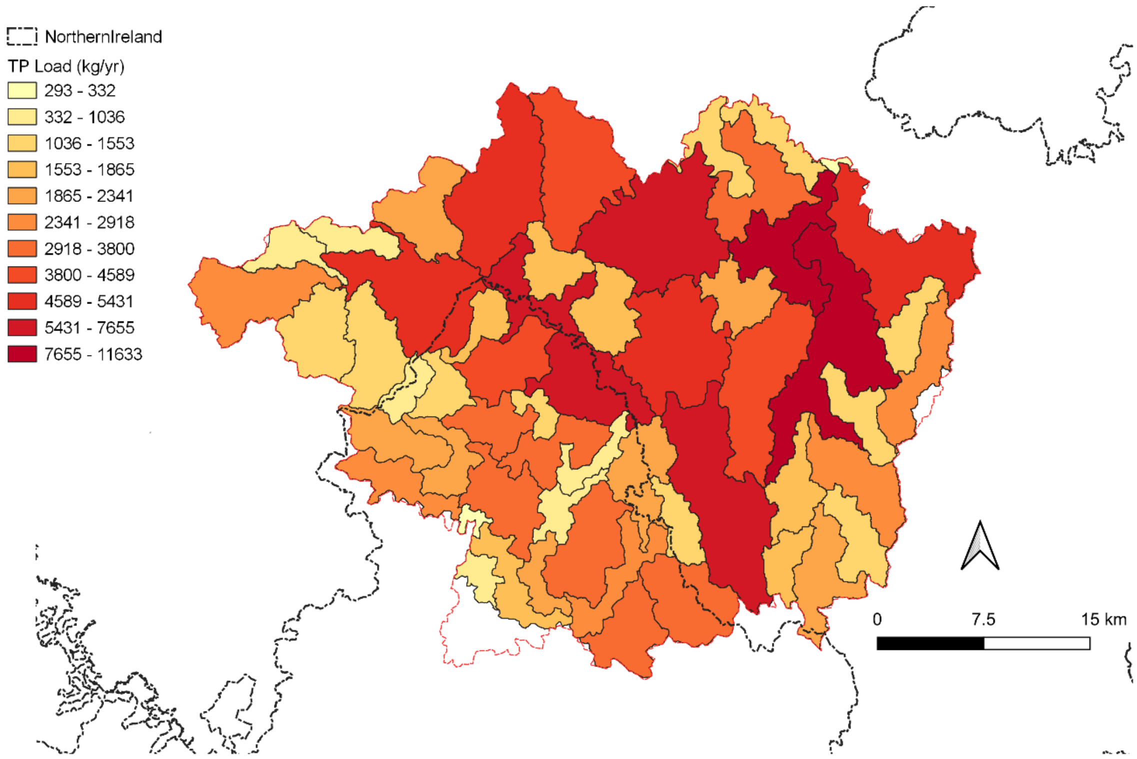


Figure 3. Predicated annual TP loads across entire Blackwater catchment (Darker colours indicate highest load of P)

The spatial unit here is a "WMU" (in NI) or sub-catchment (in the ROI), typically of 10-50 km^2. These results in Figure 3 come from a merger of the EPA and NI SLAM results for baseline conditions using CORINE land use data and with the EPA model parameters adopted in NI. A higher value of the STF parameter (0.067 vs 0.01) was used in the SLAM modelling of the NI WMUs, so a multiplier of x 6.7 was applied to the diffuse agricultural loads calculated by the EPA SLAM model to standardise the results across both parts of the catchment (based on the adjustment of the STF described in 3.2).

4.1 Load Reduction Assessment

Based on the monitoring data collected in a catchment a baseline indication of nutrient concentrations can be obtained which classify the catchment (or water body) as passing or failing a particular target status. For the Water Framework Directive (WFD) the objective for "Good" status for P is having a mean SRP concentration not exceeding a threshold that typically varies from 35 to 60 µg/L. In ROI this threshold is set at 35 µg/l (EPA, 2018) while in NI the threshold varies (dependent on the elevation and alkalinity of the waterbody (UKTAG, 2013).

For the Blackwater catchment the required load reductions to achieve this threshold can be calculated using a relatively simple approach outlined in Mockler and Bruen (2018).

The load reduction *LR* required in each WMU is calculated using the following equation (5)

$$LR = (C_{obs}-C_{target}*(1-SF)) * Q \quad (5)$$

Where $C_{obs}-C_{target}$ is the distance to threshold; *SF* is a safety factor (10%) applied to the EQS target to reduce the loads slightly below the upper limit of the target concentration. "*Q*" is the total runoff in the sub-catchment above the monitoring point which is calculated as $P_{av} – AET$, where P_{av} is the average catchment annual rainfall (obtained from CEH-GEAR data from 2005-2017; Tanguy et al., 2019) and *AET* the mean annual actual evapotranspiration (430 mm was used - from a report from the Institute of Hydrology estimating evapotranspiration for NI catchments, (IH, 1995)). The approach for internal sub-catchments (i.e. those with inflows from upstream) is slightly more complicated as the load reduction in those upstream sub-catchments needs to be removed from the total load reduction required at the downstream-most sub-catchment as it has already been removed in the headwaters.

The results of this analysis based on the observed SRP data in the Blackwater catchment are shown below in Fig. 4. The units are kg P/ha and this figure shows SRP load. The SRP loads and required load reductions were calculated from the observed data using the method outlined above.

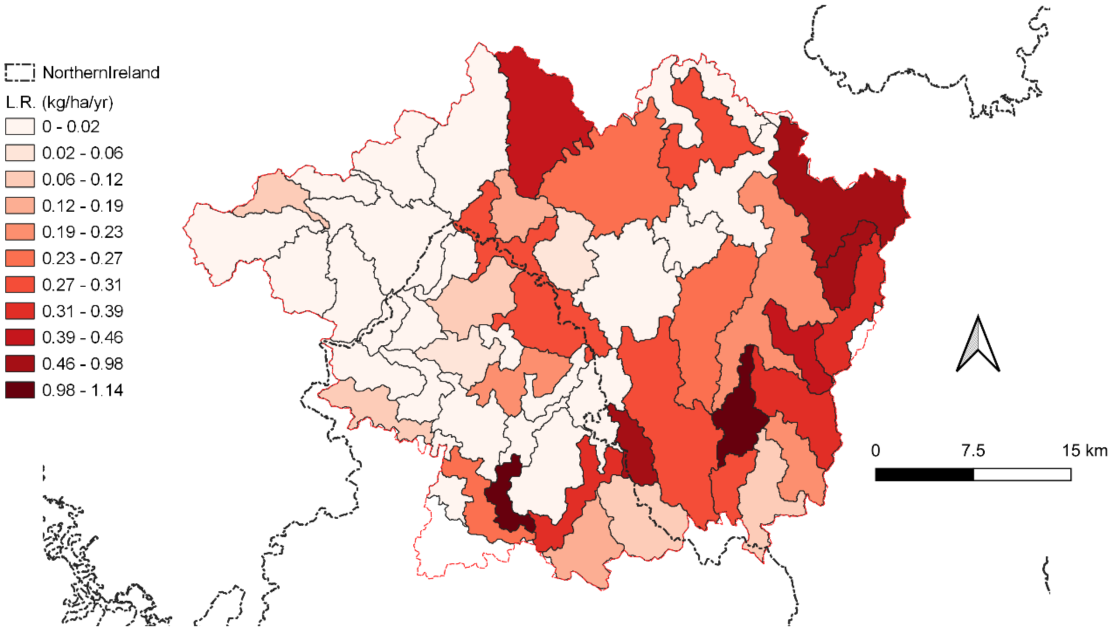


Figure 4 Load Reduction (L.R.) for Blackwater sub-catchments calculated using monitoring data (L.R. in terms of *SRP Load* shown)

5 Application of SLAM to Arney Catchment

5.1 Pressures

The varying Carboniferous age geology and the mixed land-use of the catchment exerts differing pressures on each lake (Upper and Lower Lough MacNean).

The Upper Lough catchment is dominated on the northwest shore by underlying sandstone geology and poorly drained peat with fringing wooded promontories and reed swamps. Agricultural land around this lake is mostly poorly drained, rough grazing. Pressures on the lake come mostly from under functioning septic tank systems, forestry and the 4 rivers which input the lake: Esky, Roo, Black and Lurgan.

The Lower lake has mostly limestone geology with shale to the south eastern end at the outflow to the Arney river. These well drained limestone soils are covered with mainly high quality pasture. Pressures on the Lower Lough mostly come from the waste water treatment plants at Blacklion and Belcoo, agriculture and inputs from the Drumhariff Burn which inflows from the north of the lake.

A map showing the 11 sub-catchments and the NI point sources (relative PE is indicated by the diameter of the pink circles; with Belcoo WwTW being the largest at 1578PE) is shown below (Fig. 5). The Upper and Lower Lough MacNean are the two major waterbodies in the catchment, which have Poor and Bad WFD status respectively. This is a deterioration in status for both lakes from moderate and poor respectively since 2015. Although the chemical waters status in both lakes remains good, probably as a result of the frequent flushing, both lakes are subject to a range of anthropogenic environmental pressures and are categorised as at risk under the WFD.

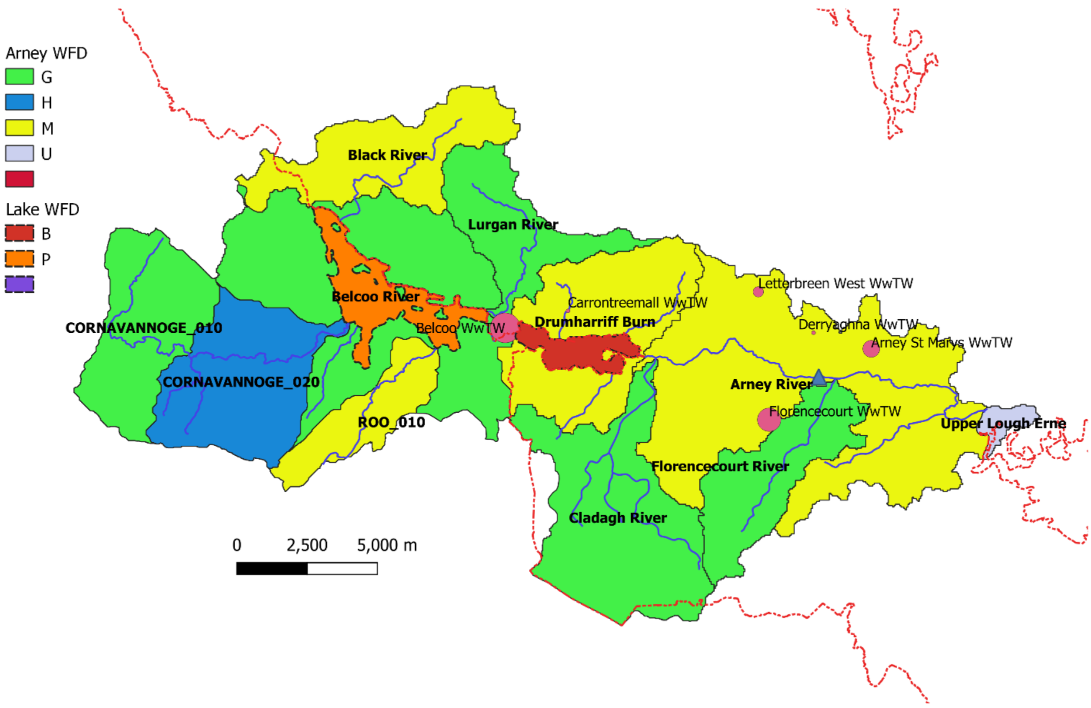


Figure 5. Arney catchment showing sub-catchments, WFD status (latest) and WwTWs (in NI only). The dashed red line is the international boundary between the RoI and NI. The blue triangle is the NI Department of Infrastructure’s flow gauging station.

5.2 Results

Results from the baseline SLAM run on the Arney catchment are shown below, the SLAM model effectively joined together results from 8 sub-catchments in the RoI or trans-border for which the EPA had compiled data, with 3 sub-catchments in NI, the EPA are acknowledged for making the SLAM results from the 8 sub-catchments available to the project.

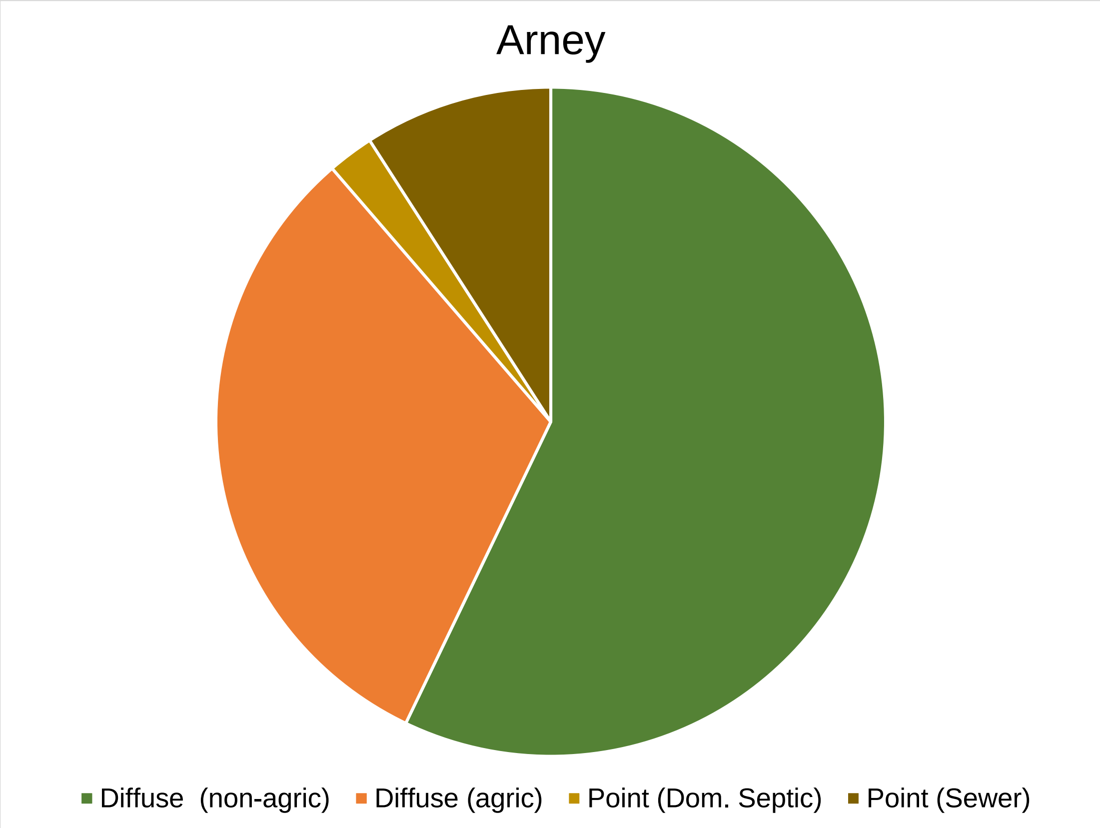


Figure 6. Breakdown of Point and Diffuse sources in Arney catchment

Figure 6 shows the percentage of different sources of P loading for the Arney catchment broken down into diffuse and non-diffuse (point) sources, and then into non-agricultural and agricultural diffuse sources, and domestic septic and WwTP point sources based on the SLAM modelling output. The Arney catchment is clearly dominated by rural non-agricultural sources as this land use is the largest source of P. In total diffuse sources comprised 88.7% of the total P loading. The total P loading (export into watercourses) was just over 9 tonnes P/year, with 1 tonnes P/year originating from point sources.

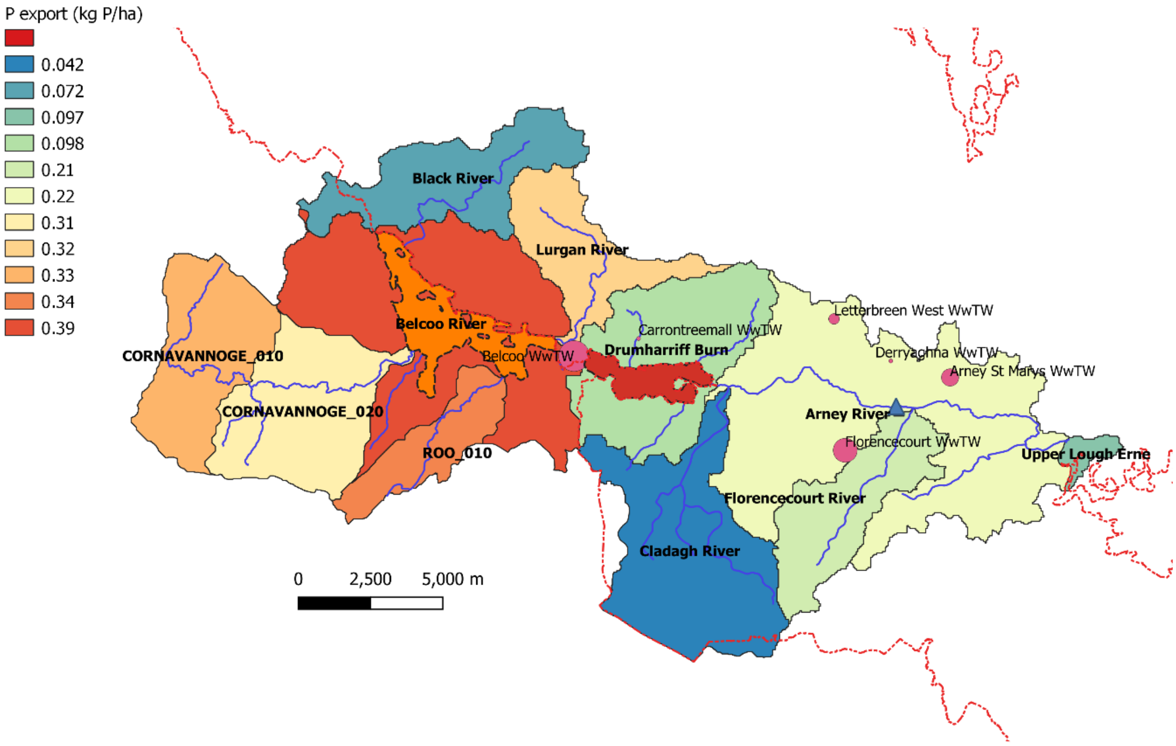
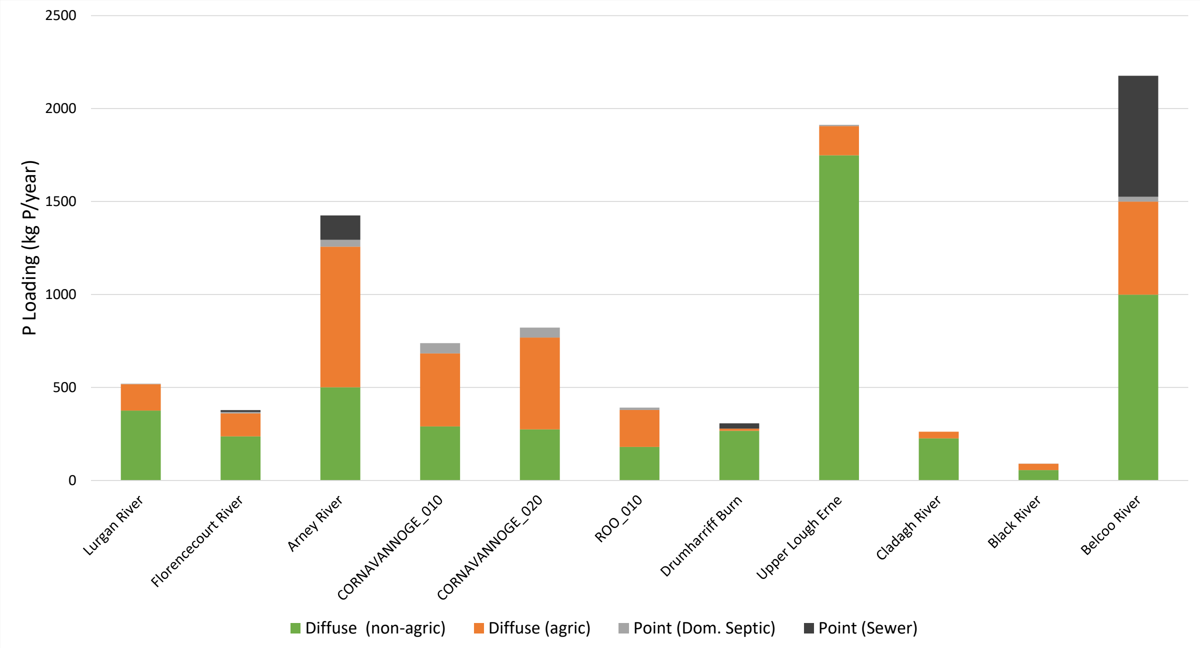


Figure 7 Map of Arney catchment showing total P export for each sub-catchment (*based on data from EPA combined with NI data*)

The results shown in Figure 7 above did not include the lake retention component which is an option to include in the SLAM framework. In overall terms the total retained by the lakes, if the component is used, was highly significant (3 tonnes P/year out of a total P load of 9 tonnes P/year). Figure 8 below therefore shows a breakdown of the point and diffuse sources in each sub-catchment, with the lake retention (from the 8 sub-catchments with downstream waterbodies) shown as a separate column.

The EPA had not included either of the two large WwTPs (Blacklion in the ROI and Belcoo in NI) in their SLAM model data for the Belcoo River sub-catchment, indicating that it had no point source loads from wastewater plants and only 26 kg P/year from septic tank systems. Combined, these two WwTPs discharged 65% (650.8 kg P/year) of the Arney catchment's point source load so they are highly significant in terms of the overall picture of P loadings in the catchment.



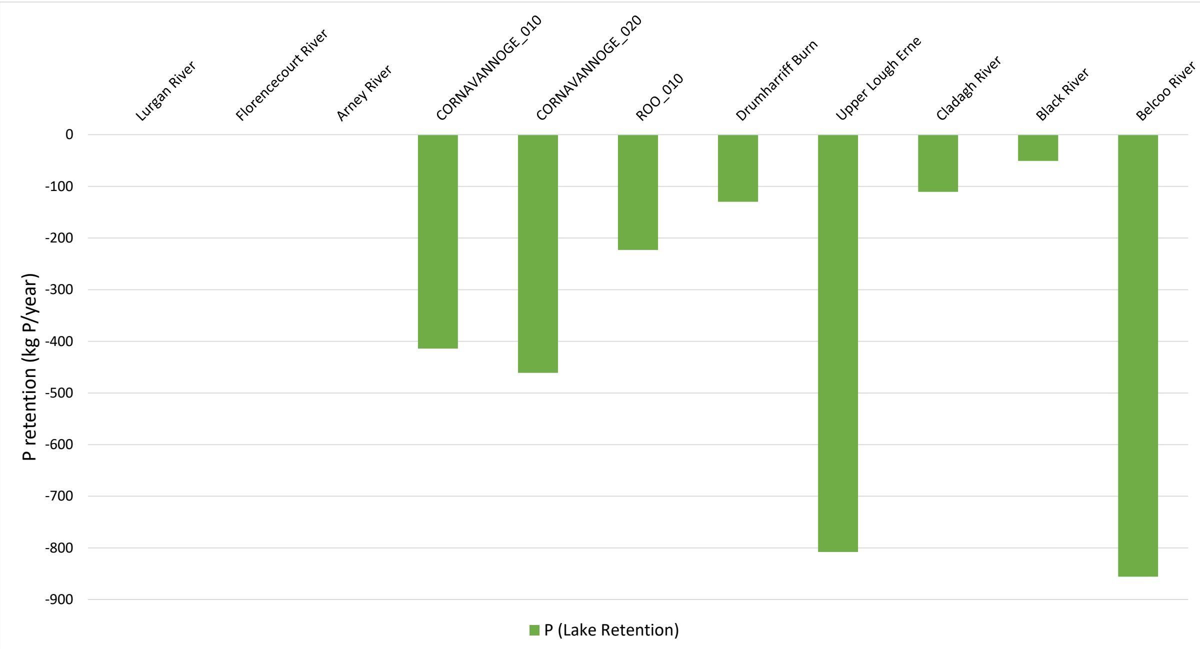


Figure 8 Breakdown of P loads by for all sub-catchments, retention by lakes shown as a separate figure. (*"Belcoo River"'s point source loads included the 2 WwTPs in this subcatchment that were identified by the project team as discharging either into the river or directly into the lower Lough)*

The total P load into the Lower Lough is 0.96 T P/year from these combined point and diffuse sources. The total load into the catchment of the Upper Lough is 4.1 T P/year, of which 3.9 T P/year comes from diffuse sources, the remainder from the domestic population's septic tanks (there are no WwTPs in the upper catchment). Therefore, the total load into the Lower Lough is 5.05 T P/year (which enters from upstream via Belcoo River plus the Drumharriff Burn sub-catchment loading). In the lower Arney catchment downstream of the Lower Lough's outlet there are no significant point sources and diffuse loads of P were also relatively small compared to the Drumharriff Burn and Belcoo River sub-catchments.

5.3 Load Reduction Calculations in the Arney Catchment

For the Arney catchment the required load reductions were calculated using the relatively simple approach outlined above for the Blackwater catchment. The results of this analysis based on the observed SRP concentration data in the Arney catchment indicated that no load reductions were required. Both the Drumharriff Burn and Belcoo River have SRP concentrations close to exceeding the "Good" status threshold which needs to be closely monitored in future.

6 Limitations and Recommendations for Future Development

The SLAM framework was developed for a very generic broad scale assessment of point and diffuse nutrient loads across the ROI by EPA. Particulate P can be a significant source of P in NI catchments (Douglas et al., 2007) and often originates from farm yards and tracks. It is not included in the current version of SLAM (Mockler and Bruen, 2018) which may account for some of the underestimation of TP in their results in catchments with a high particulate P load.

The spatial datasets used to generate the GIS layers for SLAM may or may not be present in the study area. One example is soil P status data which may be only available at a broad scale (e.g. regional to national), the model is quite sensitive to the soil P loading from arable and grassland areas so if more detailed local data are available then these can be incorporated in the model.

The SLAM framework could be extended for other nutrients and contaminants although a caveat is that seasonal and climatic factors may affect the relationship between input loads and export (for example temperature and soil moisture may affect pesticide break-down and release from soils and also the denitrification process) so careful consideration to how the model represents the transfer of the pollutant from source (e.g. farmyard) to receptor is required if the model is to work well on an annual timestep. Having a simplified N model which does not require an additional model to be used outside of SLAM would be beneficial (one approach is to generate a look-up matrix of N leaching loadings under different stocking densities and soil types to replace NCYCLE-IRL altogether).

The SANICOSE modelling framework could be applied to calculate point source loadings from domestic on-site effluent systems (i.e. septic tanks or domestic WWTPs such as sand filters, reed beds etc.) in catchments providing the necessary data are available. SANICOSE requires a GIS layer showing each septic tank or DWTS location in the catchment which could be obtained from NIEA or NI Water. It calculates the N and P loadings along 3 flow pathways into surface watercourses and groundwater, which then forms one of the source loads in the SLAM model.

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