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WHAT ARE THE MAIN SOURCES OF NUTRIENT INPUTS TO IRELAND'S AQUATIC ENVIRONMENT?

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Abstract

Where rivers and lakes are impacted by excess nutrients, we need to understand the sources of those nutrients before mitigation measures can be selected. In these areas, modelling can be used in conjunction with knowledge from local authorities and information gained from investigative assessments to identify significant pressures that contribute excessive nutrients to surface waters. Where surface waters are impacted by excess nutrients, understanding the sources of those nutrients is key to the development of effective, targeted mitigation measures. In Ireland, nutrient emissions are the main reason that surface waters are not achieving the required Good Status, as defined by the Water Framework Directive (WFD). A model has been developed in order to predict the sources of nutrients contributing to these emissions and to assess future pressures and the likely effectiveness of targeted mitigation scenarios. This Source Load Apportionment Model (SLAM) supports catchment managers by providing scientifically robust evidence to back-up decision-making in relation to reducing nutrient pollution. The SLAM is a source-oriented model that calculates the nitrogen and phosphorus exported from each sector (e.g. pasture, forestry, wastewater discharges) that contribute to nutrient loads in a river. Model output is presented as maps and tables showing the proportions of nutrient emissions to water attributed to each sector in each sub-catchment. The EPA has incorporated these model results into the multiple lines of evidence used for the WFD characterisation process for Irish catchments.

INTRODUCTION

Nutrient enrichment and eutrophication can negatively impact on freshwater ecosystems, and estuarine and coastal waters. In Europe, agriculture is typically the principal source of nitrogen in water bodies, whereas for phosphorus, households and industries tend to be the dominant contributors (Bøgestrand *et al.*, 2005).

Modelling can support catchment management by synthesising large amounts of information in order to focus resources when tackling environmental issues. Nutrient source apportionment modelling is used to estimate the nutrient load from various sectors entering water bodies, following attenuation or treatment. Different modelling approaches are available depending on the required purpose. For example, where high-resolution in-stream monitoring data are available, a load-orientated approach can be used to apportion measured loads to either point or diffuse sources based on temporal patterns typically assuming relatively constant inputs from point sources (e.g. Greene *et al.*, 2011). Conversely, source-orientated approaches calculate emissions based on emissions source information. This includes annual reported emissions from point discharges from wastewater and industry, and for diffuse sources, data on stocking densities combined with export coefficients based on the catchments hydrogeological characteristics (e.g. Jordan and Smith 2005; Smith *et al.*, 2005). The Source Load Apportionment Model (SLAM) (Mockler *et al.*,

2016) takes the latter approach, enabling estimates of the relative contribution of sources of nitrogen (N) and phosphorus (P) to surface waters in catchments without in-stream monitoring data.

The SLAM framework was developed to support the proportional and pragmatic assessment of every sub-catchment in Ireland within the national WFD characterisation process framework (Daly *et al.*, 2016). These assessments aimed to determine which of the multitude of potential pressures within a water body are significant, so that measures can be more efficiently and specifically targeted to achieve water quality improvements. The source apportionment results were considered alongside a suite of national datasets, including ecological status and trends in ecological and chemical monitoring data; information on land use, pressures, pathways and sensitivity of receptors; enforcement, audit and inspection information from regulatory agencies; and local, on-the-ground knowledge from the Local Authorities and Fisheries agency staff (Daly *et al.*, 2016). This systems-approach is vital for integrated catchment management and effective WFD implementation (Voulvoulis *et al.*, 2017).

Due to improvements in nutrient management and regulation, there have been notable reductions in total phosphorus, total ammonia and total nitrogen emissions from many Irish catchments since a peak around the mid-1990s (O'Boyle *et al.*, 2016). As regulation of point discharges continues to reduce emissions, other sources of nutrients may start to control water quality in these areas. By developing the SLAM framework, the EPA-funded *CatchmentTools* Project aimed to quantify the sources of phosphorus (P) and nitrogen (N) emissions in Irish rivers in order to support the identification of potential pressures resulting in eutrophication. The SLAM has been used for characterising existing and previous state of the water environment, including;

- Assessing the current sources of nutrient emissions to Irelands water bodies, and
- Evaluating changes in sources of nutrient emissions in recent decades.

The SLAM framework also provides capabilities for scenario analyses to support integrated catchment management in Ireland, including:

- Local-scale scenario analyses to identify potential nutrient reduction options to achieve Good Status in nutrient impacted water bodies, and
- Regional-scale scenario analyses to assess the impact of future projections of land cover and land use change, population increases and wastewater treatment improvements.

This paper briefly outlines the models and data, provides an example of the model results, and identifies further areas for development.

DATA AND MODELS

THE SOURCE LOAD APPORTIONMENT MODEL (SLAM) FRAMEWORK

The SLAM Framework incorporates multiple national spatial datasets relating to nutrient emissions to surface water, including land use and physical characteristics of the sub-catchments. Separate modules were developed for each type of nutrient source to facilitate upgrading and comparisons with new data or methods (Figure 1). For example, two of the original modules have already been upgraded with output from more advanced export-coefficient based models in the current version of the framework (v 2.05). The agriculture (pasture & arable) and septic tank systems modules use spatial outputs from the Catchment Characterisation Tool (CCT) (Archbold *et al.*, 2016) and SANICOSE models (Gill and Mockler 2016), respectively. Further details of the model development and application are

available in Mockler *et al.*, (2016), and the framework structure and user interface are described in Mockler (2016).

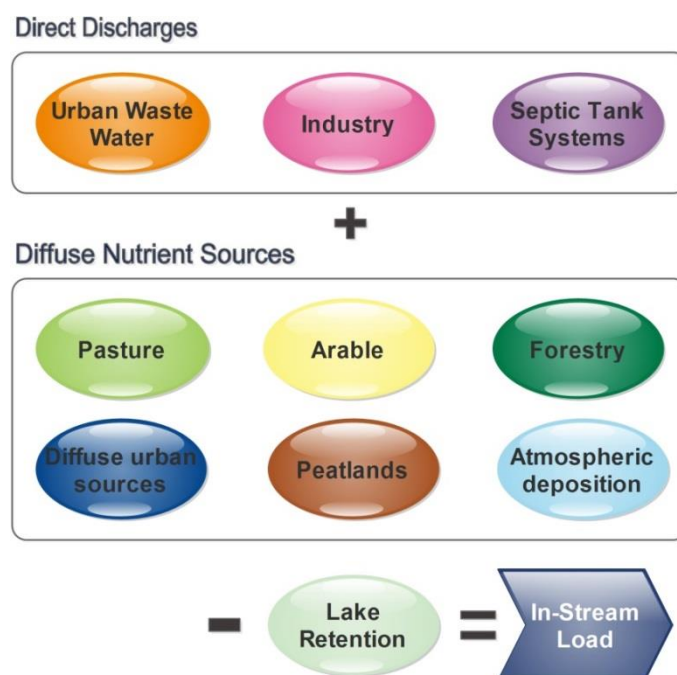


Figure 1. Sub-models of the Source Load Apportionment Model (SLAM) Framework.

The key input dataset for the agriculture module (i.e. the CCT) was the Land-Parcel Identification System (LPIS) which was combined with land management data from the Department of Agriculture, Food and the Marine (DAFM). The 2012 CORINE (Lydon and Smith, 2014) land cover data were used in the forestry, peatlands and urban sub-models. Various export coefficients were then applied in each of the modules to estimate their annual nutrient emissions to water. Loads from direct discharges were calculated from data collected by the EPA, including Annual Environmental Reports, the EPA Licensing Enforcement and Monitoring Application (LEMA), and the Pollutant Release and Transfer Register (PRTR) database.

RESULTS

LOAD APPORTIONMENT BY SECTOR: SUIR CATCHMENT

The SLAM results for the Suir catchment showed that pasture was the dominant source of nitrogen (78%), whereas pasture and wastewater discharges were equally dominant sources of phosphorus (35% each). The total catchment TP loads were biased by the large contribution from the Waterford agglomeration (33 t yr⁻¹ TP) at the mouth of the catchment, which is equivalent to 26% of the total estimated TP losses. Within the Suir catchment, there were large variations in the percentage contributions from direct discharges for phosphorus between sub-catchments (Figure 2). These ranged from 1% to 90% and reflect the population distribution in the catchment.

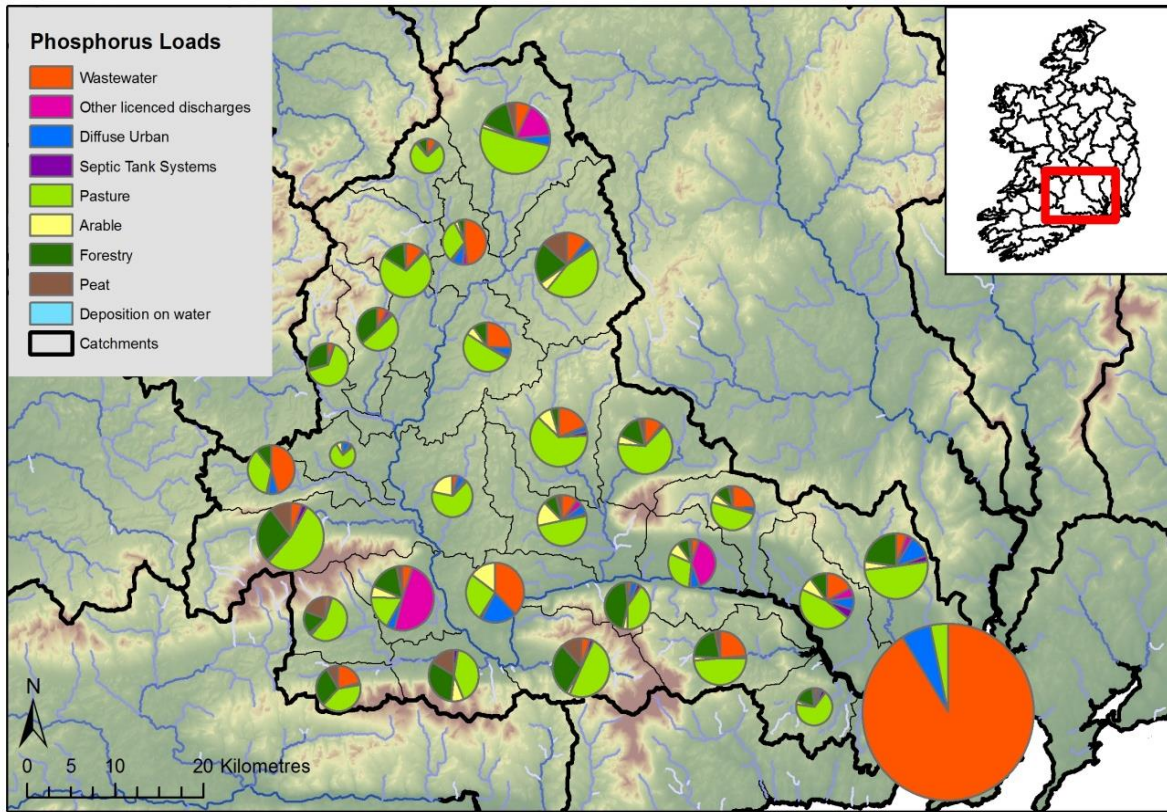


Figure 2. Phosphorus load apportionment results for the Suir catchment (size of pie indicates relative contribution of annual loads from each sub-catchment).

WHAT AND WHERE? NUTRIENTS AT NATIONAL LEVEL

The SLAM results were compared with monitoring data for 16 major river catchments covering 50% of the area of Ireland to assess the model performance prior to its extension to cover the entire country (Mockler *et al.*, submitted). These data included three years (2012 - 2014) of annual nutrient loads, calculated from flow and nutrient concentration data collected by the EPA (see O'Boyle *et al.*, 2016).

At national level, agriculture was the dominant source of N, whereas the dominant sources of P emissions varied by land use and hydrogeological setting. Further analyses with catchment characteristics confirmed that P emissions from pasture were mainly driven by hydrogeological conditions, not the magnitude of the pressure. This emphasises that phosphorus mitigation options should aim to interrupt the local source-pathway-receptor relationships.

The national load apportionment results can be used in conjunction with the WFD risk assessments to assess hot-spots for each sector. This can be used for desk-based assessments prior to, for example, detailed investigations or selection of study catchments. Figure 3 presents the estimated contributions from septic tank systems to the total annual P and N load emissions to surface waters. This information can be used to target areas that have a relatively high number of these systems in high-susceptibility settings.

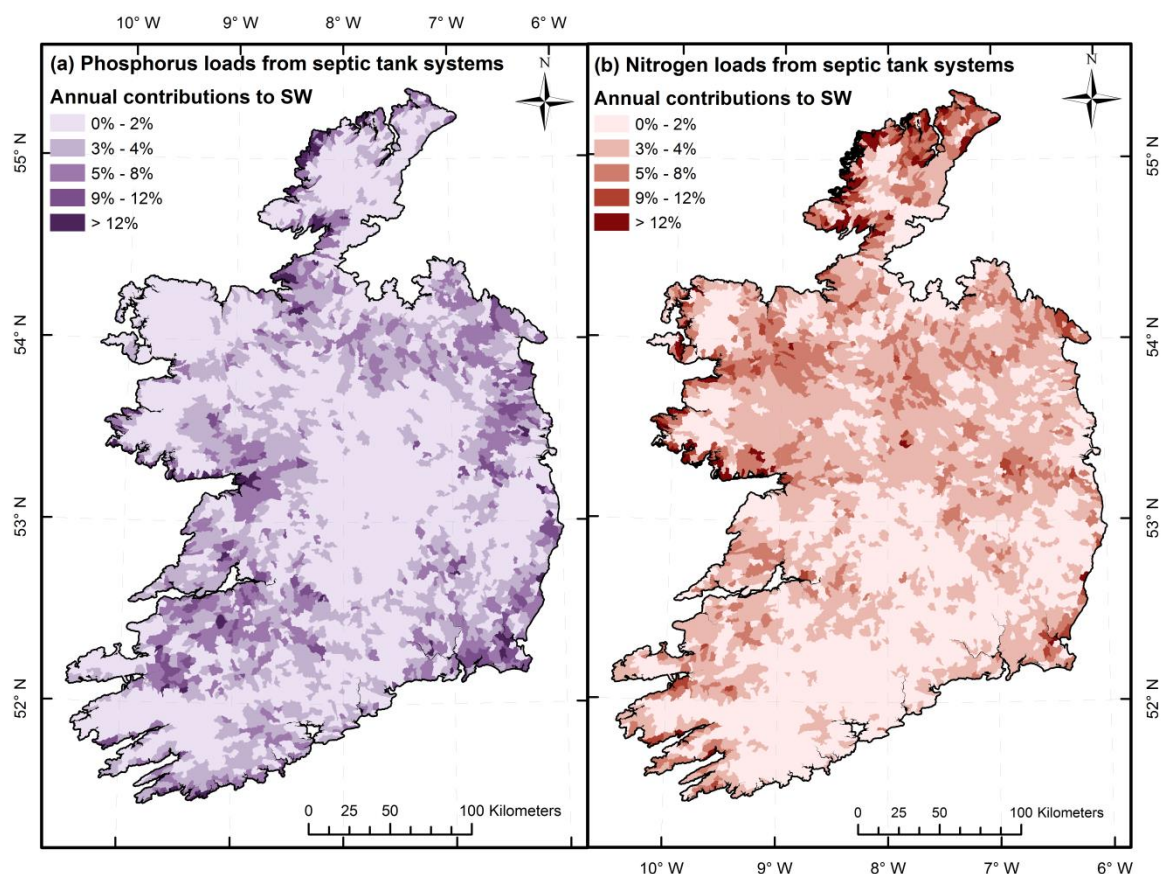


Figure 3. Modelled contribution of septic tank systems to total annual loads of (a) phosphorus and (b) nitrogen to surface water bodies in Ireland.

DISCUSSION

THE IMPORTANCE OF HYDROGEOLOGY FOR NUTRIENT MODELLING

Water mobilises and transports nutrients through the landscape and the attenuation potential varies considerably with hydrological and hydrogeological settings, and type of nutrient (Archbold *et al.*, 2016). For instance, nitrate is typically delivered to streams via subsurface pathways (Kröger *et al.*, 2007; Tesoriero *et al.*, 2009). The majority of phosphorus from diffuse sources is driven by storm events and delivered via overland flow (Jordan *et al.* 2005), although significant quantities may also be delivered via tile drainage (Monaghan *et al.* 2016; Zimmer *et al.*, 2016) and groundwater pathways (Mellander *et al.*, 2016) with individual hot-spots of nutrient loss, or critical source areas, contributing a relatively high proportion of the nutrients exported from the landscape (Pionke *et al.*, 2000).

As hydrology is a key driver of nutrient delivery at catchment scale, hydrogeological processes should be incorporated in models. For the spatial modelling approach used in this study, simplified conceptual flow paths were included in the models of emissions from agricultural and septic tank systems. The multiple complexities were reduced to two main pathways; 1) near surface including overland flow and flow through soils and subsoils, and 2) a (deep) groundwater pathway. This conceptualisation will evolve as further research explores national mapping of flow paths through Irish landscapes including, for example, the on-going GSI transition zone research project.

TIMING OF NUTRIENT EMISSIONS

The complex temporal variations of nutrient emissions are often essential to assessing impacts on ecology. This fourth dimension is not represented in the SLAM results, and can be essential for certain assessments. For example, the annual percentage contribution of loads from septic tank systems may be small overall at the sub-catchment scale, but their impact in small stream headwaters can be significant during low flow periods (Withers *et al.*, 2012).

In contrast to dynamic models that produce temporal analyses, the SLAM approach allows the model to be applied throughout Ireland, independently of the availability of measured in-stream calibration data. Development, however, is on-going in collaboration with the *ESManage* Project to couple the SLAM with an existing dynamic water quality model, the Catchment Modelling Tool (Mockler *et al.*, 2014) to produce an ecosystems services modelling framework. This dynamic model supports the investigation of temporal variations in river nutrient concentrations.

HOW TO CONTRIBUTE TO THE FRAMEWORK

This study aimed to incorporate the best available national research and data to estimate and apportion the sources of nitrogen and phosphorus in Irish surface waters. However, due to limited resources of the project, some of the models are still based on simple emission factors. For example, there is a growing body of research on nutrient emissions from forestry and peatlands that has not yet been interpreted into a national sector model. As our understanding of land cover, land use and hydrogeological connections grows, research findings can be incorporated into the SLAM Framework. Hence, where feasible, it is recommended that future related research projects attempt to extrapolate sector-specific data to produce national spatial estimates of nutrient emissions that can be incorporated into the SLAM framework.

CONCLUSIONS

The SLAM results have been analysed at a range of scales and coupled with other models in order to improve understanding of catchment dynamics. For example, the dynamic nature of anthropogenic pressures at catchment scale were examined using loading information spanning over a decade to explore the resulting impacts on Irish estuaries (Ní Longphuirt *et al.*, 2016). At local scale, Mockler *et al.*, (2016) illustrated a simple assessment of potential mitigation measures in a nutrient-enriched water body. The upgrading of the SLAM Framework with new models and data will continue in order to support integrated catchment management in Ireland.

Incorporating the SLAM results into Irish catchment science assessments has facilitated assessment of nutrient load information in a logical, structured, consistent and comparative way across the country and has therefore provided robust assessment of the information. The results however, are only one of the 'tools in the toolbox' to determine the significant pressures. The SLAM results should be used in combination with other information, as nutrient load does not necessarily mean impact. The design of measures requires integrating hydro-science and social-science assessments to ensure decision makers have the best information when evaluating cost efficiency and effectiveness (Psaltopoulos *et al.* 2017), and models such as the SLAM provide some of the necessary information to feed into these assessments.

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