Science of the Total Environment 601–602 (2017) 326–339

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Sources of nitrogen and phosphorus emissions to Irish rivers and coastal waters: Estimates from a nutrient load apportionment framework

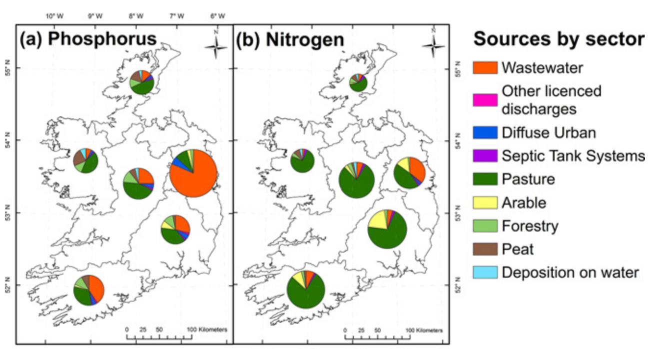
Eva M. Mockler [a,*], Jenny Deakin [b], Marie Archbold [b], Laurence Gill [c], Donal Daly [b], Michael Bruen [a]

[a] UCD Dooge Centre for Water Resources Research and UCD Earth Institute, University College Dublin, Dublin 4, Ireland
[b] Environmental Protection Agency, Clonskeagh, Ireland
[c] Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin, Ireland

HIGHLIGHTS

- Performance of the SLAM framework in 16 catchments was good for N and satisfactory for P.
- Sources of P contributions vary by land use and hydrogeological characteristics.
- P from pasture is mainly driven by hydrogeological conditions, not pressure.
- Agriculture is the dominant source of N across all regions.
- Mitigation options should reflect local source-pathway-receptor relationships.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 February 2017
Received in revised form 19 May 2017
Accepted 20 May 2017
Available online 29 May 2017

Editor: Simon Pollard

Keywords:
Nutrient Load Apportionment modelling
Phosphorus
Nitrogen
Integrated catchment management
Diffuse pollution
Water Framework Directive

ABSTRACT

More than half of surface water bodies in Europe are at less than good ecological status according to Water Framework Directive assessments, and diffuse pollution from agriculture remains a major, but not the only, cause of this poor performance. Agri-environmental policy and land management practices have, in many areas, reduced nutrient emissions to water. However, additional measures may be required in Ireland to further decouple the relationship between agricultural productivity and emissions to water, which is of vital importance given on-going agricultural intensification.

The Source Load Apportionment Model (SLAM) framework characterises sources of phosphorus (P) and nitrogen (N) emissions to water at a range of scales from sub-catchment to national. The SLAM synthesises land use and physical characteristics to predict emissions from point (wastewater, industry discharges and septic tank systems) and diffuse sources (agriculture, forestry, etc.). The predicted annual nutrient emissions were assessed against monitoring data for 16 major river catchments covering 50% of the area of Ireland. At national scale, results indicate that total average annual emissions to surface water in Ireland are over 2700 t yr^{-1} of P and 82,000 t yr^{-1} of N. The proportional contributions from individual sources show that the main sources of P are from municipal wastewater treatment plants and agriculture, with wide variations across the country related to local anthropogenic pressures and the hydrogeological setting. Agriculture is the main source of N emissions to water across all regions of Ireland. These policy-relevant results synthesised large amounts of information in order to identify the dominant sources of nutrients at regional and local scales, contributing to the national nutrient risk assessment of Irish water bodies.

* Corresponding author.
E-mail address: eva.mockler@ucd.ie (E.M. Mockler).

http://dx.doi.org/10.1016/j.scitotenv.2017.05.186
0048-9697/

1. Introduction

Identifying appropriate measures to address eutrophication remains a major challenge across Europe, where many river and lake water bodies are still failing to meet Water Framework Directive (WFD; 2000/60/EC) objectives. Indeed the management of diffuse sources of nutrients in rural catchments is of particular interest globally, as environmental objectives compete with the increasing demand for food production. A challenge for current research is to improve understanding of nutrient processes in catchments by scaling up findings from plot scale and extrapolating understanding to entire regions or countries from a relatively small number of well-studied catchments (McGonigle et al., 2012). This scientific evidence can then inform environmental policy through the provision of tools and guidance to support water quality management and decision making (Defra, 2011).

In Ireland, integrated catchment management has been used to implement a systems-based approach for assessing and managing freshwater ecosystems (Daly et al., 2016). Characterisation of water bodies for the second cycle of the WFD has been undertaken including evaluation of physical, hydrochemical and ecological characteristics, and a risk assessment of pressures, pathways and impacts. These assessments used results from water quality models (e.g. Gill and Mockler, 2016; Mockler et al., 2016) to ensure that investigations and measures are efficiently targeted, and decision makers are better informed about the effectiveness of measures to date and the possible response of water bodies to future actions (Ní Longphuirt et al., 2016).

Water mobilises and transports nutrients through the landscape and the attenuation potential varies considerably with hydrological 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, all relevant hydrological processes should be adequately represented in a water quality model (Medici et al., 2012).

In cases where water quality is impacted by excess nutrients, load apportionment modelling can support the proportional and pragmatic management of water resources. There are two broad approaches to load apportionment modelling, (i) load-orientated approaches which apportion origin based on measured in-stream loads (Grizzetti et al., 2005; Greene et al., 2011; Grizzetti et al., 2012), and (ii) source-orientated approaches where amounts of diffuse emissions are calculated using models typically based on export coefficients from catchments with similar characteristics (MCOS, 2002; Jordan and Smith, 2005; Smith et al., 2005; Campbell and Foy, 2008; Ní Longphuirt et al., 2016). The Source Load Apportionment Model (SLAM) framework (Mockler et al., 2016) takes the latter approach which enables estimates of the relative contribution of sources of nitrogen (N) and phosphorus (P) to surface waters in catchments without in-stream monitoring data. This allows the approach to be applied throughout Ireland, independently of the availability of measured in-stream data. It integrates information on point discharges (urban wastewater, industry and septic tank systems) and diffuse sources (pasture, arable, forestry, etc.) and catchment data, including hydrogeological characteristics where applicable.

Significant changes in the magnitude and sources of phosphorus in Irish rivers have occurred over the last two decades, due to both improved wastewater treatment works and changes in land management practices (O'Boyle et al., 2016), altering the relative contributions from point and diffuse sources (Ní Longphuirt 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. This study aimed to quantify the sources of P and N emissions in Irish rivers in order to support the identification of potential pressures resulting in eutrophication. The objectives of this paper are to (i) evaluate the performance of the SLAM framework for predicting nutrient loads in Irish rivers by comparing the outputs of the model with measured in-stream loads, (ii) using the SLAM results, identify the main sources of nutrients in Ireland at national, regional and local scales, and (iii) compare and contrast the main sources and delivery pathways of agricultural and wastewater emissions.

2. Data & methods

2.1. Study area

The Republic of Ireland has an area of 70,000 km^2 and a population of approximately 4.6 million people, with the largest urban centres located in Dublin on the east coast, and Cork on the south coast. The land cover is predominantly pasture supporting over 6.4 million cattle. There is a mild maritime climate, with mean annual temperatures of approximately 10 °C. Annual rainfall varies from in excess of 3000 mm in the western mountains to <800 mm along the east coast. Load apportionment results by sector were analysed nationally, for six regional (formerly River Basin) districts, and at a local scale for 583 sub-catchments ranging in area from 24 to 390 km^2.

2.2. Source Load Apportionment Model (SLAM) Framework

The Source Load Apportionment Model (SLAM) Framework (Mockler et al., 2016) 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. For example, in the current version (v 2.05) of the framework, two modules have been upgraded with output from more advanced export-coefficient based models; the agriculture (pasture & arable) and septic tank systems modules now use spatial outputs from the Catchment Characterisation Tool (CCT) (Archbold et al., 2016) and SANICOSE models (Gill and Mockler, 2016), respectively.

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). This annual average export coefficient model calculated leaching rates based on methods from existing models for N (Shaffer et al., 1994; del Prado et al., 2006) and P (Heathwaite et al., 2003). In addition, the model applied pathway-dependent attenuation coefficients related to the hydrogeological conditions, which were inferred from GIS maps of relevant properties including soil drainage, subsoil permeability and depth to bedrock (details in Appendix A.4). These coefficients were determined following a literature review and expert elicitation for the two pathway categories grouped into (i) 'near surface' pathways including overland and drain flow, and (ii) groundwater (Archbold et al., 2016). Further details on the CCT are available in Appendix A.4. The 2012 CORINE (Lydon and Smith, 2014) level 3 land cover data were used in the forestry, peatlands and urban sub-models. Various export coefficients (Table A2) were then applied in each of the modules to estimate their annual nutrient emissions to water (see Appendix A). 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. The total annual nutrient load at the outlet of each sub-catchment (L_i) was calculated as:

$$L_i = (Point_i + Diffuse_i)^*(1 - Lake_i) \quad (1)$$