Land Use Policy 62 (2017) 185–201

Contents lists available at ScienceDirect

Land Use Policy

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

# Projected impacts of increased uptake of source control mitigation measures on agricultural diffuse pollution emissions to water and air

Y. Zhang[a], A.L. Collins[a,*], P.J. Johnes[b], J.I. Jones[c]

[a] Sustainable Soils and Grassland Systems Department, Rothamsted Research, North Wyke, Okehampton EX20 2SB, UK
[b] School of Geographical Sciences, University of Bristol, University Road, Bristol BS8 1SS, UK
[c] School of Biological and Chemical Sciences, Queen Mary University of London, Mile End Road, London, E1 4NS, UK

## ARTICLE INFO

*Article history:*
Received 12 January 2016
Received in revised form 5 December 2016
Accepted 6 December 2016
Available online 7 January 2017

*Keywords:*
Diffuse pollution
Agriculture
Source control
Mitigation
Policy
Scenario analysis
Uncertainty

## ABSTRACT

A multi-pollutant modelling framework for England and Wales is described. This includes emissions of nitrate, phosphorus and sediment to water and ammonia, methane and nitrous oxide to air, and has been used to characterise baseline (no uptake of on-farm measures) and business-as-usual (BAU) annual pollutant losses, comparing these with the loss under a range of new policies aimed at increasing the uptake of relevant source control measures to 95% across England and Wales. Model outputs, including uncertainty ranges, evaluated using national water and air quality data layers have been summarised at both farm (Robust Farm Type) and water management catchment (WMC) scale. Nationally, across all farm types, the median annual reductions in pollutant losses under the new scenario, relative to BAU in 2010, were predicted to range between 9 and 16% for nitrate, 13–37% for phosphorus, 12–21% for sediment, 2–57% for methane and 10–17% for nitrous oxide. For ammonia, the range was −2–28%, indicating the potential for pollution swapping and an increase in ammonia emissions under scenarios designed to reduce nitrogen flux to waters. Increased uptake of pollution source control measures would result in a wide range of annual total (capital and operational) costs (per farm) for the major farm types, with median estimates ranging from £635 $yr^{-1}$ (Less Favourable Areas (LFA) with grazing livestock) to £15,492 $yr^{-1}$ (Cereals) in Nitrate Vulnerable Zone (NVZ) areas, compared with a range of £23 $yr^{-1}$ to £13,484 $yr^{-1}$ for the same respective farm types in non-NVZ areas. The estimated median annual load reductions for all WMCs relative to BAU, were predicted to be 16% for nitrate, 20% for phosphorus, 16% for sediment, 16% for ammonia, 15% for methane and 18% for nitrous oxide. These predictions suggest that almost perfect (95% uptake) implementation of source control measures will not deliver substantial improvements in pollutant emissions.

## 1. Introduction

Diffuse water pollution from agriculture (DWPA), sometimes referred to as nonpoint source pollution has long been recognised as a significant environmental issue at catchment, regional, national (e.g. Johnes and Burt, 1991; Heathwaite et al., 1996; Carpenter et al., 1998; Johnes et al., 2007; Environment Agency, 2007; McGonigle et al., 2012; Withers et al., 2014; Zhang et al., 2014), international (e.g. Johnes and Butterfield, 2002; Durand et al., 2011; Howarth et al., 1996) and even global (e.g. Howarth et al., 2012; Novotny, 1999; Vitousek et al., 2009) scales. In response, a large body of international literature exists on characterising DWPA and the scope for its mitigation using either empirical or modelling approaches (e.g. Iital et al., 2008; Herzog et al., 2008; Ramilan et al., 2011; Velthof et al., 2014; Schoumans et al., 2014; Refsgaard et al., 2014; Smith and Siciliano, 2015; Hashemi et al., 2016; Srivastava et al., 2016).

Recent modelled cross-sector source apportionment for England and Wales suggested that agricultural contributions of total nitrogen, total phosphorus and sediment are dominant in 53% ($63{,}030\,km^2$) of inland water bodies designated for cycle two of the EU Water Framework Directive (WFD; Zhang et al., 2014). The detrimental impacts of DWPA on downstream aquatic environments have increased water treatment costs (Mulholland and Dyer, 2010), adversely affected aquatic ecology (Kemp et al., 2011; Jones et al., 2012a,b) and been detrimental to ecosystem services (Jones et al., 2014) including those associated with recreation. Such off-site impacts of DWPA pose serious challenges for governments and environmental protection agencies in their attempts to meet

---

[*] Corresponding author.
*E-mail address:* adrian.collins@rothamsted.ac.uk (A.L. Collins).

http://dx.doi.org/10.1016/j.landusepol.2016.12.017

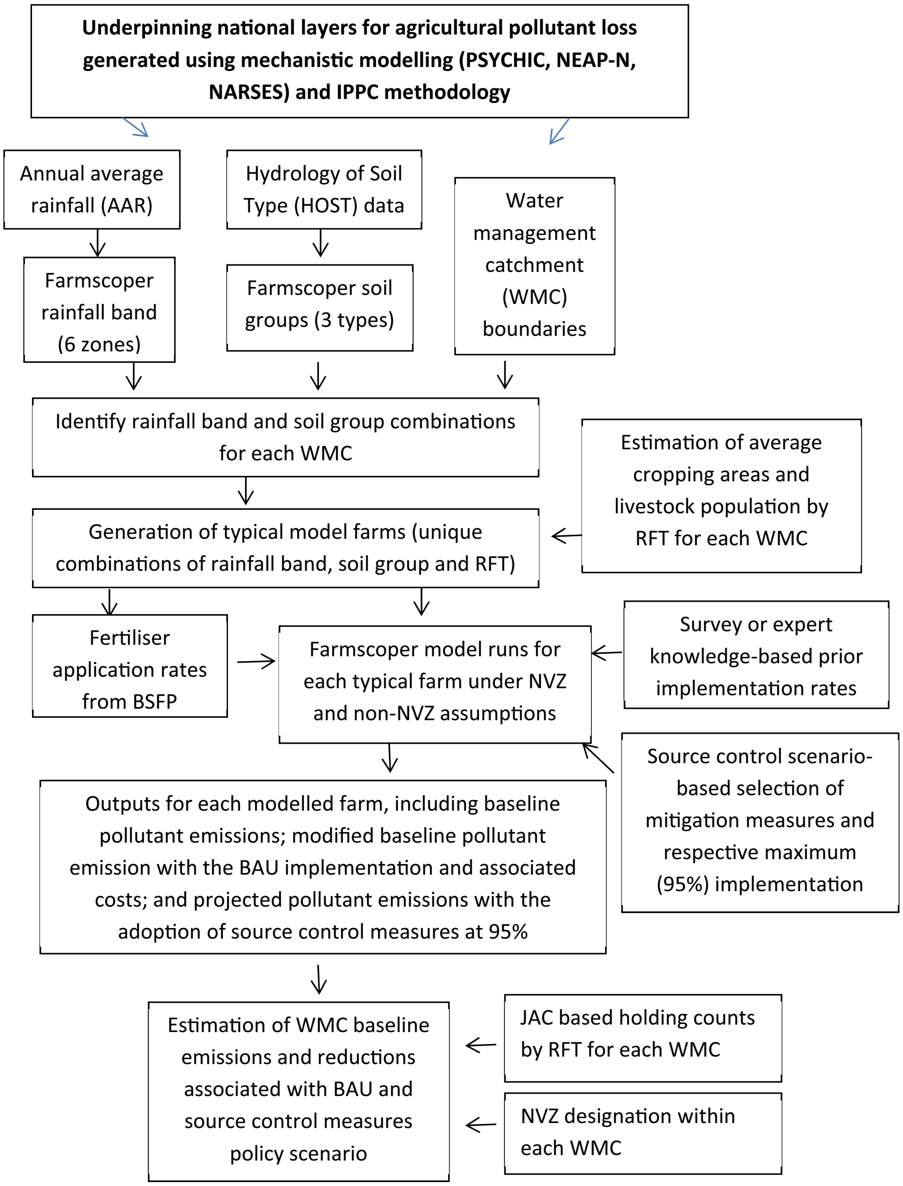

**Fig. 1.** Key elements of data flow for running FARMSCOPER at national scale.

the requirements prescribed by the EU WFD and daughter directives. As an example, DWPA and rural land use has been directly attributed to 28% of failures to meet WFD standards in England (House of Parliament, 2014) and the actual proportion which may be indirectly attributed to DWPA is much higher. In a recent paper by Greene et al. (2015) in which total N and total P flux to all UK waters, including DWPA, was simulated for the period 2000–2010, annual DWPA flux to waters ranged from 0.16–1.41 kg P/ha and from 6.56–29.2 kg N/ha. The% contribution from DWPA to the total flux varied from 5% P and 13% N in lowland grazed heathlands to over 76% of total P flux and 81% of total N flux to waters in more intensively farmed areas, mirroring rates reported for P flux to waters in England and Wales in an earlier study by Johnes et al. (2007).

In a bid to reduce pollutant loadings from agricultural sources, extensive research has been undertaken to design and test, individually or in combination, on-farm mitigation options which can be incorporated into existing farming practices. Field scale experiments (e.g. Deasy et al., 2009; Stevens et al., 2009), process-based modelling (e.g. White and Arnold, 2009), literature reviews (Collins et al., 2009a; Newell-Price et al., 2011; Schoumans et al., 2011, 2014) and national scale scenario analysis based on farming sector reductions of N, P and sediment flux (Johnes et al., 2007; Collins et al., 2009a,b; Greene et al., 2015; Collins and Zhang, 2016) have all been carried out to summarise the likely impact of mitigation measures for the agricultural sector on the rate of DWPA. As a result, some progress is being made in understanding their cost-effectiveness as well as their interactions in reducing multiple water-borne pollutant loads (including nitrogen, phosphorus, sediment), lowering emissions of green-house gases (including ammonia, methane, nitrous-oxide) and lessening impacts on the wider environment, such as delivering benefits for biodiversity and ecosystem services.

Internationally, a range of modelling tools has been developed and applied to explore the potential impacts of mitigation options for DWPA. Examples at farm scale include the DairyNZ Whole Farm Model (Vogeler et al., 2012), DairyMod (Johnson et al., 2008) and Fasset (Beukes et al., 2008), Farmax® Pro and Farmax® Dairy Pro (www.farmax.co.nz), as well as Overseer (Vogeler et al., 2014). Landscape models include SWAT (Soil and Water and Assessment