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Simulation modelling to investigate nutrient loss mitigation practices

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ABSTRACT

One important way that agriculture influences water quality is through nitrogen (N) losses from farmland, and several variables affect the extent of losses. The present research used RF-MAS (Rural Futures Multi-Agent Simulation), a system model of New Zealand agricultural industries that incorporates natural resources, land use, policies, prices and farmer behaviour. Scenarios included several levels of on-farm mitigation activities, changes in information available and the willingness of farmers to change practices, and different social parameters. The outputs from the modelling included changes in N losses from farms, changes in total regional agricultural revenue and impact per kilogram of N loss reduction. Results suggested that nutrient caps applied by industry appeared the most profitable for farmers, and the result was insensitive to the size of a farmer-agent's peer network. Less effective were nutrient caps applied uniformly to all farms or caps set according to Land Use Capability class. Assumptions about famer behaviours had considerable impacts on model outputs. The assumed level of profit-maximising behaviour among farmers affected the amount of mitigation achieved. Calibrating models to observed economic objectives of farmers may be important for generating accurate water and nutrient policy modelling.

1. Introduction

New Zealand has relatively high water quality by international standards. Water quality, however, is showing signs of decline: for example, 39% of groundwater sites have nitrate levels above natural levels (Ministry for the Environment, 2010). The change is particularly noticeable in agricultural areas; farm animal urine is the biggest source of N in New Zealand waterways (Ledgard, 2009) and a correlation between conversions of land to dairy farming and nitrogen levels in waterways is shown in New Zealand data (Parliamentary Commissioner for the Environment, 2013). The use of N fertiliser in intensive dairy farming is a major contributor to high concentrations of nitrate in groundwater (Jarvis, 1993). From 1990–2005, New Zealand had the largest increase (>800%) in N fertiliser use in the OECD (Land and Water Forum, 2010, p. 15), and increases in N seen in New Zealand are in contrast to declines seen in almost all other OECD countries (OECD, 2013). Agriculture also influences water quality through phosphorus losses, sedimentation and faecal contamination, but the present research focused on nitrogen.

Oversight of water quality has been devolved to the regional level in the National Policy Statement for Freshwater Management 2011 and the National Objectives Framework (NOF) (Ministry for the Environment, 2013). As a result, the Southland Regional Council has set a short term goal of 10% reduction in nitrogen leaching, as part of the 'Water and Land 2020 and Beyond' initiative. There are many policy options available to achieve targets and they will have different impacts on land use and economic outcomes in the region. The harmful effects of N fertilisers and farming on water quality can be mitigated in many ways, which can be organised in three classes: land-based treatments at source, interception of contaminants along hydrological pathways and bottom-of-catchment methods that treat contaminants within receiving waters (McDowell et al., 2013). Examples of some strategies include the following:

- Reducing N by reducing fertilisers or reducing stocking rates (Daigneault et al., 2012; Tilman et al., 2002).
- Excluding cattle from streams (Davies-Colley et al., 2004; McDowell et al., 2013).
- Constructing wetlands by changing landscape features (McDowell et al., 2013; McKergow et al., 2007).

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The present research linked N mitigation practices with different policy options and the net effect on N losses from farmland. Several approaches have been used to model N losses from farmland, such as process models (e.g., Whitehead et al., 2002) and non-linear programming (e.g., Daigneault et al., 2012). The present analysis used agent-based modelling, which can be used to explore rule-based behaviours as well as interactions amongst agents (Tesfatsion and Judd, 2006). Agent-based models have seen prior use in agricultural and land-use modelling (Berger and Troost, 2012; Kaye-Blake et al., 2010). Kremmydas (2012) provided a summary of the modelling approach and reviewed a number of agent-based agricultural models in the European context, including Agripolis, RegMAS, MP-MAS and SWISS-Land.

The model is a multi-agent simulation model built with data on land quality and geography, land uses and farming practices. The farming practices included mitigation techniques for pastoral land uses, similar to the options described above. In addition, the modelling included behavioural and social elements to assess the impact of economic objectives and peer networks of farmers. Simulations were then used to model policy scenarios, with the aim of understanding how the policies produced reduced N losses from the farms and changes to farm production.

The most straightforward mechanism for reducing nutrient discharge is through uniform discharge caps. Discharge caps place maximum limits of the amount of N losses on an individual farm. A uniform discharge cap calculates the limit as a simple function of the area of a farm. Uniform caps require all farms to have the same per-hectare limits on nutrient losses, regardless of the farm system or the underlying natural resources and their ability to absorb nutrients. Uniform caps can therefore lead to economically inefficient outcomes (Kaye-Blake et al., 2014a).

The drawbacks of uniform caps can be overcome with more complex approaches to allocating nutrient limits. The One Plan in the Horizons district proposed to allocate nutrients to new dairy farms on the basis of Land Use Capability (Lynn et al., 2009). This is referred to as a natural capital approach in Daigneault et al. (2012), which evaluates a similar policy that allocated permits in a cap-and-trade policy in this manner to all dairy farms. Grandparenting is another way of allocating nutrients by considering how the farms have been used previously. By allocating nutrients based on historical land use or stocking rate, grandparenting allocations recognise that dairy farmers have made higher capital investments in their farms than dryland sheep and beef farmers and would therefore be more significantly harmed by stringent N limits. Grandparenting, however, limits the ability of farmers to make changes in the future and locks in an uneven production of environmental externalities.

The present research used the RF-MAS (Rural Futures Multi-Agent Simulation) model (Kaye-Blake et al., 2014b) to analyse the potential for reducing N loss under different policies and modelling assumptions. RF-MAS was developed as part of a multi-year, multi-disciplinary research programme focused on the multiple pressures and drivers affecting New Zealand farmers and rural communities. The framework of RF-MAS was designed to model New Zealand's agricultural industries, combining inputs from social and behavioural sciences, in particular focusing on location-specific data for an agricultural region. In the present research, the Southland RF-MAS data were specific to the land, farms and people of the Southland region. The data were a mix of bio-physical and socio-economic inputs, including the type of land available to farmers, the cost of different farming practice, the prices received for farm outputs, the farmers' ages and presence of successors (someone to take over running the farm) and the farmers' risk profiles. RF-MAS then produced a number of outputs, such as land use, intensity of farming and environmental practices.

2. Methodology

2.1. RF-MAS model outline

RF-MAS is an agent-based simulation model. The agent of change in the model is farmers. They decide which farming systems to use on their farms, selecting from a library of options. These options are linked to the suitability of the farm for particular uses, and include more and less intensive ways of producing several different commodities. Each year, farmer-agents review their own performance and compare it to that of a peer group. If a farmer-agent discovers that a peer is performing better with another land-use option or farm system, then the farmer adopts that better farm system (with some probability). 'Better' can be defined differently across the farmer-agents: in this modelling both cost-minimisation (low-input) and profit-maximisation were modelled. Over time, land use in a region can shift in response to farmer goals, farmer demographics, policies and market conditions.

The structure of RF-MAS can be described by the layers seen in Fig. 1. The initial layer was the dataset of farms that described their location, sizes and productive capacity as shown by their Land Use Capability (LUC) classes. The land layer contained Geographical information System (GIS) data, which was sourced from the Land Resources Inventory (Landcare Research Ltd, 2012) and the Agribase database (AsureQuality, multiple years). One key variable in the land layer was the LUC category, a measure of the potential productivity of land parcels (Lynn et al., 2009). In RF-MAS, each farm was classified into one of three categories (A, B, C), representing the average productivity of the farm. A second key variable in the land layer was soil drainage type, which was either Well drained or Poorly drained. Together, those two variables categorised each farm into one of six different groups that described the natural land resource of the farm. Additional variables in the land layer included area in hectares, perimeter and farm location.

The second layer contained the production budgets for all the land uses in a region. There were production budgets for three industries: dairy, sheep/beef and forestry. Pastoral budgets (dairy and sheep/beef) were generated by analysing example farms using APSIM (Holzworth et al., 2014), Farmax (Bryant et al., 2010) and OVERSEER (Wheeler et al., 2003) models. APSIM provided information on possible pasture production, including pasture growth curves. Farmax was used to generate production budgets given those pasture growth curves. OVERSEER used the Farmax files to estimate nutrient losses from the farms. The production budgets represented the potential uses of each farm, given its land resources as described in the first layer. For example, there were several dairy budgets for farms on well drained soils in LUC category A, other dairy budgets for farms on poorly drained soils in LUC category A, etc. Further detail is available in Vibart et al. (2013).

The second layer also contained the parameters related to practices and technologies to mitigate discharge of N and P. In the

Fig. 1. Layers in RF-MAS.