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OVERSEER AND PHOSPHORUS: STRENGTHS AND WEAKNESSES

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Abstract

Increasingly, decision support tools such as OVERSEER® Nutrient Budgets (OVERSEER) are being used by consultants and policy makers to estimate the likely effects of land management practices on off-farm losses of nutrients, for nutrient allocation, and decisions in policy relating to nutrient management. OVERSEER estimates phosphorus (P) loss. The aim of this paper is to highlight how well OVERSEER currently estimates P loss from farming systems, along with comment on some of its perceived weaknesses and recommendations for improvements to P modelling in OVERSEER.

The core of the P loss sub-model was developed and integrated into OVERSEER a decade ago. It accounted for most combinations of P loss from pastoral agricultural systems. However, some agricultural systems were not included due to a lack of data at the time of the sub-model's development. Since then, new research has been undertaken on P loss from agricultural systems, some of which has been integrated into the P loss sub-model. A number of additions and changes to other sub-models in OVERSEER, which directly affect P loss have also occurred. Currently, comparison between measured P losses from 46 sites with different land use (dairy, deer, forest, sheep/beef and mixed), at a range of scales (<1 ha plots to catchments) indicate OVERSEER can predict P loss well (R^2 >0.80; P<0.001).

However, despite the good prediction of P loss, there are modifications that could be made to OVERSEER to improve P loss estimates. It is recognised that some agricultural systems are inadequately modelled e.g. arable cropping, cut and carry, and fodder crop. There is also an opportunity for the standardisation in reporting of separate estimates of P loss via runoff and leaching. Consideration of new features in OVERSEER could include the better estimation of P loss from sediment, and for the model to increase its spatial and temporal capability.

Introduction

Diffuse losses of phosphorus (P) from agricultural land are increasingly being recognised worldwide as a major cause of surface water degradation (Carpenter et al. 1998). In New Zealand for instance, surface water quality data collected from 35 major river systems between 1989 and 2009 indicated increasing P concentrations (Ballantine and Davies Colley 2014), with some sites exceeding national water quality trigger values.

As a result of water quality issues related to nutrient enrichment, increasingly tools such as OVERSEER® Nutrient Budgets (OVERSEER) are being used by consultants and policy makers to estimate the likely effects of land management practices on off-farm losses of nutrients, for nutrient allocation, and decisions in policy relating to nutrient management. However, because of the importance of OVERSEER in estimating nutrient losses, understandably it is being increasingly examined with respect to the underpinning science and how well it is performing. As an example, the P loss sub-model in OVERSEER has recently come under scrutiny by some users as to how well it can predict P loss.

The aim of this paper is therefore to highlight how well OVERSEER currently estimates P loss from farming systems, along with comment on some of the perceived weaknesses and recommendations for improvements to P loss modelling in OVERSEER.

The P loss sub-model

OVERSEER contains a sub-model to predict P losses from blocks within a farm and the overall farm P losses. The core of the P loss sub-model in OVERSEER is based on the work of McDowell et al. (2005) which estimates P losses due to runoff up to second order streams (a stream that has two first order tributaries) from a grazed-pastoral system. Run-off includes the combined losses from surface [viz. surface runoff] and sub-surface [viz. leaching] flows, but excludes deep drainage to groundwater and mass movement.

The model estimates sources of P losses into two types i) background (soil) losses and ii) incidental (fertiliser and effluent) losses (Figure 1). Background or soil P losses arise from P that has had an opportunity to react with the soil and is lost in flow events that may occur throughout the year. It is estimated as the sum of total P (TP) losses from the soil, as influenced by different transport (i.e. topography, rainfall) and management factors (i.e. irrigation type, mole/tile drainage). Incidental P (particulate and dissolved P in overland flow) losses occur in situations where a concentrated source of available P, i.e. fertiliser and/or farm dairy effluent (FDE) application and a flow event coincide, leading to short-term P losses. Incidental P losses are calculated separately to background losses, but rely on the same transport factors, along with additional management factors such as the concentration, rate and timing of fertiliser/effluent application, the type of P fertiliser applied, and the speed of effluent application.

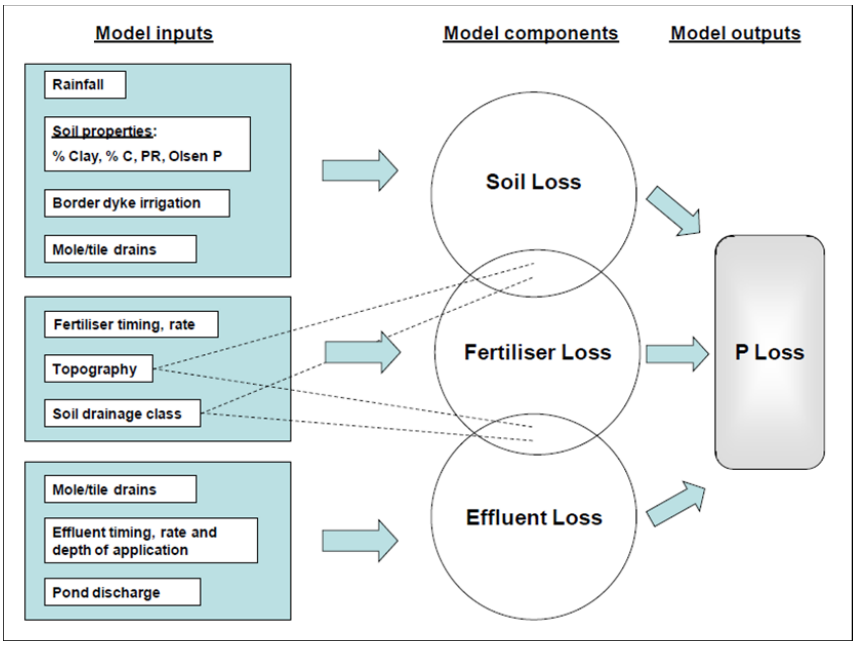

Figure 1. Conceptual diagram of model structure.

Strengths

The core of the P loss sub-model was developed and integrated into OVERSEER a decade ago. It accounted for most combinations of P loss from pastoral agricultural systems. However, some agricultural systems were not included due to a lack of data at the time of the sub-model's development. Since then, new research has been undertaken on P loss from agricultural systems, some of which has been integrated into the P loss sub-model. A number of additions and changes to other sub-models in OVERSEER, which directly affect P loss have also occurred. However, with the exception of deer systems, no reported re-calibration has been undertaken since.

To determine how well OVERSEER currently estimates P loss, a comparison was made with measured P losses from 46 sites across all regions of New Zealand. Spatially, P losses were spread between 8 plot (<1ha), 8 paddock (1-10ha), 8 block (10-100 ha), 14 farm (100-1000 ha) and 8 catchment (>1000 ha) scales (Figure 2a). A range of soil orders (including Allophanic, Brown, Gley, Pallic, Podzol and Pumice, NZ soil classification; Hewitt, 2010) and land use activities (dairy, deer, exotic and native forest combined, mixed, and sheep and beef farms) were represented (Figure 2b). It was found there was a wider range of P loss at the farm scale than other scales, and in dairy farming than other land uses.

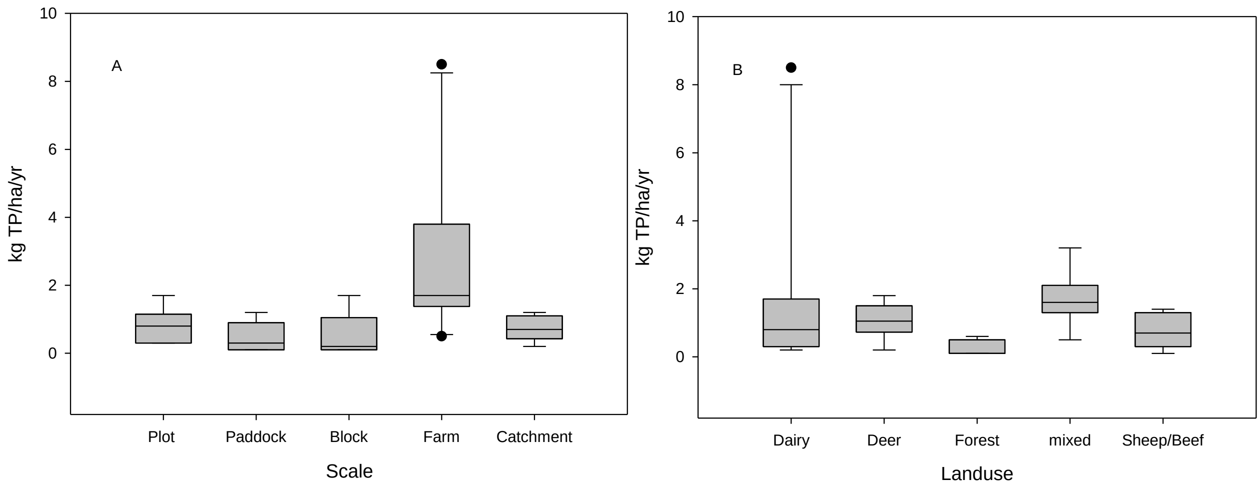

Figure 2. Measured P loss according to scale (2a) and to land use (2b). The top and bottom of the boxes represent the 25th and 75th percentiles, respectively, whiskers represent the 10th and 90th percentiles (where calculated) and the line in the box is the median value.

Results indicate that despite some potential uncertainty in some of the OVERSEER input data at some sites, OVERSEER can predict P loss reasonably well (R^2 >0.80; P<0.001) Figure 3. Although there were some exceptions, with OVERSEER estimates of P loss from catchment studies often higher than the measured values from those sites. This was likely a function of scale, where catchments integrate sources and sinks of P over a large areas making prediction more difficult. Further, the relationship is weighted by a few high values and more data in the mid-range would be useful.

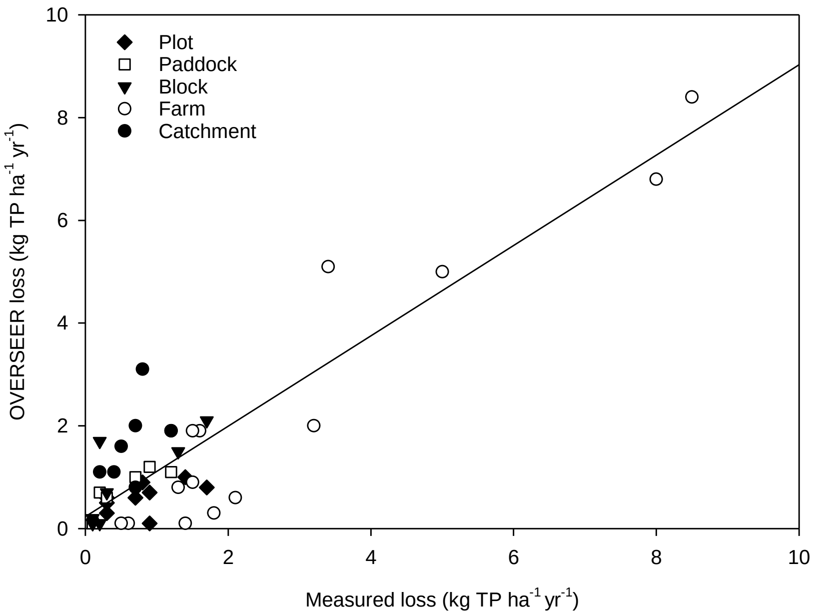

Figure 3. Measured losses and OVERSEER estimated losses (excluding 'other sources') of phosphorus by scale where Plot < 1ha; Paddock 1-10 ha; Block 10-100 ha; Farm 100-1000 ha; and Catchment >1000 ha.

Gaps or weaknesses

Because OVERSEER is a model that represents a wide range of farming systems across many different environments i.e. soil types, climates etc. it is therefore not surprising that there will be some components or agricultural systems in OVERSEER that are considered better 'developed' than others. As discussed, the P loss sub-model was developed and integrated into OVERSEER a decade ago. While it has been intermittently updated as new science has become available, it is recognised that some agricultural systems are currently inadequately modelled, and that some individual components of systems could be considered for inclusion or updated into the sub-model to improve P loss estimates. As a consequence, there are three areas where we consider there is either insufficient data or areas where there potentially could be improvement to the current modelling approach through enhancement or addition of new features.

Data gaps

Some agricultural systems are inadequately modelled due to a lack of data.

Arable cropping blocks

There is no experimental data on P losses from arable cropping systems for New Zealand. It is therefore difficult if not impossible to determine how well OVERSEER is currently estimating P loss from arable cropping sites. Measured P loss data is therefore required from arable cropping systems in New Zealand, so that with time we can test and validate P loss from this system. As an interim measure, although there is a lack of New Zealand P loss data for arable cropping systems, it is recognised that there are similarities with systems in other parts of the world. A useful first step could be to review the potential for overseas systems (in similar eco-regions) to estimate P loss compared to OVERSEER. Factors that could be considered include the cultivation method, frequency of cropping, the type of crop grown, and, where undertaken, the impact of timing of grazing.

Cut and carry blocks

Currently in OVERSEER, P losses from cut and carry blocks use a modified version of the pastoral P loss model. This modification is based on the findings of one study investigating relative P losses from pasture, soil, treading and dung from a single grazing rotation on one soil type (McDowell et al. 2007). It is recommended this approach is re-visited based on any new research data that may now be available.

Fodder (forage) crops blocks

Phosphorus losses from grazed forage crops have been identified as high relative to other parts of the farm. For example, winter-grazed forage crop systems often occur at a very high stocking density at periods when soil moisture is often near to or at field capacity (Drewry and Paton 2005). These are conditions likely to promote losses of nutrients (P) from soils. For example, recent studies reported a P loss of 1.9 kg ha^{-1} yr^{-1} from winter forage crops grazed by dairy heifers in South Otago (McDowell 2006), and P losses of 0.95 kg ha^{-1} yr^{-1} in overland flow from cattle-grazed winter forage crop plots at a site in North Otago (McDowell and Houlbrooke 2008). However, the current model used to quantify P loss from fodder systems relies on only a limited number of studies. It is recommended that relevant New Zealand data is collated, that could then better inform (calibrate) P loss for fodder systems with respect to other soil types and topography.

Enhancements

Some individual components of farm systems could be considered for inclusion or updated in OVERSEER.

Subsurface P losses

Intensive land use activities are increasingly expanding on irrigated stony soils that are recognised as having a high vulnerability to P leaching because of low ASC (Carrick et al. 2013). Currently surface and subsurface P loss are reported together as ‘runoff losses’. It is therefore recommended that P losses via subsurface flow and surface runoff are reported separately. It is also recommended that the subsurface flow component is integrated with aquifer characteristics to indicate a risk of connectivity to groundwater and influencing stream baseflow (e.g. McDowell et al. 2015a) where feasible. These pathways have potentially different mitigation strategies and identifying them separately allows for more specific mitigation decisions to be modelled.

Irrigation

Increased runoff or drainage may also occur due to non-uniformity in application depths across a block, or over-irrigating. Research could therefore be undertaken to investigate the effect different irrigation system types and management strategies have on surface and subsurface runoff, and hence on P loss in surface and subsurface runoff.

Farm structures

Currently farm scale P losses from farm infrastructure i.e. laneways, feed pads, silage stacks etc are reported cumulatively as ‘other sources’ in OVERSEER. Attenuation of these losses is likely to happen before P leaves the farm, but currently is not taken into account. A review of these structures is required to identify whether additional P loss should be included in the model, in particular, a review of P loss from lanes should be undertaken to determine whether the current loss factor is reasonable.

Standardising runoff estimation

The hydrology sub-model was originally designed to provide input into the wetland and riparian strip model (Rutherford et al. 2008). It consists of two sub-models i.e. a soil water model and groundwater model.

Within the hydrology sub-model, surface runoff is estimated using the concept of an infiltration threshold as described in the Hydrology chapter of the Technical Manual (Wheeler and Rutherford 2015), using a daily time step. The infiltration threshold is adjusted for hydrophobicity, soil wetness and a feed-back if the soils become over-saturated. In the P loss sub-model, surface runoff is based on a probability of monthly surplus rainfall, the hydrological class, and topography, and risk months. Surplus rain uses a New Zealand average potential evapotranspiration, whereas the hydrology sub-model estimates a site specific value. Both approaches offer advantages, although neither covers all conditions that can lead to surface runoff (e.g. irrigation events or micro-topography channelling). One of the advantages of the integration of the hydrology sub-model is that total runoff is moving to a daily time step. A finer temporal scale may better target tactical mitigation strategies, but have little effect on strategic decisions.

New features

There are also a range of potential new features which could be considered for inclusion in OVERSEER which improve estimates of P loss.

Sediment loss

Phosphorus in sediment as a result of soil erosion can be an important source of P loss to water bodies in some circumstances. OVERSEER currently takes into account sediment associated losses of P from some types of erosion i.e. sheet flow and some gully erosion. However, it does not estimate P that is lost in sediment associated with mass movement due to extreme events such as earthflows or landslides. Given OVERSEER is a nutrient budget model; it could be argued that it should be accounting for nutrient loss such as P associated with sediment from other types of erosion.

There are a number of empirical erosion models developed for New Zealand that relate suspended sediment yields to mean annual rainfall and an ‘erosion terrain’ classification (i.e. Suspended Sediment Yield Estimator (Hicks et al. 2011); SPARROW (Elliot et al. 2008); NZeem (Dymond et al. 2010). Indeed NZeem and OVERSEER were used together by Parfitt et al. (2013) to estimate TP and DRP losses and their likely sources for catchments across New Zealand. However, none of these models provide information on the contribution of different processes to sediment yield. Given the wide range of erosion processes that occur in the New Zealand landscape, an assessment of the contribution of different erosion process would assist in effective targeting of erosion mitigation strategies (Palmer et al. 2013). To address this limitation, a model (i.e. SedNet) has been developed (Wilkinson et al. 2004) and is being further developed for application in New Zealand (as SedNetNZ) by incorporating landslides, earthflows, large-scale gully erosion and stream bank erosion into the model (De Rose and Basher 2011). SedNetNZ is a spatially distributed, time-averaged model that routes sediment through the river network, and could be used as a tool to inform P loss in sediment for most erosion processes that occur in the New Zealand landscape. However, incorporating this would require OVERSEER to be spatially explicit.

Spatial variability
Increasingly it is being recognised that P loss from agricultural systems is highly variable in both space and time. For example, McDowell and Srinivasan (2009), Lucci et al. (2012) and others have demonstrated that in some catchments, the majority of P loss originates from a small part of the catchment, where areas of high potential for supply of P (source) and transport (e.g. surface runoff) overlap. These areas have been termed critical source areas (CSAs). Gaining a better understanding of these CSAs across spatial and temporal scales is clearly important in ensuring we apply mitigation to the right areas of a catchment or farm to minimise P loss and impact on water quality.

Currently the way OVERSEER is used may not be the most effective method of capturing CSAs and losses of P. This is because current guidelines for completing a nutrient budget in OVERSEER (i.e. using blocks which are not geo-referenced) are set up to reflect the farm operation and not necessarily the factors responsible for P loss per se (i.e. CSA's). As a consequence, it may be difficult for a user of OVERSEER to see where and when on their farm P losses are occurring, with the exception being the ability to set up sub-blocks for some systems i.e. camp and non-camp areas in pastoral blocks, headlands and uncultivated areas in a crop block and sward area in a fruit block. There is, therefore, a potential benefit to obtaining spatial P loss data to help manage P loss that accurately captures the mechanisms involved and their yields.

With OVERSEER now being a web-based platform, the move to a more spatially explicit system is possible, with the ability to incorporate different modules within a geographic information system (GIS). For example a GIS layer would essentially be a module contributing towards a different function such as hydrology or connectivity of contaminants with a waterway within a discrete area.

Temporal variability
It is recognised that an annual time step may not be appropriate for estimating nutrient loss processes. Recent changes to OVERSEER mean nutrient loads for N are now calculated monthly. Estimates for P loss are also made monthly, but presented for a year. Presentation of P loss on at least monthly intervals would be desirable to better represent event based losses and improve the ability to link OVERSEER to catchment scale models such as CLUES or TRIM, which in turn could enable better estimation of seasonal periphyton growth (Biggs and Smith 2002).

Conclusions

The P loss sub-model was developed and integrated into OVERSEER about a decade ago. Currently, comparison between measured P losses from 46 sites with different land use, at a range of scales indicates OVERSEER can predict P loss reasonably well (R^2 >0.80; P<0.001).
However, there are a number of potential data requirements and changes which could be implemented into OVERSEER that could improve estimates of P loss from agricultural systems, such as follows.

- More P loss data for some agricultural systems such as arable cropping, cut and carry, and fodder crop to allow calibration of the P loss sub-model and validate the approach taken for these systems.
- Standardisation of the estimation of runoff, and separate reporting of P losses via surface runoff and sub-surface flows.

- New features in OVERSEER that could include accounting for P loss in irrigation (separately from other sources), and for the model to increase its spatial and temporal capability.

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