Developing a farm nutrient loss index for grazed pastures in Australia

Alice R. Melland[1,2], Cameron J.P. Gourley[1], Andrew P. Smith[1], Ian S. Tarbotton[3] and Ken I. Peverill[4]

[1]Primary Industries Research Victoria, RMB 2460 Hazeldean Rd. Ellinbank, Victoria 3821, Australia. [2]Email Alice.Melland@dpi.vic.gov.au
[3]AgResearch, Ruakura, Hamilton, New Zealand
[4]KIP Consultancy Services Pty Ltd, Wheelers Hill, Victoria, Australia.

Abstract
Australian grazing industries are under pressure to increase the efficiency, productivity and viability of their farms whilst minimising the impact of grazing systems on the wider environment. A key requirement is the efficient use of nutrients. A simple index is being developed to assess the spatial and temporal risks of nutrient losses from these farms to surface waters, groundwater and the atmosphere. The 'Farm Nutrient Loss Index' incorporates nutrient source and transport factors, as well as indicators of the degree of connectivity between the farm and off-farm streams, reservoirs and groundwater. The risk assessment index will help identify where, when and how nutrient management may need to be modified in order to optimise productivity and environmental goals. An advantage of a risk assessment approach is that it organises complex biophysical process-related knowledge into a format that can be used to educate and inform farm and nutrient management advisers. A participatory workshop approach is being used to harness regionally specific scientific knowledge of nutrient loss processes from technical specialists across Australia. Outcomes from three regional workshops are discussed in relation to implications for the development of the Farm Nutrient Loss Index.

Key Words
Risk assessment, grazing, phosphorus, nitrogen, Modified Delphi technique, water quality

Introduction

The cost-price squeeze, intensification and market signals for higher quality and more uniform products have stimulated a significant rise in fertiliser use in the grazing industry of Australia over the past decade. However the efficiency of fertiliser use is often low (Peverill *et al.* 1999). For example, less than 10 % of P applied in fertiliser may be utilised by the pasture, with the remainder largely accumulating in poorly available forms (Burkitt *et al.* 2004). Similarly, the use of N fertilisers can be highly inefficient. For example, annual N losses from dairy systems are estimated between 20 – 40 % of that applied in fertiliser (Eckard *et al.* 2003). In addition, for intensive grazing industries such as dairy production, the inputs of N and P (in fertilisers and purchased feed) can far exceed the off-farm export of these nutrients in farm products (Reuter 2001), leading to a build up of nutrients and risk of pollution of waterways. Nutrients that move off-farm from dairy, beef and sheep pastures can increase the risk of degradation of surface (Melland 2003; Nash *et al.* 2000) and ground waters (Di *et al.* 1998) through eutrophication, and the risk of greenhouse gas accumulation in the atmosphere through nitrous oxide emissions (Eckard *et al.* 2003).

Whilst there is relatively little regulation of farm nutrient management practice in Australia compared with Europe, USA and New Zealand, agricultural industry and government bodies are continually working towards triple bottom line sustainability (environmental, economic and social). For example, the Fertiliser Industry Federation of Australia is establishing an accreditation program (Fertcare®) for industry staff to set and maintain industry standards of environmental stewardship. Self-assessment approaches to documenting and improving environmental stewardship are also being adopted by individual industries, companies and landholders in response to foreseeable quality assurance and market access drivers for producers (Gourley and Ridley 2004). Research and development within the Australian grazing industries is focussed on developing realistic strategies to meet natural resource conditions and management targets set within state and federal government catchment management plans (Ewing 2003).

A key part of balancing production and environmental objectives in grazed pasture systems is the efficient use and careful management of nutrients (Gourley 2004). A national project called 'Making Better Fertiliser Decisions' was instigated to help inform farm nutrient management decisions made by sheep, beef and dairy farmers. The project aims to inform farm advisers, particularly fertiliser industry agronomists, of the best knowledge available on the pasture production response relationships to fertilisers, and to develop an environmental risk assessment system that can be used to identify where and when there is a risk of nutrient losses from farms to the wider environment.

Environmental Risk Assessment Approaches

Risk assessment and environmental risk management theories are well developed (Burgman 2004) and applied in a wide range of contexts such as weeds, salinity, erosion and nutrient management. In a nutrient management context, risk can be defined as a product of the likelihood and consequence of a nutrient loss process occurring. The 'likelihood' refers to the chance of an event or process that can potentially have an environmental impact occurring (i.e. a hazard) whereas the 'consequence' refers to the type and degree of impact.

As well as nutrient input, a range of factors such as water residence time, temperature and radiation governs the severity of impact, or ecological consequence, of nutrient losses from farms to the wider environment. The potential consequences of nutrient losses can be assessed in terms of adverse ecological impact in Australian waterways using approaches described in the Australia and New Zealand Environment and Conservation Council guidelines (ANZECC/ARMCANZ 2000; Hart *et al.* 1999). However, in order to identify the potential consequence of a hazardous process or event occurring (i.e. nutrient loss from farms in this case), a conceptual model that sufficiently and systematically identifies the likelihood and severity of the hazards is also needed.

Conceptual models define components in a system such as inputs and outputs, system boundaries, cycles and causal links and can be represented using mathematical equations, diagrams and logic trees (Burgman 2004). Process-based models that can quantitatively predict the likelihood of nutrients moving from pastures are often appropriate for research purposes although many have limited capability to accurately predict nutrient loss at a land unit or paddock scale. Spatially referenced biophysical process based models that can be run at whatever scale is desired are often data intensive and require specialist knowledge to be utilised. This complexity limits their use by farmers and their advisers. At the other end of the conceptual modelling spectrum, simple best management practice guidelines are useful for raising awareness of potentially hazardous management practices but do not usually provide advice that is specific to individual farms or paddocks.

In contrast, qualitative risk assessment at the paddock scale offers a practical alternative to quantitative modelling by allowing an assessment of the potential, or relative probability, for nutrient losses to occur. A benefit of conducting a risk assessment during nutrient management decision making is that it can help communicate and educate farmers, farm advisers and environmental regulators about all the dimensions of a potential environmental problem in a transparent and logically robust way (Burgman 2004). A simple yet comprehensive approach for qualitatively assessing both the spatial and temporal likelihood of nutrient losses from grazed pastures is not currently available for farmers and nutrient management advisers in Australia.

Index Development

A popular approach to integrating complex pools of data into one or a few numbers, usually in order to make the data more accessible and assimilable, is to use index systems. Index systems can use additive, multiplicative or minimum factor approaches to aggregate scores or values given to individual factors (Smith 1990). Each aggregation method has merits and limitations that will influence its appropriateness for different indexing purposes. Additive and multiplicative aggregation methods either add or multiply a series of factors together to calculate the final index score and each factor is often given a weighting that reflects its perceived importance. Minimum factor methods identify individual factors that limit the outcome in some way, not unlike a limiting nutrient for plant growth. Whilst minimum factor methods may be suitable for indicator-type index systems, a multiplicative approach is better suited to indices of nutrient loss where there is interaction between factors (Bramley *et al.* 2003; Gburek *et al.* 2000). For example, one factor alone, such as high soil P test level, is unlikely to confer a high risk of P movement from a paddock without a concomitant pathway and active P transport mechanism. Some of the limitations of a multiplicative index system, however, are that the influence of each factor reduces as the number of factors increases, that computations need to be revised on addition of any new factors and that a need for factor weightings adds complexity to the development of the index (Smith 1990).

A number of techniques have been used to develop indices in a way that integrates and simplifies complex data without compromising the scientific credibility of index outcomes. Indices can be developed from conceptual or process models (eg Sun *et al.* (2003)). Delphi techniques (in Adler and Ziglio (1996)) and other expert panel (Groves *et al.* 2001) approaches can also be used to harness expert judgement, and identify appropriate weightings and ratings for factors or indicators. The Delphi technique is a method for harnessing, structuring and distilling vast amounts of information from experts. The technique is particularly useful when hard data is unavailable, too costly to obtain, or when the available evidence is incomplete or imperfect. Imperfect evidence often underlies what can be described as 'informed judgement' as distinct from 'knowledge', which is developed from strong evidence, and 'speculation' which is often associated with weak or no evidence. 'Often, the expert's judgment will be based on observations and experience, both of which constitute data' (Burgman 2004). Another benefit of using the Delphi technique is that it allows the socially constructed nature of risk perception to be incorporated with the reductionist approach to risk assessment by seeking collective judgements about the likelihood and severity of particular outcomes. Modified Delphi technique is the term for using the approach in a group setting where individual contributions are collated and discussed for refinement and agreement. The Modified Delphi technique was chosen for the Farm Nutrient Loss Index (FNLI) development process in order to facilitate agreement through face to face discussion in a one-day workshop rather than through individual correspondence over a longer time frame. This paper describes an expert panel workshop process used to develop a Farm Nutrient Loss Index (FNLI) for identifying when and where phosphorus and nitrogen losses can occur from pasture-based grazed farms in Australia.

Methods

Risk Index

An initial version of the FNLI was developed based on a literature review of nutrient management and loss processes in pasture-based grazing systems in Australia (Melland *et al.* unpublished data), meetings with a technical review group comprised of scientists and fertiliser industry representatives from across Australia (named the 'National Network'), and from formats of indices developed in Australia and overseas. At a meeting of National Network, the aim of the risk assessment was refined as being to assess the risk of phosphorus and nitrogen losses from beef, sheep and dairy pastures to off-farm surface waterways, groundwater and the atmosphere. A multiplicative index approach was chosen for the reasons outlined above, with the risk of nutrient loss being a product of the likelihood and magnitude of nutrient transport and connectivity to the wider environment and the likelihood and magnitude of a nutrient source being available for transport. Factors included in the initial version of the index are summarised in Table 1. Initially, each factor was given equal weighting and arbitrary scores of 1 (low), 2 (medium), 4 (high) and 8 (very high) for the level of risk within each category.

Table 1 : Factors included in an intial version of the Farm Nutrient Loss Index .

Flow transport and connectivity factors	Nutrient source and management factors
Surface runoff likelihood	Phosphorus source
• Soil profile texture & structure	• Soil P test (0-10 cm)
• Slope gradient	• Fertiliser P application rate
• Slope shape	• Timing of P fertiliser application
• Observed drainage class	• Soil P retention capacity (0-10 cm)
Deep Drainage Likelihood	Nitrogen source
• Soil profile texture and structure	• N fertiliser rate
• Plant perenniality and rooting depth	• Timing of N fertiliser application
Flow magnitude factors	Effluent source
• Annual rainfall	• Effluent application rate
• Groundcover	• Effluent application method and timing
• Flow modifying features eg drains and dams	Stocking rate
• Proximity to receiving surface water	• Nutrient Hotspots
• Minimum depth to water table	

Participatory Technical Workshops

A range of technical experts in the fields of nutrient and water management in pasture systems, including scientists, extension officers, independent consultants and fertiliser industry representatives were invited to participate in a half (Western Australia) or one-day (South Australia and northern Victoria/southern NSW) workshop. Prior to the workshops, participants were given background information about the overall project objectives, the most recent version of the FNLI and supplementary notes briefly explaining the rationale for inclusion of each factor in the index. The objective of the workshops was to gain technical and practical advice from participants sufficient to contribute to the development of a scientifically robust and user-friendly next version of the FNLI. The Delphi-technique was modified into a workshop process in order to systematically query and aggregate judgements made by the participants as has been successfully done in similar research (Tarbotton and Sparling 2003).

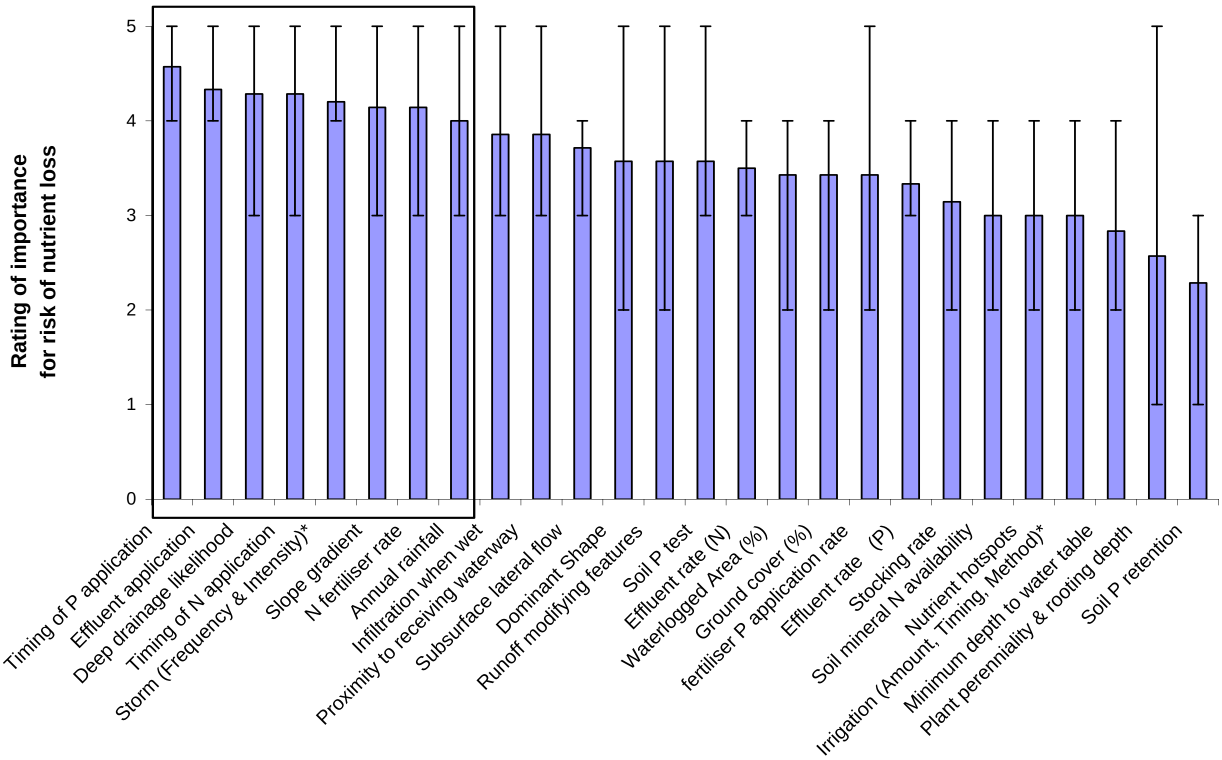
At the workshops, participants were first asked a series of questions to identify potential users of the index and those users' needs, in order to guide the format of the FNLI. Following this, participants were asked to identify any factors that should be either added or removed from the FNLI. For the agreed list of factors, participants were then asked to individually rate the relative degree of importance of each factor with respect to the overall risk of nutrient loss from pastures to the wider environment. Each participant assigned rating scores from 1 (least important) to 5 (most important) to each factor and an average aggregated rating for each factor was then calculated. This exercise was used to help identify whether factors should be given different weightings in the FNLI. Different symbols were used by the participants to represent their degree of confidence for each response throughout the workshop. Using the highest rated factors, and the range of expertise represented by the group as a guide, the group then chose which factors to assess in more detail. Factor ratings assigned by participants of three workshops are discussed below.

For each factor that was assessed in detail, each participant created a set of x-y graphs. The y-axis of the graph was assigned as the 'risk of nutrient loss' with levels of none, low, medium, high and extreme. Units for the x-axis that were objective and readily measurable were negotiated and then agreed on through facilitated group discussion. This discussion helped consolidate or modify the description of levels of risk within each factor in the FNLI. More than one graph was used for factors where necessary, for example where interactions occurred or when the response of factors for different nutrient loss pathways varied. Participants were asked to draw curves or points with dashed lines or circles when the response was based on experience and solid lines or crosses when the response was based on measured data to indicate their degree of confidence in the response. During the workshops individual response curves were collated by the project team and presented back to the group. Participants were asked to explain their responses where outliers from a combined curve were drawn. Consensus on an appropriate combined curve was reached through discussion. These combined curves will be used to revise the risk levels assigned within each factor in the next version of the FNLI.

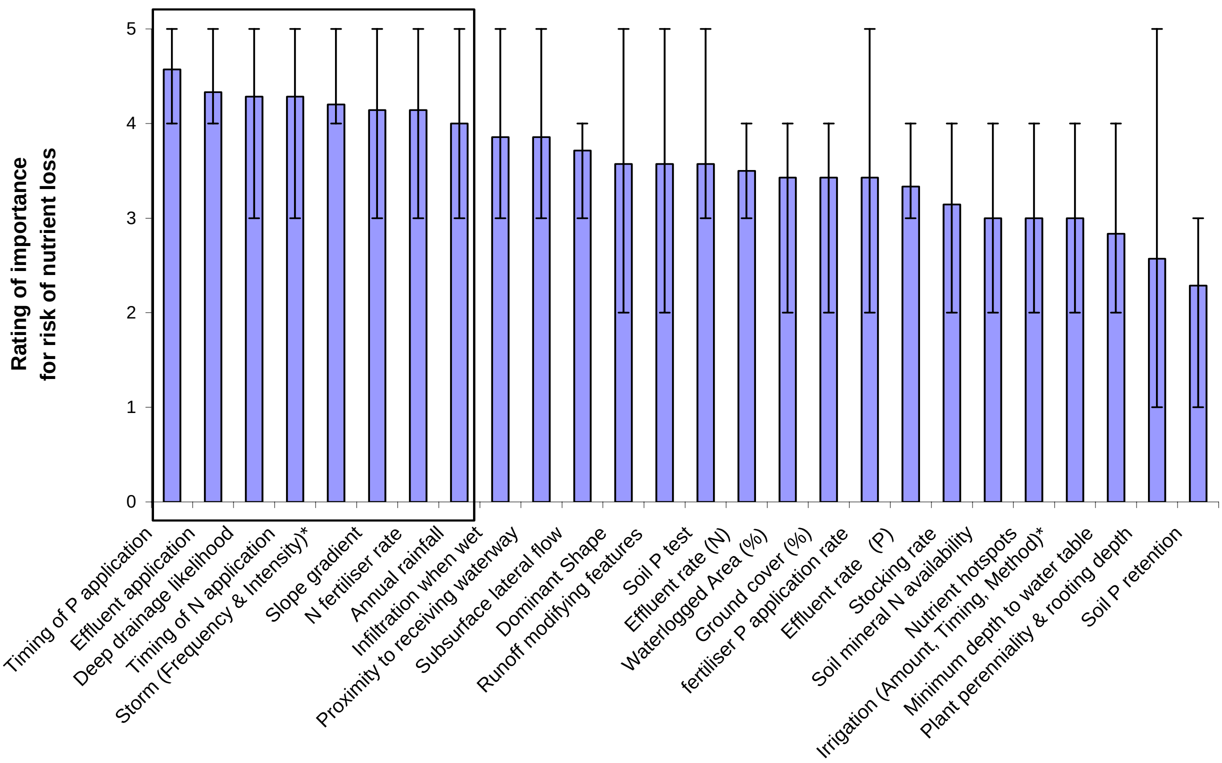
Results and Discussion

Factors and their ratings

Factors that were agreed by the Western Australian (WA) South Australian (SA) and Northern Victorian/ Southern NSW (held at Rutherglen) workshop groups as being relevant for inclusion in the FNLI are shown in (Figure



1
Figure 2), (Figure 2)and (Figure 3), with the average rating each factor received and the range of ratings given. Responses that were marked as 'guesses' using the symbol code were not included in the summary charts. At the WA workshop, slope length, subsurface lateral flow and legume species as an N source were identified as factors relevant to grazing systems in WA that should be added to those already in the FNLI. However, slope length and legume species then received low average ratings of importance for the risk of nutrient loss overall. Subsurface lateral flow was included in the FNLI that was reviewed at the SA workshop, where it received a moderate average rating of 3.7 (Figure



2
Figure 2). At the SA workshop, storm intensity and frequency, and irrigation timing, frequency and rate were added to the list of factors in the FNLI. Of these, storm intensity and frequency received a high

average rating of importance (4.2), whereas irrigation timing was considered less important (average rating of 3). At the Rutherglen workshop, percentage legume in the pasture and storm intensity/frequency were again agreed upon for inclusion in the rating exercise for the FNLI. These factors were given high average ratings of importance of 4.2 and 4.3 respectively.

At the WA and Rutherglen workshops, over half the factors were assigned average ratings of ≥ 4 ('strong' to 'most important' influence on the risk of nutrient loss), whereas in SA, less than a third of the factors were allocated this level of importance on average (see 'boxed' factors in Figures 1, 2 & 3). There was also greater difference between the highest and lowest average ratings for factors rated in SA compared with responses from the other two workshops. Factors that received average ratings of ≥ 4 at all three workshops were timing of P application, effluent application timing and method, timing of N application, N fertiliser rate, slope gradient and annual rainfall. Farmers would have some control over all but the last two of these factors which suggests there may be ways for farmers to minimise the risk of nutrient losses to waterways and the atmosphere. Some factors, such as soil P retention capacity, rated highly in WA where some of the sandy topsoils over gravel infer very little soil P retention capacity for drainage waters. In contrast, in SA and Rutherglen, the influence of topsoil P retention capacity was considered to be of lesser importance than other factors.

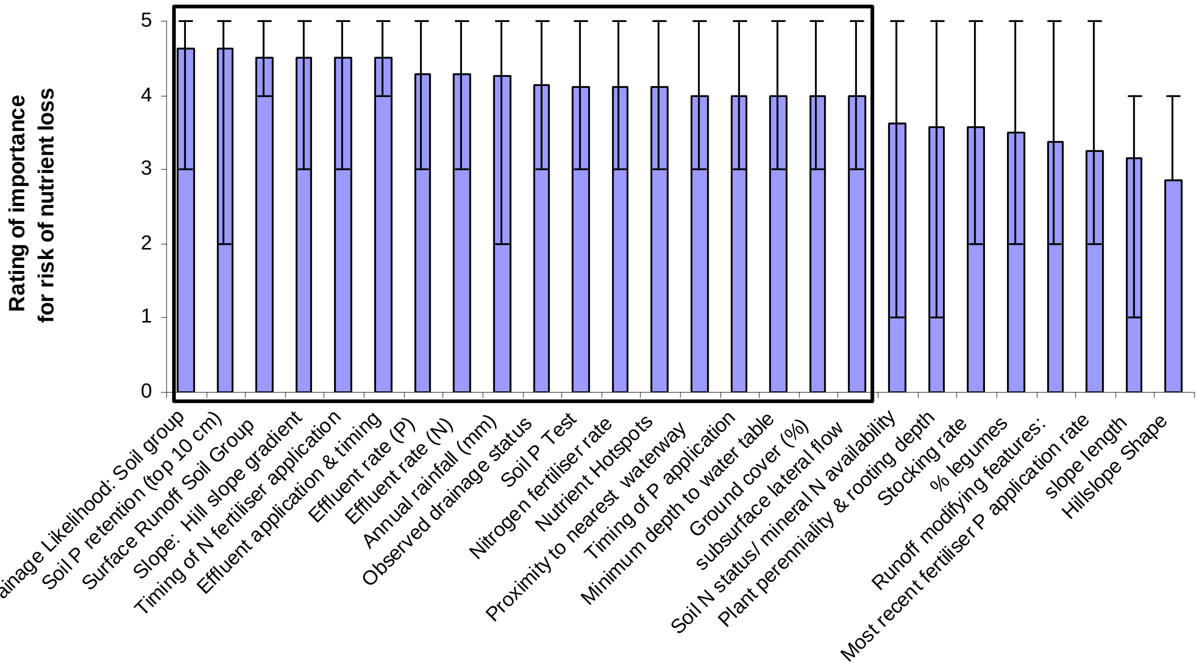


Figure 1: Average ratings of the relative importance of factors in the FNLI calculated from responses at a technical workshop held in Western Australia. (Bars indicate the range of responses. Box indicates factors with average ratings ≥ 4.)

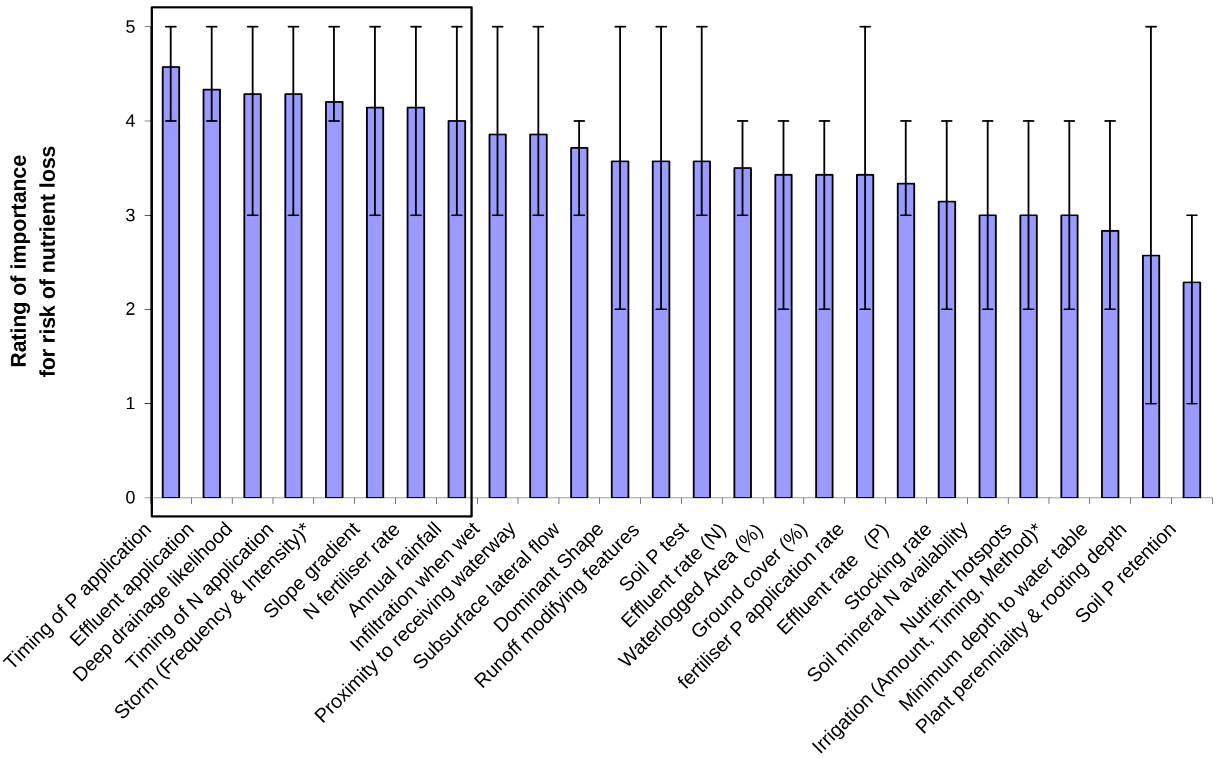


Figure 2: Average ratings of the relative importance of factors in the FNLI calculated from responses at a technical workshop held in South Australia. (Bars indicate the range of responses. Box indicates factors with average ratings ≥ 4.)

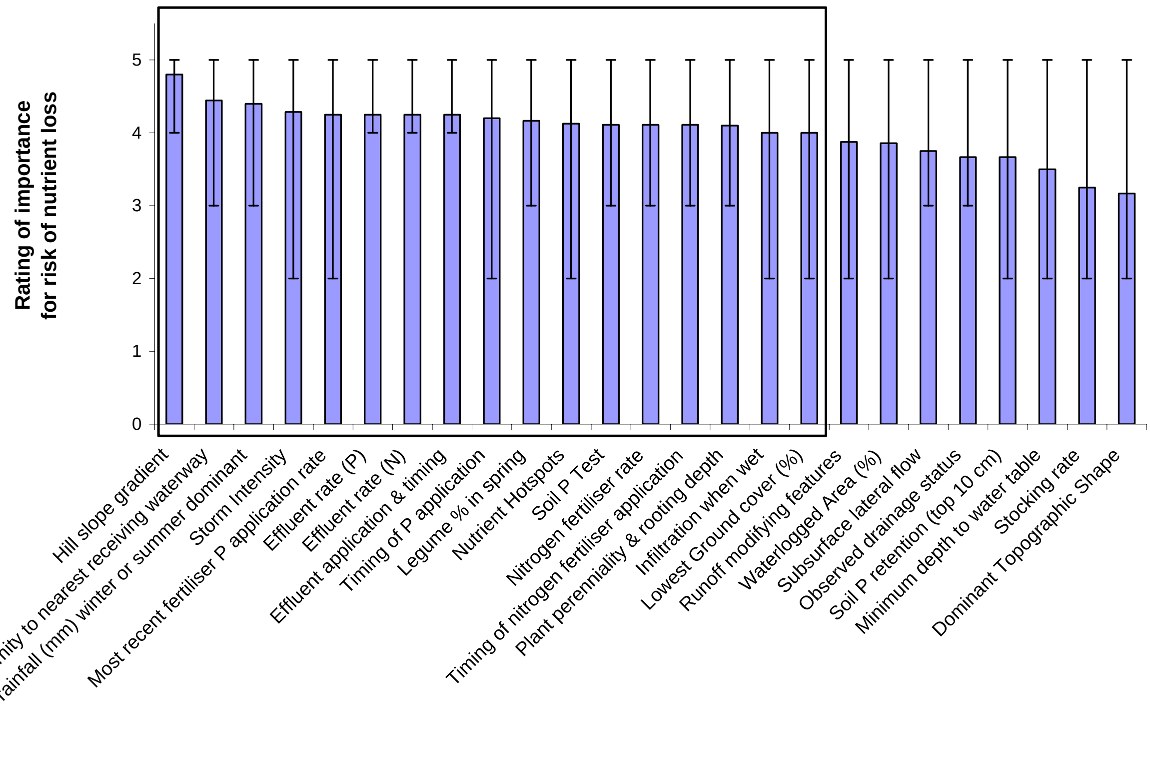


Figure 3: Average ratings of the relative importance of factors in the FNLI calculated from responses at a technical workshop held in Rutherglen, Victoria. (Bars indicate the range of responses. Box indicates factors with average ratings ≥ 4.)

The error bars in Figures 1, 2 and 3 show the range of ratings assigned for each factor by the workshop participants. For example, there was considerable variation in the perception of the relative rating of importance of plant perenniality and rooting depth in WA and SA (rated from 1-5) whereas in Rutherglen, there was greater consensus (rated from 3-5). A high degree of variance in the factor ratings suggests that participants in the group have differing opinions or perceptions of the risk of these factors. It is likely this diversity reflects both the composition of the group (knowledge, exposure, expertise) and the variability in the range of influence that the factors themselves have on the risks of nutrient loss in each region. Given the large range of responses given for individual factors, particularly at the WA and Rutherglen workshops, there was little indication that factors should be given different weightings of importance in the FNLI. However, the diversity does give us an indication of the extent to which these perceptions differ in each region and these perceptions will be compared when the workshops have been completed across six other grazing regions to highlight any major regional differences. Statistical approaches for this analysis are being investigated. It was highlighted that there were difficulties in rating the relative influence of the entire list of factors for all nutrient loss pathways simultaneously. Further investigation may be warranted where factors have received a wide range of ratings before conclusions can be drawn about the relative influence of each factor on nutrient loss risk.

Conclusion

A participatory technical workshop approach is being used in the conceptual development of an index for identifying the relative risks of nutrient losses from grazed farms to the wider environment. The workshop process combines individual input and consensus among a group of experts in nutrient management for a range of grazing regions in Australia. Scientific judgement of the factors influencing the risk of nutrient loss from farms provides a basis for the relative importance of each factor and regional variations in nutrient loss processes to be explored. The process also identifies physical processes that are less well understood in terms of their relative influence on the risk of nutrient losses.

References

Adler M, Ziglio E (1996) (Ed.) 'Gazing Into The Oracle. The Delphi method and its application to social policy and public health.' (Jessica Kingsley Publishers: GB)

ANZECC/ARMCANZ (2000) 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality Paper No. 4 Volume 1 The Guidelines - Aquatic Ecosystems.' Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Bramley RGV, Roth CH, Wood AW (2003) Risk assessment of phosphorus loss from sugarcane soils - A tool to promote improved management of P fertiliser. *Australian Journal of Soil Research* **41**, 627-644.

Burgman MA (2004) 'Risks and Decisions for Conservation and Environmental Management.' (Cambridge University Press: Cambridge (in press))

Burkitt LL, Gourley CJP, Sale PWG (2004) Phosphorus auditing can not account for all of the phosphorus applied to different pasture soils. *Australian Journal of Soil Research* **42**, 89-98.

Di HJ, Cameron KC, Moore S, Smith NP (1998) Nitrate leaching from dairy shed effluent and ammonium fertiliser applied to a free-draining pasture soil under spray or flood irrigation. *New Zealand Journal of Agricultural Research* **41**, 263-270.

Eckard RJ, Chen D, White RE, Chapman DF (2003) Gaseous nitrogen loss from temperate perennial grass and clover dairy pastures in south-eastern Australia. *Australian Journal of Agricultural Research* **54**, 561-570.

Ewing S (2003) Catchment Management Arrangements. In 'Managing Australia's Environment'. (Eds S Dovers and S Wild River) pp. 393-412. (Federation Press: Annandale, New South Wales)

Gburek WJ, Sharpley AN, Heathwaite L, Folmar GJ (2000) Phosphorus management at the watershed scale: a modification of the phosphorus index. *Journal of Environmental Quality* **29**, 130-144.

Gourley CJP (2004) Improving nutrient management on commercial dairy farms. *Australian Journal of Dairy Technology* **59**, 84-88.

Gourley CJP, Ridley AM (2004) Controlling non-point pollution in Australian agricultural systems. *Pedosphere, in press*.

Groves RH, Panetta FD, Virtue JG (2001) (Eds) 'Weed Risk Assessment.' (CSIRO Publishing: Collingwood, Victoria)

Hart BT, Maher B, Lawrence I (1999) New generation water quality guidelines for ecosystem protection. *Freshwater Biology* **41**, 347-359.

Melland AR (2003) Pathways and processes of phosphorus loss from pastures grazed by sheep. PhD thesis, The University of Melbourne.

Melland AR, O'Hara C, Smith AP, Gourley CJP (unpublished data) Assessing the risk of nutrient movement from grazed pasture systems in Australia.

Nash D, Hannah M, Halliwell D, Murdoch C (2000) Factors affecting phosphorus export from a pasture-based grazing system. *Journal of Environmental Quality* **29**, 1160-1166.

Peverill KI, Sparrow LA, Reuter DJ (1999) (Ed.)^(Eds) 'Soil Analysis; an interpretation manual.' (CSIRO Publishing: Australia)

Reuter DJ (2001) 'Nutrients - farm gate nutrient balances. Australian national land and water audit 2001' http.//audit.ea.gov.au/ANRA/land/farmgate/Nutrient_Balance.pdf

Smith DG (1990) A better water quality indexing system for rivers and streams. *Water Research* **24**, 1237-1244.

Sun H, Cornish PS, Freebairn DM, Rattray D, Silburn DM (2003) Environmental risk estimator for farming (E-ref) - Developing indices to measure environmental performance of agriculture. In '3rd National Conference of Environmental Management Systems in Agriculture'. Tanunda, South Australia pp. 1-12. (Primary Industries and Resources South Australia)

Tarbotton IS, Sparling GP (2003) Development of Soil Quality Indicators. In 'New Zealand Agriculture and Resource Economics Conference'. Bleinheim, New Zealand