Farm Nutrient Loss Index

An index for assessing the risk of nitrogen and phosphorus loss for the Australian grazing industries

User Manual

For FNLI Version 1.18

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Better Fertiliser Decisions

Alice Melland, Andrew Smith and Raquel Waller

Department of Primary Industries, Ellinbank Centre, 1301 Hazeldean Rd Ellinbank, 3821, Victoria, Australia

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INTRODUCTION

Nutrient loss from farms can be costly and has potential to cause degradation of waterways, groundwater and add to greenhouse gases. While there is ample information on nutrients and the problems they can cause if they escape from farms, to date there is no industry standard to guide farm advisors on identifying risky nutrient practices. The dairy, beef, sheep and fertiliser industries in Australia identified a need for a simple and practical tool to help farm advisors identify nutrient loss issues on individual farms.

The Farm Nutrient Loss Index (FNLI) draws together current knowledge on how nutrient loss occurs in a simple to use computer program available from the internet site www.asris.csiro.au. Over 90 nutrient management researchers, extension staff and fertiliser company representatives were consulted in the development of the FNLI.

The FNLI identifies the average annual risk of nitrogen (N) and phosphorus (P) loss from paddocks within pasture-based grazing systems, to waterways, groundwater and the atmosphere. For each paddock assessed, the FNLI identifies factors that pose a significant risk of nutrient loss. Alternative management practices can be trialled to check strategies aimed at lowering nutrient loss risk. The FNLI is not designed to estimate actual loads of nutrients lost from farms.

The FNLI was developed for nutrient management advisors to use in consultation with producers to help make environmentally-sound and cost-effective nutrient management decisions. Users can test year to year changes such as soil test levels. The FNLI can also be used to demonstrate the principles of nutrient loss.

The FNLI should be used in conjunction with soil fertility testing and nutrient budgeting in order to make informed decisions about how to maximise nutrient use efficiency and profitability, and minimise negative environmental impacts.

This User Manual provides background information on how to navigate through the FNLI software, how the FNLI calculates risks, and the scientific principles of nutrient loss that underpin the index.

HOW THE FNLI WORKS

The FNLI assesses the risk of N and P loss. Risk of nutrient loss is described as the likelihood and magnitude of nutrient loss occurring from a paddock or a group of paddocks that have similar features and are managed the same way.

The pathways of nutrient loss addressed by the FNLI are (Figure 1):

- runoff across the soil surface (runoff),
- drainage past the root zone (deep drainage),
- lateral flow through subsurface layers in the soil profile (subsurface lateral flow),
- emission of nitrous oxide, a significant ‘greenhouse’ gas (gaseous N emissions).

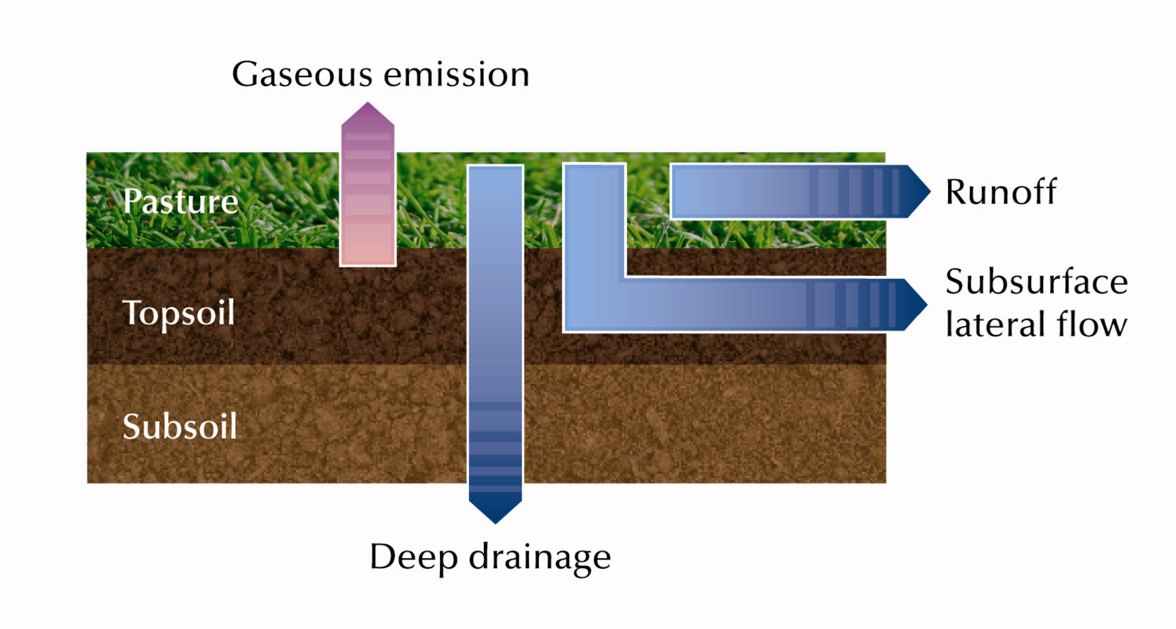


Figure 1. Pathways of nutrient loss.

The FNLI identifies the key factors that influence or reflect the availability of nutrients ('source' factors), and the transport and delivery of nutrients ('transport' factors). Where there is a source of nutrients, and the potential for nutrient movement, nutrient loss can occur. Figure 2 shows the source and transport factors addressed in the FNLI. The source and transport factors used to calculate the risk of nutrient loss via each loss pathway are presented in Figure 3 and Figure 4. Definitions for these factors are described in detail in the following section and summarised in the Glossary.

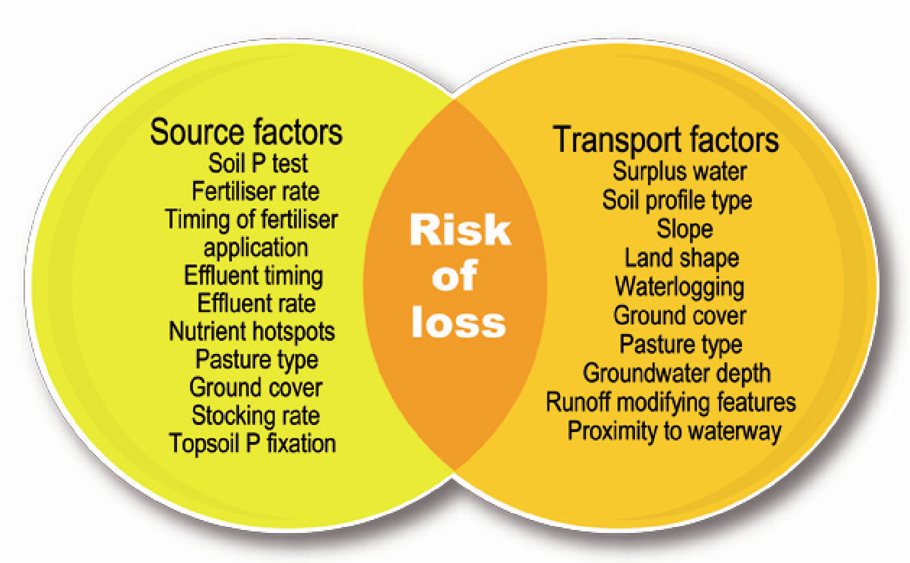


Figure 2. When there is both a source of nutrients and the potential for nutrient transport, there is a risk of nutrient loss.

Phosphorus

Runoff		Subsurface lateral		Deep drainage	
Transport	**Source**	**Transport**	**Source**	**Transport**	**Source**
Surplus water	Timing of P[1]	Surplus water	Timing of P	Surplus water	Timing of P
Soil profile	Hotspots	Soil profile	Hotspots	Soil profile	Hotspots
Slope	P rate[1]	Proximity to waterway	P rate	Pasture type	P rate
Land shape	Stocking rate	Pasture type	Stocking rate	Groundwater	Stocking rate
Waterlogged area	Groundcover		Soil test		Soil test
Runoff modifiers	Soil test		Topsoil P fixation		Topsoil P fixation
Proximity to waterway	Topsoil P fixation				
Groundcover					
Pasture type					

Figure 3. Land features and management factors that contribute to risk the of P movement from grazed pastures. [1]Fertiliser or effluent P.

Nitrogen

Runoff		Subsurface lateral		Deep drainage		Gaseous emissions
Transport	**Source**	**Transport**	**Source**	**Transport**	**Source**	
Surplus water	Timing of N[1]	Surplus water	Timing of N	Surplus water	Timing of N	Timing of N[1]
Soil profile	Hotspots	Soil profile	Hotspots	Soil profile	Hotspots	Hotspots
Slope	N rate[1]	Proximity to waterway	N rate	Pasture type	N rate	N rate
Land shape	Stocking rate	Pasture type	Stocking rate	Ground water	Stocking rate	Stocking rate
Waterlogged area	Groundcover					Waterlogged area
Runoff modifiers						
Proximity to waterway						
Groundcover						
Pasture type						

Figure 4. Land features and management factors that contribute to the risk of N movement from grazed pastures. [1]Fertiliser or effluent N.

Calculating risk

To obtain a risk ranking using the FNLI, users must work through a series of questions selecting the options that best match their paddock characteristics and management.

The options for each factor are assigned a rating of 1, 2, 4, or 8, based on their potential to increase the risk of nutrient loss. For example, for the factor '*Fertiliser P application rate*', the risk of P loss via runoff is higher when a high P rate is applied compared with a low P rate.

Each factor rating is weighted by a multiplier, indicating the relative importance of that factor in influencing nutrient loss via each pathway. The relative importance of a factor varies between grazing regions. For example, the amount of groundcover may have a relatively large influence on the source of P for loss in runoff in lower rainfall grazing regions, whereas the timing of fertiliser application may have a larger influence in high rainfall dairy systems.

The sum of all the weighted source factors, and the sum of all the weighted transport factors, are also weighted by multipliers to reflect how much the source of nutrients varies relative to the transport of nutrients in any environment (i.e. which aspect of loss is more limiting). The overall risk is the sum of the weighted source and transport factor totals (Figure 5). The weights may be modified as new knowledge about nutrient loss processes emerges. Risk ranking categories (low, medium, high or very high) have been assigned for each pathway based on validation against field data.

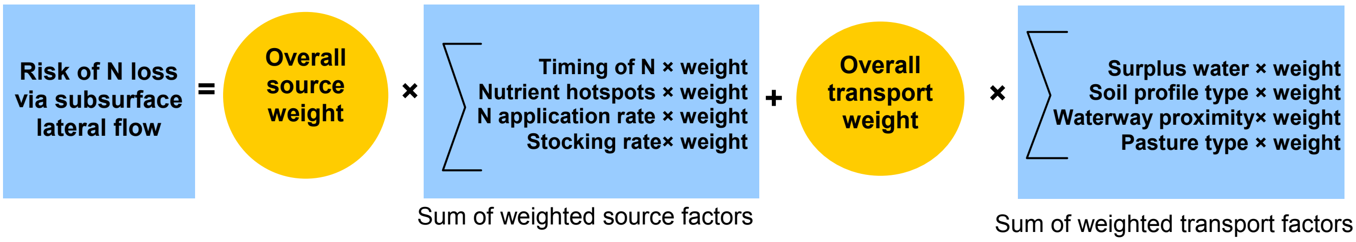


Figure 5. Diagram representing the calculation of the risk of N loss in subsurface lateral flow

Example: Calculation of risk score for N loss in subsurface lateral flow

A paddock was assessed for N loss via subsurface lateral flow. The ratings for each factor are listed in the third column. Beneath the table is the calculation of the overall risk score for subsurface lateral flow for this paddock.

Factor	Assessed criteria	Rating
Timing of N fertiliser application	Apply when low runoff or drainage risk	**2**
Nutrient hotspots (% area)	Low < 5%	**1**
N fertiliser (kg N ha^{-1})	30-60 per application, 100-250 per year	**2**
Stocking rate	2.5 – 3.5 milking cows/ha	**4**
Surplus water region	NSW - South Coast	**4**
Soil profile type	Moderate infiltration but poor drainage	**4**
Proximity to waterway (m)	<30	**8**
Pasture type	Winter active perennials	**2**

Risk score of N loss in subsurface lateral flow

$= 0.30\times((\mathbf{2}\times0.18)+(\mathbf{1}\times0.15)+(\mathbf{2}\times0.37)+(\mathbf{4}\times0.31))+0.7\times((\mathbf{4}\times0.2)+(\mathbf{4}\times0.41)+(\mathbf{8}\times0.24)+(\mathbf{2}\times0.14))$

= 3.0 out of a maximum total of 8

Risk ranking = low, there is a low risk of N loss via this pathway from this paddock.

Interpreting FNLI results

The FNLI reports the scores and risk ranking of nutrient loss for each loss pathway and nutrient. When a high or very high risk ranking is indicated, the main contributing factors are listed. These factors are either intrinsic features of the landscape, such as *surplus water* and *soil type*, or imposed by management, such as *stocking rate*. The listed factors indicate aspects of the farm that may need to be modified or managed differently to minimise nutrient losses.

Alternative management practices to lower the risk of nutrient loss can be trialled. Refer to the page linked by the button labelled 'Management options to reduce P and N risk' for management suggestions.

It is important to note that the risk scores are unique to each pathway, and therefore only the risk rankings (eg. low, medium, high risk) should be compared between pathways.

Instructions to use the FNLI

To load: Download the FNLI from *www.asris.csiro.au* and select the setup.exe file.

If installing from CD, a menu will automatically open if your operating system allows. If not, select 'StartupScreen.pdf' from your CD drive.

Follow the prompts to install the FNLI. The FNLI extracts to your C drive.

To start the program, select the FNLI icon from your desktop. Fnli.lnk

To use: Assess each paddock or farm land management unit individually. If two or more paddocks are physically similar and are managed in the same way, then these paddocks can be assessed as one management unit.

Within the program, use the 'More info' windows ? to assist selecting the most appropriate choice for each factor. A response to each factor is required. The following section describes the factors to assist selecting the most appropriate rating for each factor.

At the 'Report' page, select 'Save this paddock' to save a record of the paddock in the FNLI program.

Select 'Print Report' to view a standalone report file. The report file can be printed or exported as an html or txt file. Paddock reports appear in the order they are first created. Scroll through the report file pages to view each report. If you make changes to an existing paddock, the report updates but stays in the original order.

If you make changes to factors for a saved paddock record, the previous paddock selections will be overwritten with the changes. Changes will be reflected in the report file, once the report file is closed and reopened.

To delete a paddock and its report, select 'Delete paddock' from the 'Load a paddock' tab on the 'Farm Information' page.

To remove the FNLI from your computer, select 'Start', 'Settings', 'Control Panel', 'Add/Remove Programs', find FNLI, and click 'Remove'.

DESCRIPTIONS OF THE FACTORS

Surplus water and storm likelihood

Definition: Surplus water is the rainfall and irrigation not lost as evapotranspiration or held in the soil profile.

Rationale

Nutrients can be transported from farms in this surplus water that moves throughout the landscape as surface runoff, subsurface flow or drainage. In general, the volume of surplus water increases as the amount of rainfall or irrigation increases and evapotranspiration decreases.

Most nutrients are transported from land to water during storm events. Storm intensity tends to decrease from the coast to inland regions, and from the north of Australia to the south.

Factor assessment criteria and ratings

Rating[1]	**1 Low**	**2 Medium**	**4 High**	**8 Very high**
Surplus water & storm likelihood	**New South Wales** Central & Southern Tablelands Southern Slopes & Plains **South Australia** Adelaide Hills Kangaroo Island Lower Murray **Western Australia** Great Southern	**New South Wales** Northern Slopes & Plains **Queensland** Darling Downs & Burnett **Victoria** North Central Wimmera	**New South Wales** Northern Tablelands South Coast **Tasmania** Midlands and East Coast North East South **South Australia** South East **Queensland** Dry Subtropics Coastal South East **Victoria** East Gippsland North East South West	**New South Wales** North Coast **Queensland** Wet Tropical Coast **Tasmania** North North West **Victoria** West Gippsland **Western Australia** South Coast South West West Midlands

[1]Increase to next higher rating level if pasture is irrigated

Method for calculating surplus water and assigning ratings to regions

Rainfall surplus was estimated using the winter surplus rainfall approach of White *et al.* (2003) from average monthly precipitation and actual evapotranspiration data (Bureau of Meteorology 2004) for each Australian rainfall district. The differences in soil water-storage capacity are partly accounted for by the evapotranspiration estimates, which were derived from long-term water balances (Wang *et al.* 2001). Data from May to October were used to estimate surplus water for winter dominant rainfall zones and for other climate zones, surplus water was calculated on an annual basis in monthly steps. A rating was assigned to each grazing region assuming that the risk of nutrient loss increases as the volume of surplus water increases (Raupach *et al.* 2001) (Figure 6). In cases where pasture is irrigated, the risk rating assigned is one higher than the surplus water rating derived from climate.

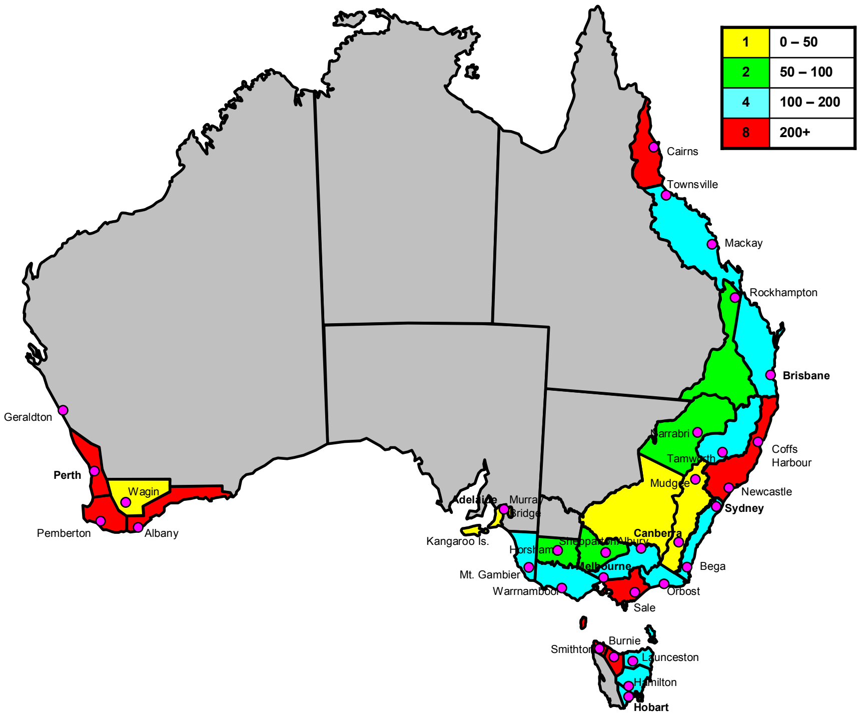


Figure 6. Pasture-based grazing regions of Australia, with colour-coded surplus water (mm year^{-1}) ratings. The FNLI is not applicable to the grey regions.

Supporting Information

On a regional scale evapotranspiration patterns broadly resemble the corresponding patterns for rainfall (Raupach *et al.* 2001). In the winter-dominant rainfall environments of southern Australia, surplus water occurs mainly between May and October (White *et al.* 2003). However, where rainfall is more evenly distributed throughout the year, or occurs mainly during summer, surplus water is intermittent and harder to estimate.

Surplus water calculated using the method above does not account for water lost as runoff during intense storms, when the soil is not already saturated (Murphy *et al.* 2004). The relative intensity of these storms broadly matches the geographic variation in the volume of surplus water within each state (Canterford 1987) so the FNLI partly accounts for storm runoff.

Slope

Definition: Average hill slope gradient of the assessment area.

Rationale

The frequency and volume of surface runoff increases with the hill slope gradient.

Factor assessment criteria and ratings

Rating	**1** **Low**	**2** **Medium**	**4** **High**	**8** **Very High**
Slope	Flat: < 1 %	Gentle: 1 - 5% (traction required, 2WD) 	Hilly: 6 – 15 % (4WD) 	Steep: > 15% (tractor) 

Supporting Information

The volume and frequency of runoff from pastures in southern Australia tends to increase with slope gradient of more than 15 % (Greenhill *et al.* 1983) and lateral flow tends to dominate over vertical drainage for slopes greater than 20% (Rassam and Littleboy 2003). The risk of particulate nutrient loss also increases in relation to slope because steeper slopes increase the velocity and energy of surface flows, which increases the potential for soil particulates to be suspended and transported in runoff.

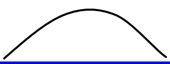
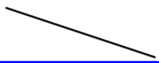
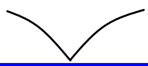
Dominant land shape

Definition: Topographic shape of the assessment area (*eg.* uniform, converging or diverging slope).

Rationale

Lateral flow accumulates in convergence zones, such as drainage lines and gullies, leading to waterlogging and a higher likelihood of surface runoff compared with diverging slopes where water disperses.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
Dominant land shape	Flat < 1 % slope	Diverging 	Uniform 	Converging 

Supporting Information

Topographic features can control the spatial variability of soil moisture (Woods *et al.* 1997). Areas of topographic convergence are prone to waterlogging and runoff due to an increased frequency of perched and groundwater tables intersecting with the soil surface (Smettem *et al.* 1991). Waterlogging also occurs when the water holding capacity and transmission capacity of the soil are exceeded by converging subsurface and surface flows (Ward and Robinson 2000). On steep convex (diverging) slopes, subsurface lateral flow may dominate over surface runoff (Cox and McFarlane 1995), and sometimes develop into springs that contribute surface runoff downslope (Cooke and Dons 1988).

Waterlogged area

Definition: Percentage of assessment area that remains waterlogged to the surface between major rainfall events.

Rationale

Sloping soils that are waterlogged are the main source of surface runoff during rainfall or irrigation.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
Waterlogging	0 – 1 %	1 – 10 %	10 – 50 %	> 50 %

Supporting Information

In any catchment area, the parts of the landscape that stay waterlogged between storms usually generate the total storm flow (Betson and Marius 1969) or stream base flow (Cooke and Dons 1988). Areas most prone to waterlogging and runoff generation are those close to streams, local depression lines, where slope decreases abruptly, at the base of hillslopes, in areas with thin topsoils and impermeable subsoils and at catchment outlets The volume of runoff, and the quality of the water are therefore affected by the size and degree of saturation of these areas (Dunne 1978).

Runoff modifying features

Definition: Overall effect of natural or man made features that accelerate, slow or prevent water in the assessment area from leaving the farm.

Rationale

Landscape features either decrease or increase the travel time of surface and subsurface flow, and hence nutrients, from leaving the farm.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
Runoff modifying features	**Net Retention**: Features retain all or most runoff on-farm *eg* farm dams, irrigation re-use systems.	**Net Deceleration**: Overall, features slow runoff from leaving the farm *eg* riparian buffer strips, wetlands, overflow dams.	**No features**: or the overall effect of the features neither slows or accelerates runoff.	**Net acceleration**: Overall, features accelerate runoff leaving the farm eg surface or tile drain, gully.

Supporting Information

Landscape features such as drains, gullies and stock tracks quickly remove water from paddocks, and increase the water's speed and energy compared with the tortuous flow routes in undrained landscapes (Cox and Pitman 2001; Hairsine *et al.* 2001). As the velocity of runoff water increases, erosion of soil particles increases but there is less time for soluble nutrients to be extracted from the soil.

Features such as dams, diversion or contour banks, riparian buffer strips and wetlands slow the rate of water movement and can trap nutrients from leaving the farm (Chambers *et al.* 1993; McKergow *et al.* 2006). Naturally occurring macropores or biopores such as old root channels, cracks and soil invertebrate channels also increase the rate of infiltration into the soil and therefore reduces nutrient loss via runoff.

Proximity to receiving waterway

Definition: Distance from midpoint of assessment area to the receiving waterway (river, stream, creek) that leaves the farm.

Rationale

The risk that surface or subsurface flow will reach the nearest (perennial or intermittent) down-slope waterway decreases as the distance to waterway increases.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
Proximity to nearest receiving waterway (m)	300+	100 - 300	30 - 100	<30

Supporting Information

The time taken for water to reach a waterway increases as the length of the flow path increases. As the time and distance between a source of nutrient-rich runoff and a receiving waterway increases, the potential for re-infiltration or re-distribution of the runoff increases and the risk of nutrient loss from the farm decreases. The proximity of nearby surface waters is commonly used as an indicator of the risk of nutrient delivery in nutrient loss indices (Bundy and Ward Good 2006).

Soil profile type

Definition: Structure and texture of the top 1 m of the soil profile.

Rationale

The soil type influences whether surplus water moves mostly as runoff, sub-surface lateral flow or deep drainage. Infiltration, redistribution and drainage of water throughout the profile are influenced by soil structure and texture. Soil profile type is therefore a surrogate for the likelihood of surplus water moving as surface runoff, vertical deep drainage or subsurface lateral flow.

Factor assessment criteria and ratings

Runoff & subsurface lateral flow rating	**1**	**2**	**4**	**8**
Deep drainage rating	**8**	**4**	**2**	**1**
Soil profile description (0-1 m)	**High infiltration and drainage:** Uniform or gradational sandy to light clay profiles which are well structured. No horizon is wet for more than a day after saturation. Excess water flows downward past the root zone readily.	**Moderate infiltration and drainage:** Medium textured profile with a deep A horizon (>50 cm) and well structured B horizon or poorly structured gradational profile. Horizons may remain wet for days but less than a week after saturation.	**Moderate infiltration but poor drainage:** Sand to loam A horizon (<50 cm) over uniform medium to heavy clay or poorly structured B horizon. Seasonal ponding of water and perched water tables may occur.	**Poor infiltration and drainage:** Heavy clay or hard surface. Water remains at or near the surface for most of the wet period of the year. Very little infiltration into B horizon.

Soils are scored on a visual assessment of the infiltration of water into wet soil, in addition to some knowledge of the soil texture and structure throughout the profile. Generally speaking, if excess water does not move as runoff or lateral subsurface flow then it will leave the profile as deep drainage, so the FNLI ratings are reversed accordingly as shown in Figure 7. The likelihood of subsurface lateral flow is considered similar to the likelihood of surface runoff so the same FNLI ratings are assigned. In some soils, water that moves laterally through subsurface layers re-emerges elsewhere in the landscape. This type of subsurface lateral flow is accounted for in the FNLI as a potential cause of surface waterlogging (refer to *Waterlogged area %*).

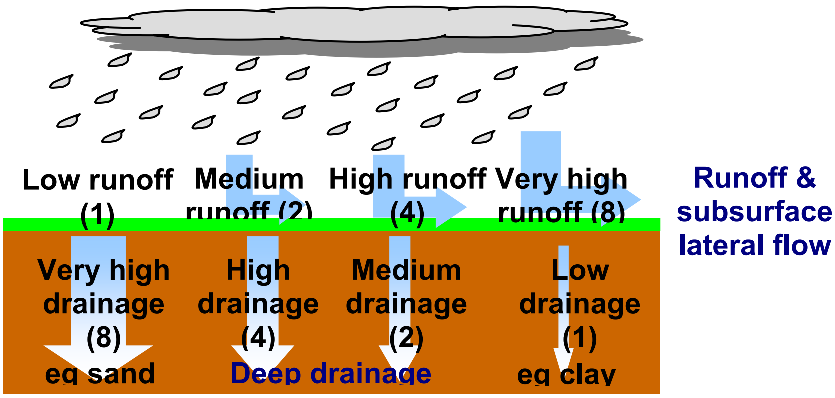


Figure 7. FNLI risk ratings assigned to different combinations of poor to high infiltration and drainage as determined by soil texture and structure.

Supporting information

The soil profile groupings used in the FNLI are based on the Principle Profile Form and Structure as described by Northcote *et al.* (1975). Similar soil groupings, based on hydrological characteristics, have been used in other nutrient loss indices, for example Overseer, McDowell *et al.* (2005) and P index for Alabama (USDA/NRCS 2001).

Groundwater depth

Definition: Minimum depth to groundwater table at the wettest time of year (excludes temporary shallow water tables after rain).

Rationale

The shallower the watertable, the more likely nutrients that drain beyond the root zone will be delivered to the groundwater.

Factor assessment criteria and ratings

Rating	**1**	**2**	**8**
Groundwater	> 1.5 m	Groundwater discharges to the surface	<1.5 m

Supporting Information

The potential for N or P to be transported to susceptible groundwater resources is partly influenced by the travel time to reach the groundwater (Shaffer and Delgado 2002). Like the *Proximity to waterways* factor, the travel time is governed not only by the tortuosity of the pathway (in this case, the soil permeability and macroporosity) but also by the distance between the nutrient source and the receiving groundwater. The depth of the water table also influences the drainage characteristics of the soil (Bramley *et al.* 2003). Shallow water tables will slow the rate of drainage, and groundwater with upward pressure can cause surface discharge rather than drainage (recharge).

The susceptibility of the groundwater, in terms of whether it supplies a surface water body further down in the catchment, or is used as a drinking water supply, is not accounted for in the FNLI, and should be considered when interpreting the N deep drainage risk rating.

Topsoil P fixation

Definition: Topsoil P fixation describes the capacity of the soil to bind P. Soils with high P fixation require more applied P to achieve an increase in soil P test value because much of the applied P is bound to the soil.

Rationale

Soils with a high clay or iron content fix most of the P in drainage water but when this soil is eroded in runoff, it transports the fixed P. In contrast, soluble P is readily drained through sandy soil due to the low P sorption capacity.

Factor assessment criteria and ratings

Subsurface lateral flow or deep drainage rating	**1**	**2**	**4**	**8**
Runoff rating	**8**	**4**	**2**	**1**
Topsoil P fixation (P buffering index[1])	Very high eg clay PBI > 280	High eg clay loam PBI 140 - 280	Medium eg sandy loam PBI 35 - 140	Low eg sand PBI < 35

[1]P buffering index (PBI) is a laboratory measure used to indicate soil P sorption capacity

Supporting Information

Most P in drainage water is retained by the soil because subsoils are usually low in P and the clay content of subsoils usually increases with depth, enabling higher levels of

P fixation (Costin and Williams 1983). However, P in drainage can be significant in fertilised sandy soils and in soils that are artificially drained or have large macropores, including cracks and old root channels, because drainage volume is high and the capacity for adsorption of solution P is low (Lewis *et al.* 1981; Ritchie and Weaver 1993; Cox *et al.* 2000). Soil amendments with high P fixation properties that are applied to sandy soils can reduce P leaching (Summers *et al.* 1996; Pathan *et al.* 2002).

Soil P test

Definition: Soil test for plant available phosphorus.

Rationale

Increasing the agronomic soil P test level can increase the concentrations of P in runoff.

Factor assessment criteria and ratings

Rating	**1** **Low**	**2** **Medium**	**4** **High**	**8** **Very High**
		Olsen P (mg P kg^{-1})		
10 cm sample depth	<7	7 - 15	16 - 25	>25
7.5 cm sample depth	<9	9 - 19	20 - 30	>30
		Colwell P (mg P kg^{-1}) 10 cm sample depth		
light soils	<6	6 - 18	18 - 30	>30
medium soils	<12	12 - 35	35 - 60	>60
heavy soils	<18	18 - 50	50 - 90	>90

Supporting Information

Soil P tests, such as Olsen and Colwell, can be positively correlated with P concentrations (particularly the soluble P component) in runoff from pastures (Melland *et al.* 2003; Dougherty *et al.* 2004). However when fertiliser is applied during the runoff season, the effect of fertiliser will be greater than the effect of soil P status on runoff concentrations (see '*Fertiliser P rate*' and '*Timing of Fertiliser Application'*).

Fertiliser P rate

Definition: Typical amount of fertiliser P applied annually (kg P ha^{-1}).

Rationale

Increasing the rates of P fertiliser applied during the runoff or drainage season can directly increase P concentrations in the water.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
P fertiliser rate (kg P ha^{-1})	None or <11 annually	11-25 annually	25-59 annually	> 60 annually; single dose or no soil test

Supporting Information

Applying P fertiliser at rates required by plants will help maintain plant growth, water uptake and groundcover thus reducing the potential for runoff and erosion (Costin 1980). However, when P fertiliser is applied in excess of plant needs, or within two weeks of runoff occurring, the rate applied can influence P concentrations in runoff (Sharpley and Menzel 1987).

Fertiliser N rate

Definition: Typical rate of fertiliser N applied per application and annually (kg N ha^{-1}).

Rationale

Nitrogen loss increases in relation to the rate of N applied because most fertiliser N is not utilised by pasture.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
N fertiliser rate (kg N ha^{-1})	None or < 30 per application, < 100 annually	30 - 60 per application 100 -250 annually	30 - 60 per application >250 annually	> 60 per application and or > 250 annually

Supporting Information

Nitrogen fertiliser rates are directly or indirectly (*ie*. via stocking rate) related to N losses (Monaghan *et al.* 2003). Applying N at rates greater than can be taken up by the pasture will increase the risk of N losses in drainage (Whitehead 1995). Applying greater than 50 kg N/ha in any single application will exponentially increase N losses in drainage (Eckard 2004). Applying more than 250 kg N ha^{-1} may also lead to soil acidification.

Nutrient hotspots

Definition: Percentage of the area being assessed where nutrients are likely to have accumulated at the soil surface (*eg.* near feed or watering points, gates, dairy sheds, silage pits, laneways, stock camps, yards and tracks, stock access to waterways, areas for effluent disposal and fertilisers storage and handling).

Rationale

Hotspots are areas with a high risk of nutrient loss due to the accumulation of excess nutrients and can be exacerbated by soil surface disturbance from animal treading or cultivation.

Factor assessment criteria and ratings

Rating	**1**	**2**	**4**	**8**
Nutrient hotspots (% area of paddock)	Low < 5%	Medium 5 - 10%	High 10 - 20%	Very high > 20%

Supporting Information

On grazing farms there are many potential point sources for nutrient losses, such as zones where high concentrations of nutrients are retained for management reasons or due to the accumulation of nutrients from animals. In intensive systems such as dairy farms, a large amount of nutrients from dung and urine accumulate on laneways, yards and tracks due to frequent stock movement (Ledgard *et al.* 1999). In other systems such as sheep and beef, the disproportionate deposition of dung and urine in stock camps and laneways increases the risk of nutrient losses where these hotspots coincide with water flow pathways (McColl and Gibson 1979; Fillery 2001). Hotspots are easier to identify than diffuse nutrient sources as they are visible (*eg.* sheds, gate ways, silage pits, fertilisers storage and handling, stock access points) or are also accompanied by soil surface degradation and possibly accumulation of opportunistic weeds.

Timing of fertiliser application

Definition: Timing of fertiliser application in relation to season, rainfall and irrigation.

Rationale

The risk of loss of fertiliser nutrients in runoff or subsurface drainage decreases with time after fertiliser is applied. Emission of nitrous oxide from denitrification is greatest from fertilised, warm and wet soils.

Factor assessment criteria and ratings

Rating	1	2	4	8
Timing of fertiliser application	**Apply when very low runoff or drainage risk** Apply P when soil is dry and storm event is not forecast within 4 days. If N is used, apply during active pasture growth when soil is moist, but not waterlogged, except 2 days before or after storm rain or irrigation. More than 28 days between N applications.	**Apply when low runoff or drainage risk** Apply P when soil is dry and storm event is not forecast within 4 days. Apply N during active pasture growth at any time of year, except 2 days before or after storm rain or irrigation. More than 28 days between N applications.	**Apply when moderate runoff or drainage risk** Apply P when soil is dry or moist, but not waterlogged, and storm event is not forecast within 4 days. Apply N more than 3 times per year at any time, except 2 days before or after storm rain. N might be applied to waterlogged soil or before irrigation. More than 28 days between N applications.	**Apply when high runoff or drainage risk** Apply P or N at any time of year regardless of heavy rain forecast and/or less than 28 days between N applications.

Supporting Information

During the first few days after application, fertiliser nutrients are highly available to plants and are also vulnerable to loss to the environment. In the case of runoff, the concentrations of P decrease exponentially with time, halving every 4 days after application (Nash *et al.* 2000). Similarly, fertilising prior to flood irrigation increases the risk of P loss (Bush and Austin 2001). Direct effects of fertiliser application on runoff or drainage P concentrations are negligible several months after application.

In the case of N, plants take up only about a third of that applied, with the remainder being microbially bound or available for loss (Whitehead 1995). In most cases the risk of nitrate leaching is greatest immediately after fertiliser is applied and a moderate risk will remain for about 2-3 weeks. Nitrogen rates lower than the maximum recommended of 50 kg/ha should be used if applications are made less than 28 days apart (Eckard 2004). Cycling of N in soil will continue regardless of fertiliser application, however, making nitrate intermittently available for loss. Emissions of nitrous oxide from denitrification are greatest from fertilised, warm and wet soils (Eckard *et al.* 2003).

Effluent rate

Definition: Typical rate of effluent applied. Effluent includes dairy shed effluent and wash, effluent pond slurry, dairy factory effluent, reclaimed water, feedpad solids, re-use dam water and other animal manures

Rationale

Concentrations of N and P in drainage and runoff increase as annual rates, and concentrations per application of effluent increase.

Factor assessment criteria and ratings

Rating	2	4	8
Effluent rate	**Applications match pasture needs** Applied according to pasture needs and after testing effluent quality.	**Low rate regardless of pasture needs** Low rate irrespective of soil condition or plant needs: eg. < 25 mm ha^{-1} dairy effluent per application.	**Effluent not tested and/ or applied at high rate** High rate irrespective of soil condition or plant needs: >25 mm ha^{-1} dairy effluent per application.

Supporting Information

Applying effluent at rates in excess of that used by the pasture increases the risk of nutrient loss. A rate of 25 mm ha^{-1} is approximately the maximum N that should be applied in a single dressing. However, the composition of the effluent is highly variable depending upon the effluent source and collection system. For example, dairy effluent in second ponds have lower nutrient content than from first ponds, so will always be less risky to apply than first pond effluent. Rates of effluent up to 200 kg N ha^{-1} (~130 mm and 44 kg P ha^{-1}) applied in small doses over the dry season did not markedly increase nutrient losses in runoff or drainage compared with pasture where no effluent was applied because the extra nutrients were used for pasture growth (Jacobs and Ward 2006). Increases in soil potassium, salt and sodicity are likely after repeated effluent applications and need to be monitored.

Effluent application timing

Definition: The time of the year, frequency and proximity to rainfall.

Rationale

The risk of loss of effluent nutrients in runoff or subsurface drainage decreases with time after effluent is applied.

Factor assessment criteria and ratings

Rating	1	2	4	8
Effluent application and timing	Summer or Autumn surface application or incorporation. Back - up recycle dam used to capture excess flood irrigated effluent	Spring application when no heavy rain forecast for 7 days 'Short watering' used to eliminate runoff from flood irrigation	Effluent applied when soils already waterlogged or heavy rain expected in <7 days	Effluent applied to land during winter and/ or no effluent storage system and/ or effluent drains directly off-farm

Supporting Information

Effluent, like fertiliser, that is applied to wet soil when rain is forecast can lead to considerable nutrient losses in runoff and drainage (Preedy *et al.* 2001). The physical and chemical composition of effluent varies with time, effluent retention system and diet of the animal. However, organic forms of P, which are found in manure, are less readily adsorbed by soil than inorganic forms in fertilisers (Chardon *et al.* 1997) which increases the risk of P loss via both subsurface flow and runoff after effluent application. Also see Department of Primary Industries Victoria information notes on Effluent Management at http://www.dpi.vic.gov.au/dpi/nreninf.nsf.

Stocking rate

Definition: Average yearly stocking rate for the area being assessed.

Rationale

The availability of nutrients for movement from pastures in runoff, drainage and gaseous emission generally increases with increasing stocking rate.

Factor assessment criteria and ratings

Rating	1	2	4	8
Stocking rate per hectare	**Low** 1.5 or less milking cows Less than 1 beef cattle 8 or fewer DSE[1]	**Medium** 1.5-2.5 milking cows 1-1.5 beef cattle 9 -13 DSE	**High** 2.5-3.5 milking cows 1.5-2 beef cattle 14 -24 DSE	**Very high** 3.5 or more milking cows More than 2 beef cattle 25 or more DSE

[1]DSE, dry sheep equivalent

[2]Stocking rate is not directly comparable across stock types. The stocking rate ranges represent the stocking rates used within each industry.

Supporting Information

When nutrients are cycled through the animal they are transformed into forms that are readily transported from pastures by water and as gaseous emissions, which increases the risk of loss to the environment (Tate *et al.* 2000; Di and Cameron 2002). To support higher stocking rates, higher rates of nutrient inputs are normally required (Di and Cameron 2002) and in the case of dairy cattle, 75 - 80% of N consumed is excreted, so the risk of nutrient losses from pastures increases with stocking rate. As well as this, Smith and Monaghan (2003) found that N and P losses in overland flow were greatest within the 1 to 2 week period following spring grazing, rather than the period shortly following P fertiliser applications. Therefore losses were greater in the presence of a grazing animal, compared with fertiliser only (Monaghan *et al.* 2003; Mundy *et al.* 2003).

Pasture type

Definition: Dominant pasture composition indicates plant perenniality and rooting depth.

Rationale

Perennial species have a longer growing season than annual species, and deeper rooted plants exploit a greater volume of soil than shallow rooted species. Summer active species are also able to use rain when it falls in summer rainfall environments. Therefore swards dominated by perennial, deep rooted and summer active species use more water on an annual basis, leading to less drainage.

Factor assessment criteria and ratings

Rating	1	2	4	8
Pasture type	**Lucerne** eg >30% lucerne.	**Deep rooted perennials** eg >30% phalaris, kikuyu or native red grass.	**Shallow rooted perennials** eg >30% perennial ryegrass, white clover, cocksfoot or wallaby grass.	**Annual Species** such as grasses and sub clover, eg <30% perennial species.

Supporting Information

Field and modelling studies in high winter rainfall zones have demonstrated that replacing annual pasture species with deeper-rooted perennial species can reduce the volume of deep drainage (Ridley *et al.* 1997; Heng *et al.* 2001; White *et al.* 2003). Summer activity allows plants to use summer rain when it falls.

Groundcover

Definition: Lowest level of groundcover (%) during the year

Groundcover includes any green or dead pasture, organic matter, dung, leaves, sticks, stubble and rocks, either in the plant canopy or in contact with the soil surface.

Rationale

Runoff and erosion from pastures increases markedly when groundcover falls below 70%.

Factor assessment criteria and ratings

Rating	1	2	4	8
Groundcover	>80 %	70 - 80 %	50 - 70 %	< 50 %

Supporting Information

During intense rainfall or when runoff occurs on bare soil, nutrients attached to soil and organic matter can be lost via erosion. When groundcover is greater than 70%, bare ground tends to occur in isolated patches so runoff can re-infiltrate and eroded sediment is trapped by plant material, whereas as groundcover decreases and the bare patches connect, the erosivity of runoff increases (Lang and McDonald 2005). Therefore the importance of groundcover in reducing runoff and erosion generally increases as rainfall amount and intensity increase (Murphy *et al.* 2004). In southern or winter rainfall regions, 50% groundcover has been identified as an important threshold for reducing the risk of erosion (Ridley *et al.* 1997).

Irrigation

Irrigating pasture increases the potential amount of surplus water in an environment. Therefore if irrigation is used, the surplus water rating is increased to next score level. See section on *Surplus water and storm likelihood* for further details.

GLOSSARY

Term	Definition
Converging slope	Slopes that meet at the base in a drainage line.
Deep drainage	Vertical drainage past the root zone.
Diverging slope	Slopes that meet at the top at a peak or ridge
Drainage	Movement of water past the root zone.
Effluent application timing	The time of the year, frequency and proximity to rainfall.
Effluent rate	Typical rate of effluent applied.
Fertiliser N rate	Typical rate of fertiliser N applied per application and per year (kg N/ha).
Fertiliser P rate	Typical amount of fertiliser P applied annually (kg P/ha).
Gaseous emission	Emission of nitrous oxide significant to exacerbating the greenhouse effect.
Groundcover	Lowest level of groundcover (%) during the year. Groundcover includes any green or dead pasture, organic matter, dung, leaves, sticks, stubble and rocks, in the plant canopy or in contact with the soil surface.
Groundwater depth	Minimum depth to groundwater table at the wettest time of year (excludes temporary shallow water tables after rain).
Irrigation	Water applied to paddock.
Land management unit	Two or more paddocks that are physically similar and managed in the same way.
Land shape	Topographic shape of the assessment area (eg. uniform, converging or diverging slope).
Nutrient hotspot	Area where excess nutrients are likely to have accumulated at the soil surface (eg. near feed or watering points, gates and yards).
Pasture type	Dominant pasture type (>30%) indicating perenniality, rooting depth and season(s) of activity.
Proximity to waterway	Distance from midpoint of assessment area to the receiving waterway (river, stream or creek) that leaves the farm.
Risk	Chance (likelihood) and degree of severity (magnitude) of a nutrient loss event or process occurring.
Runoff	Movement of water across the soil surface.
Runoff modifying features	Overall effect of natural or man made features that accelerate, slow or prevent water from leaving the farm.
Slope	Average hill slope gradient of the assessment area.
Soil P test	Colwell or Olsen soil test for plant available phosphorus.
Soil profile type	Structure and texture of the top 100 cm of the soil profile.
Source factors	Factors that influence the availability of nutrients such as fertiliser application rate and timing of application.
Stocking rate	Average yearly stocking rate per hectare for the area being assessed.
Subsurface lateral flow	Movement of water laterally through subsurface layers within the root zone of the soil profile.
Surplus water	Surplus water is the rainfall and irrigation not lost as evapotranspiration or held in the soil.
Timing of fertiliser	Timing of fertiliser application in relation to season, rainfall and irrigation.
Topsoil P fixation	Topsoil P fixation describes the capacity of the soil to bind P.
Transport factors	Factors that influence the movement of nutrients such as surplus water and soil profile type.
Waterlogged area	Percentage of assessment area that remains waterlogged to the surface between major rainfall events.

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APPENDICES

Table 1. Weights used in risk score calculation for P and N loss via runoff, subsurface lateral flow and gaseous emission pathways.

N in runoff = 0.32 × ((Timing of N × 0.26) + (Groundcover × 0.07) + (N fertiliser or effluent rate[1] × 0.21) + (Stocking rate × 0.12) + (Nutrient hotspots × 0.16)) + (Effluent timing × 0.18)) + 0.68 × ((Slope × 0.06) + (Soil profile type × 0.10) + (Runoff modifying features × 0.09) + (Land shape × 0.06) + (Surplus water × 0.25) + (Waterlogged area × 0.12) + (Groundcover × 0.11) + (Proximity to waterway × 0.17) + (Pasture type × 0.04))
N in subsurface lateral flow = 0.30 × ((Timing of N × 0.18) + (Nutrient hotspots × 0.15) + (N fertiliser or effluent rate[1] × 0.37) + (Stocking rate × 0.31)) + 0.70 × ((Surplus water × 0.20) + (Soil profile type × 0.41) + (Proximity to waterway × 0.24) + (Pasture type × 0.14))
N as greenhouse gas emission = (Timing of N × 0.14) + (Effluent timing × 0.05) + (Nutrient hotspots × 0.16) + (N fertiliser or effluent rate[1] × 0.07) + (Stocking rate × 0.15) + (Waterlogged area × 0.42)
P in runoff = 0.40 × ((Timing of P × 0.19) + (Soil P test × 0.13) + (Nutrient hotspots × 0.07) + (P fertiliser or effluent rate[1] × 0.15) + (Groundcover × 0.25) + (Topsoil P fixation$_{\text{Runoff}}$ × 0.06) + (Effluent timing × 0.13) + (Stocking rate × 0.13)) + 0.60 × ((Slope × 0.06) + (Soil profile type × 0.10) + (Runoff modifying features × 0.09) + (Land shape × 0.06) + (Surplus water × 0.25) + (Waterlogged area × 0.12) + (Groundcover × 0.12) + (Proximity to waterway × 0.17) + (Pasture type × 0.04))
P in subsurface lateral flow = 0.38 × ((Timing of P × 0.14) + (P fertiliser or effluent rate[1] × 0.16) + (Stocking rate × 0.14) + (Soil P test × 0.14) + (Nutrient hotspots × 0.17) + (Topsoil P fixation$_{\text{Drainage}}$ × 0.25)) + 0.62 × ((Surplus water × 0.20) + (Soil profile type × 0.41) + (Proximity to waterway × 0.24) + (Pasture type × 0.14))

[1] Use rating from P application rate or effluent rate, whichever is highest.

Table 2. Weights used in risk score calculation for N loss in deep drainage

Risk of N loss in deep drainage = **Source weight × ((Timing of N × Q) + (Hotspots × H) + (N fertiliser or effluent rate[1] × D) + (Stocking rate × P)) + Transport weight × ((Surplus water × A) + (Pasture type × J) + (Groundwater × F) + (Soil profile type × O))**

	Overall weights		Source weights				Transport weights			
Regions	**Source**	**Transport**	**Q**	**H**	**D**	**P**	**A**	**J**	**F**	**O**
New South Wales North Coast Northern Tablelands **Queensland** Darling Downs Burnett	0.83	0.17	0.560	0.150	0.253	0.037	0.125	0.567	0.077	0.222
New South Wales Northern Slopes & Plains	0.50	0.50	0.560	0.150	0.253	0.037	0.560	0.166	0.046	0.228
New South Wales South Coast **South Australia** Lower Murray South East **Victoria** East Gippsland West Gippsland	0.20	0.80	0.19	0.05	0.28	0.481	0.183	0.184	0.1	0.533
New South Wales Central Southern Tablelands Southern Slopes & Plains **South Australia** Adelaide Hills Kangaroo Island **Victoria** North Central North East South West Wimmera **Western Australia** Great Southern	0.17	0.83	0.337	0.16	0.039	0.463	0.221	0.038	0.083	0.658
Queensland Coastal South East Dry Subtropics Wet Tropical Coast	0.30	0.70	0.560	0.150	0.253	0.037	0.125	0.567	0.077	0.222
Tasmania Midlands East Coast North East South	0.25	0.75	0.072	0.072	0.464	0.392	0.405	0.163	0.246	0.186
Tasmania North North West	0.10	0.90	0.059	0.391	0.219	0.330	0.272	0.039	0.568	0.121
Western Australia South West West Midlands	0.17	0.83	0.096	0.169	0.368	0.368	0.176	0.045	0.625	0.154
Western Australia South Coast	0.47	0.53	0.096	0.169	0.368	0.368	0.102	0.112	0.479	0.308

[1] Use rating from P application rate or effluent rate, whichever is highest.

Table 3. Weights used in risk score calculation for P loss in deep drainage

Risk of P loss in deep drainage = **Source weight × ((Timing of P × Q) + (P fertiliser or effluent rate[1] × D) + (Stocking rate × P) + (Soil P test × N) + (Hotspots × H) + (Topsoil P fixation$_{Drainage}$ × R)) + Transport weight × ((Surplus water × A) + (Pasture type × J) + (Groundwater × F) + (Soil profile type × O))**

	Overall weight		Source weights						Transport weights			
Regions	Source	Transport	Q	D	P	N	H	R	A	J	F	O
New South Wales North Coast Northern Tablelands **Queensland** Coastal South East Darling Downs Burnett Dry Subtropics Wet Tropical Coast	0.20	0.80	0.189	0.271	0.183	0.111	0.213	0.033	0.125	0.567	0.077	0.222
New South Wales Northern Slopes & Plains	0.50	0.50	0.074	0.200	0.031	0.443	0.105	0.146	0.560	0.166	0.046	0.228
New South Wales South Coast **South Australia** Lower Murray South East **Victoria** East Gippsland West Gippsland	0.14	0.86	0.101	0.252	0.048	0.181	0.325	0.094	0.150	0.452	0.164	0.235
New South Wales Central Southern Tablelands Southern Slopes & Plains **South Australia** Adelaide Hills Kangaroo Island **Victoria** North Central North East South West Wimmera **Western Australia** Great Southern	0.33	0.67	0.072	0.033	0.057	0.085	0.142	0.612	0.221	0.038	0.083	0.658
Tasmania Midlands East Coast North East South	0.75	0.25	0.252	0.092	0.317	0.060	0.212	0.067	0.405	0.163	0.246	0.186
Tasmania North North West	0.13	0.87	0.045	0.084	0.028	0.149	0.179	0.516	0.272	0.039	0.568	0.121
WA South West West Midlands	0.86	0.14	0.070	0.188	0.051	0.343	0.039	0.309	0.176	0.045	0.625	0.154
WA South Coast	0.47	0.53	0.07	0.188	0.051	0.343	0.039	0.309	0.102	0.112	0.479	0.308

[1] Use rating from P fertiliser or effluent rate, whichever is highest.