SUSTANZA™ FARM ENVIRONMENT MAPS: A PRACTICAL TOOL TO ASSESS AND MANAGE RISK OF NUTRIENT LOSSES FROM AGRICULTURE TO SURFACE AND GROUNDWATER

M. R. Hart and B. F. Quin

Summit-Quinphos (NZ) Ltd., P.O. Box 24-020, Auckland, New Zealand

INTRODUCTION

One of the major current issues facing the agricultural industry in general is the loss of nutrients from farmland to streams, rivers and lakes, and the problems of eutrophication, algal blooms, excessive weed growth etc. that this causes. Phosphorus (P) is usually considered the main limiting nutrient in freshwater ecosystems, and has been the main focus of this project to date. Very small concentrations of dissolved P are all that are needed for eutrophic conditions to develop, with the threshold levels specified by the Ministry for the Environment for New Zealand being 0.015 – 0.03 mg P/litre (MfE, 2001).

The amount of P transferred from pasture to waterways is influenced by a range of factors including grass cover, slope, soil properties (e.g. P status, infiltration rate, erodibility), riparian management and climate. Although some of these factors cannot readily be managed to reduce P losses, others are more amenable to management strategies. One such factor is fertiliser, where losses of P from recently applied soluble fertiliser can be a major component of total annual P losses, constituting as much as 50% or more of the overall loss (P. M. Haygarth; C.J.P. Gourley, pers. com.). Although typically less than 5% of applied fertiliser is lost in runoff (Sharpley *et al.*, 1993), this may still be more than enough to cause environmental problems. For example, experiments in New Zealand in the late 1970s showed a large increase in dissolved inorganic (equivalent to dissolved reactive) P losses in surface runoff immediately after application of single superphosphate, followed by a gradual decline over the next two months back to background levels (Sharpley *et al.*, 1978).

Similar results were also found in more recent work using micro-plots in a field experiment on a hill-country pasture in New Zealand (Nguyen *et al.*, 1999). This trial also included two direct application phosphate rock (DAPR) treatments (Gafsa and Kosseir). Dissolved reactive P (DRP) lost over the same initial period of the experiment from the DAPR-treated plots was orders of magnitude less than that from the superphosphate-treated plots, and only slightly higher than the control plots' losses. Approximately 1.7–2.2% of the applied P was lost as DRP from the superphosphate-treated plots, compared to 0.07–0.08% from the DAPR treatments. Whilst caution should be applied in extrapolating these findings to other situations, nevertheless, the size of the differences in DRP losses between the two different types of P fertiliser, i.e. fully water-soluble vs. slow release, is very significant in the context of P losses to the environment in surface runoff.

It was considered that the best way to utilise these research findings was to devise a practical farm management tool that farmers could use to strategically manage their fertiliser applications in a way that would minimise the risk of loss of P from recently applied fertiliser, as well as taking other potential sources into consideration. For reasons of cost and to facilitate application on as wide a basis as possible, a simple approach, such as that of the P Index developed by the USDA (Lemunyon and Gilbert, 1993; Gburek *et al.*, 2000) was decided on. This would enable the relative risk of P loss to water over different areas of a farm to be assessed, provide a visual guide to these areas in the form of a farm map, and would be relatively easy and cost-effective to produce, i.e. the necessary input data would be readily available, or if not, then at least easy to generate. With this in mind, a simple model that could be run in a Geographical Information System (GIS) environment was constructed to produce such a tool (Stroud *et al.*, 2001, 2002; Hart *et al*., 2002).

SOURCES OF INFORMATION

Information that was needed to build up an individual farm map and provide input data for the model was sourced from a number of commercially-available national databases. These included the 1:50,000 NZ Topographic Vector Database produced by Land Information New Zealand, from which the position of rivers, streams, canals and lakes were obtained, as well as other geographical features such as contour lines, roads, tracks, forests, scrub, etc. Information on soil types and characteristics was obtained from the 1:63,360-50,000 New Zealand Land Resource Inventory (NZLRI) Soils Database produced by Landcare Research Ltd. Data at the soil series level utilised in the model consists of P retention class (5) and internal drainage class (5) (Webb and Wilson, 1995; Milne *et al.*, 1995), and a soil erodibility factor determined empirically by Summit-Quinphos. A few examples are shown in Table 1.

A digital elevation model (DEM) of New Zealand, with a grid cell size of 30 m x 30 m, was computed from 20 m contour lines and used to calculate a grid of slope values used in the model calculations. All other input data grids were aligned with this slope grid, which was divided into classes using the slope factor in the Revised Universal Soil Loss Equation as a guide (<7° = 1, 7-12° = 2, 12-17° = 3, 17-22° = 4, 22-28° = 5, >28° = 6). A rainfall intensity factor was incorporated, based on the average number of days per year with greater than 10, 20, 30, 40 or 50 mm of rain. These were calculated from data from all rainfall monitoring stations in the country with 10 or more years of complete data record over the last 30 years. The values for each station were interpolated to produce grid maps for New Zealand. The value of each grid cell was used as an index of the likelihood of a runoff-producing rainfall event occurring at that location. The level of intensity used was directly related to the soil drainage class, so that grids where the drainage class was 1 (lowest) used the 10mm rain grid, drainage class 2 used the 20mm rain grid, and so on. Rainfall intensity was used rather than total average rainfall, as research indicates that most loss of P in runoff occurs during storms (Sharpley and Rekolainen, 1997; Gburek *et al*, 2000).

Table 1. Selected examples of NZLRI soil series and ascribed data for factors relating to P runoff.

SOIL SERIES	**Description**	**P Retention class**[a]	*Drainage class*[b]	**Erodibility factor**[c]
Kakatahi loam	Yellow brown loam	1	3	1
Parau clay loam	Brown granular clay	2	4	2
Tarawera hill soils	Recent soil	2	5	3
Te Kopuru sand	Podzol	4	1	2
Waiotira clay loam	Yellow brown earth	3	2	2

[a] 1 (very high) – 5 (very low); [b] 1 (very poor) – 5 (well); [c] 1 (low) – 3 (high)

The further surface runoff has to travel across land to a stream the more opportunity there is for particulate P to be trapped by vegetation, and for runoff water to re-infiltrate the soil, allowing the opportunity for dissolved P to be adsorbed by the soil. Therefore, the bodies of water – lakes, canals, streams and rivers – from the NZ Topographic database were incorporated into the model, and used to calculate a 'distance to stream' grid, which was then simplified to a 3-level 'delivery potential' factor, based on distances of 0-30m, 30-150m, and >150m. This factor was used in the model to decrease the relative risk of P loss for those areas that are further away from bodies of water.

The final input data are soil Olsen P values, usually site specific, from recent soil test results, or in the absence of this, default values of 20, 25 or 31 are used, depending on broad soil type (sedimentary, ash or pumice). Most of the input data layers are converted to grids, and combined in a geographical information system, ArcView GIS 3.2 (ESRI, 1999), through a series of calculations to create the model, termed the Phosphorus Loss Risk Index (PLRI), which is described below.

PLRI MODEL

Fig. 1 summarises how the PLRI is calculated, showing the inputs, and the intermediate and final outputs. There are two main final indices: a background P loss index, reflecting longer-term risk, and a soluble P fertiliser loss index, estimating the risk associated with recently-applied fertiliser. The degree of relative risk is related to end users by classing the index ranges into simple terms of different degrees of low, medium and high risk of loss of P. These two main indices are calculated as follows:

Background P loss index

This is calculated by combining baseline particulate and soluble P loss sub-indices. The baseline particulate P loss index represents the risk of P loss in particulate forms (i.e. associated with eroded soil and solid organic material) if no fertiliser were applied in that year). Information from the DEM on degree of slope is obtained for each grid cell, and placed into a slope factor class as described above. The slope factor is then multiplied by the appropriate soil erodibility factor and by the runoff factor above, to give a sediment factor. This factor is then multiplied by the soil Olsen P factor to give the particulate P loss index. The baseline soluble P loss index represents the risk of P loss in soluble forms if no fertiliser were applied in that year (i.e. leakage from the soil P store). A runoff generation factor is calculated by multiplying the average number of rain events > 10-50 mm/day according to the soil drainage class. This factor is then multiplied by a delivery potential factor, calculated from the distance of each cell to the nearest body of water, using the classes 0-30 m, 30-150 m, >150 m, to produce an overall runoff factor. This in turn is multiplied by the soil Olsen P factor and soil P retention factor to give the soluble P loss index. An example of the final index results is shown in Fig. 2.

Soluble Fertiliser P loss index

The soluble fertiliser P loss index represents the risk of P loss in runoff from water-soluble fertiliser in a short-term period following fertiliser application, such as single and triple superphosphate, ammonium phosphates etc. The runoff factor calculated above is multiplied by the soil P retention factor to estimate this index. The P loss risk index values are categorised into nine relative risk classes. These classes are presented in the model outputs using a colour ramp from dark blue for 'very low', through yellow for 'medium' and up to bright red for 'very high'. Hardcopy maps are produced from the model outputs for farmers. It is then possible to see how the risk varies over a farm, and also how high the risk is overall. An example is shown in Fig. 3, where the influence of the distance to stream factor is clearly seen in most areas.

Means to reduce the risk of loss of P

The main way that Summit-Quinphos intends to use the model outputs to assist farmers to manage the risk of loss of P from their land, is through the strategic use of DAPR and DAPR-based fertiliser blends to minimise the risk of loss from

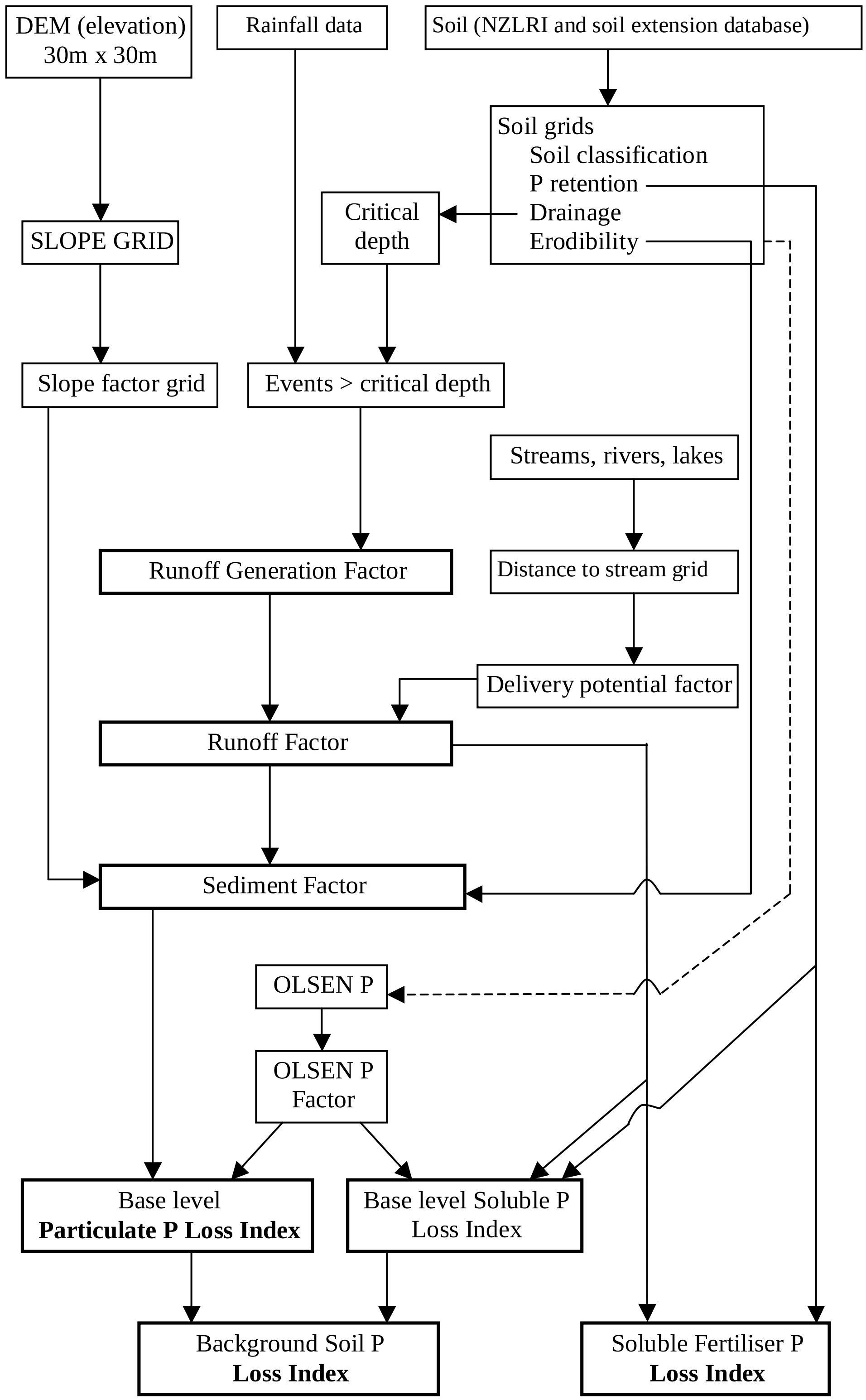

Figure 1 *Flow diagram of P loss risk index calculations*

recently-applied fertiliser. Thus as the relative risk of loss of P increases, so the proportion of DAPR in a recommended fertiliser mix would also increase. However, the model also allows other risk factors to be estimated. Thus if an area of a farm has excessive Olsen P levels, which are significantly contributing to the overall level of risk, this can be brought to the farmer's attention, and strategies employed to reduce the soil test levels to somewhere closer to the economic optimum. Similarly, if there are sites with a large erosion component, farmers may be advised to manage stock in a way that minimises treading damage to these areas, or to consider sediment-control measures such as wetland protection or buffer strips.

Nitrate leaching index

Components of the PLRI model were used to make maps estimating the risk of nitrate leaching to groundwater, namely the soil drainage class and 30mm rainfall intensity factors (Fig. 4). This Mk I version gives a very basic estimate of the risk, and we are currently working with NIWA to create a more robust model using new information from the NZLRI soils database, which may include soil macroporosity, profile readily available water and soil temperature regime class, and also rainfall data based on total annual precipitation, and more site-specific factors such as farm type, stocking rate, and annual N fertiliser application rate.

Faecal bacterial runoff index

Similarly, relevant components of the PLRI model were used to create maps estimating the risk of contamination of surface water from faecal material. Areas of different risk are delineated through factors such as degree of slope, proximity to water, rainfall intensity and soil drainage class (Fig. 5). This model is more robust than the Mk I nitrate leaching model, but ways to improve it are still being considered. For both the nitrate leaching and faecal bacteria loss maps, general and specific management advice is given regarding farming practices, including rate and timing of fertiliser spreading, location and rate of effluent spreading, grazing practices, location of sacrifice paddocks, runoff/erosion control, and wetland/riparian areas, to attempt to minimise the potential risks.

FURTHER DEVELOPMENTS

Improvements planned include use of continuous data rather than classes for many input variables, and displaying of model outputs using continuous colour ramps. Upgraded ArcView extensions will allow the model outputs to be draped over the DEM and displayed in 3D, and also for animated video clips to be created. These may be watched using standard viewer software. Other refinements to the PLRI model that may be considered in the future include incorporating a 'length of slope' factor and the risk of sub-surface losses of P.

CONCLUSIONS

The Phosphorus Loss Risk Index model allows different areas of relative risk of loss of P from land to water to be mapped on an individual farm basis, and the various sources of this risk to be identified. By combining the PLRI model outputs with knowledge of P loss mitigation measures, farmers can expect to significantly reduce the potential for P to be lost from their farms to the environment. These mitigation measures may include grazing management, riparian fencing, and strategic fertiliser application, including the appropriate use of DAPR.

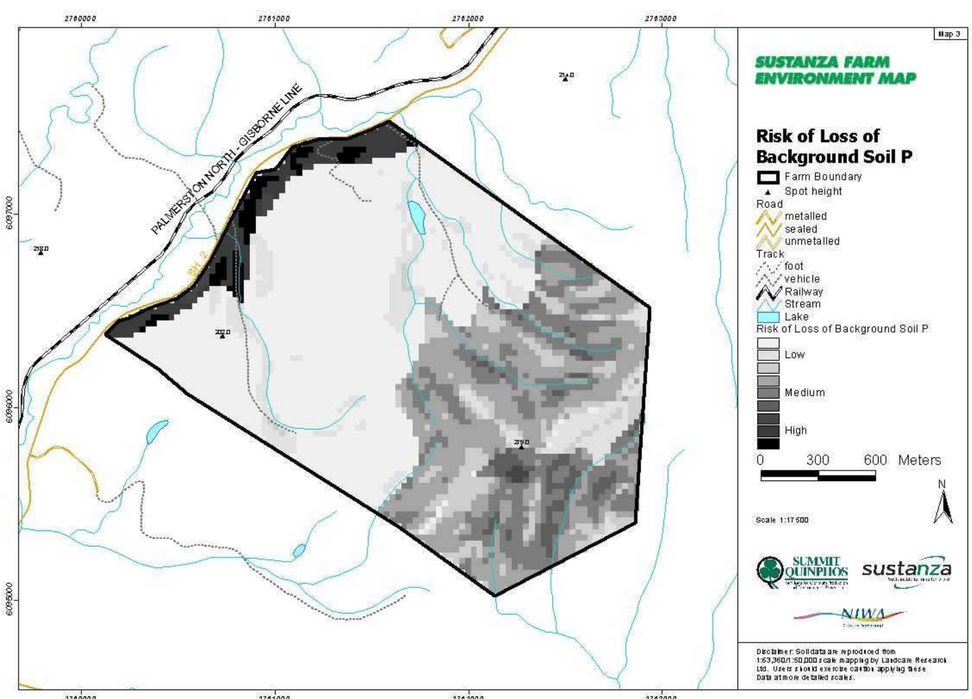

Fig. 2. Farm map showing risk of loss of background P, ranging from all degrees of low, medium and high.

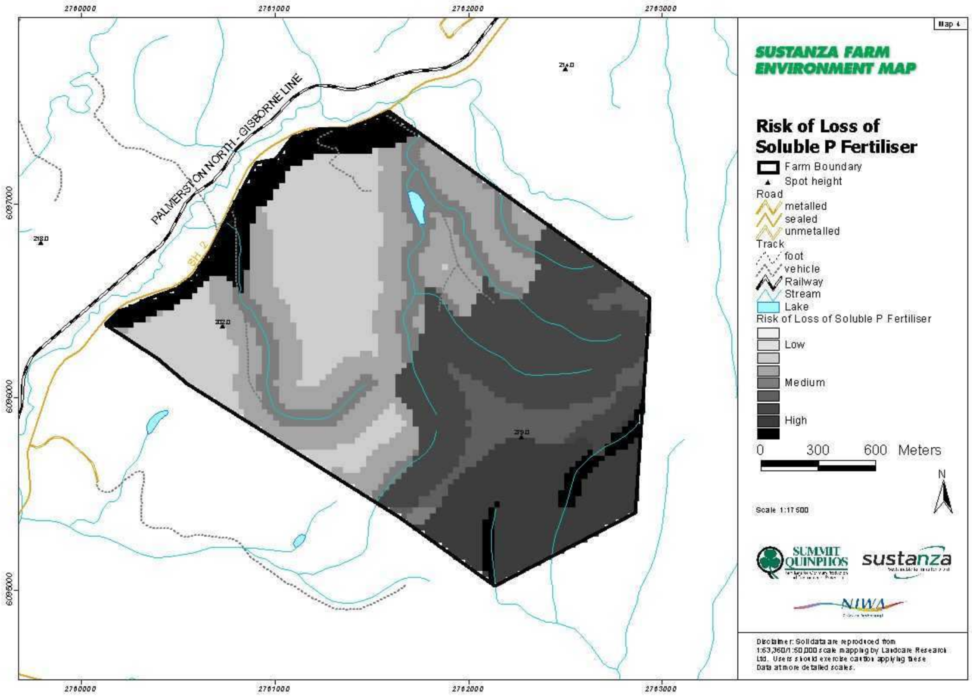

Figure 3. *Farm map showing risk of loss of soluble fertiliser P, ranging from medium-low up to very high.*

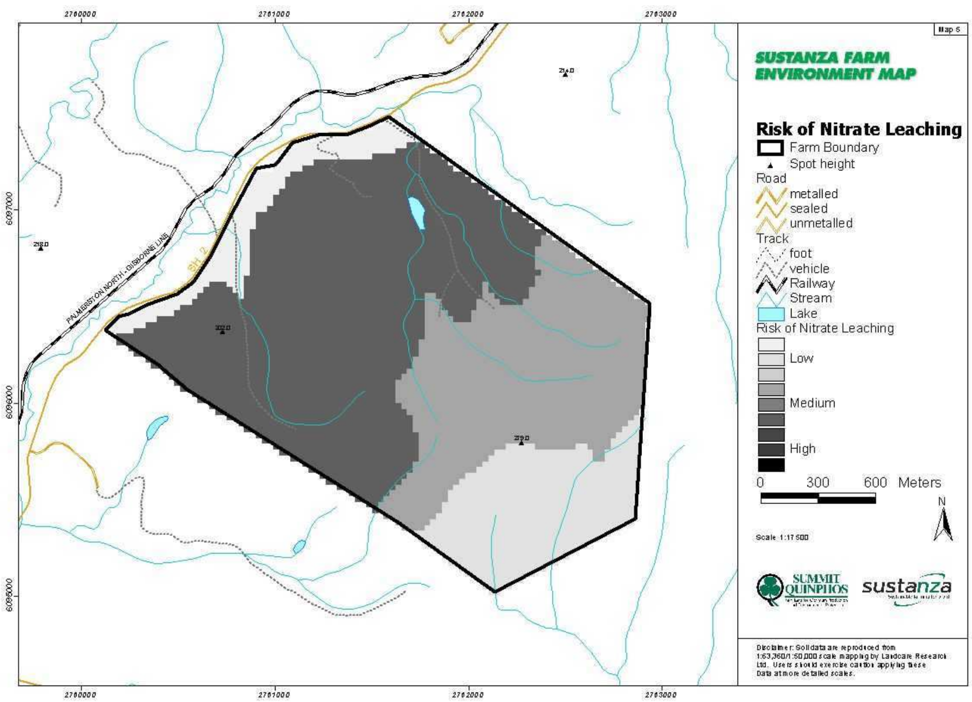

Figure 4. *Farm map showing risk of nitrate leaching, estimated to range from very low to high-medium.*

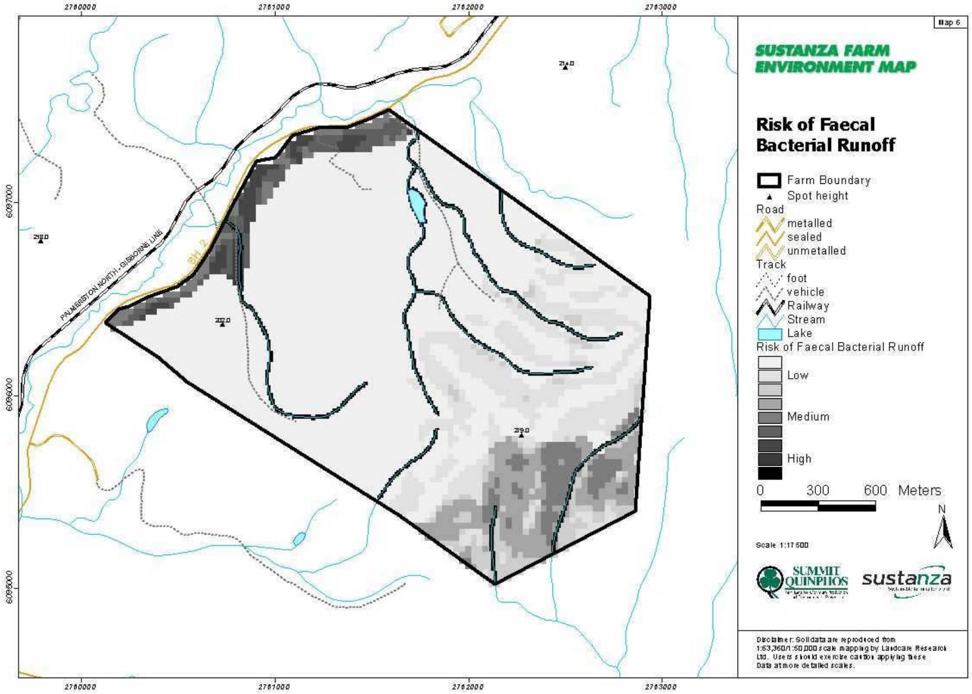

Figure 5. *Farm map showing risk of runoff of faecal bacteria, estimated to range from very low to high-medium/medium-high, and by default to very high in the immediate vicinity of surface water.*

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