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# SOIL QUALITY TARGETS FOR OLSEN P FOR THE PROTECTION OF ENVIRONMENTAL VALUES

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## Introduction

Agricultural land contributes considerable amounts of nutrients to surface water in many regions throughout New Zealand, particularly land managed under intensive farming practices. Considerable focus has been on nitrogen (N) but, as the community continues to raise concerns about the health of streams and rivers, regional councils are increasing scrutiny on the role of phosphorus (P) in water quality. The loss of P (and N) in agricultural runoff and its input to surface freshwater bodies is known to accelerate eutrophication and increase the probability of periphyton growth.

Regional councils need tools to assess potential risks to the environment, including those associated with P. Currently, soil quality monitoring (SQM) is used to assess soil health. An established set of seven indicators have been monitored in several regions of NZ since 2000. Olsen P is one of these indicators. Targets are regularly reviewed for effectiveness by the Land Monitoring Forum (LMF) e.g. are they sensible, is there new research that impacts on the understanding of environmental and production impacts, can we increase understanding of P issues by using this data better?

Historically, it has been assumed that P is not often transported through soil. However, overland flow (viz surface runoff), subsurface flow, and groundwater all contribute to the transport of P, while it is the mix of source, release and transport factors that determine the magnitude of loss by each pathway. For example, depending on soil type, land use and management, P can move laterally along mole drains (McDowell et al. 2001) or down the soil profile to groundwater (McDowell et al. 2014) or in surface flow discharges from irrigation systems (Monaghan et al. 2009, Carey et al 2004). The potential for loss increases with soil P concentration regardless of the transport mechanism. Sometimes concentrations of the dissolved P component in subsurface matrix flow can be greater than P concentrations in overland flow where the soil is of low anion storage (viz sorption) capacity and facilitated by a greater contact time with soil than occurs with overland flow. P loss in overland flow commonly has a greater particulate P component from erosion than P loss in subsurface flow (Sharpley et al. 1993). But where preferential or by-pass flow occurs, contact time with soil is lessened and the dissolved P component is less.

An important component of strategies to decrease P loss from agriculture is the determination of critical source areas where there is a high risk of P loss due to the coincidence of runoff (the combination of overland and subsurface flow) and erosion with high soil P levels (Sharpley et al. 2001, 2003; Coale et al. 2002). Traditional soil P tests to estimate for crop P availability have been used as surrogate estimates of runoff P enrichment by soil P as soil P concentration can determine the availability of P for loss in overland and subsurface flow (McDowell et al. 2003; McDowell et al. 2005).

The Olsen P test (Olsen et al. 1954) has a long history of use worldwide for assessing soil-available P to determine P fertiliser requirements. The Olsen P test is sensitive to land management, such as fertiliser additions (O'Halloran et al. 1985) or manure (Qian et al. 2004), although Olsen P is not suitable for soils amended with relatively water-insoluble P materials, such as rock phosphate (Mackay et al. 1984; Menon et al. 1989). It has been successfully used as a soil test for P in both acid and calcareous soils (Kamprath and Watson 1980). Olsen P is a commonly used soil fertility and soil quality monitoring indicator in New Zealand. Soil quality indicators can be used to assess how land use and management practices influence soil for plant growth or for potential risks to the environment. Olsen-P has been used as a surrogate measure of potential P loss through runoff (Pote et al. 1996) and or as a criterion in soil P indices for assessing risk of P loss and impact on surface waters (Sharpley et al. 1994). Therefore in conjunction with P-retention, it may be useful as a screening tool to identify areas at greatest risk of P loss and practices that have the greatest potential to decrease water quality. These areas then can be targeted for remediation or for more restrictive management.

Low concentrations of Olsen P tend to inhibit production, while high concentrations have been associated with transfer of P to surface water. Avoiding both extremes is important in retaining soil quality, while avoiding excessive Olsen P is important in maintaining water quality. Targets for indicators were developed and are now commonly used by regional councils (Hill and Sparling 2009). An upper Olsen P target of 50 mg/L for soil quality monitoring has been set to protect environmental values, especially water quality but this target has often been exceeded by land under intensive agriculture.

In this paper we estimate potential P loss from different soils and demonstrate two risk assessment models that use SQM data collected from 4 regions of NZ. The upper Olsen P target for SQM is discussed in the light of the model results.

**Method**

Soil quality data, collected over up to 15 years from across the Auckland, Southland, Waikato and Wellington regions were used. Soils were classified according to the New Zealand Soil Classification (Hewitt 2010). The P saturation factor (Olsen P/P retention) has been shown to give an indirect estimate of the magnitude of P lost in surface runoff (McDowell and Condron, 2004) and is used in both models. P retention (anion storage capacity) is an intrinsic soil property so need only be measured once at each soil quality monitoring site. Two regression models of P risk loss between soil orders were compared:

1. Dissolved Reactive Phosphorus (DRP) risk loss model: The overland flow risk equation of McDowell et al. (2005) was used to estimate risk of DRP movement.

DRP (mg/L) = 0.024 * (Olsen P/P retention) + 0.024

2. Overland flow model: The overland flow risk equation modified by site vulnerability to P loss in runoff as assessed by selecting rating values for a variety of source and transport factors (as per McDowell et al., 2005). Inputs of soil texture class, soil order (to determine mean slaking/dispersion indexes), slope class, Olsen P and P retention were considered. The P loss risk was normalised to give 100% for the highest reading.

P loss risk = ((Olsen P/P retention)*texture index * slaking/dispersion index* slope index)

**Results**

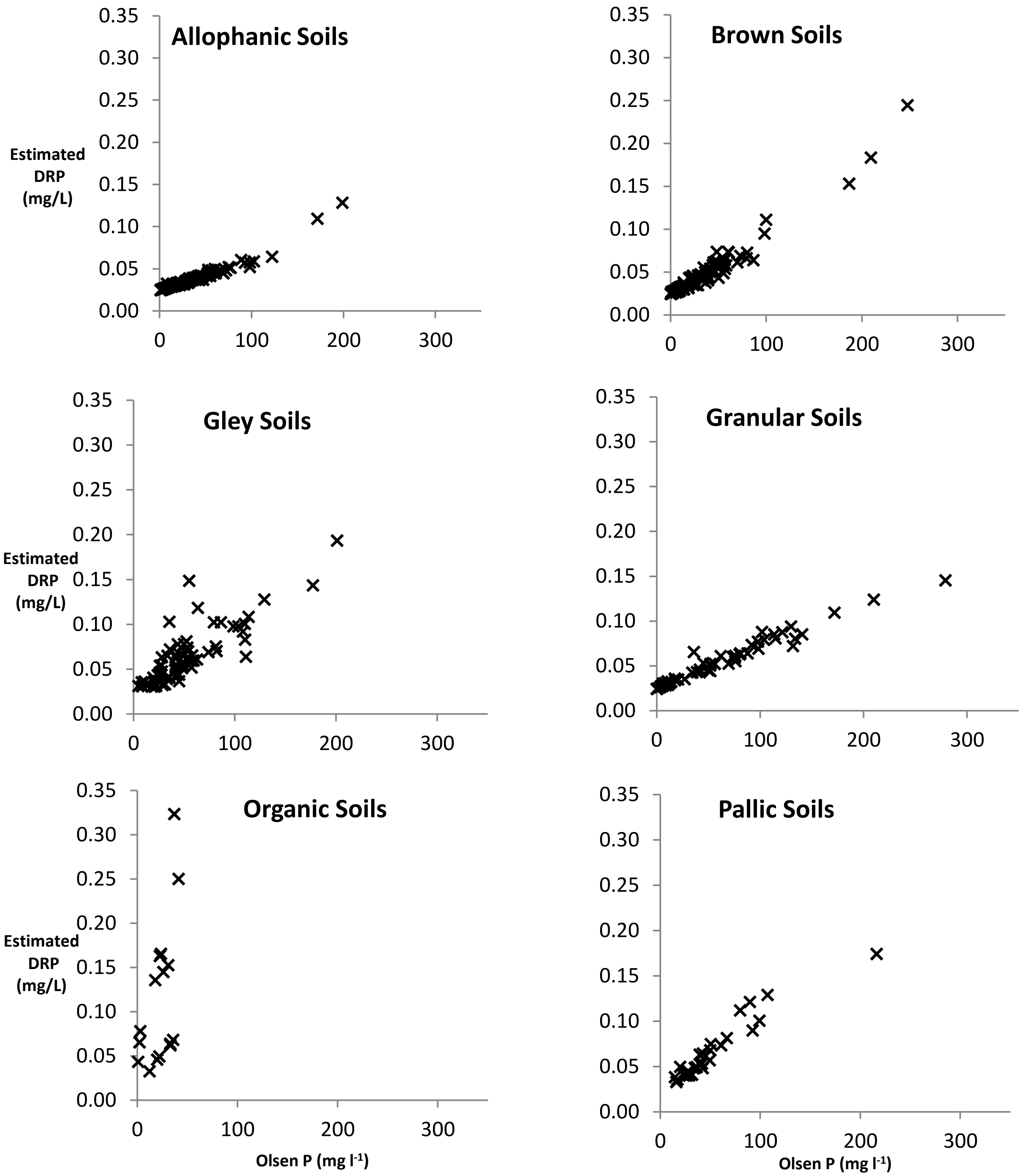
Estimated DRP and the % P loss risk were plotted against Olsen P concentration (Figures 1 and 3). The greater the slope of the scatter plot trendlines the higher the P loss risk (Tables 1-2, Figures 2 and 4).

***DRP Risk Loss Model***

Organic Soils were the most sensitive to Olsen P content having the greatest risk of P loss in overland/surface flow on flat land. In comparison, soils with high P retentions (e.g. Allophanic Soils) were least sensitive to Olsen P content and had lower risk factors. The DRP model gave an estimate of dissolved P concentration at each site and at the upper Olsen P target (50 mg/L) used for soil quality monitoring (Table 1).

Table 1. Relative risk of P loss using the DRP model and estimate of DRP at the upper soil quality Olsen P target (50 mg/L).

| Soil Order | Slope from scatter plot | DRP for Olsen P = 50 (mg/L) |
|---|---|---|
| Organic | 0.0035 | 0.21 |
| Pumice | 0.0010 | 0.06 |
| Recent | 0.0009 | 0.07 |
| Pallic | 0.0009 | 0.07 |
| Ultic | 0.0008 | 0.06 |
| Brown | 0.0008 | 0.06 |
| Gley | 0.0007 | 0.06 |
| Podzol | 0.0005 | 0.05 |
| Granular | 0.0005 | 0.05 |
| Allophanic | 0.0004 | 0.04 |



Allophanic Soils
Brown Soils
Gley Soils
Granular Soils
Organic Soils
Pallic Soils
Estimated DRP (mg/L)
Olsen P (mg l-1)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0
100
200
300

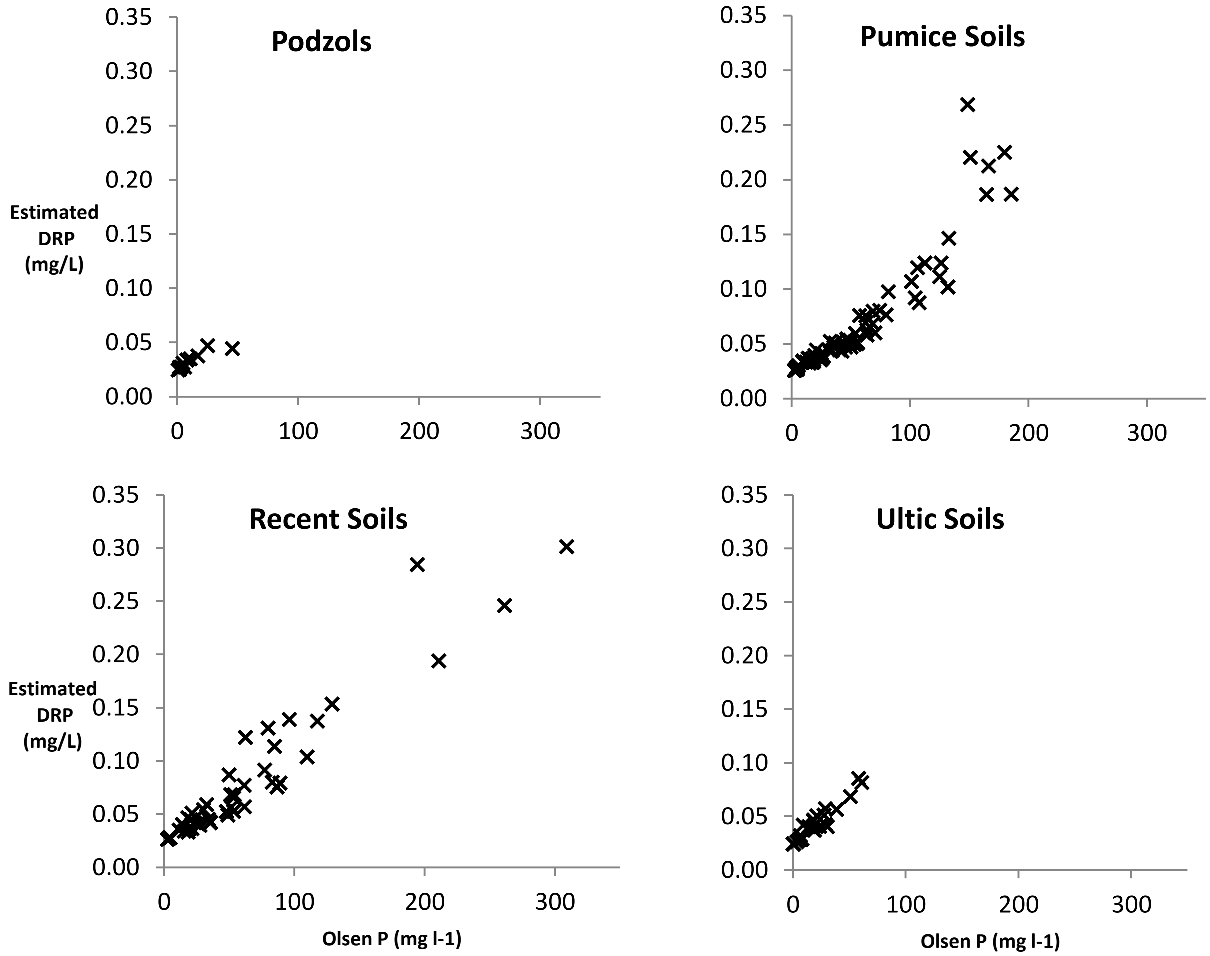



Figure 1. The DRP model: Effect of Olsen P concentration on estimated DRP. The greater the slope, the greater the risk of P loss.

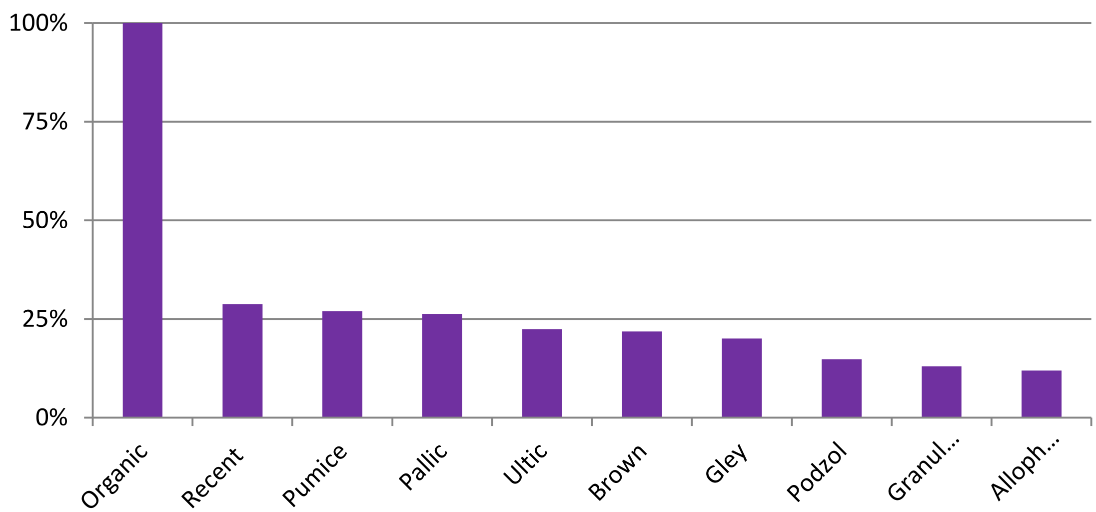
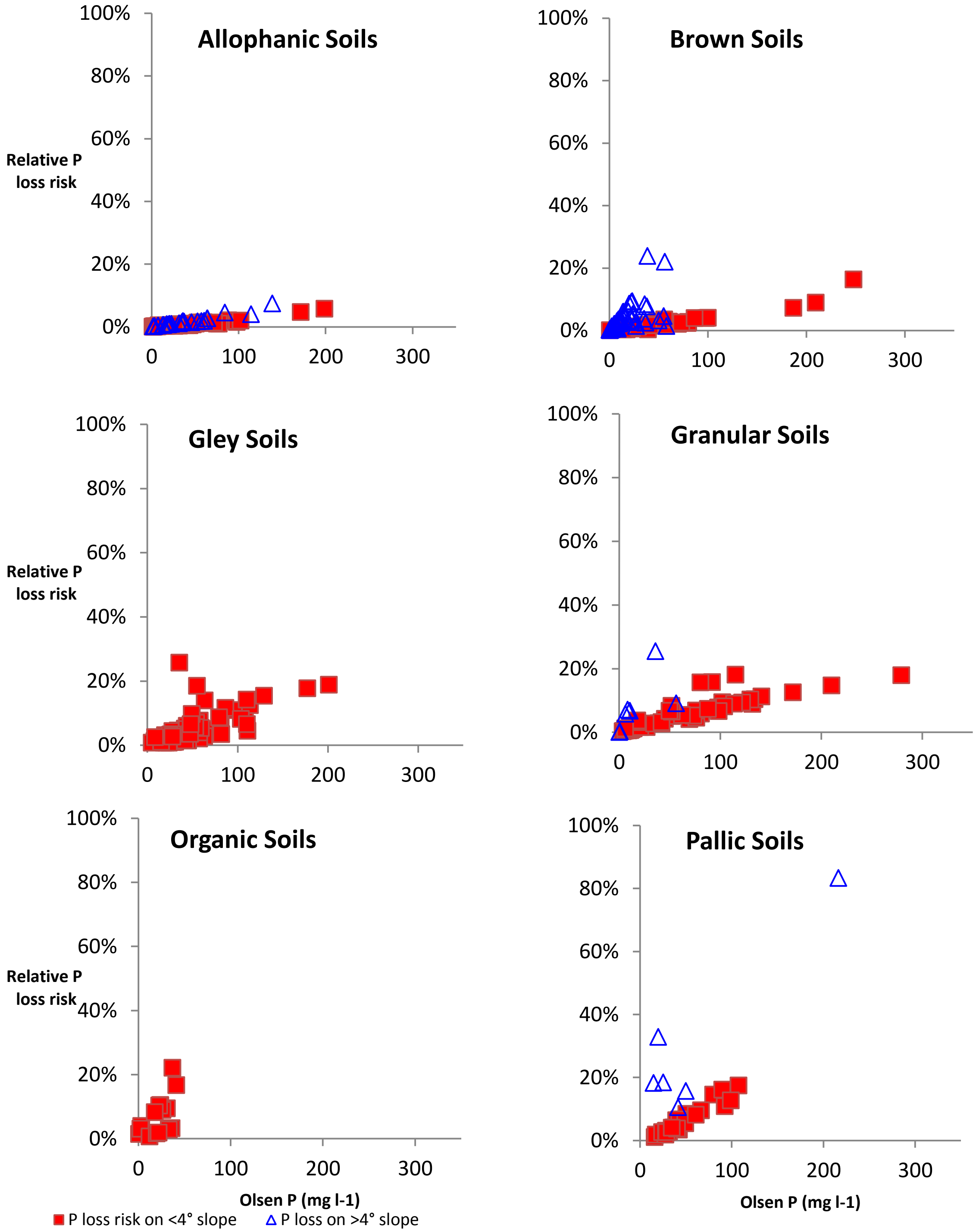



Figure 2. Relative P loss risk by soil order using the DRP model.

### *P loss risk*

Organic Soils were the most sensitive to Olsen P content having the greatest risk of P loss in overland/surface flow on flat land. In comparison, soils with high P retentions (e.g. Allophanic Soils) were least sensitive to Olsen P content and had lower risk factors. The effect of slope is presented in Figures 3-4 and Table 2). A sandy Recent soil on a steep slope had the highest risk factors measured at an individual site.



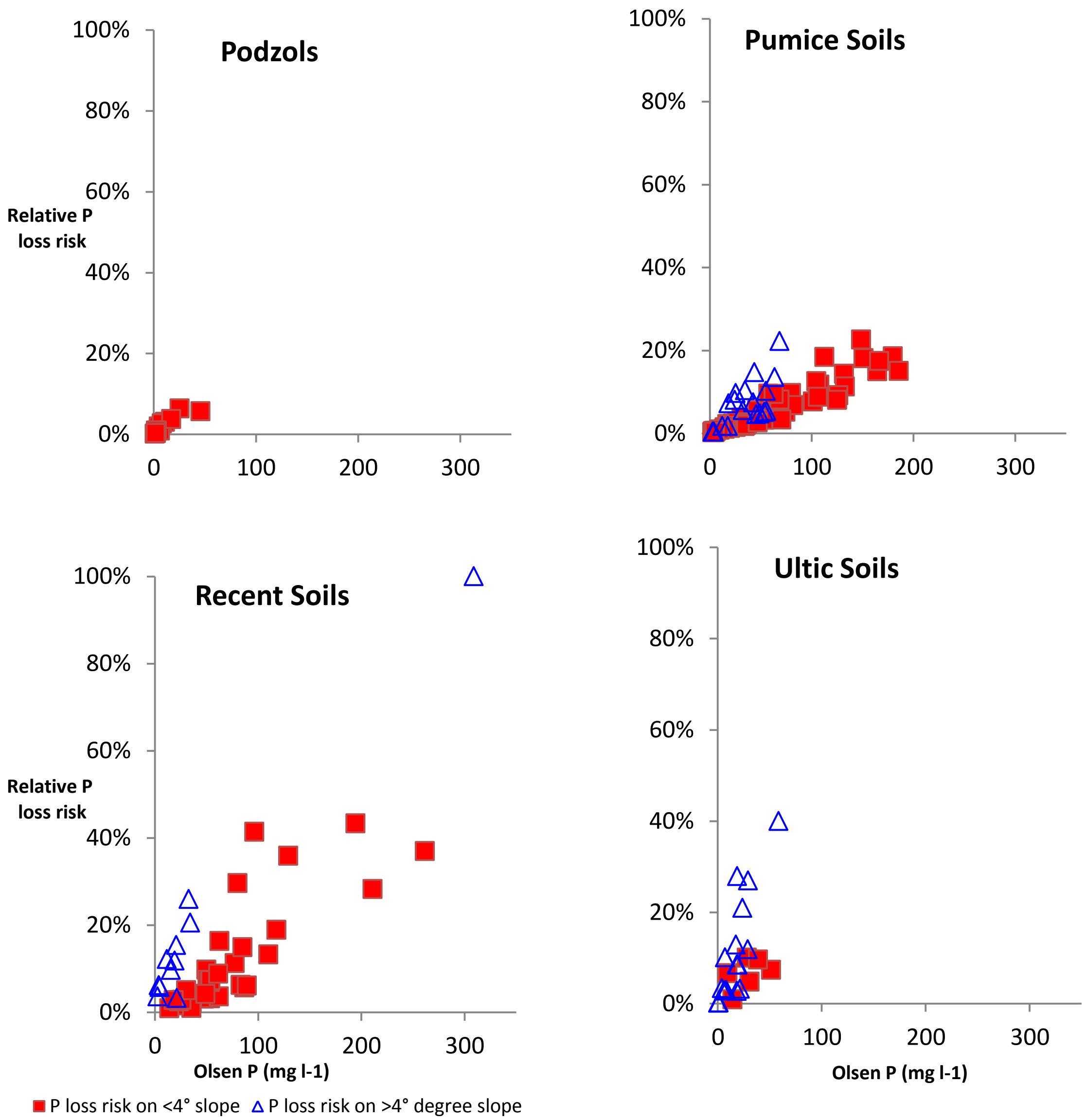



Figure 3. Overland flow model: Effect of Olsen P concentration on relative P loss risk. The greater the slope, the greater the risk of P loss.

Table 2. Relative risk of P loss using the overland flow model

| Soil Order | Slope from scatter plot | |
|---|---|---|
| | <4° | >4° |
| Organic | 0.0035 | 0.21 |
| Pumice | 0.0010 | 0.06 |
| Recent | 0.0009 | 0.07 |
| Pallic | 0.0009 | 0.07 |
| Ultic | 0.0008 | 0.06 |
| Brown | 0.0008 | 0.06 |
| Gley | 0.0007 | 0.06 |
| Podzol | 0.0005 | 0.05 |
| Granular | 0.0005 | 0.05 |
| Allophanic | 0.0004 | 0.04 |

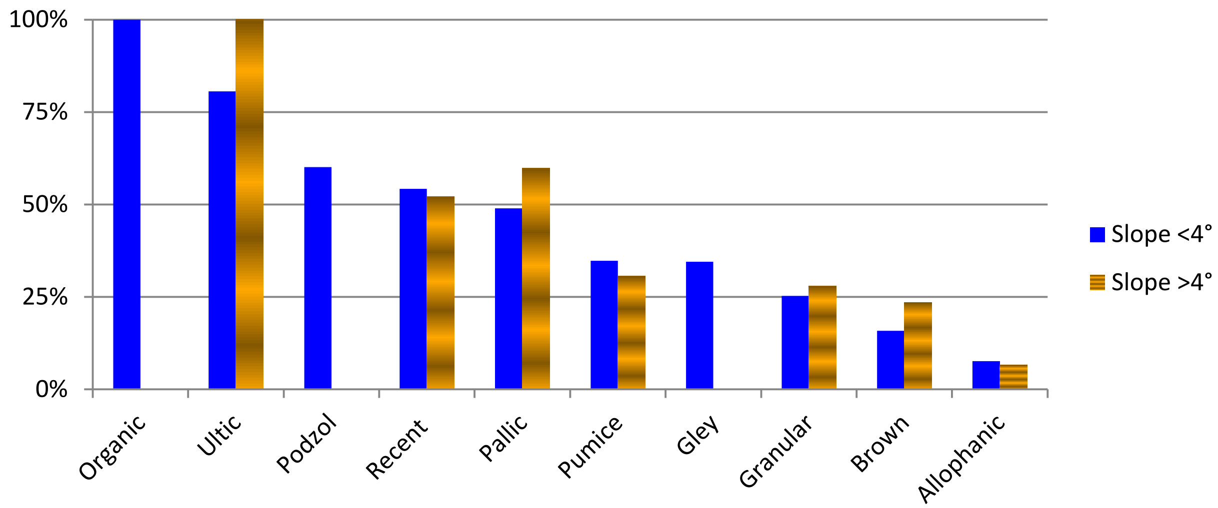



Figure 4. Relative P loss by soil order for flat land (<4°) and slopes (>4°) using the overland flow risk model.

**Discussion**

Both risk assessment models identified the relative risk of P loss in overland/subsurface flow. Both models showed Organic soils had the highest P loss risk, while Allophanic soils had the lowest risk, regardless of P saturation status. Organic soils have low P-retention due to their low mineral content, so have limited storage for P. However, Organic soils represent <1% of NZ soils (Molloy, 1993) but can represent up to 4% of area in certain regions, such as the Waikato and Southland.

The DRP model rated Recent, Pumice and Pallic soils as having the next greatest risk of P loss in overland or subsurface after Organic soils. Organic and Pumice soils have naturally low bulk density allowing relatively easy transport of soil particles along with any sorbed P. In comparison, the overland flow model rated Ultic, Podzol and Recent soils as having the next greatest risk of P loss in overland flow on flat land after Organic soils. The different results between the models reflect the inclusion of soil texture, slaking/dispersion and slope data to the overland flow risk model. P would be expected to be bound more tightly to clay than sandy soils (Sharpley and Tunney 2000); slaking/dispersion results in more fine particles that are susceptible to transport and can carry a greater concentration of P if mobilised (McDowell and Sharpley 2003; 2002); while P concentrations are greater on steeper slopes (Ahuja et al. 1982).

Recent soils were ranked 2$^{nd}$ and 4$^{th}$ for P loss risk by the DRP and overland flow models, respectively. Although Recent soils represent only 6% of NZ (Molloy 1993), these inherently fertile soils are largely used for farming purposes and should be managed appropriately to reduce the amount of potential P loss from land to water. Recent soils are commonly used in Southland for winter forage cropping as they provide suitable grazing conditions for animal health over the wet winter months. However, the environmental impact of P-loss under this intensive activity is not as well-known as N.

The risk of P loss from subsurface flow on flat areas, less likely to experience overland flow, and where the P sorption capacity of the soil has been exceeded (i.e. concentrations of Olsen P are excessive and P retention low) may be much higher than that for steeper, lower fertility areas (Figure 3). The amount of P sorption saturation affects the capacity of a soil to sorb further P. McDowell et al. (2004) reported P transported through soil via soil macropores and subsurface pathways provided P baseflow when storm events were absent, while the addition of P to a soil with a high P sorption saturation was shown to enrich runoff P more than if P was added to a soil with a low P sorption saturation, independent of soil test P level (Sharpley 1995, Leinweber et al. 1997). Therefore, the controlling mechanisms of P loss in subsurface flow from flat land, possible transport mechanisms and mitigation below the rooting zone should be further researched, as should the degree that the relationships identified by the models change under the range of New Zealand environmental conditions.

P retention has a much greater influence on an environmental upper limit than the usual soil classifications, such as soil order, used in New Zealand as each category of soils covers a considerable range of possible P retention values. Using P retention rather than soil order or another classification system is recommended when setting environmental Olsen P targets.

Soils with low P retention, such as some Pumice, Raw and Organic soils, have limited storage capacity for P, so it may be better to apply P fertilisers little and often, similar to N fertiliser management, to maintain productivity on these soils.

The National Science Challenge seeks to enhance primary productivity while maintaining and improving our land and water quality. MPI also have goals to double primary industry exports from 2012 levels by 2025. Both statements allude to or will require a level of farming intensification so tradeoffs between productivity and environmental ecosystem services are not unrealistic. How the national policy statement for freshwater management, with its aims of safeguarding life-supporting capacity, maintaining and improving overall water quality, protecting outstanding water bodies and addressing over allocation, is implemented may be an overriding factor.

Although the relative risk of P loss from different soils were identified and concentrations of DRP were estimated, caution should be used with these numbers directly as the model has been verified for just over 100 New Zealand soils (e.g. McDowell and Condron 2004). Even so, this information will assist regional councils contributing to the development of the land-based component of the Environmental Monitoring and Reporting (EMaR) project with the Ministry for the Environment and other agencies, and to generate information that will help inform the National Policy Statement for Freshwater Management process.

## Conclusion

Both risk assessment models can be used with regional council soil quality monitoring data to identify the relative risk of P loss in overland /subsurface flow. These models estimated the relative risk of P loss for different soil orders at various P saturation factors. Results showed there were substantial soil type effects on P loss risk and losses from flat land, while less than losses from slopes of the same soil type, can still be considerable.

Caution should be used in extrapolating the data beyond the intended purpose of this paper. The models have not been validated to give situation specific quantitative data on P losses across New Zealand.

Both models showed Organic soils had the highest P loss risk, while Allophanic soils had the lowest risk. Recent soils also ranked highly for P loss risk in both models. However, Organic soils represent <1% of NZ soils but can represent up to 4% of area in certain regions. Similarly, while Recent soils represent only 6% of NZ, these inherently fertile soils are largely used for agricultural purposes and should be managed appropriately to reduce the amount of potential P loss from land to water. NZ’s most valued soils, e.g. Allophanic or Brown soils, on Land Use Class 1 or 2, fertilised near the agronomic optimum (Olsen P of 30 for ash or sedimentary soils; Roberts and Morton 2009) have relatively very low P loss risk (Figures 1 and 3).

The risk of P transport may be low, due to the slope and less likely to cause overland flow, yet, if concentrations of Olsen P are excessive and P retention low, the risk from a flat high fertility area may be ultimately much higher than that for steeper, lower fertility areas.

It may be that protecting all environmental values will be impracticable if the goal of enhancing primary production is to be achieved and there will need to be a tradeoff between production and water quality.

Further research is needed to assess the controlling mechanisms of P loss in subsurface flow from flat land, possible transport mechanisms and mitigation below the rooting zone, and the degree that the relationships identified by the models change under the range of New Zealand environmental conditions.

**References**

Ahuja, L. R., Sharpley, A. N., and Lehman, O. R. (1982). Effect of soil slope and rainfall characteristics on phosphorus in runoff. Journal of Environmental Quality, 11, 9-13.

Carey, P. L., Drewry, J. J., Muirhead, R. W., and Monaghan, R. M. (2004). Potential for nutrient and faecal bacteria losses from a dairy pasture under border dyke irrigation: a case study. In Proceedings of the New Zealand Grassland Association, 66, pp. 141-149.

Coale, F. J., Sims, J. T., & Leytem, A. B. (2002). Accelerated deployment of an agricultural nutrient management tool. Journal of Environmental Quality, 31, 1471-1476.

Hewitt, A. E. (2010). New Zealand soil classification, third edition. Manaaki Whenua Press.

Hill, R. B. and Sparling, G. P. (2009). Soil quality monitoring. In 'Land and soil monitoring: A guide for SoE and regional council reporting'. Land Monitoring Forum.

Kamprath, E.J. and Watson, M.E. (1980). Conventional soil and tissue tests for assessing the phosphorus status of soil. In The Role of Phosphorus in Agriculture (Eds. F.E. Khasawneh, E.C. Sample, and E.J. Kamprath). American Society of Agronomy, Madison, WI, pp. 433–469.

Leinweber, P., Lünsmann, F., and Eckhardt, K. U. (1997). Phosphorus sorption capacities and saturation of soils in two regions with different livestock densities in northwest Germany. Soil Use and Management, 13, 82-89.

Mackay, A. D., Syers, J. K., Gregg, P. E. H., and Tillman, R. W. (1984). A comparison of 3 soil-testing procedures for estimating the plant availability of phosphorus in soils receiving either superphosphate or phosphate rock. New Zealand Journal of Agricultural Research, 27, 231-245.

McDowell, R. W., and Condron, L. M. (2004). Estimating phosphorus loss from New Zealand grassland soils. New Zealand Journal of Agricultural Research, 47, 137-145.

McDowell, R. W., and Sharpley, A. N. (2003). The effects of soil carbon on phosphorus and sediment loss from soil trays by overland flow. Journal of Environmental Quality, 32, 207-214.

McDowell, R. W., and Sharpley, A. N. (2002). The effect of antecedent moisture conditions on sediment and phosphorus loss during overland flow: Mahantango Creek catchment, Pennsylvania, USA. Hydrological Processes, 16, 3037-3050.

McDowell, R.W. and Houlbrooke, D.J. (2009) Management options to decrease phosphorus and sediment losses from irrigated cropland grazed by cattle and sheep. Soil Use and Management 25**,** 224-233.

McDowell, R. W., Cox, N., Daughney, C. J., Wheeler, D., and Moreau, M. (2015). A national assessment of the potential linkage between soil, and surface and groundwater concentrations of phosphorus. Journal of the American Water Resources Association, 51, 992-1002.

McDowell R.W., Monaghan R.M., and Wheeler D. (2005) Modelling phosphorus losses from pastoral farming systems in New Zealand. New Zealand Journal of Agricultural Research 48, 131-141.

McDowell R.W., Monaghan R.M., and Morton, J. (2003). Soil phosphorus concentrations to minimize potential P loss to surface waters in Southland. New Zealand Journal of Agricultural Research 46**,** 239-254.

McDowell, R. W., Sharpley, A. N., Condron, L. M., Haygarth, P. M., and Brookes, P. C. (2001). Processes controlling soil phosphorus release to runoff and implications for agricultural management. Nutrient Cycling in Agroecosystems, 59, 269-284.

Menon, R. G., Hammond, L. L., and Sissingh, H. A. (1989). Determination of plant-available phosphorus by the iron hydroxide-impregnated filter paper (Pi) soil test. Soil Science Society of America Journal, 53, 110-115.
Molloy, L. (ed.) 1993. Soils in the New Zealand Landscapes: The Living Mantle, New Zealand Society of Soil Science: New Zealand Society of Soil Science, Lincoln University, Canterbury, New Zealand.
Monaghan, R. M., Carey, P. L., Wilcock, R. J., Drewry, J. J., Houlbrooke, D. J., Quinn, J. M., and Thorrold, B. S. (2009). Linkages between land management activities and stream water quality in a border dyke-irrigated pastoral catchment. Agriculture, Ecosystems & Environment, 129, 201-211.
O'Halloran, I. P., Kachanoski, R. G., and Stewart, J. W. B. (1985). Spatial variability of soil phosphorus as influenced by soil texture and management. Canadian journal of soil science, 65, 475-487.
Olsen, S. R., Cole, C. V., Watanabe, F. S., and Dean, L. A. (1954). Estimation of available P in soil by extraction with NaHCO3. USDA Circular, (939).
Pote, D. H., Daniel, T. C., Moore, P. A., Nichols, D. J., Sharpley, A. N., and Edwards, D. R. (1996). Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal, 60, 855-859.
Qian, P., Schoenau, J. J., Wu, T., and Mooleki, P. (2004). Phosphorus amounts and distribution in a Saskatchewan soil after five years of swine and cattle manure application. Canadian journal of soil science, 84, 275-281.
Roberts, A.H.C. and Morton, J.D. (2009). Fertiliser use on New Zealand dairy farms. New Zealand Fertiliser Manufacturers' Research, Auckland.
Sharpley, A. N. (1995). Dependence of runoff phosphorus on extractable soil phosphorus. Journal of Environmental Quality, 24, 920-926.
Sharpley, A., and Tunney, H. (2000). Phosphorus research strategies to meet agricultural and environmental challenges of the 21st century. Journal of Environmental Quality, 29(1), 176-181.
Sharpley, A. N., Daniel, T. C., and Edwards, D. R. (1993). Phosphorus movement in the landscape. Journal of Production Agriculture, 6, 492-500.
Sharpley, A. N., Chapra, S. C., Wedepohl, R., Sims, J. T., Daniel, T. C., and Reddy, K. R. (1994). Managing agricultural phosphorus for protection of surface waters: Issues and options. Journal of Environmental Quality, 23, 437-451.
Sharpley, A. N., McDowell, R. W., and Kleinman, P. J. (2001). Phosphorus loss from land to water: integrating agricultural and environmental management. Plant and Soil, 237, 287-307.
Sharpley, A. N., Weld, J. L., Beegle, D. B., Kleinman, P. J., Gburek, W. J., Moore, P. A., and Mullins, G. (2003). Development of phosphorus indices for nutrient management planning strategies in the United States. Journal of Soil and Water Conservation, 58, 137-152.