CALIBRATION OF THE MAGETTE PHOSPHORUS RANKING SCHEME: A RISK ASSESSMENT TOOL FOR IRELAND

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ABSTRACT
Phosphorus (P) in agricultural runoff can cause serious water quality problems. Critical to reducing P inputs to surface waters is the identification of areas within a landscape that are at a high risk for P loss. Multi-criteria analysis based ranking systems have been used for this purpose, of which Magette's P Ranking Scheme (PRS) is one. The objective of this research was to evaluate two P ranking schemes, both based on modifications of the Magette PRS, for field (PRS-I) and catchment (PRS-II) scale application. Factors in the Magette PRS only related to edge-of-field P loss were also evaluated. Edge-of-field P loss factors and the PRS-I were evaluated by comparing the predicted risk level against measured edge-of-field P losses from three fields with varying soil P values. The PRS-II was evaluated by comparing predicted catchment risk for 15 catchments and sub-catchments against measured in-stream P values. Results indicate that the edge-of-field factors of the Magette PRS and the PRS-I predicted the rank and appropriate risk level for the three field sites, and that the PRS-II was also effective at predicting risk associated with the 15 catchments for which it was evaluated.

Keywords : Diffuse pollution, phosphorus, risk assessment

INTRODUCTION
In a survey on water quality in Ireland, Bowman (1996) concluded that diffuse phosphorus (P) pollution from agriculture is "of major significance in the upward trend in the spread of eutrophication of rivers and lakes", and that this trend is set to continue in the absence of corrective action. Identification of areas in the landscape that pose the greatest risk for P loss to surface waters is a critical component of P management. In general, almost all of P exported from catchments on an annual basis occurs from a minimal portion of the catchment area during one or two storm events (Sharpley and Rekolainen, 1997; Pionke *et al.*, 1997). "Strategies to remediate water quality problems associated with P movement in the landscape will be most efficient if sensitive or source areas within a watershed are identified, rather than implementing general strategies over a broad area" (Sharpley *et al.*, 1993).

As the vulnerability of a particular site to P loss is dependent on numerous factors, multi-criteria analysis approaches, designed for application to both the field and catchment scales, have been proposed as a means of deriving a P loss risk assessment. In the U.S., Lemunyon and Gilbert (1993) published a P Site Index designed to rank a field according to the relative risk for contributing P to surface waters. The primary objective of this index was that it should be easy to use and based on readily obtainable information. This original P Site Index was meant to serve as a template subject to 'local' modification to account for additional research as well as regional variations in agricultural management practices, climate, topography, hydrology and surface water characteristics.

Based on this original index, Magette (1998) developed a P ranking scheme (PRS) modified specifically for Ireland. The PRS was designed for use at both the field and catchment scale, and considers factors associated with both. Tables 1 and 2 outline the Magette PRS. The Magette PRS is based on three premises: (1) the loss and transport of P from agricultural areas to surface waters is affected by a combination of factors; (2) some factors have a greater impact ('weight') on P loss than others; and (3) the effect of a factor on the overall risk for P loss depends on the magnitude of that factor. The nine factors in the Magette PRS are each assigned a relative 'weight' ranging from 0 to 1, which is designed to account for the impact of that factor on the overall risk assessment. Based on the magnitude of each factor, a 'risk level' is assigned. For a low magnitude, the assigned risk is 1, medium = 2, and high =4. The final score is obtained by multiplying the risk level by the weight for each factor, and then summing these products. Interpretation of the final scores is as follows: < 10.8 = low risk, 10.8-21.6 = medium risk, and >21.6 = high risk.

Hubbard *et.al.* (2001) and Magette (2002) evaluated the Magette PRS on a catchment scale using data from the Lough Derg and Lough Ree Catchment Monitoring and Management System Project (Kirk, McClure, Morton, 2001). These analyses showed that the scheme accurately predicted levels of risk when using in-stream water quality as an independent measure of risk. However, there were several problems identified when implementing the PRS. No specific information on farmyard conditions was available, so 'farmyard density' was proposed as a proxy and rated according to the following distribution: > yard/30 ha = 'low', yard/15-30 ha = 'medium', and < yard/15 ha = 'high' risk. Additionally, no data were available on the timing of P application. Both evaluations also noted that inclusion of the 'P usage rate' factor at both the catchment and field scale may be redundant, as at the catchment scale, P usage in the catchment is the same value as P usage in the field. Also, with respect to the 'overland flow distance' factor, at the field-scale, "overland flow distance is a logical, and easily visualized component of the ranking system", while at the catchment scale, it "becomes less easy to visualize, but is very much related to the concept of drainage density" (Hubbard *et. al.*, 2001).

Table 1. Magette phosphorus ranking scheme.

Catchment or Field Factor	Factor Weight	Phosphorus Source and/or Transport Risk		
		Low (1)	**Medium (2)**	**High (4)**
P usage in catchment	0.5	0-5 kg P ha^{-1}	5-10 kg P ha^{-1}	>10 kg P ha^{-1}
Condition of receiving waters	0.5	Saline waters, non-impounded waters, free flowing rivers and streams w/o nutrient problems	Oligotrophic and Mesotrophic lakes	Eutrophic and Hypertrophic lakes, other special designation waters
Ratio of land to water	0.75	Ratio < 36:1	36:1 < Ratio < 44:1	Ratio > 44:1
Farmyard conditions	0.8 (0 if no animals)	See supplement (Table 2), below		
P usage rate	1.0	0-5 kg P ha^{-1}	5-10 kg P ha^{-1}	>10 kg P ha^{-1}
P application time	0.9	Spring or just prior to crop needs	Late Summer or Early Fall	All other times
Soil test P (Morgan's test)	0.8	0-6 mg P l^{-1}	6.1-15 mg P l^{-1}	>15 mg P l^{-1}
Overland flow distance	0.75	Further than catchment average	Catchment average	Less than catchment average
Runoff risk	1.0	Soil groups: 6a, 6b, 6c; 7a, 7b; 8, excluding peats	Soil groups: 4; 5 but excluding peats	Soil groups: 1;2;3a, 3b, 3c, but excluding peats

The objectives of this research were to evaluate the Magette PRS at both the catchment and field scales, and incorporate modifications, as suggested by previous research by Hubbard *et. al.* (2001) and Magette (2002), as appropriate.

Table 2. Supplemental Scoring System for Farmyards.[1]

Factor	Excellent (3 points each)	Good (2 points each)	Poor (1 point each)
Manure/slurry storage*	> 24 weeks	20-24 weeks	<20 weeks
Dirty water storage	≥12 weeks	12 weeks>x>2 weeks	<2 weeks
Silage effluent	greater than 3 days	3 days	<3 days
"dirty areas"**	100% covered	50% covered	<50% covered
Managerial Level***	Top 5% of producers	5%<x<50%	<50%
"Fatal Flaw"****	No		Yes

* Applicable to operations with animals only; allocate 3 points if no animals present; storage periods may require regional adjustment to take account the shorter winter in southern compared to northern areas

** Implies that roofed areas are fitted with gutters that divert all clean water.

*** Characteristics of exceptional managers would be attention to detail in terms of environmental as well as production issues, *e.g.* active use of nutrient management planning, well maintained equipment and facilities (*e.g.* non-leaking waterers), *etc.*

**** A "fatal flaw" is a situation that poses an imminent pollution threat (such as a cracked slurry store, a stream running through a farmyard, or a 'clean' water drain very near a pollutant source) and is cause to assign the farmyard an overall high pollution potential, regardless of other factors.

[1]Scoring - Add points. 13 or more = low ranking; 8-12 = medium ranking; less than 8 = high risk.

METHODS

Field Scale Evaluation

Factors of the Magette PRS related directly to edge-of-field P loss (P usage rate, P application time, soil test P and runoff risk) were evaluated using data collected and reported by Kurz (2000). As modification of the Magette PRS also changes final risk categorisation, categories for final risk assessment were recalculated using the procedure described in Magette (1998). The objective was to determine if P loss risk as predicted by these factors (and their associated weights) correctly categorised fields according to measured edge-of-field P exports.

Kurz (2000) investigated edge-of-field P losses in overland flow from three fields, managed as pastures, with varying soil P values. Overland flow from two fields, one with high (Cowlands) and one with low (Warren 1) soil test P (STP, as measured by Morgan's test) was collected for a period of 16 months and analysed for P content. Overland flow was collected and analysed from a field with medium STP (Warren 2) for five months, during which time sampling at Cowlands and Warren 1 continued. Measured P exports indicated that the highest rates of P loss occurred from the Cowlands, followed by those from Warren 2 and Warren 1. For the 16-month monitoring period, DRP exports were 778 g ha^{-1} for the Warren 1 and 5,300 g ha^{-1} for the Cowlands. For the 5-month monitoring period, DRP exports were 111 g ha^{-1} for the Warren 1. Soils associated with these sites are dominated by gleys.

Based on these results, and previous research by Hubbard *et. al.* (2001) and Magette (2002), a version of the Magette PRS, modified for field scale application (PRS-I, Table 3), was proposed and applied to the three fields in the Kurz (2000) study. Five of the PRS-1 factors (P usage rate, P application time, soil test P (STP), runoff risk, and condition of receiving waters) are adopted directly from the Magette PRS. The overland flow distance factor was modified for field application, as suggested by Coale and Layton (1999), to consider measured distance from the field to receiving waters as well as to include vegetative buffer width to reflect the mitigating effect of vegetative buffers on P transport to surface waters. The 'farmyard conditions' factor of the Magette PRS was included indirectly. If farmyard conditions rate as 'high' risk, P usage rate and time factors were assigned a 'high' risk, assuming that improper farmyard conditions (*i.e.* lack of adequate manure storage) are associated with high risk practices for P application. A factor for soil erosion was added to expand the applicability of the Magette PRS to include fields under tillage, row cropping, or that are poorly managed as pasture (*i.e.* overgrazed), where soil erosion would be expected to contribute to P loss. This factor was assigned a weight of '0.5' to reflect the low intensity of rainfall in Ireland (Keane, 1992). Additionally, a risk value of '0' was allowed for P usage and application timing factors on fields where no P was applied.

Table 3. PRS-I. Adapted from Magette (1998) for field scale application.

Factor	Weight for Factor	Phosphorus Loss and/or Transport Risk		
		Low (1)	Medium (2)	High (4)
P usage rate*	1.0 (0 if no P applied)	0-5 kg P ha^{-1}	5-10 kg P ha^{-1}	>10 kg P ha^{-1}
P application* time	0.9 (0 if no P applied)	Spring or just prior to crop needs	Late Summer or Early Autumn	All other times
Soil test P (Morgan's test)	0.8	0-6 mg P l^{-1}	6.1-15 mg P l^{-1}	>15 mg P l^{-1}
Runoff risk	1.0	Soil groups: 6a, 6b, 6c; 7a, 7b; 8 but excluding peats	Soil groups: 4; 5 but excluding peats	Soil groups: 1;2;3a, 3b, 3c, but excluding peats
Overland flow distance	0.75	> 30 m, or < 30 m and >15 m of vegetated buffer	< 30 m and > 8m vegetated buffer	< 30 m and < 8 m vegetated buffer
Condition of receiving waters	0.5	Saline waters, non-impounded waters, free flowing rivers and streams w/o nutrient problems	Oligotrophic and Mesotrophic lakes	Eutrophic and Hypertrophic lakes, other special designation waters
Soil Erosion	0.5	Well managed pastures	Poorly managed pastures with either overgrazing, direct access of animals to surface waters, or bare soil areas. or No-till crop systems	Row crops under tillage

*P application rate and time factors should be assigned a 'high' risk if farmyard conditions indicate a high risk farmyard (from Table 2).
Final risk values are: <8.2 = 'low', 8.2-16.4 = 'medium' and >16.4 = 'high' risk of P loss from the site.

Catchment Scale Evaluation
The PRS-II (Table 4), a modified version of the Magette PRS was proposed for catchment scale P loss risk assessment, and applied to catchments and sub-catchments using data provided by Kurz (2002), Morgan *et.al.* (2000), the Lough Derg and Lough Ree Catchment Monitoring and Management System Project (Kirk, McClure, Morton, 2001), and the Three

Rivers Project (MCOS, 2002). The PRS-II consists of 6 of the original 9 Magette PRS factors. The three factors eliminated were overland flow distance, field P usage rate and P application time. Overland flow distance was eliminated because it is related to the ratio of land to water, and also difficult to average for an entire catchment. The P application time factor was also eliminated because it is generally not available at the catchment scale, while the field P usage rate factor was eliminated because it in practice is the same as the catchment P usage rate factor. Because information on farmyard conditions for an entire catchment are also difficult to obtain, this factor was modified. If farmyard conditions for a catchment are known, then the factor remains unchanged. If they are not known, then farmyard density is used, as described by Magette (2002).

Table 4. PRS-II (adapted from Magette, 1998) for catchment-scale evaluation of P loss risk.

Factor	Weight for Factor	Phosphorus Loss and/or Transport Risk		
		Low (1)	Medium (2)	High (4)
P usage in catchment	1.0 (0 if no P applied)	0-5 kg P ha^{-1}	5-10 kg P ha^{-1}	>10 kg P ha^{-1}
Condition of receiving waters	0.5	Saline waters, non-impounded waters, free flowing rivers and streams w/o nutrient problems	Oligotrophic and Mesotrophic lakes	Eutrophic and Hypertrophic lakes, other special designation waters
Ratio of land to water	0.75	Ratio < 36:1	36:1 < Ratio < 44:1	Ratio > 44:1
Farmyard conditions/ density	0.8 (0 if no animals)	> 1 yard / 30 ha and/or as assigned by the Magette PRS	1 yard / 15-30 ha and/or as assigned by the Magette PRS	< 1 yard / 15 ha and/or as assigned by the Magette PRS
Soil test P (based on Morgan's test)	0.8	0-6 mg P l^{-1}	6.1-15 mg P l^{-1}	>15 mg P l^{-1}
Runoff risk	1.0	Soil groups: 6a, 6b, 6c; 7a, 7b; 8 but excluding peats	Soil groups: 4; 5 but excluding peats	Soil groups: 1;2;3a, 3b, 3c, but excluding peats

Final risk values were categorised according to guidelines in Magette (1998), as follows: <7.3 = 'low', 7.3-14.6 = 'medium' and >14.6 = 'high' risk of P loss from the site.

The PRS-II was evaluated by comparing PRS-II predicted risk against measured in-stream median molybdate reactive P (MRP). Water quality was assigned a rank of 'acceptable' or 'unacceptable' based on the median MRP levels, as streams with median MRP values > 30 μg P L^{-1} generally show signs of eutrophication (Bowman *et. al.*, 1996). A correlation analysis was performed to measure the association between the total PRS-II value and median in-stream MRP.

RESULTS AND DISCUSSION

Field Scale Evaluation

Results from both the edge-of-field factor PRS and the PRS-I evaluations are given in Table 5. For both versions, P application rate was high risk for the Warren 2 and Cowlands sites, and application time was assigned a low risk value, as P was applied in March. Soil test P was low, medium and high risk for Warren 1, Warren 2, and Cowlands respectively. The Warrren 1 site scored a '0' value for P application rate and timing because no P was applied to this site. The gleyed soils present at these sites indicate high water tables and frequent wetting, hence runoff risk was considered to be high.
For the PRS-I, overland flow distance was assigned a low risk value for all three fields, as the distance to nearby streams (or, in the case of Warren 1, an open drain) was 100, 75 and 250 m for Warren 1, Warren 2 and Cowlands, respectively. The condition of receiving waters factor for all three fields was assigned a low risk value to reflect that receiving waters are freshwater streams and not specifically designated for remediation. The soil erosion factor for all three sites was also assigned a 'low' risk factor to reflect the fact that all three sites are well-managed pastures.

The edge-of-field factors of the Magette PRS correctly predicted the rank order of P export, and therefore, P risk, for the three fields (Table 5). The PRS-I categorised the Warren 1 site as low risk, while both the Warren 2 and Cowlands fields were categorised as 'medium' risk (Table 5). This might seem initially to be a failure of the PRS-I to distinguish between the Warren 2 and Cowlands fields. However, edge-of-field P exports from the Cowlands field must be transported across 250 m to reach the nearest stream. While P exported from the field may be high, the overland flow distance mitigates the impact of edge-of-field P losses on receiving waters. In this respect, a 'medium' overall risk for P loss *and* transport to receiving waters may be appropriate for this site.

Table 5. Final risk assessment values and ranks for Edge-of-field Magette PRS factors and the PRS-I as applied to the Kurz (2000) sites.

Site	P Export (g ha^{-1})	Edge-of-Field Magette PRS [1] factors only	PRS-I[2]
Warren 1	778 (16-months)	4.8 (low)	6.6 (low)
Warren 2	300 (5-months)	10.5 (medium)	12.3 (medium)
Cowlands	5,300 (16-months)	12.1 (high)	13.9 (medium)

1 Final risk values for the Edge-of-field factors were categorised as follows: <5.5 = 'low', 5.5-11.1 = 'medium' and >11.1 = 'high' risk of P loss from the site.

2 Final risk values for the Edge-of-field factors were categorised as follows: <8.2 = 'low', 8.2-16.4 = 'medium' and >16.4 = 'high' risk of P loss from the site.

Catchment Scale Evaluation

Results from application of the PRS-II at the catchment scale are summarised in Table 6. Of the 15 catchments analysed, 3 ranked 'high', 2 ranked 'low' and 10 ranked 'medium', for overall risk of P loss and transport. All corresponding water quality for 'high' and 'low' risk sub-catchments ranked 'unacceptable' and 'acceptable', respectively. For the 'medium' risk watersheds, 50% of the corresponding water quality rankings were 'unacceptable', and 50% were 'acceptable'. Correlation analysis concluded that there was a significant positive correlation between PRS-II and median MRP ($r = 0.53$, $P = 0.04$). Although confidence in this evaluation would be enhanced by additional data, results indicated that the PRS-II is an appropriate tool for identifying P loss risk at the catchment scale.

Table 6. Summary of final PRS-II catchment risk values and rank order as compared to water quality and water quality rating.

Sub-catchment	PRS-II Total Numerical Score	PRS-II Risk Categorisation	Measured Water Quality Median MRP (µg L^{-1})	Corresponding Water Quality Rating*
Dripsey – D2	15.8	HIGH	91	Unacceptable
Lossetkillew	15.5	HIGH	58	Unacceptable
Beef Unit	15.4	HIGH	50	Unacceptable
Dripsey-D1	13.4	MEDIUM	26	Acceptable
Omard	13.2	MEDIUM	68	Unacceptable
Bellsgrove	12.7	MEDIUM	32	Unacceptable
Ballyheelan	12.0	MEDIUM	34	Unacceptable
Drumnavrick	11.2	MEDIUM	18	Acceptable
Dairy Farm	10.9	MEDIUM	50	Unacceptable
Clonshanbo	9.4	MEDIUM	89	Unacceptable
Yellow River	9.4	MEDIUM	28	Acceptable
Clarianna	8.7	MEDIUM	16	Acceptable
Ballina	7.9	MEDIUM	29	Acceptable
Grange Rahara	6.7	LOW	5	Acceptable
The Cottage	6.4	LOW	29	Acceptable

It is, however, important to consider that using one measure of stream water quality to define and categorise overall water quality in a stream may not be entirely accurate. For example, catchment P export rates over 0.35 kg P ha^{-1} yr^{-1} can lead to eutrophic conditions in some lakes (Tunney *et. al.*, 1998). In the Dripsey D1 catchment, which exported 1.61 – 1.64 kg P ha^{-1} yr^{-1}, median MRP was only 26 µg L^{-1} (Morgan *et.al.*, 2000), thus qualifying it as an 'acceptable' stream despite the high P export rate.

CONCLUSIONS

Results from this evaluation of the Magette PRS edge-of-field factors, the field scale PRS-1, and the catchment scale PRS-II indicate that these approaches have potential for identifying critical source areas for P loss at both the field and catchment scales. Further evaluations using data collected simultaneously on field and catchment characteristics (including P usage) and in-stream P concentrations could potentially help refine and improve the predictive capability of these ranking schemes.

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