Développement d'un système agroenvironnemental d'aide à la décision pour la réduction de la pollution de l'eau par des sources agricoles diffuses

Introduction

Phosphorus (P) is an essential element for crop and animal production. The high P concentration accelerates the eutrophication of receiving fresh waters. This process may be accelerated by the P losses from agricultural lands. In Quebec, the nonpoint sources of P are recognized as the main source of P in surface water bodies (MENVQ, 1999). The P concentration in several agricultural watersheds in Quebec was found ranging from 0.1 to 0.2 mg/l (Gangbazo, 1997; Painchaud, 1996), which is higher than the guideline limit for Quebec's Rivers (0.03 mg/l) (MENVQ, 2001). Therefore, recently attention has been drawn towards the control of agricultural P nonpoint sources to minimize the surface water degradation. Despite its importance, controlling P loads from agricultural nonpoint sources by using limiting parameters such as soil test phosphorus (STP) or threshold of P saturation % is not sufficient to assess the risk of P losses from cropland (Sharpley et al., 2002). Neither is a simple reduction in P applications through fertilization an acceptable solution. Moreover, the problem with this method is that conventional soil test analysis is designed to estimate the availability of agronomic P present in the soil than the potential of P loss (Sharpley et al., 1996). This project seeks to work with stakeholders to build a comprehensive and robust modeling framework to reduce phosphorus loads in rural watersheds. Stakeholders will be involved in evaluating and recommending P levels that run off their lands, aiming to attain acceptable water quality standards. This will permit the development of a policy and decision-making framework for use by watershed managers, policy makers, government regulatory agencies and agro-environmental consultants. The quality of local water resources will be improved and more reliable and cost-effective P management plans will be achieved. The overall result will be an improvement in the quality of life and health of rural communities and an improvement in the socio-economic and environmental conditions of rural watersheds.

The modeling framework will be developed and tested on the Beaver Brook (Castor) watershed in Quebec. The P index will be used to identify individual high-risk sites, and P flux models will be used to assess the cumulative effects of P loads from the watersheds. The P-Index is a tool for risk assessment that ranks the relative potential of P movement. The original version was developed in the USA by Lemunyon and Gilbet (1993). The concept of P-Index is used by planners and stakeholders to assess the potential of P leaving cropland to receiving waters. The current version of the Québec phosphorus index (Q_P-Index) has an additive structure which combines source and transport factors of phosphorus (P). However, many studies have demonstrated that such an algorithm does not consider the interaction between these factors adequately. This study focuses on the development and validation of a modified P Index (QM_P-Index) to improve management of P on agricultural lands, by taking the effects of subsurface drainage into account. Subsurface drainage has a significant increase in the amount of P loading into receiving water bodies. Enright and Madramootoo (2004) observed that as much as 40 % of total annual TP losses took place by subsurface drains. However, subsurface drainage class was determined based on drain spacing which explains the volume of water drained. In a study performed by Chikhaoui et al. (2009), simulation of drain spacing effects on phosphorus loss through tile drainage from the two sites showed that every incremental increase of 5 m in tile drain spacing might result in a decrease of 20 % of TP loads in subsurface drainage for a fine textured soil.

Chandra Madramootoo

Methodology

Data used in this study were collected at four experimental fields located near Bedford in the Pike River watershed, which drains into Missisquoi Bay (Figure 1). These agricultural sites are characterized by different soil types (sandy loams to clay loams) and crops grown were corn, alfalfa, soybean or hay. Two sites with tile drainage were established in October 2000, while two other sites (without tile drainage) have been monitored since December 2004.

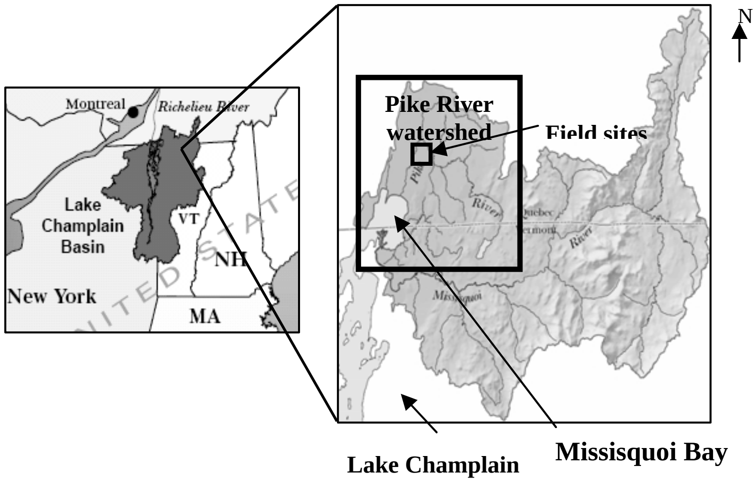

Figure 1.

Location of two experimental sites in the Pike River watershed (Adapted from LCBP).

The experimental fields were instrumented to monitor surface runoff and tile drainage flow and various water quality parameters. The instrumentation, data collection, and sampling methodology are identical for all sites. Automatic water samplers were installed on all sites to obtain water samples during storm events. These samples are analyzed for total phosphorus (TP) and total dissolved phosphorus (TDP). However, the total particulate phosphorus (TPP) was estimated as the TP minus TDP.

In order to develop a MQ_P-Index simple and multiple regressions were utilized. A threshold of 0.1 was used to establish the significance of the different parameters. Stepwise regression was performed to evaluate the relationship between TP losses (dependent variable) and the source and transport factors (independent variables) and to identify which factor contributed highly to the P potential movement. The analysis and interpretation of the collected data improved the understanding of the mechanism of P transport and the interaction between different factors. This information, together with a literature review formed the basis of the modified P index, which for the first time includes a subsurface drainage component. It should be noted that the data used in the multiple regression analysis were collected in Castor watershed by IRDA.

To evaluate the performance of this tool, the MQ_P-Index values were compared with TP observed data from four experimental fields. The MQ_P-Index was calculated for each experimental site for three years, in total 12 years. The MQ_P-Index values were plotted against the corresponding observed values of TP. However, the MQ_P-Index performance was evaluated by calculating the coefficient of determination (R^2). In addition, field-level P loss predictions from SWAT for 2 fields (with tile drainage) were compared with values from the MQ_P-Index for the same fields.

Results

The relationship between measured annual edge-of-field TP loads from the experimental sites and the MQ_P-Index values edge-of-field values calculated for the same areas is shown in figure 2. A highly significant correlation was found with R^2 = 0.92. Further, this coefficient of determination was improved from 0.36 to 0.92 as compared to results of Q_P-Index in previous study (Goulet et al., 2006).

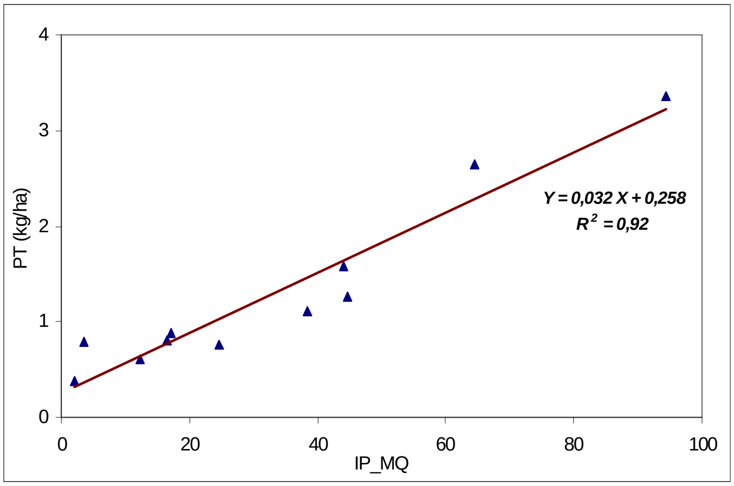

Figure 2. Compared measured annual TP losses with MQ_P-Index values for the same fields.

However, an analysis was performed to evaluate the performance of the MQ_P-Index with data from field with and without tile drainage separately. Figure 3 illustrates the separate relationships. The MQ_P-Index was strongly and significantly correlated to annual measured TP loads for both types of experimental field (figure 3).

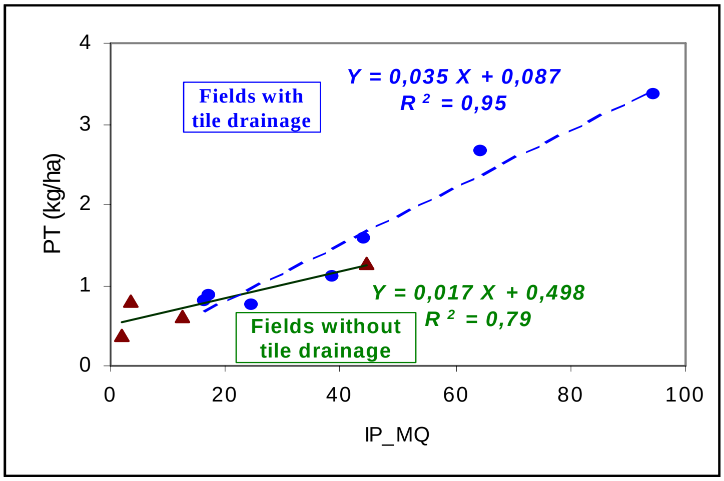

Figure 3. Compared measured annual TP losses with MQ_P-Index values for the same fields (with and without tile drains).

Results from this study give a more interesting indication of P loss than the Q_P-Index. Therefore, the MQ_P-Index appears to be best adapted to Quebec conditions and to reflect accurately soil characteristics, management practices, and P loss pathways. Additionally, this result can probably be explained by the fact that the MQ_P-Index considers adequately the interaction between source and transport factors and takes in account certain factors neglected by the MQ_P-Index, such as connectivity and crop residues. The result shows that the MQ_P-Index is a reliable tool to assess P loss risk from cropland than STP and P saturation threshold. The analysis of observed data show that the TP loss was 70% greater from the cropland with STP equal to 143 kg ha^{-1} than it was from the cropland with STP equal to 289 kg ha^{-1}. Therefore, fertilization regulations that only consider STP and P Saturation levels are not a reliable predictor tool of P loss risk.

A second correlation was established between M_PI values and management practice simulations using SWAT (Soil and Water Assessment Tool) predicted TP. The comparison of MQ_P-Index values and management practice simulations using SWAT predicted TP for the same fields and input data is shown in figure 4. A highly significant correlation existed between MQ_P-Index values and SWAT results with a R^2 equal to 0.79. Moreover, figure 4 shows that points are distributed symmetrically around the regression line. The simulations data were not used in the development of MQ_P-Index, but only for evaluation. This result indicates that the MQ_P-Index is a suitable tool and can be used successfully for P risk assessment. Moreover, the MQ_P-Index values were very sensitive to BMPs as presented previously. Based on those results we can conclude that the MQ_P-Index can be used to select conservation practices in order to improve downstream water quality. The MQ_P-Index uses also readily available data compared to SWAT model.

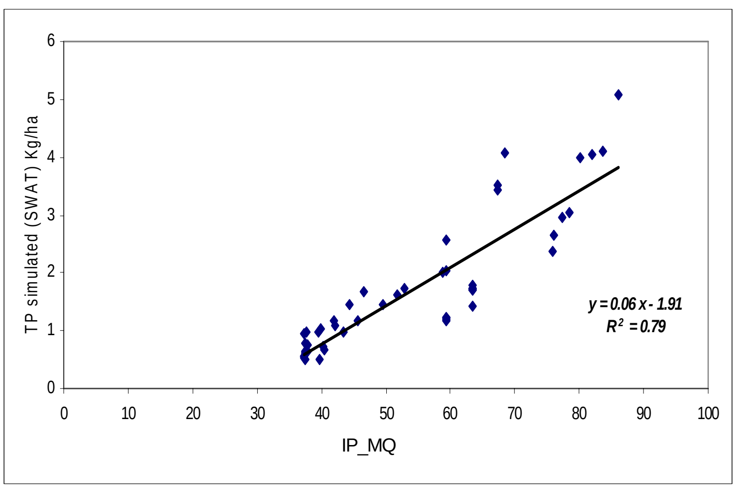

Figure 4. Compared field scale TP loss predictions from SWAT with values from the MQ_P-Index for the same fields.

Conclusion

Results indicated that the MQ_P-Index is a suitable tool, which can be used successfully for P risk assessment. The M_PI with a multiplicative structure improves risk assessment for agricultural P losses. TP losses were significantly correlated to runoff, applications of fertilizer and balance of P while STP, erosion and drainage were the most important factors affecting the TP losses. The STP accounted 52 % of variability of TP losses. Further, this result shows that at field scale, the STP alone is not sufficient to assess the potential of P movement unless it's used in conjunction with transport factor as erosion, surface runoff and subsurface drainage. Furthermore, the suggested P-Index reflects Québec conditions and incorporates all potential P loss pathways. Unlike the determinist models, the MQ_P-Index used available data to reflect P loss potential without any calibration. Its user friendliness and its flexibility lend itself to be used by a simple farmer. Moreover, the MQ_P-Index can help decisions makers to identify sites with high P vulnerability, and select conservation practices in order to improve downstream water quality. To make easy calculating MQ_P-Index, a computer user interface under Excel was developed. This tool includes many screen of field and soil input data. Further, the application of the MQ_P-Index at watershed scale is underway. More results will be published in Chikhaoui et al., 2009).

References

Chikhaoui, M.**,** C.A. Madramootoo, N. Stämpfli and A. Sarangi (2009). Simulation of phosphorus losses from two tile-drained fields in Quebec. Submitted to Biosystems Engineering.

Chikhaoui, M., Madramootoo, C. A., Gollamudi, A. and N. Stämpfli (2009) Development and validation of a modified Quebec phosphorus index. Submitted to Agriculture, Ecosystems & Environment.

Enright, P. and C.A. Madramootoo. 2004. Phosphorus losses in surface runoff and subsurface drainage waters on two agricultural fields in Quebec. *In* Proceedings of the Eighth International Drainage Symposium, Sacramento, California, March 21, 2004. St. Joseph, MI: American Society of Agricultural Engineers.

Gangbazo G. 1997. Contrôle de la pollution diffuse agricole par l'approche des objectifs environnementaux de reject. Vecteur Environnement 30(4):25-31.

Goulet, M., J. Gallichand, M. Duchemin, M. Giroux. (2006). Measured and computed phosphorus losses by runoff and subsurface drainage in eastern Canada. American Society of Agricultural and Biological Engineers. Vol. 22(2): 203-213.

Lemunyon, J.L., & Gilber, R.G. (1993). The concept and need for a phosphorus assessment tool. Journal of Production Agriculture, 6, 483–496.

Ministry of Environment of Quebec (MENVQ). 1999. Water management in Quebec: A public Consultation Document. Quebec, QC, Quebec Government.

Ministry of Environment of Quebec (MENVQ). (2001). Critères de qualité de l'eau de surface au Québec. Direction du suivi de l'état de l'environnement. Ministère de l'Environnement, Québec, QC.

Painchaud, J. (1996). La qualité de l'eau des rivières du Québec. État et tendances. Compte-rendu des conferences du 2e colloque sur la gestion de l'eau en milieu rural. Conseil des Productions Végétales du Québec inc, Québec, QC.

Sharpley, A. N. (1996). Availability of residual phosphorus in manured soils. Soil Sci. Soc. Am. J. 60: 1459–1466.

Sharpley, A.N., Kleinman, P.J.A., McDowell, R.W., Gitau, M., & Bryant, R.B. (2002). Modelling phosphorus transport in agricultural watersheds: Processes and possibilities. Journal of SoilWater Conservation, 57, 425–439.

Chandra Madramootoo