The Nutrient Loading Model (NLM) for Agricultural Soils

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Abstract

When manure is applied to supply crop nutrients, the application rate is based primarily on the nitrogen (N) content. As a result, the situation arises where manure as applied contributes more phosphorus (P) to the soil than is required by the crop. This has a potential environmental consequence: runoff and erosion may eutrophy streams and ponds. Few analytical tools are available to facilitate the establishment of application limits for P on agricultural land. The task is complex because the impact is usually downstream of the farmland and can be episodic in nature. A modeling approach is best suited in order to integrate all of the factors.

The Nutrient Loading Model (NLM) is a simple representation of the environment as a topsoil compartment, a subsoil compartment and a water compartment. Nutrient, both background (historic) and applied, is lost from the topsoil by leaching, erosion and crop removal. In the water compartment, the model includes processes of sedimentation to the stream bed and flushing. When reasonable input parameter values are used, representative of Manitoba farmland, the model indicates that over an average year, P contributions to water result in acceptable water concentrations. However, after severe storm events, the water P concentrations will be markedly higher than the annual average and the potential for impact is greater. Present soil fertility recommendations may lead to decreased soil P with time, but the current guidelines for manure application may result in accumulation of P in the soil. This accumulation coupled with periodic severe storm events has a significant potential to result in impacts such as eutrophication. The NLM can compute estimates of impacts following specific inputs (forward computation), but is intended to provide reverse computation, where P loading limits are defined based on the criteria for acceptable water concentrations.

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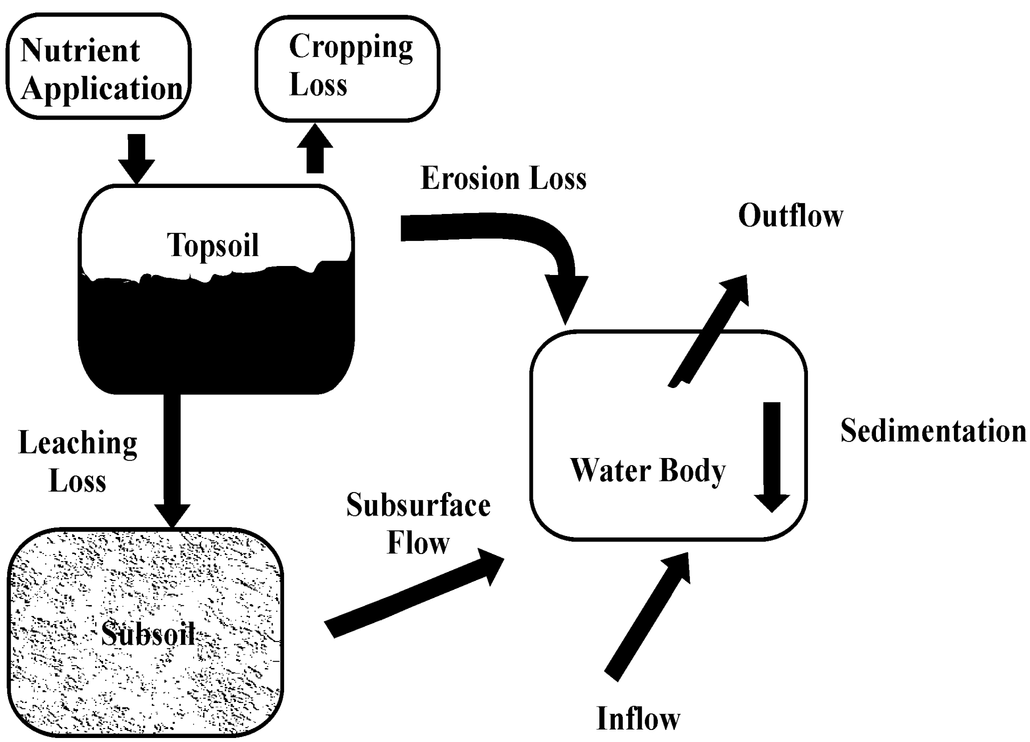
Introduction

The Nutrient Loading Model (NLM) was developed to address the specific needs of regulators interesting in sustainable applications of phosphorus (P) and nitrogen (N) to crop land. These could be manure or fertiliser applications, but the most resent interest has been in manure application guidelines. The NLM was structured to be a simple model, but to incorporate the most important soil aquatic and landscape processes. Figure 1 is a schematic of the model, and indicates the model deals with loss of nutrient:

- from land by erosion,
- from land by leaching,
- from land by crop removal,
- from water by sedimentation,and
- from water by flushing.

Figure 1. Schematic of the NLM



The underlying equations (the following text boxes) are derived from relationships described in the literature. Their integration together in the NLM is the important feature. The NLM was designed to deal with both single events and annual processes (flow chart for annual-process model shown in Figure 2). It can compute in a ‘forward’ or predictive mode, and in a ‘reverse’ mode to set load limits based on a specified stream P concentration limit. It can also be run in a deterministic or probabilistic mode.

The mass flow rate of the erosive component from the topsoil is given by:

$$F_e = \frac{[A_o Lw + C_B Lwh(t)]ELw}{Lwh(t)Tp_B}, \quad t \le T$$

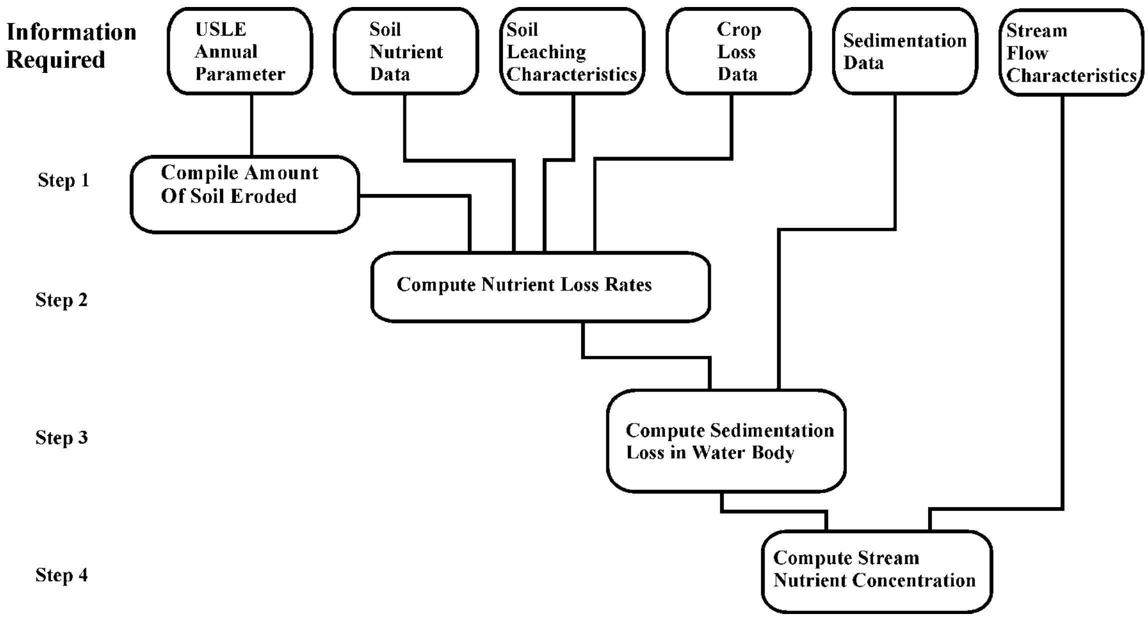
Here:
E **is the amount of soil eroded during the storm**
P_B **is the bulk density of the soil**
T **is the duration of the storm**
h **is the depth of the layer in which the contaminant is mixed upon deposition**
A_o **is the total amount of contaminant initially deposited per unit area**
C_B **is the initial concentration of contaminant present in the soil per unit area before deposition**
K **is the saturated hydraulic conductivity**
L **is the length of the field and**
w is the width of the field.

The subsurface discharge rate is given by:

$$F_s = \frac{[A_o Lw + C_B Lwh(t)]Kswh(t)}{100Lwh(t)(a + p_B K_d)}, \qquad t \le T, \quad I > K$$

Here:
w **is the width of the field and**
a **is the porosity of the soil**
s is the percent slope of the field
K **is the saturated hydraulic conductivity.**

Figure 2. Annual Erosion Loss Flowchart



Results

Only initial results are available at this time, model verification and validation is underway in 2001/2002. For what were considered ‘central values’ of the input parameters, the model shows slow depletion of soil P at the present fertiliser guideline rates, and slow increase in soil P if the upper limit for P application based on manure guidelines were used. The latter would only occur in very intensive application situations. These deterministic results, for 100 years from present, are shown in Figures 3 and 4.

Probabilistic results indicate, as expected, a strong skew in stream P concentrations (Figure 5). This has an important implication. There is a finite probability of exceedances of water P concentration guidelines in any setting. It is important that the guidelines, if they are developed, be worded in a way to recognise that this variability exists. Occasional exceedances are normal, and are beyond the control of the farmer or the regulators.

Figure 3. Application of P at the rate recommended to meet crop needs: Simulation of the change in total soil P concentration (kg m^{-2}) for 100 years.

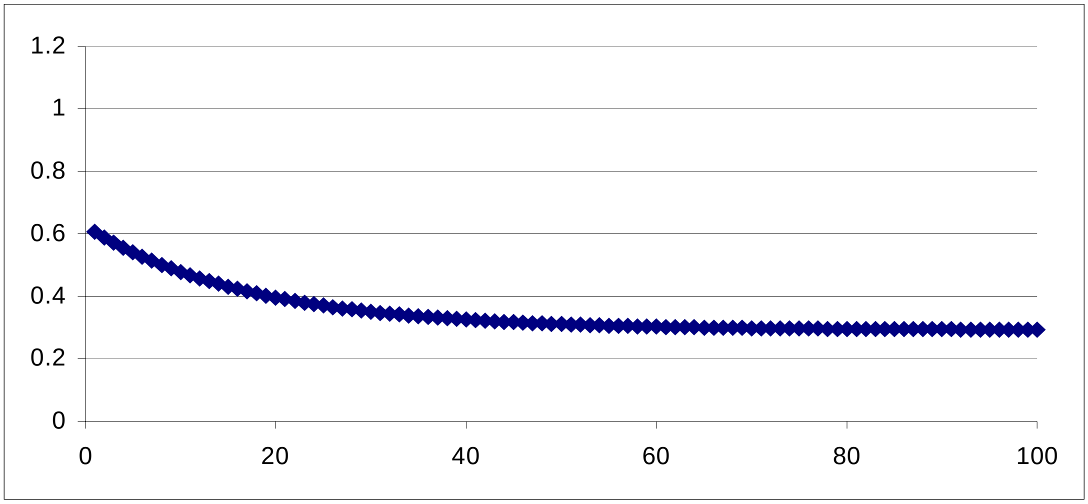
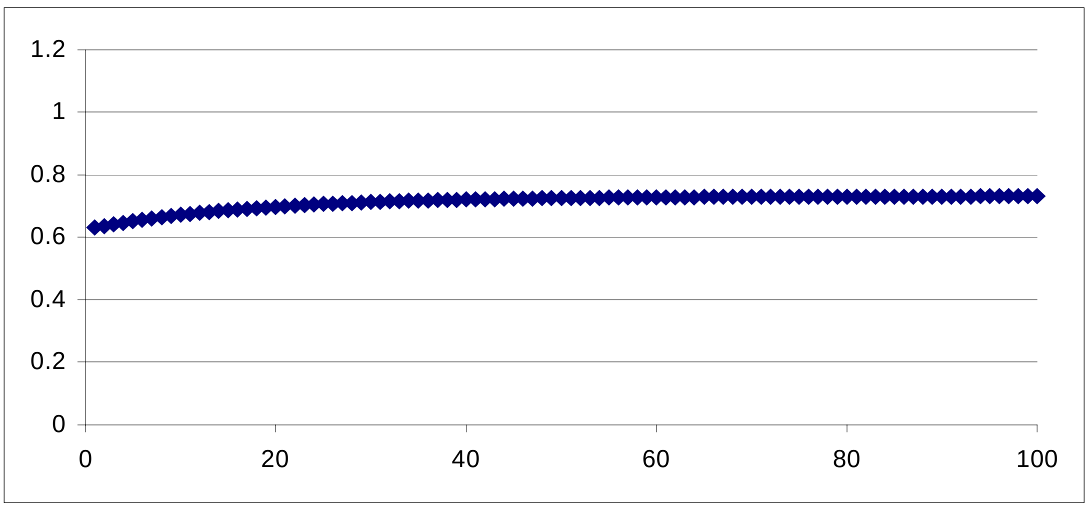


Figure 4. Application of P at the limit indicated in the manure application guidelines: Simulation of the change in total soil P concentration (kg m^{-2}) for 100 years.



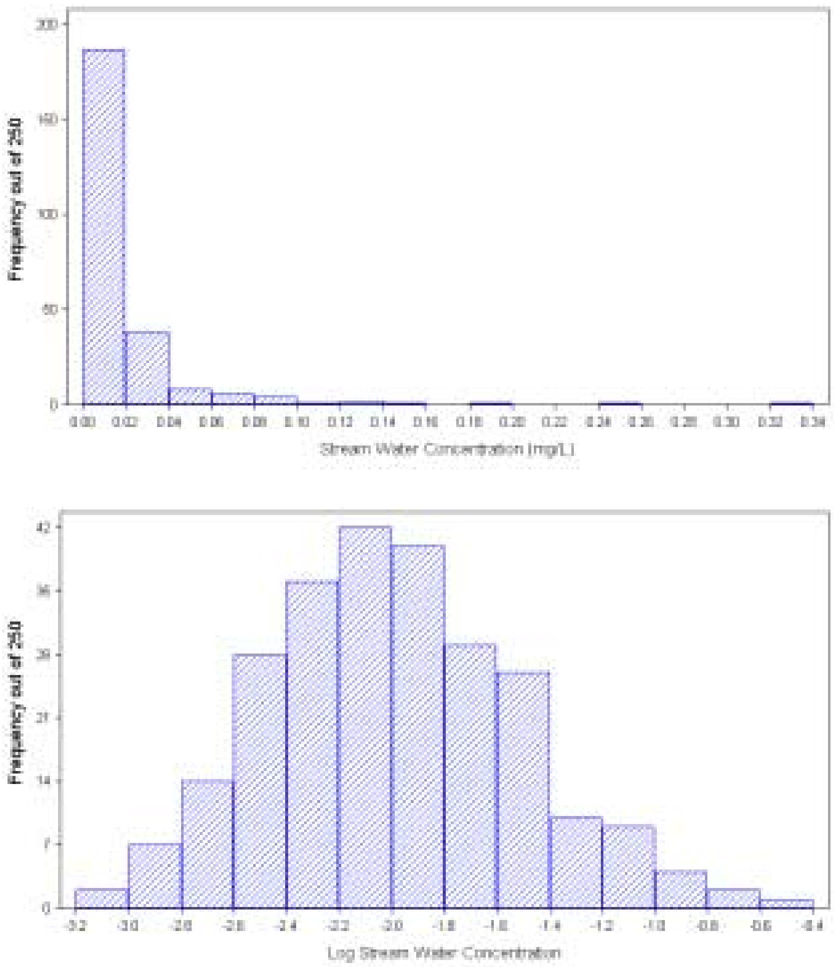


Figure 5. Frequency histograms of stream water concentration for 250 probabilistic runs where rainfall, soil erodibility and stream volumetric flow rate were randomly varying through ranges 2-fold above and below their values from the central case.