Mapping Ground water Vulnerability to Pesticide Leaching with a Process-based Metamodel of EuroPEARL: The Molignée catchment case, Belgium

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Introduction

Pollution of water resources by plant protection products (PPP) is a key issue in the European environmental policy. European directives and strategies, such as the Water Framework Directive (Directive 2000/60/EC) or the Thematic Strategy on the Sustainable Use of Pesticides, impose Member States to take measures to limit environmental hazards caused by the use of PPPs. This study was conducted in the Walloon Region, Belgium, to consolidate the scientific basis for implementing these measures at the local and regional level. It is performed in the framework of the PESTEAUX project that aims implementing a GIS tool for assessing diffuse (non-point sources) pollution of water resources by PPPs.

The main objective of the study here is to parameterise the MetaPEARL metamodel for assessing groundwater pollution risk by PPPs in the Molignée Catchment, located in the Belgian Condroz region.

The Molignée catchment area (76 km^2) (Fig. 1) consists of alternate (in the North-South direction) anticlines micaceous sandstone Devonian (Famennian level) and synclines limestone Carboniferous (Tournaisian, Visean level), oriented east-west. Schists of Houiller level are encountered by location. The main soil types encountered are: loamy-stony soils with micaceous sandstone load (30 % of the catchment) in the crests (anticlines) and loamy-stony soils with limestone load (20 %) in the calcareous depressions (synclines). The best arable land are loamy soils with good natural drainage (10 %), based mostly in the calcareous depressions. Main land uses are: meadowland (30%), wheat (20 %), barley (15 %), sugar beet (6 %) and maize (5 %).

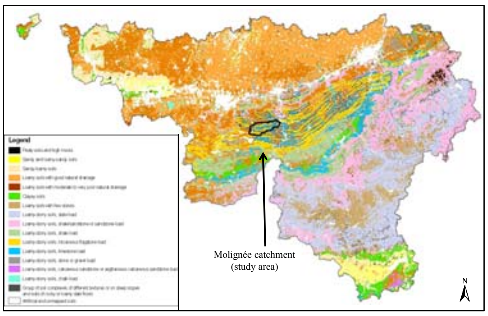


Fig. 1 – Generalisation of the Digital Soil Map of the Belgian Walloon region (Bah et al., 2006, FUSAGx – DGA, MRW), considered as Main Soil types of Wallonia (southern part of Belgium).

MetaPEARL Parameterisation

Material and methods

The process-based metamodel MetaPEARL (Tiktak et al., 2006) was inferred from predicted leaching concentrations obtained with a spatially distributed, dynamic, multi-layer, mechanistic leaching model, referred to as EuroPEARL (Tiktak et al., 2004). MetaPEARL ignores soil profile vertical parameters variations, assumes steady flow and aims to predict the leaching concentration percentiles of PPPs at 1-m depth. MetaPEARL is based on an analytical expression that describes the concentration (µg L^{-1}) of pesticide leached (C_L):

$$\ln C_L = \alpha_0 - \alpha_1 X_1 - \alpha_2 X_2 - \alpha_3 X_3$$

in which α_0, α_1, α_2, and α_3 are the regression coefficients and where X_1 (unitless), X_2 (unitless) and X_3 (unitless) are independent regression variables, which are defined as follows :

$$X_1 = \frac{\mu \theta L}{q} \qquad X_2 = \frac{\mu.\rho.fom.kom.L}{q} \qquad X_3 = \frac{gSL}{q} \approx 0$$

in which μ (days^{-1}) is the first-order degradation rate coefficient, θ (m^3 m^{-3}) is the soil water content at the field capacity, L (m) is the depth considered (standard depth of 1-m), q (m d^{-1}) is the volume flux of water, ρ (kg dm^{-3}) is the dry bulk density of the soil, *fom* (g g^{-1}) is the organic matter content, *Kom* (dm^3 kg^{-1}) is the coefficient for distribution over organic matter and water , *g* (unitless) is the transpiration stream concentration factor and *S* (d^{-1}) is the water uptake by plant roots.

Only arable lands were taken into account, by overlying the Digital Soil Map of Wallonia (Fig. 1) with the digital land use map named SIGEC (*Système Intégré de Gestion et de Contrôle*). The resulting units were used for the metamodel parameterisation. Data on soil profiles with arable land use were extracted from both the Agricultural University of Gembloux (Belgium) and the RéQuaSud (*Réseau Qualité Sud*) databases. In all, 7 detailed soil profiles descriptions for the different soil horizons and 86 composite samples were taken into account to extract soil basic properties (fraction of main soil texture classes – clay, loam and sand, and soil organic carbon content) needed to determine soil and hydrodynamic parameters of MetaPEARL. The soil organic matter content (f_{om}) was obtained by multiplying soil organic carbon by 1,74 (conversion factor for arable land) ; the soil dry bulk density (ρ) was estimated according to the Rawls (1983) pedotransfer function (PTF) as calibrated for Belgian soils by Boon (1984).

Soil water content at field capacity (θ) was estimated with the Van Genuchten (1980) equation and Vereecken (1988) PTFs developped for Belgian soils. The water flux (q) was calculated as the difference between the average rainfall in the Molignée catchment (924 mm/year) minus actual evapotranspiration.
In order to consider the wide variety of pesticides used, the PPP concentration leached was calculated for a set of four generic PPPs characterized by a wide variety in sorption and degradation behaviour (FOCUS, 2002) (Table 1). The PPP dose was 1 kg ha^{-1}. Spring and autumn applications were considered in order to investigate the effect of application time on PPP leaching risk.

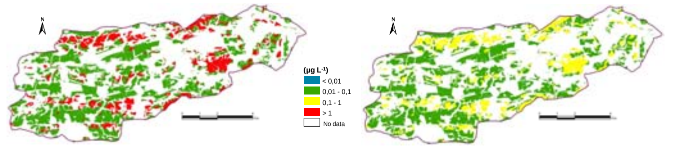
Table 1. Four generic substances defined by the FOCUS group.

Pesticide	**Koc (dm^3 kg^{-1})**	**Kom (dm^3 kg^{-1})**	**$t_{1/2}$ (days)**	**Pvap (mPa)**	**S (mg L^{-1})**	**MM (g mol^{-1})**	**µ (days^{-1})**
A	103	60	60	1.10^{-7}	90	300	0,0116
B	17	10	20	1.10^{-1}	90	300	0,0347
C	52	100	20	1.10^{-7}	50	200	0,0347
D	60	35	20	1.10^{-1}	90	300	0,0347

Results

1) Predicted leaching concentration spatial pattern

Maps of the predicted leaching concentration (C_L) for the generic pesticide “A” are shown in Fig. 2. Low predicted leaching concentration (between 0.01 and 0.1 µg L^{-1}) is observed for arable lands with a high OM content (between 1.28 and 1.35 %) both in autumn and spring. These lands correspond in the Molignée catchment area to loamy soils with a good natural drainage, and to loamy-stony soils with stone and gravel load. High predicted leaching concentration (> 0.1 µg L^{-1}), more significant in autumn than in spring, is observed for arable lands with and OM content less than 1 %.



(a) Autumn application – Pesticide A (b) Spring application – Pesticide A

Fig. 2 – Predicted leaching concentration in response to annual applications in autumn (a) and in spring (b) as calculated with MetaPEARL for pesticide A. Areas without agricultural land use or where soil properties data are not available (No data), are not parameterised.

2) Sensitivity analysis

In order to identify the most significant soil and hydrodynamic parameters, a sensitivity analysis using the approach One-Factor-At-a-Time (OAT) was carried out. The method consisted in modifying each soil and hydrodynamic parameters of the metamodel by -10% and +10% around its initial value. The effect of each modification is analysed on the predicted pesticide leaching concentration (output of the metamodel), for which his sensitivity was quantified by calculation of an index called “Sensitivity Index” (SI) and a percentage of variation. As shown in Fig. 3, the predicted leaching concentration is particularly sensitive to the soil profile depth (L), dry bulk density (ρ) and OM content. Also, negative values of SI obtained for these three parameters signify that they vary in the opposite direction compared to the predicted leaching concentration. For example, an increase of 10 % of the OM content causes a reduction of near 50% to the predicted leaching concentration.

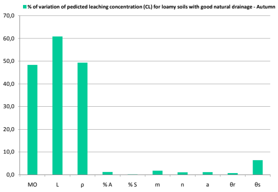


Fig. 3 – % of variation of the predicted leaching concentration to the soil and hydrodynamic parameters using the approach One-Factor-At-a-Time (OAT), for loamy soils with good drainage, in response to autumn application.

3) Uncertainty analysis

Uncertainty analysis of the predicted leaching concentration, based on the most three sensitive parameters (L, ρ and OM), was conducted. Figure 7 represents, for autumn application, the frequency distribution of 1000 random simulations of pesticide leaching concentration for loamy-stony soils with limestone load. The uncertainty (variability) associated to each of the three sensitive input parameters produces a very large dispersion (uncertainty) of the predicted pesticide leaching concentrations.

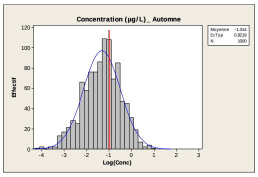


Fig. 4 – Frequency distribution of 1000 random simulations of pesticide leaching concentrations for loamy-stony soils with limestone load, for autumn application. For this example, average concentration obtained (0.04 µg L^{-1} for autumn application) is less than 0.1 µg L^{-1} (recommended value for groundwaters).

Conclusions

- Available data sets in the Molignée catchment (Belgium) allowed implementing the MetaPEARL metamodel to assess the spatial distribution of groundwater pollution risk by PPPs.
- The sensitivity analysis identified soil depth, bulk density and organic matter content as critical parameters in the assessment.
- The spatial variability of most sensitive input parameters results in a large uncertainty in the predicted pesticide leaching concentration.

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General Assembly of the European Geosciences Union, 19 – 24 April 2009, Vienna, Austria

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