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Testing the PEARL model in the Netherlands and Sweden

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Abstract

The Plant Protection Product Directive (91/414/EEC) stresses the need of validated models to calculate predicted environmental concentrations. The use of models has become an unavoidable step before pesticide registration. The main topic of the research presented here is the validation of the PEARL model for two well-instrumented sites located in the Netherlands and Sweden. First the water transport module was calibrated, and then the solute transport module, keeping unchanged the water transport parameters. The Dutch site is characterised by a sandy soil. PEARL predictions were very satisfactory for both soil moisture content and groundwater level. Predictions for the tracer, bentazone and ethoprophos concentrations in the soil profile were also successful. The Swedish site is characterised by a structured clay soil. PEARL was successful in predicting soil moisture profiles and the draining water. PEARL performed well in predicting the soil concentration of bentazone at different depths, however, it did not predict accurately solute concentration in the drainage water. A sensitivity analysis of the PEARL model performed on the Swedish site showed the greater importance of the pesticide degradation properties over the soil hydraulic properties.

Keywords: PEARL; Pesticide leaching; Model; Sensitivity analysis

Software availability

Name of software: PEARL
Developers: RIVM/ALTERRA/MNP
Contact address: Alterra Green World Research, PO Box 47, 6700 AA Wageningen, The Netherlands; The National Institute of Public Health and the Environment (RIVM), PO Box 1, 3720 BA Bilthoven, The Netherlands; Netherlands Environmental Assessment Agency (MNP), PO Box 303, 3720 AH Bilthoven, The Netherlands.
Email: pearl@mnp.nl
Availability: Available for download at: http://www.alterra-research.nl/pls/portal30/docs/folder/pearl/pearl/home.htm

1. Introduction

Plant Protection Products (PPPs) are part of the modern agricultural production system and are used to control occurrence of weeds, insects, and diseases prejudicial to crop production, and to minimise the labour requirements. They are also used for regulating vegetative crop growth. In Europe, about 800 substances were registered in 1993 for use as PPPs. This number has decreased to about 400 in 2003 as a result of the legislation enacted in the beginning of the 90s. Groundwater contamination by pesticides can seriously limit water availability since such type of contamination is expensive and/or impossible to mitigate, and could persist for long periods. This is of particular concern since Europe relies on 65% of groundwater supply for drinking water. The European Commission has been setting stringent regulation to control and limit the adverse effect that might come from the use of pesticides. In the Sixth Environmental Action Plan (1600/2002/EC), emphasis is placed on pesticides with the specific objectives to reduce the risks to human health and environment

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from the use of pesticides by banning or limiting strictly the placing on the market of the most hazardous pesticides, and ensuring that best practices are used for the authorized pesticides.

The European Directive on Drinking Water 80/778/EEC (amended by Directive 98/83/EC) sets the maximum allowable concentrations for pesticides in water for human consumption to 0.1 μg/l for individual substances and for total amount of pesticides and their residues to 0.5 μg/l. This standard of 0.1 μg/l has consequently been proposed by the Commission in the proposal for a new Directive on groundwater. No legislation exists about the PPP concentration in soil. However, Annex VI of Council Directive 91/414/EEC prohibits the placing on the market under certain specific conditions of very persistent active substances or substances that form in laboratory tests non-extractable residues, unless it is scientifically proven that there is no accumulation in the soil that might harm the environment or the succeeding crops. A second Directive directly affecting PPP use is the Council Directive 79/117/EEC that prohibits the placing on the market of PPPs containing certain active substances. In addition, to reduce the impacts of pesticides on human health and the environment and achieve a more sustainable use of pesticides, the Sixth Environmental Action Programme calls for the development of a thematic strategy on the sustainable use of pesticides. A wide consultation of all stakeholders was launched in 2002 with the adoption of a Communication that outlined a number of measures that could be adopted in the framework of the Thematic Strategy [Com (2002) 349].

In the EU, the placing on the market of PPPs is regulated at the Community Level by the Council Directive (91/414/EEC). This Directive includes six annexes and in particular Annex VI that outlines the ''Uniform Principles'' for harmonized evaluation and risk assessment of products. The Council Directive states that Member States shall evaluate the potential pesticide leaching to groundwater under the proposed use. Many models have been developed to assess the fate of pesticides (Denzer et al., 2005; Röpke et al., 2004; Vanclooster et al., 2000a). However, the Council Directive recognizes the lack of Community validated calculation models. To address this specific issue a FOrum for the Co-ordination of pesticide fate models and their USe (FOCUS) was co-jointly established by the European Commission and the European Crop Protection Association. Guidance is available for pesticide leaching to groundwater (FOCUS, 1995, 2000), for pesticide persistence in soil (FOCUS, 1996), and for pesticide loss to surface water (FOCUS, 1997). Four pesticide-leaching models are currently used in the context of FOCUS groundwater working group. These four tools include three chromatographic pesticide-leaching models, which are PEARL (Tiktak et al., 2000), PRZM (Carsel et al., 1998), and PELMO (Klein, 1995), and one macro-pore flow model MACRO (Jarvis, 1994). Even though these models were widely used, their validation still needs further work (Trevisan et al., 2003). To this end, the Directorate General of Research of the European Commission funded the project APECOP (Vanclooster et al., 2003), with major objectives to assess the validation status of the pesticide-leaching models and associated land use, land management, and climate scenarios, and to reduce the uncertainty in the present models and scenarios, based on the validation exercise. The purpose of this paper is to present the validation study of the PEARL model conducted in the frame of the APECOP project on two different sites, one located in the Netherlands (Vredepeel) and one in Sweden (Lanna). In addition, a sensitivity analysis of the model on the Lanna site was performed to identify the major parameters affecting pesticide fate.

2. Material and methods

2.1. Model description

The PEARL – Pesticide Emission Assessment at Regional and Local scales-model (Tiktak et al., 2000) was used in this study. The PEARL model deals with the pesticide transformation and fate and is linked with the SWAP model (van Dam et al., 1997) for the water cycle and transport. The water transport is based on the Richard's equation and is expressed as follows:

$$C(h)\frac{\partial h}{\partial t}=\frac{\partial}{\partial z}\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]-R_{\mathrm{u}}-R_{\mathrm{d}} \tag{1}$$

where C is the specific capacity or differential water capacity (L^{-1}), h is the soil water pressure head relative to atmospheric pressure (L), $K(h)$ is the unsaturated hydraulic conductivity as a function of h ($\mathrm{L\,T}^{-1}$), t (T) is time, z is depth (L), and R_{u} and R_{d} represent sink terms corresponding to the rate of root water uptake ($\mathrm{L}^3\,\mathrm{L}^{-3}\,\mathrm{T}^{-1}$) and rate of lateral drainage discharge ($\mathrm{L}^3\,\mathrm{L}^{-3}\,\mathrm{T}^{-1}$), respectively. The soil functional relationships are expressed by the van Genuchten (1980) equations and are described as follows:

$$S_{\mathrm{E}}=\frac{\theta(h)-\theta_{\mathrm{r}}}{\theta_{\mathrm{S}}-\theta_{\mathrm{r}}}=\left[1+\left(\frac{h}{h_{\mathrm{g}}}\right)^{n}\right]^{-m} \tag{2}$$

and

$$\frac{K(h)}{K_{\mathrm{s}}}=S_{\mathrm{E}}^{\lambda}\left[1-\left(1-S_{\mathrm{E}}^{1/m}\right)^{m}\right]^{2} \tag{3}$$

where S_{E} is the relative saturation, θ_{r} is the residual water content ($\mathrm{L\,L}^{-1}$), θ_{s} is the water content at saturation ($\mathrm{L\,L}^{-1}$), h_{g} is the air entry value (L), K_{s} is the hydraulic conductivity at natural saturation ($\mathrm{L\,T}^{-1}$), and n, m and λ are shape parameters. The parameters n and m are linked to each other according to the Mualem (1976) theory ($m=1-1/n$).

Two options are available to compute the potential evapotranspiration, the Penmann–Monteith (Monteith, 1965) that is used when daily values of air temperature, solar radiation, wind speed, and air humidity are available, and the Makkink (1957) approach when only air temperature and solar radiation are available. Lateral discharge can be computed for up to five levels and is estimated using a linear relationship. Heat transport is modelled according to Fourier's equation and is expressed as:

$$C_{\mathrm{heat}}\frac{\partial T}{\partial t}=\frac{\partial}{\partial z}\left(\lambda_{\mathrm{heat}}\frac{\partial T}{\partial z}\right) \tag{4}$$

where C_{heat} is the soil heat capacity ($\mathrm{M\,L}^{-3}\,\mathrm{K}^{-1}$), T is the soil temperature (C), λ_{heat} is the thermal conductivity ($\mathrm{M\,L}^{-1}\,\mathrm{K}^{-1}\,\mathrm{T}^{-1}$).

PEARL allows pesticides to be either injected into the soil or spread at the surface. When the latter option is selected, the applied pesticide is then distributed over the crop canopy using the soil cover fraction, the remainder of the dosage being applied to the soil. PEARL then simulates at the plant surface volatilisation in the air, penetration in the plant, degradation using first order kinetics, and wash-off via rainfall. The soil pesticide mass balance is expressed as:

$$\frac{\partial c_{\mathrm{eq}}}{\partial t}=R_{\mathrm{S}}-\frac{\partial J_{\mathrm{l}}}{\partial z}-\frac{\partial J_{\mathrm{g}}}{\partial z}-R_{\mathrm{t}}+R_{\mathrm{f}}-R_{\mathrm{u}}-R_{\mathrm{d}} \tag{5}$$