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ArcNEMO, a spatially distributed nutrient emission model developed in Python to quantify losses of nitrogen and phosphorous from agriculture to surface waters

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Pollution of surface water bodies with nitrogen (N) and phosphorous (P) from agricultural sources is a major problem in areas with intensive agriculture in Europe. The Flemish Environment Agency requires information on how spatially explicit policy measures on manure and fertilizer use, and changes in land use and soil management affect the N and P concentration in the surface waters in the region of Flanders, Belgium. To assist in this, a new spatially distributed, mechanistic nutrient emission model was developed in the open-source language Python. The model is called ArcNEMO (Nutrient Emission MOdel). The model is fully integrated in ArcGIS, but could be easily adapted to work with open-source GIS software.

In Flanders, detailed information is available each year on the delineation of each agricultural parcel and the crops grown on them. Parcels are linked to farms, and for each farm yearly manure and fertilizer use is available. To take full advantage of this information and to be able to simulate nutrient losses to the high-density surface water network, the model makes use of grid cells of 50 by 50m. A fertilizer allocation model was developed to calculate from the yearly parcel and farm data the fertilizer and manure input per grid cell for further use in the ArcNEMO-model.

The model architecture was chosen such that the model can be used to simulate spatially explicit monthly discharge and losses of N and P to the surface water for the whole of Flanders (13,500 km^2) over periods of 10-20 years. The extended time period is necessary because residence times in groundwater and the rates of organic matter turnover imply that water quality reacts slowly to changes of land use and fertilization practices. Vertical water flow and nutrient transport in the unsaturated zone are described per grid cell using a cascading bucket-type model with daily time steps. Groundwater flow is described by solving the 2D-groundwater flow equation using an explicit numerical solution with daily time steps. Solute transport is described using a mixing cell concept in the unsaturated zone, and by numerically solving the 2D solute transport equation in the groundwater.

Denitrification in soil and groundwater is described as a first order process. Mineralisation of organic N and P in the top soil of every grid cell is modelled according to the principles of the RothC model and by assigning C:N and C:P ratios to organic matter pools. As mineralization is a slow process, it is modelled with monthly rather than daily time steps. Soil erosion and N and P transport with sediment flow is modelled in line with the WaTEM/SEDEM spatially distributed soil erosion and sediment delivery model, also with monthly time steps.

The performance of the model was evaluated with discharge and water quality time series from small catchments in Flanders.