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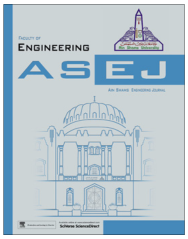

CIVIL ENGINEERING

Stochastic approach to assess a nitrate process-factor in soil water

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Abstract A process-factor was driven for the NO_3^--N concentration in the soil water. The process-factor was calculated to a catchment in Belgium. The NO_3^--N concentration in the surface water at the outlet of the catchment was used as C_s. The model was run on each individual field within the catchment for four consecutive winter periods. A Monte Carlo approach was used (i.e. the simulation was repeated 1500 times with new picks from the NO_3^--N distribution functions on October 1st considering the crop rotation. The results indicated that, the process-factor, calculated as the ratio of the simulated NO_3^--N concentration in the soil water at 90 cm and the measured NO_3^--N concentration in the surface water, for the catchment is 2.35. Moreover, the proper management of crop nutrients (nutrient source, application rate and timing) is an important way to help control the loss of nutrients through surface runoff and subsurface drainage water.

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1. Introduction

A variety of projects have used computer modeling to investigate the performance of drainage systems and landscapes over several (often many) years. This work complements field research that is typically conducted over a shorter time frame. Some of these projects include simulating the effects of various management practices on drained watersheds, assessing the hydrology of drainage systems, and evaluating best management practices for drained fields. Agricultural drainage is the use of surface ditches, subsurface permeable pipes, or both, to remove standing or excess water from poorly drained lands. Many soils have poor natural internal drainage and would remain waterlogged for several days after excess rain or irrigation without artificial drainage [1]. This prolonged wetness prevents timely fieldwork and causes stress to growing crops because saturated soils do not provide sufficient aeration for crop root development. Soil conditions that make drainage a necessity for some agricultural lands include those with slow water permeability or dense soil layers that restrict water movement, flat or depressional topography and, in some areas, high levels of salts at the soil surface. Although agricultural

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Abbreviations: C_g, average simulated NO_3^--N-concentrations of the drain water, C_s, average measured NO_3^--N-concentrations of the surface water, GIS, Geographic Information Systems, *I*, number of Monte Carlo iteration, *J*, number of days, *K*, number of fields, N, nitrogen, N_{catch}, nitrate nitrogen losses, NO_3, nitrate, NO_3^--N, nitrate-nitrogen, V_{catch}, area-weighed daily water, *W*, process-(weighing) factor

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drainage has benefited agricultural production in many regions and countries, there are concerns about its potential environmental impact [2]. Subsurface drainage systems have a positive impact because they generally decrease the amount of surface runoff, thereby reducing the loss of substances generally transported by overland flow. There are concerns, however, about the potential negative impacts of drainage on the hydrology of watersheds, the water quality of receiving water bodies, and the amount and quality of nearby wetlands [3].

There seems to be a discrepancy between the simulated and measured NO_3^--N concentrations [4]. The simulated NO_3^--N concentration in the soil water, calculated from the net nitrate nitrogen and water flux at a depth of 90 cm below soil surface, is too high compared to the measured NO_3^--N concentrations in the surface water. Based on scenario-analyses in the N-eco^2 project [5], a residue of 40 kg NO_3^--N on October 1st would still lead to exceeding the regulations of the Nitrate Directive (being 11.3 mg NO_3^--N L^{-1} or 50 mg NO_3^- L^{-1}) [6]. On the other hand, 50% of the 266 points of the surface water quality net met the regulations of the European Nitrate Directive in the period from July 1 2000 until June 30 2001 [7]. These points are meant to verify the current Flemish nitrate residue norm (90 kg NO_3^--N ha^{-1} in the period from October 1st until November 15) and the NO_3^--N concentrations at those selected locations are not influenced by industrial discharges or discharges by wastewater treatment plants. The measured NO_3^--N concentrations can be therefore be attributed to agriculture. Because of these seemingly contradictory facts, it can be suspected that NO_3^--N concentrations in soil water cannot be translated directly to concentrations in the surface water [8]. The aim of this research is to calculate the process-factor for the Wijlegem catchment, Belgium. The simulated concentration of the water draining from the soil profile (at a depth of 90 cm), instead of the NO_3^--N concentration in the drain water, will be used to calculate C_g. The simulations will be done with the Burns α model. The NO_3^--N concentration in the surface water at the outlet of the catchment will be used as C_s.

2. Description of the catchment

The Wijlegem catchment is a small (230 ha) subcatchment of the Zwalm river (Flanders, Belgium). Land use within the catchment is mostly arable land and pasture [9]. The soil textures in the catchment are mainly silt loam and sand loam (USDA classification). For each field in the catchment, a GIS database holds, besides the area of the field, also the crop cultivated in 1999. Four leaching periods are simulated. Therefore, it was necessary to incorporate crop rotation. It is assumed that corn was grown in mono culture, grasslands are permanent and that potatoes, sugarbeets and winter wheat are grown in rotation. Field coverage by green manure was not considered in this study.

In October 1999, five fields of the most common crops (sugarbeets, winter wheat, maize, potatoes and grass) were sampled to a depth of 90 cm (in layers of 30 cm each) [10]. The distribution of the amount of nitrate nitrogen between the fields of each crop was considered to be lognormal [11] and could be derived from the average and standard deviation of the nitrate residues. At regular intervals, samples were taken from the surface water at the outlet of the Wijlegem catchment (January 1997–May 2001). The Wijlegem catchment is mostly agricultural catchment (90%) that drains to the Zwalm. Following measurements were made in the catchment:

- Soil samples were taken with three weeks intervals in layers of 30 cm, up to a depth of 90 cm. Samples of drainage water, groundwater and surface water were analyzed for nitrate. The soil moisture content was measured at several depths in the soil profile, taking with an auger soil samples in the layers 0–30 cm, 30–60 cm and 60–90 cm. The water content was derived from the wet and dry weight of the soil samples.
- Inventory of the post-harvest NO_3^--N residue In October 1999, five fields of each of the most common crops (sugar beets, winter wheat, maize, potatoes and grass) were sampled to a depth of 90 cm (in layers of 30 cm each) [12]. A log–normal distribution was drawn up for each of the above-mentioned crops.
- Measurement of the NO_3^--N concentration at the outlet of the Wijlegem at regular intervals, samples were taken from the surface water by an auto-sampler. These measurements started in January 1997 and ended in May 2001. Also, the mineralization rate and denitrification capacity of the soils were measured to get a better estimation of the nitrate leaching. N-mineralization and denitrification rate is measured based on incubation experiments [13]. NO_3^- and NH_4^+ on the soil samples are determined by a KCl (potassium chloride) extraction followed by spectrophotometric analysis [13].

3. The available models

Burns [14] developed a simple model to predict the distribution of non-adsorbed solutes subject to leaching and upward movement. The model divides the soil profiles into several layers, each is characterized by its moisture content at field capacity and at wilting point. The original evaporation excess module was modified according to suggestions made by Mary et al. [15], so that the evaporative demand is met by several layers at once, contrary to Burns' original idea of successive layer exhaustion. This model has the advantage of accounting for both upward and downward movement of solutes without using parameters that may be difficult to measure or have to be determined during model calibration.

One of the major drawbacks of the Burns model is the fact that no water content above field capacity can be simulated and thus limiting its use to light textured soils only. Therefore, the model was adjusted by adding one extra parameter. This rate parameter α denotes the proportion of water above field capacity that drains to the underlying layer. This adjustment enables the model to simulate moisture contents between field capacity and saturation. The Burns model, extended with the alpha parameter, will hereafter be referred to as the Burns α model.

4. The used model (Burns α model)

A simple, mechanistic and deterministic model, based on Burns' model [14] was used to simulate leaching losses. The model divides the soil profile into several layers, each charac-

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