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Including subsurface drainage in hydrological models using seepage nodes to improve surface and groundwater flow simulations

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Summary

North American and European agricultural landscapes often require tile drainage systems to enhance agricultural production due to humid clayey soils formed by glacial deposits. These systems reduce the water table levels and change the water flow patterns causing nitrate surpluses to be carried to rivers and coastal waters in a short time period. In Denmark, new regulation strategies based on spatially differentiated nitrogen (N) fertilizer application have been studied to reduce nitrate leaching from agriculture and achieve the water quality status established by the European Union. The regions where the N fertilizer application most contributes to the nitrate load to the surface water bodies can be identified through hydrological-nitrate transport models. However, representing tile-drains in hydrological models at catchment-scale requires a long modeling and computational times and detailed information of de tile-drains location, which is rarely available. This research proposes a straightforward methodology for including tile-drains in hydrological models in agricultural catchments to be used for nitrate transport analyses. The physically-based numerical model HydroGeoSphere have been used for 3D modeling in the Fensholt catchment (6 km^2). The upper geology is dominated by clayey till of the Weichselian age, followed by glaciofluvial sand and freshwater peatland. Primary results show that including tile drainage in hydrological models as seepage nodes at 1 m depth in all drainage areas within a catchment is a suitable approach to represent tile drainage in hydrological models and overcome the lack of data on tile drains location. This study is expected to simplify and increase the accuracy of hydrological models in humid agricultural catchments to support legislative demands that water-regulatory agencies might use for surface and groundwater management.

Method

Hydrological simulations have been developed using the most recent version of the physically-based numerical model HydroGeoSphere (Aquanty, 2017), where the physical phenomena ruling the water flow and nutrient transport can be accurately simulated. HydroGeoSphere combines groundwater flow, surface water flow and solute transport between the three-dimensional (3D) subsurface porous medium, two-dimensional (2D) surface medium and with the one-dimensional (1D) hydraulic feature elements. Subsurface drains were represented in the model by seepage nodes, such as recent published researches on integrated hydrological models in tile-drained catchments (Hansen et al., 2019 and De Schepper et al., 2017). The seepage nodes act as a sink in the model extracting water from the porous medium when the hydraulic head at the node is higher than its elevation. The extracted volume of water from each drainage area in included back to the surface medium at the drainage outlet position. Two different configurations using seepage nodes at 1 m depth were applied in a 6 km^2 catchment

(Fensholt) to simulate surface and groundwater flow. In the Main Drains (MD) model (Figure 1a) the seepage nodes were located along the main collector drains positions. This approach was used by De Schepper et al. (2017) to fast computational times when simulating tile drainage in two drainage areas in the same catchment. Then, all nodes at 1 m depth were defined as seepage nodes in the drainage areas within the catchment (DA model, Figure 1b), which includes the parts of the agricultural areas that do not have tile drains. With this approach the location of tile drains is not necessary to develop the mesh, simplifying the construction of the model. All simulations were developed at transient state in the saturated and unsaturated zones using triangular grids. The results accuracy using different approaches were analyzed by the accumulated errors and the curve fit between simulated and observed stream water flow rates from 2 gauging stations, 8 drainage discharge measurement stations and using water level measures from 20 piezometers.

Results and Conclusions

Primary results show that when all the nodes at 1 m depth in the drainage areas are defined as seepage nodes the water table simulations are improved compared with the model where only the main drains are represented. One possible reason is that the approach proposed by De Schepper et al. (2017) used in the MD model do not represent all drains in the study area. However, the drainage discharges from the 8 monitored drainage areas were better simulated by the MD model. Using seepage nodes all over the drainage areas (DA model) increased the drainage discharges, which is expected considering the higher number of seepage nodes. This behavior is presented in the Figure 1d (drainage outlet of the drainage area D1). The stream flow rate at the outlet had similar performance for both models, therefore only the outlet discharge from the MD model is presented in Figure 1c. Including tile drainage in hydrological models as seepage nodes at 1 m depth in all drainage areas within a catchment is a suitable approach to improve hydrological models, especially when the drains position is unknown, which is usually the case. We expect this approach to be useful for modelers who need to include tile drains in hydrological models for a better understanding of the contamination caused by the nitrate transported by tile drains, streams and groundwater.

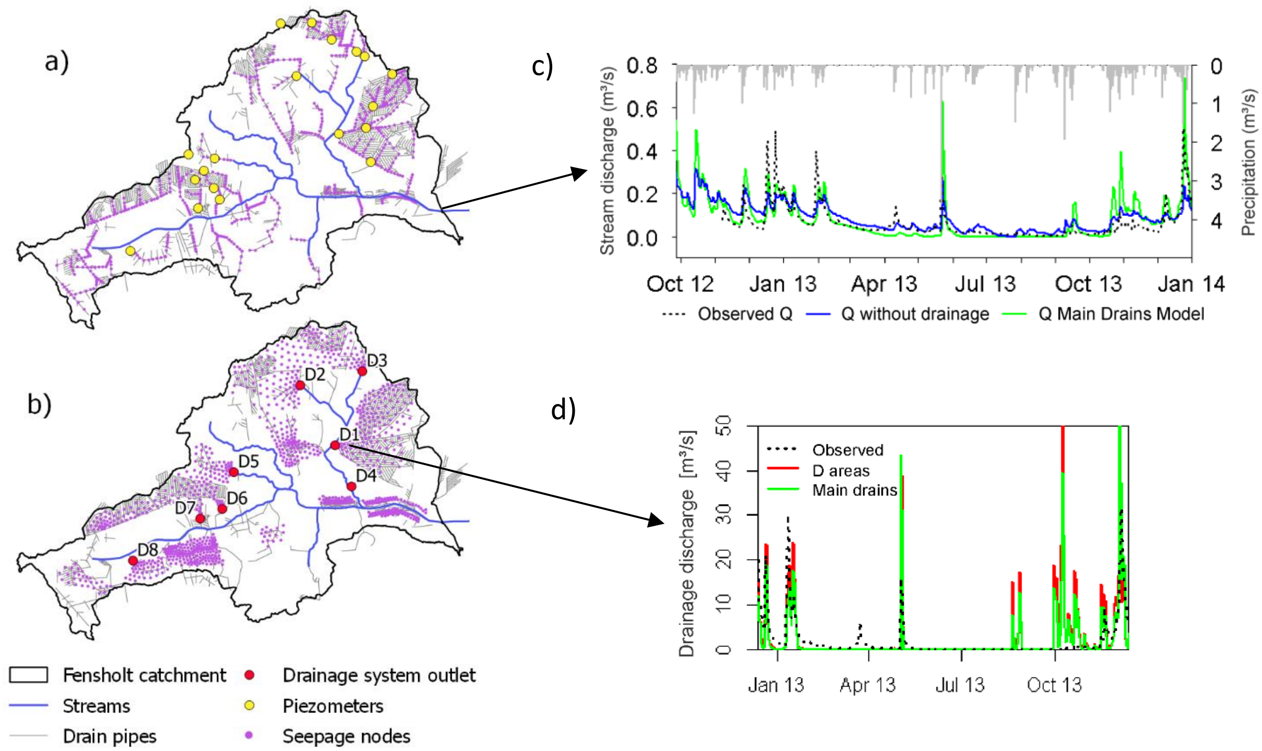

Figure 1 – a) Main drains model : seepage nodes located along the main collector drains in Fensholt catchment; b) D areas model: seepage nodes located at 1 m depth from the drainage areas; c) observed stream discharge, simulated stream discharge (Q) of a model without seepage nodes and with seepage nodes on the main drains position and observed precipitation; d) observed and simulate drainage discharge (station D1) for the Main Drains and D areas models.

Novel

The water flow paths of a catchment were modeled with agricultural subsurface drains represented by a novel approach to overcome the lack of data on the tile drains location and compared with a method where tile drains are explicitly represented. From the authors knowledge, tile drainage was for the first time included as seepage nodes in a catchment model for all the agricultural tile-drained fields.

Acknowledgements

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