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# Determination of till hydraulic properties for modelling flow and solute transport in a forested hillslope

H. Laine-Kaulio (1), T. Karvonen (2), H. Koivusalo (3), A. Lauren (3), and S. Saastamoinen (4)

(1) Helsinki University of Technology, Finland (hanne.laine@tkk.fi), (2) WaterHope, Helsinki, Finland, (3) Finnish Forest Research Institute, Joensuu, Finland, (4) University of Oulu, Finland

Shallow till layers typically overlay bedrock in forested areas in the boreal region. In forested tills, preferential flowpaths related to the soil structure have a decisive influence on hydrogeological properties such as the soil hydraulic conductivity. Hydraulic conductivity is also proven to depend on the observation scale. Traditional soil core samples cannot capture the impact of soil structure on hillslope scale conductivities. Measurements and observations made at different scales, combined with simulation models, are essential for investigating conductivity properties and flow and transport processes in forest soils. This study combined a set of soil analyses and field experiments with physics-based modelling to investigate the hydraulic properties of a forested till slope in Finland. The main objective was to i) determine the saturated hydraulic conductivity in the study slope with methods related to different scales, and to ii) study the utilisation of the conductivity results in modelling flow and solute transport in the slope.

Soil sampling, dye, and ion tracer experiments were conducted in a forested hillslope in Eastern Finland. In the 20 m long study section of the slope the mean slope was about 15 %. The haplic podsol profile above bedrock had a thickness of 0.8 m and was formed of sandy till. The soil was very stony and heterogeneous in terms of granularity and pore size distribution. Granularity, porosity and proportion of macropores reduced clearly with depth. Dye tracer experiments revealed three types of preferential flow routes in the slope: i) stone surfaces, ii) areas of coarse-grained soil material, and iii) decayed root channels. Both living roots and preferential flowpaths reached the transitional zone of the podsol at about 0.5 m depth, but living roots were not found to function unequivocally as preferential flowpaths.

The saturated hydraulic conductivity was determined using three methods: i) from soil core samples in laboratory, ii) with Guelph permeameter in the field, iii) and by means of inverse modelling. The inverse model application was based on calibration of a one-dimensional groundwater model against data on groundwater levels in the study slope. Conductivities of the different soil horizons were adjusted to reproduce the measured groundwater levels of a recession period after artificial irrigation. Conductivity results, together with soil physical and water retention data were applied to parameterise a three-dimensional flow and advection-dispersion model. The model was used to simulate the transport of a chloride tracer plume in the study slope during artificial irrigation. A line-type irrigation source was installed upslope from the study section of the slope. Changes in groundwater levels and chloride concentrations within the study section were observed through well screens. Chloride as a conservative tracer provided an indicator for subsurface flow in the study slope. Intensive irrigation rates were applied to initiate fast lateral preferential flow.

Saturated hydraulic conductivities obtained with the three methods were remarkably different. Conductivities obtained with the Guelph permeameter and the groundwater model reduced clearly with soil depth. Higher conductivities near soil surface were due to loose soil structure and preferential flowpaths. Soil core samples yielded the lowest estimates for the saturated hydraulic conductivity, as they represented the small-scale conductivity of the soil texture and soil matrix. The hillslope-scale groundwater model produced the highest estimates that characterised the large-scale structural properties and their impact on lateral preferential flow. Average saturated hydraulic conductivities in the soil core samples were 6E-6 m/s in the eluvial horizon, transition zone and subsoil, and 1E-5 m/s in the illuvial horizon. The average conductivities based on the Guelph measurements varied from 2E-5 m/s in the subsoil to 5E-5 m/s in the eluvial horizon, and based on the groundwater model from 6E-5 m/s in the subsoil to

3E-4 m/s in the eluvial horizon.

The dual nature of the soil structure complicated the simulation of the chloride plume in the study slope. The closest correspondence between the observed and simulated flow velocity and concentration of the chloride plume was reached by i) using the conductivity values from the inverse groundwater model, and by ii) restricting the transport of water and solute to an active fraction of the total pore space in the model. The modelled flow velocity did not increase to the observed level with increasing conductivities, because in the highly conductive soil the irrigation intensity was no longer able to saturate the soil. As for the strength of the plume, the modelled chloride concentrations remained too low when the solution was allowed to spread to the entire pore space. The study suggests that a more accurate simulation of the fast preferential flow and chloride transport requires parallel and coupled simulation of water and solutes in the two domains of slow and fast flow.