Hydraulic properties of recent volcanic ash soils from the high slopes of the Rucu Pichincha volcano (Quito - Ecuador)

J-L. Perrin[1], J. Poulenard[2]

[1]IRD Montpellier, 911 av. Agropolis, BP5045, 34032 Montpellier Cedex 1
[2]CNRS, Centre de Pédologie Biologique, 17 rue Notre dame des Pauvres, BP5, 54501, Vandoeuvre-lès-Nancy, Laboratoire de Science du Sol, CISM, Université de Savoie, 73376 Le Bourget du lac

Introduction

The hydrological behaviour of the volcanic catchments is directly related to the specificity of their soils, developed above recent ashes and volcanic tuffs. These soils belonging to the Andisol order are well known for their low bulk density and high water retention capacities. These properties are mainly due to the presence of i) secondary short range order minerals such as allophanes or imogolite and ii) organo-metallic complexes, which are able to promote a soil structural organisation with high porosity. However, we have few knowledge of the hydrodynamic properties of such soils. A conceptual scheme for the infiltration process at the catchment scale in volcanic ash soils is therefore difficult to draw.
A hydro-pedological research program has been carried out at the foot of the Rucu Pichincha volcano in Quito (Ecuador). An experimental network was installed in 1995 on the Rumihurcu catchment, located at the upper periphery of Quito. This 7.5 km^2 catchment, ranging from 4627 m to 3280 m, was chosen because it included most of the physiographic characteristics that can be found on the high slopes of the Pichincha.
Perrin et al. (2001) showed that surface runoff is not likely to occur on the slopes because of the low rainfall intensities of these high altitude zones and the high infiltration capacity of the recent volcanic soils. Conversly, it was found to be generated on continuously saturated areas situated close to the main drain. Saturated area extension which conditions the flood runoff coefficient is directly related to base flow, i.e. infiltrated water storage of the catchment.
Then, the objective of this study is to improve knowledge of punctual infiltration process which appears as a fundamental work subject before to better quantify sub-surface water transfer along the slope and water table recharge at the bottom of it.

Materials and methods

Soil stratification is very homogeneous on the slopes of the catchment and is composed of distinct ash deposits. A reference profile was selected. The topsoil is constituted by two organic-rich horizons (Pic1, 0-20 cm and Pic2, 20-40 cm depth) derived from a 300 years B.P. pyroclastic deposits. A thin organic layer (Pic3, 40-55 cm depth) overlays an un-weathered layer of pumice (Pic 4, 55-80 cm depth) with high proportion (85%) of coarse elements (diameter > 2 mm). Both horizons derived from 980 years B.P. volcanic deposits of the Guagua Pichincha.
Undisturbed soil samples (five replicates) were collected using 250 cm^3 cores in the three topsoil layers: Pic1, Pic2 and Pic3. For each sample, water contents were determined by plate methods using undried and undisturbed cores between 10 and 300 kPa (7 points) and undried but disturbed samples at 1500 kPa. Total porosity was determined using particle and bulk density measurements (3 replicates for each layer). Brooks-Corey's and Van Genuchten's (with a Burdine's or Mualem's capillary models) soil characteristic relations have been fitted to give simple empirical expressions for the _(h) relationships and derived K(_) expressions.

Rainfall simulations were carried out on two one-square-metre plots. The simulations were performed, using a mini rainfall simulator. The intensity of each simulated rainfall was increased from 20 to 120 mm/h during the 90-minute duration of the event to generate surface runoff. Two rainfall events were conducted on each plot, at an interval of a few hours. This experimental protocol allowed us to characterise infiltration and runoff for a large range of rainfall rates and gave an estimation of saturated surface hydraulic conductivity during steady-state conditions.

Results and discussion

Soil water content is very high, with values ranging from 0.65 cm^3/cm^3 at saturation to 0.40 cm^3/cm^3 at the wilting point. This shows up that in spite of the sandy character of these soils, their micro-porosity is very high. The high amounts of organic matter and particularly Al-humus complexes, which strongly cement the micro-structure explain this apparent contradiction between the youth of the soils and the physical properties close to those of developed ones.

Both Van Genuchten's and Brooks-Corey's _*(h)* equations with a Burdine's or Mualem's capillary models fitted well experimental data. Fitted curves showed stable retention level from saturation to 10 kPa suction which was one of the main characteristics of these soils.

Conversely, the comparison between Van Genuchten's and Brooks-Corey's *K(_)* equations showed significant differences. Van Genuchten's *K(_)* equations is characterised by a large decrease of the relative K values near saturation probably due to inconsistency, for these soils, of fitting parameters of the Van Genuchten's *K(_)* equations, with the infiltration theory (Fuentes et al., 1992).

Finally, a combination of Van Genuchten's _*(h)* and Brooks-Corey's *K(_)* equations with Burdine's capillary model, for which the fitting parameters are physically consistent, have been chosen to describe soil water retention and relative conductivity curves.

These equations and their parameters have been directly used to simulate infiltration and runoff processes in the two one-square-metre rainfall simulation plots. A one-dimensional vertical numerical solution of a two-dimensional model SWMS_2D (Simunek et al., 1994) modified to use the selected _*(h)* and *K(_)* equations, has been tested in order to obtain, by calibration, the saturation conductivity of each soil layer (Pic1, Pic2 and Pic3) and to try to validate the _*(h)* and *K(_)* equations.

This model applied to the two one-square-metre rainfall simulation plots showed quite good results in term of water balance but also runoff simulation at a 1-minute time step. The calibrated values of the saturated hydraulic conductivity of each soil layer showed little difference from one plot to the other and are consistent with the values of steady-state infiltration capacity obtained during rainfall simulation.

This analysis, which underlines the specificity of volcanic ash soils was a necessary preliminary to runoff modelling in an area where very few experiments have been carried out. Calibrated and partially validated at the rainfall simulation plot scale, the model could be used, at a catchment scale, to better quantify sub-surface water transfer along the slope and water table recharge.

References

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