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## **A VIRTUAL LAB ENVIRONMENT FOR IMPROVING STUDENTS' UNDERSTANDING OF INFILTRATION AND RUNOFF PROCESSES**

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Infiltration of water in the soil is a key process in the hydrological cycle and its understanding is paramount for students of any course related to natural resources management. Different equations describing hydrological processes have been proposed. The solutions of these equations can be very complex in function of boundary conditions to which they are subjected, and of the level of detail required in any particular case. Water movement in the soil, for example, can be described by the Richards equation, but its solution requires numerical methods in most of the cases. Therefore, amongst the most used ways of calculating water infiltration are the Green and Ampt method, Horton's equation, Philip's equation and the Curve Number method. In all these equations, different soil parameters intervene that can be measured in the field or estimated from soil properties. The understanding of the physical meaning of these parameters, their relative influence, and of the differences between the abovementioned methods is important for students. Infiltration measurements in the field or lab are time-consuming. We therefore developed a tool that helps the students to calculate infiltration in a step-by-step way, allowing to easily change the input parameter values so as to understand the importance of the different variables. This virtual lab environment was coded in MATLAB and used for the first time during the academic year 2013-2014. In this study, we present the main characteristics of this didactic software tool and present an evaluation of its usefulness by students.

### **INTRODUCTION**

A key process in the study of the water cycle in all Hydrology courses is infiltration. The importance of this process, where water infiltrates and redistributes in previously air-filled pores, is double as it recharges the soil moisture and controls runoff generation. Because the infiltration process is important to a wide range of fields of study, such as hydrology, soil science, agriculture, forestry, civil engineering or geography, its study is key to many students, often with a different mathematical background.

Infiltration equations result from solving the equations of balance in a control volume and defining the initial and contour conditions. Water flow in the soil is described by the Richards equation. Its solution requires costly and complex numerical methods, which often surpass

classroom application potential. Therefore, often-used infiltration methods in practical applications are the Green and Ampt equation, Horton equation, Philip equation or the SCS Curve Number method. All of these equations include physical soil parameters that can be measured in the field. Understanding the importance of these parameters and the difference between each of these methods is crucial for students. Given the complexity of some of these equations and time constraints, students typically only solve a limited number of cases in the classroom. While these equations are often used in existing hydrological models, these models are often too complicated to isolate the infiltration process of a pedon alone and are also not suited for classroom use.

The objective of this study is therefore the presentation of a simple, interactive and visual tool that helps students calculate soil water infiltration. This tool can then be used with different student groups and the complexity of the case studies can easily be varied depending on the level of detail required and background knowledge.

## **MATERIALS AND METHODS**

The teaching tool was coded in MATLAB and was compiled to two versions, one for computers with a MATLAB compiler and one without. Finally, each user needs to download a simple compressed file (.zip) and ends up with a windows-executable tool (.exe) that is presented to the user as a GUI. In this way, students do not need any previous programming experience to use the tool.

The different infiltration equations that were coded are:

- Horton's equation [1]
- Philip's equation [2]
- Soil Conservation Service Curve Number method [3]
- Green and Ampt's equation [4]

A help function and FAQ section were included and easily accessible from the GUI, with explanation on each of these methods and on typical parameter values for soil hydraulic properties. Graphs and tables created with the tool can be exported for student's reports or further analysis in other programs such as excel.

Finally, a field infiltration experiment was set up with students (Figure 1) to generate input data for a first case study, data which is then provided with the model documentation. Videos and photos from the field experiment are also used to illustrate important concepts in the help files.



Figure 1. Single-ring and double-ring field infiltration experiments with students to generate input data for the model help files.

## RESULTS AND DISCUSSION

The start screen of the tool is shown in Figure 2. Here, students can select a method for calculation (top row buttons) or can review theory previously covered in the classroom by selecting one of the buttons on the lower row. In the current version, four different equations were included, although this could be extended in the future.

The next screen then takes the students to the heart of the module, where the students can calculate infiltration. In the case of using the Green and Ampt equation, there is an additional second option. By selecting the first option, the student has to manually iterate to obtain the correct cumulative infiltration amount  $I$  (Figure 2). This option is ideal for familiarizing students with solving implicit equations, such as the Green and Ampt infiltration equation, especially for those students that have a limited mathematical background. The second option then calculates the amount of infiltration and runoff (or surface ponding when slopes are flat) during each time step of an entire rainstorm event. This option is ideal for exploring the sensitivity of the results to changing soil hydraulic parameters, such as the saturated hydraulic conductivity,  $k_s$ , or the suction of the matric potential at the wetting front,  $\psi_m$ .

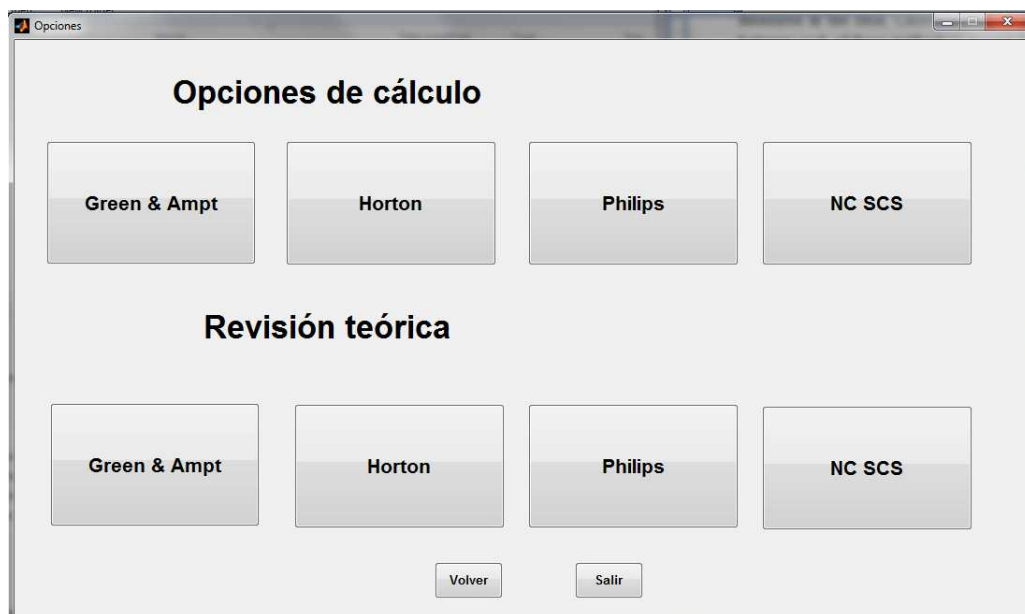


Figure 2. Input screen where students can select a method to do an infiltration calculation (top buttons) or where they can review class notes on each of the methods (bottom buttons).

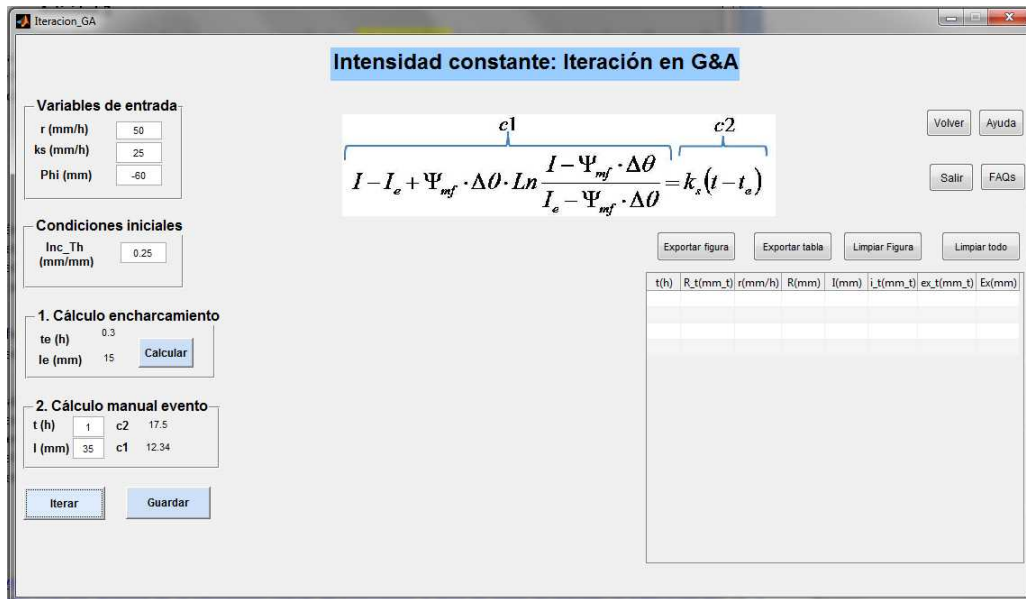


Figure 3. Example screen of solving Green and Ampt equation through the manual iteration option.

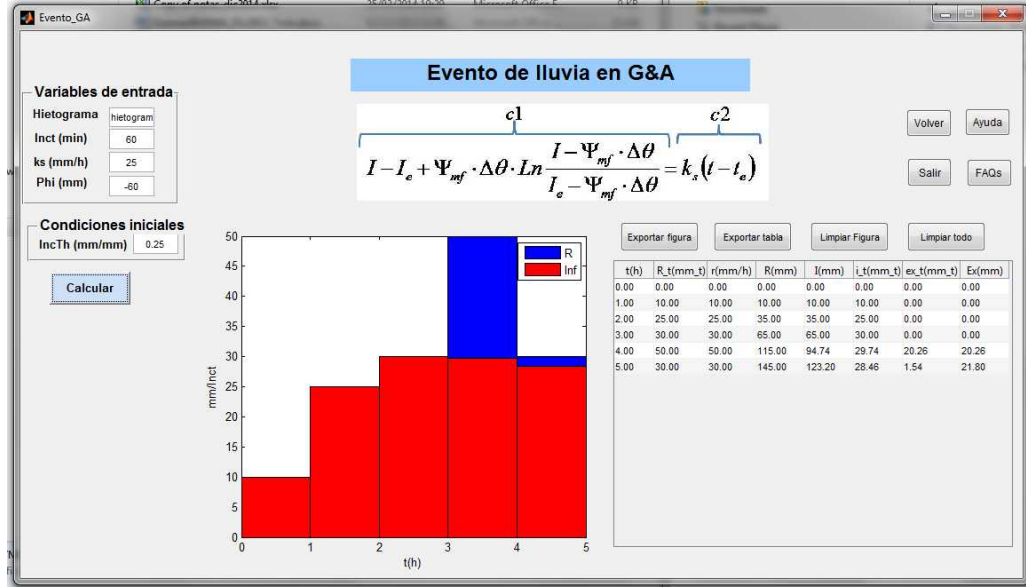


Figure 4. Example output of one case study where infiltration (red) and runoff (blue) of an entire rainstorm was calculated with Green and Ampt's equation, using the automated solving option.

This tool was first used in the classroom during the academic year 2013-2014 in several courses where infiltration problems had to be applied, ranging from general undergraduate courses such as "Introductory Hydrology" to more specialized graduate courses. Although the results of objective questionnaires will have to be evaluated over several academic years to check for significant results, first results show that in all cases, student response was very positive. All

students could easily use the tool in an independent manner and found it helpful over traditional calculation by hand or in a spreadsheet.

## **CONCLUSIONS**

A stand-alone tool was developed to help students understand the calculation of soil water infiltration by different equations, the importance of key soil hydraulic parameters and the interpretation of results. This tool permits easy switching between different infiltration equations and varying soil hydraulic parameters on-the-go. The graphical interface promotes the learning process.

## **Acknowledgments, appendices, and references**

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