Numerical simulation of soil water dynamics using a 1D Richards model

Term paper in course:

"Water and Energy Cycles in Hydrological Systems: Processes, Predictions and Management" – WS 22/23

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The main objective of this project deals with the analysis of small-scale soil hydrology processes and the simulation of vertical water flow through the unsaturated zone of a 1D soil domain. You will use a numerical soil water dynamics model that solves the 1D Richards equation (Eq. 1) using an Euler forward scheme. The overall goal is to predict soil moisture changes in different soils driven by transient rainfall infiltration and the sensitivity of the model towards soil hydraulic parameters according to van Genuchten (1980) and Mualem (1976). You should use your lecture and exercise notes for more detailed information on the underlying theory.

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left(k(\theta)\frac{\partial(\psi + z)}{\partial z}\right); \qquad \text{Eq. 1}$$

where θ is the volumetric soil moisture (m³ m^{-3}), k the hydraulic conductivity (m s^{-1}), Ψ the matric potential (m) and z the vertical soil depth (m) (= gravity potential).

We provide the model code with all sub-routines and the datasets for the following tasks in the folder *"Code_Richards_1D"*. You may use any notes and codes, which we provided in the lectures and exercises to accomplish the tasks. More specific information and hints on the respective tasks can be found below. Please also see the requirements and general information on the structure and content of your written report at the end of this document.

Task 1: Soil hydraulic properties of three different soils

Calculate and plot the soil water retention and soil hydraulic conductivity curve for three given soils:

Table 1: Soil hydraulic properties of three soils: saturated hydraulic conductivity k_s, saturated and residual water contents θ_s, θ_r, air entry value α, shape parameter n.

Soil	k_s ***(m s***$^{-1}$***)***	θ_s ***(-)***	θ_r ***(-)***	α ***(m***$^{-1}$***)***	***n (-)***
Sandy Loam (SL)	$2.23\ 10^{-5}$	0.41	0.065	7.50	1.89
Sandy Clay Loam (SCL)	$6.00\ 10^{-6}$	0.39	0.10	5.90	1.48
Clay Loam (CL)	$1.00\ 10^{-6}$	0.41	0.095	2.90	1.31

- Explain the general meaning of the two curves and compare the curves of the three soils. What are the differences and why?

- In the soil water retention curve, highlight the range of effective field capacity. What is the effective field capacity of each soil? Discuss your findings.

Task 2: Simulation of water flow and sensitivity of a 1D Richards model

Use the model in *"Richards_theta.m"* to simulate the temporal development and final state of soil moisture profile (0-1.5 m) in three different soils in reaction to rainfall input. Several input data are given in the following folders:

- *"boundarycon"*: contains .csv-files with different rainfall timeseries

- *"initial_states"*: contains .csv-files with different initial soil moisture profiles and final, observed soil moisture of a real experiment (needed for Task 3)

- *"soils"*: contains .csv-files with hydraulic parameters of different soils

Go through the model in *"Richards_theta.m"*, get familiar with the code and add comments if useful. Run the model with different input data and model parameterizations. To understand the model code with all functions and routines, read the manual *"richards_Code_manual.txt"* and the comments within the MATLAB codes. Set up the paths to the data files you want to use in the main control file *"richards_input_task2.dat"*.

- Use one input data configuration and model parameterization to simulate the final soil moisture profile of different soils after a total simulation time of 42000 s. Are there any differences between the soils and can you explain the resulting soil moisture profiles with the properties of the respective soils? Present plots of the soil moisture time series at the upper and lower boundary of the soil domain for different soils. Analyze and discuss your findings.

- Explore the model sensitivity to different input data configurations and model parameterizations. You may use different rainfall inputs, soil properties (e.g. several k_s values) or initial soil moisture profiles and vary the soil domain discretization and simulation time step. The style of sensitivity analysis is completely up to you. You can, for instance, create new artificial input data and test the limits of the numerical model. Present plots of final soil moisture profiles and time series at upper and lower boundaries of soil domain for the different input data configurations and model parameterizations. Discuss the difference of results and the sensitivity of the model.

Task 3: Comparison of simulation results with observed data

Use the model in *"Richards_theta_obs.m"* and simulate the soil moisture change with time and final state in reaction to a real rainfall event in the Weiherbach catchment on the 9 May 1995 and compare the simulation results with the observed soil moisture data 6 hours after begin of rainfall. The needed input data are given in the following files:

- initial soil moisture profile → *initialmoisture_real.csv*;
- precipitation time series → *rain_real.csv*;
- zero evapotranspiration → *etp_zero.csv*;
- parameters of loess soil with two layers → *soil_real.dat*;
- final, observed soil moisture profile → *finalmoisture_real.csv*.

Set up the paths to these files and the total simulation time of 21000 s (~ 6 hours) in the main control file *"richards_input_task3.dat"*.

- Present a plot with the initial, simulated and observed soil moisture profiles. Explain and compare the different profiles. Also, calculate the performance metric RMSE (Root

Mean Square Error) to evaluate the quality of the simulation results. Are the simulated and observed soil moisture profiles in a good accordance? If there is no good accordance between the profiles in certain depths, discuss why.

- Try to fit the saturated hydraulic conductivity k_s of the two soil layers to find a better match of simulated and observed soil moisture profiles. You may use a Monte-Carlo algorithm and present dotty-plot to estimate the model sensitivity to k_s. Can you obtain a better match by fitting the saturated hydraulic conductivities? Discuss the quality of the k_s measurements with respect to your findings. If you want, you may also do this for other soil hydraulic parameters like α and n.

General remarks on your report

Each student has to submit an **own report** which is structured as outlined below. In general, your report should have the **structure of common scientific papers with a continuous text** (no bullet point style) and a **length of around 10 to maximum 15 pages** (appendix excluded). Use English language. Further, it is up to you, which programming language you use to work on the project (MATLAB is recommended). However, you need to **hand in all your developed codes** in digital form with the data. Your work must be **reproducible.**

<u>Structure of the report:</u>

- Title page with the topic, course, your name and Matriculation-Number
- List of Contents
- Introduction
    - give a short background on your topic
    - formulate the objectives of your report
- Methods
    - briefly describe the used datasets and catchments
    - shortly explain the used methods, approaches, models with all equations
- Results
    - show instructive and relevant figures and tables
    - properly describe your findings
- Discussion
    - extensively discuss your results **(IMPORTANT!!!)**
    - compare your findings to relevant literature
- References
- Appendix (e.g. your codes)

<u>Conventions:</u>

- mind your language using proper grammar, spelling and syntax; write in scientific style
- show informative plots with labels, title, legend, units
- use consistent units, name units and number equations
- number all tables and figures and add captions, which explain what is presented in a brief but exhaustive manner
- use and refer to relevant literature

References

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