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H45I-1492

# Layered Green-Ampt with Redistribution (LGAR): an efficient, accurate, and reliable approximation of the Richards equation

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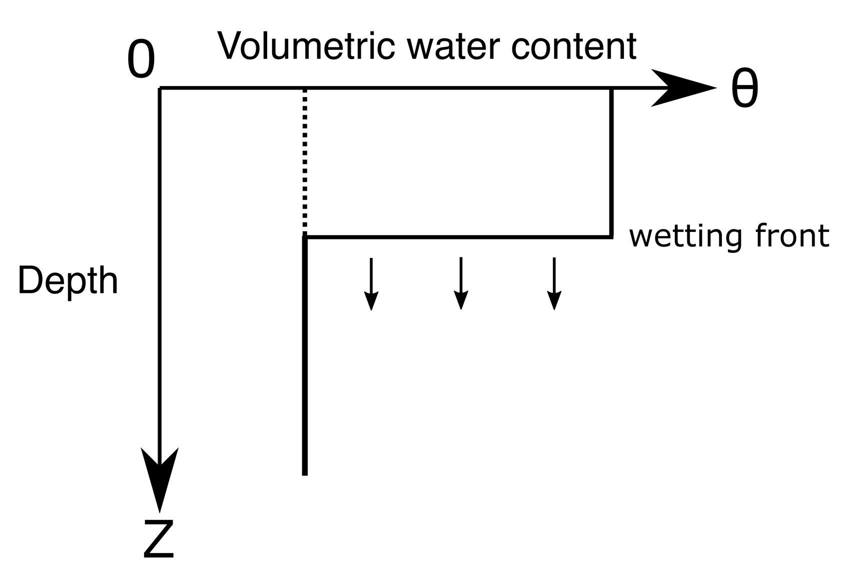
## LGAR Method

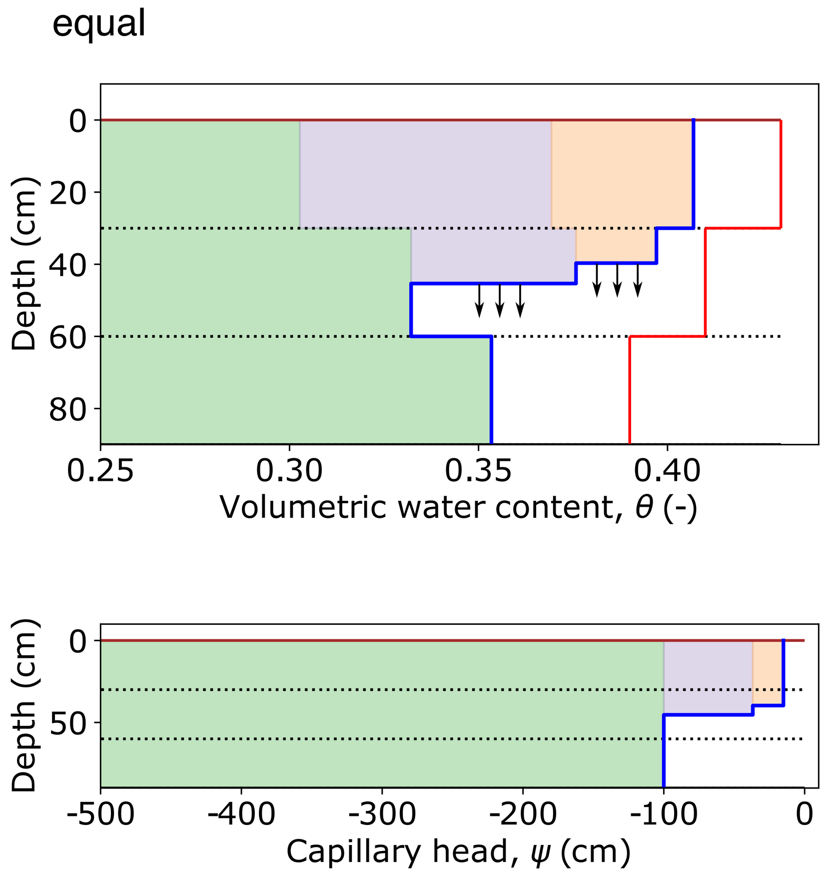
**The original Green-Ampt model (1911):**

- Partitions precipitation into infiltration and runoff
- Represents soil moisture with a single distinct wetting front, which can be represented as a depth-moisture pair
- Uses the physical concepts of capillary suction and gravity drainage to simulate both wetting front dynamics and precipitation partitioning
- Can only be used when precipitation is intense enough to cause superficial saturation, and only for homogeneous soils
- The wetting front moisture can only assume the saturated value




**LGAR (2022):**

- Also partitions precipitation into infiltration and runoff
- Still represents wetting fronts as depth-moisture pairs, although multiple wetting fronts are now allowed
- Precipitation partitioning and soil moisture dynamics are still driven only by capillary suction and gravity drainage
- Can be used regardless of precipitation intensity, and can be used with heterogenous soils
- Enforces that capillary head on either side of a soil layer boundary is equal

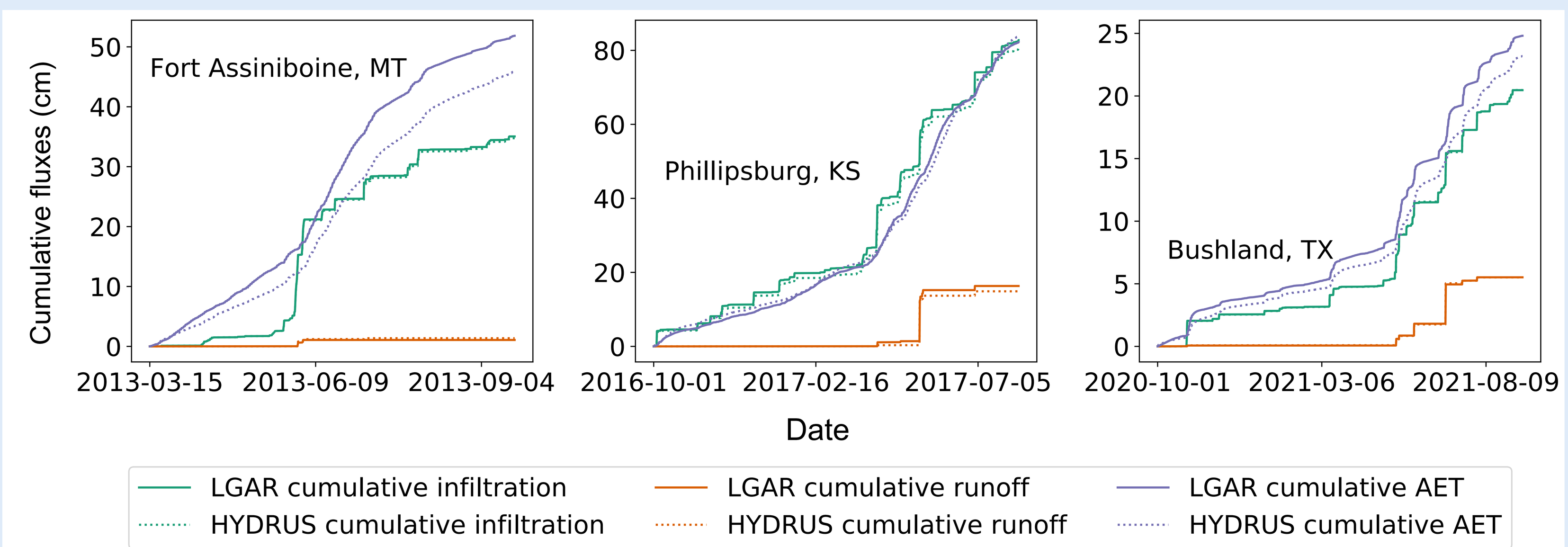



- Red line: maximum volumetric water content per soil layer
- Blue line: LGAR simulation
- Dotted lines: soil layer boundaries
- Distinct wetting fronts, which are mass conservative and have a single capillary head value, are each indicated with a distinct color

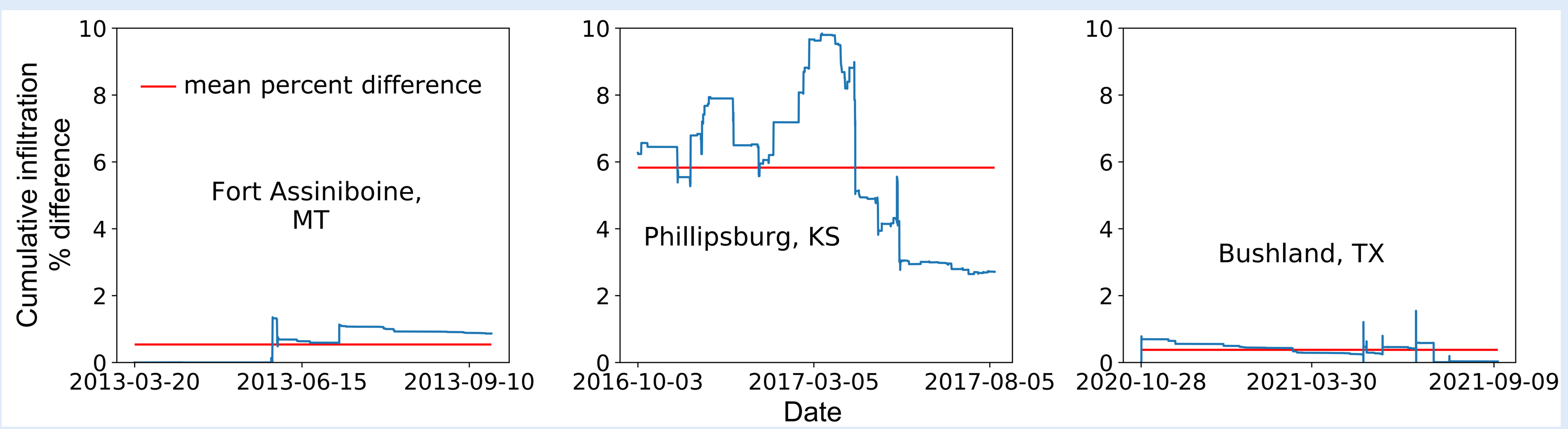
## LGAR reproduces infiltration and runoff as simulated by the Richards equation, with half the runtime

LGAR was compared against HYDRUS-1D, a popular Richards equation solver. Simulations in both LGAR and HYDRUS-1D use the same soil hydraulic parameters, and the same forcing data, taken from USDA SCAN sites. We find that both models yield similar precipitation partitioning results. This was also observed with tests using synthetic forcing data and soil hydraulic parameters.

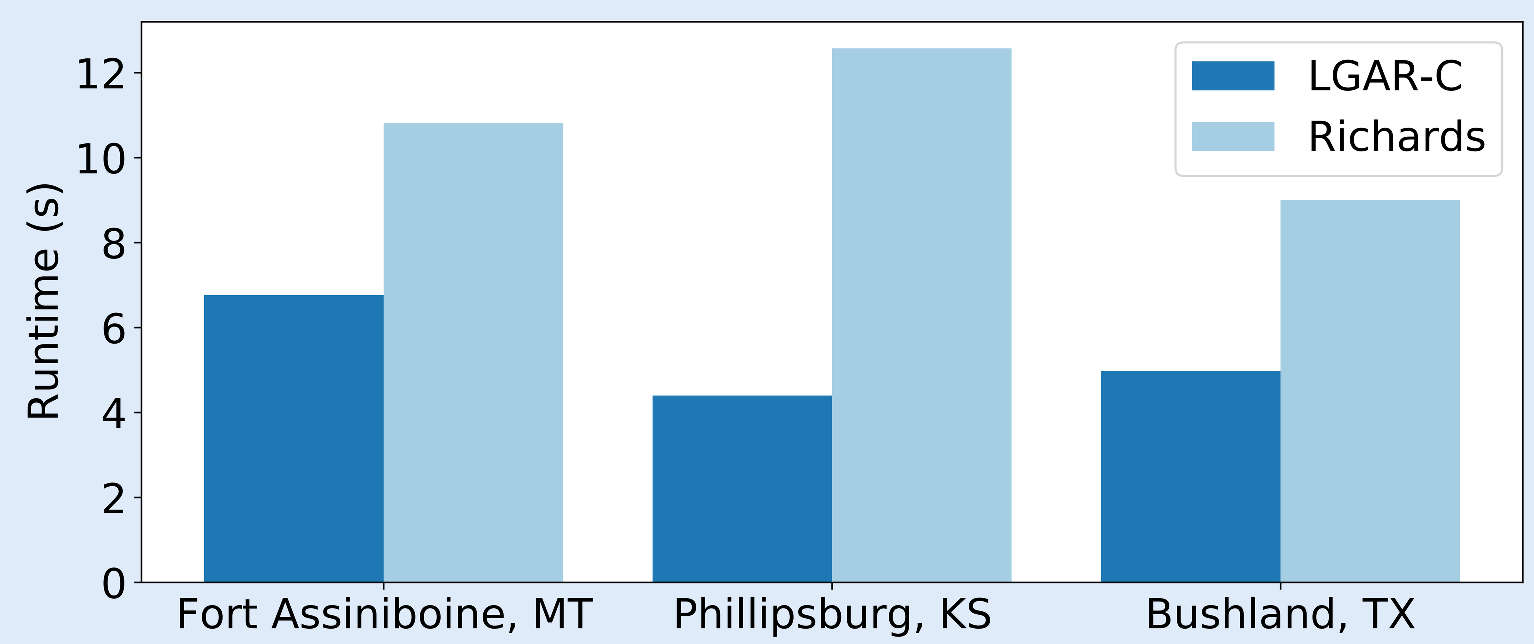
Cumulative fluxes as simulated by LGAR and HYDRUS-1D are similar




Infiltration as simulated by the Richards equation and LGAR tend to differ by less than 10%




LGAR is approximately twice as fast as the Richards equation, with potential for more computational optimization. Further, LGAR is unconditionally stable.




## Videos and other resources

LGAR is best explained with a video, showing both soil moisture dynamics and precipitation partitioning. Please scan the QR code on the left for videos showing examples of LGAR simulations, and the QR code on the right for the public GitHub repo of LGAR, in Python.

LGAR Videos

GitHub repo: LGAR-Py

## Limitations and future work

- LGAR is suitable for arid or semi-arid environments
  - Best agreement with the Richards equation occurs when the lower boundary condition is set to no-flow
  - This is realistic in areas where potential evapotranspiration is substantially greater than precipitation
- Groundwater lower boundary condition is currently in development, which will extend the utility of LGAR to all environments
- LGAR was developed in Python and is being refactored to C for increased speed

## Computational advantage of LGAR: speed and unconditional stability

Currently, the Richards equation is a popular way to simulate both vadose zone dynamics and precipitation partitioning, owing to its high accuracy. However, the Richards equation is often computationally expensive, requiring dozens or hundreds of nodes in which this partial differential equation must be solved per time step. Further, the Richards equation can have problems with stability and does not always converge. In contrast, LGAR has a relatively small number of state variables, and is inherently stable and mass conservative. This enables the use of LGAR over large spatial regions, over which many different parameter sets must be used. Preliminarily, we find that LGAR as implemented in C is approximately twice as fast as comparable simulations using the Richards equation.

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