SESSION NUMBER: H31L

Layered Green and Ampt infiltration with redistribution, with Talbot-Ogden groundwater bi-directional coupling

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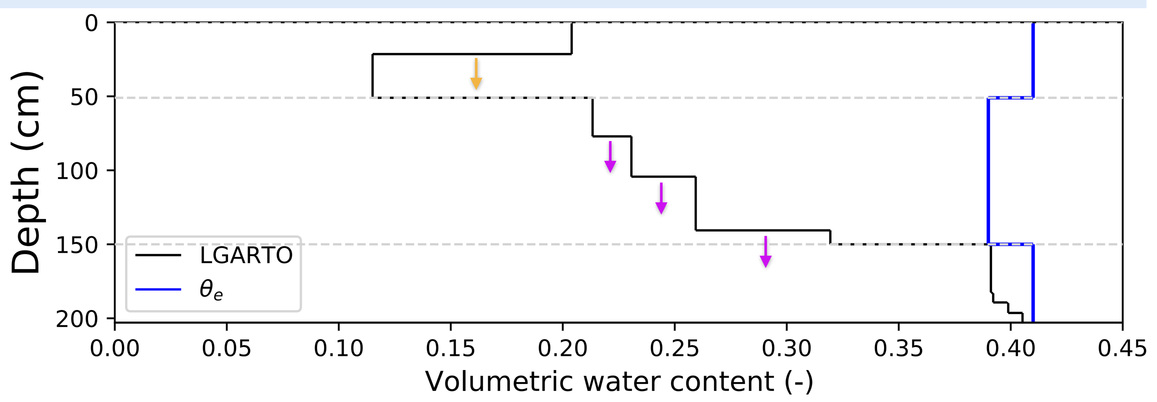
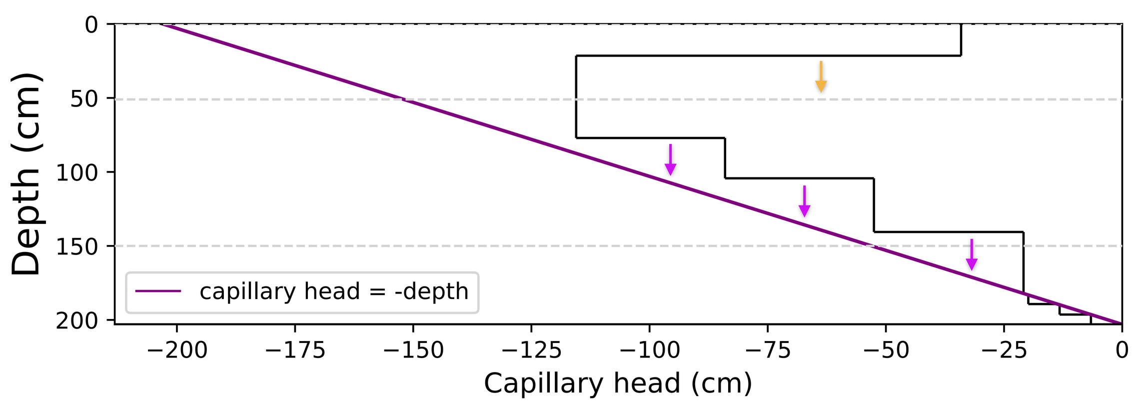
LGARTO method





- Surface wetting fronts represent regions of soil water in contact with the soil surface and can only move downward. Their speed is controlled by both hydraulic conductivity and capillary drive (in a similar way to the Richards equation), given by:

$$\frac{dZ}{dt} = \frac{1}{\theta-\theta_b}\left(\frac{K_{s,N}G_N(\theta_b,\theta)}{Z} + K_c(\psi(\theta))\right)$$

Where θ is the moisture of a wetting front, θ_b is the moisture below it, G is the capillary drive, Z is the wetting front depth, ψ is the capillary head of the wetting front, and K_c is the composite hydraulic conductivity of the wetting front. The top most wetting front controls infiltration capacity.

- Groundwater wetting fronts, representing regions of soil water in contact with the water table, can move up or down. The TO model leverages the fact that soil water in contact with the water table tends to move towards its hydrostatic position. GW wetting front velocity is controlled by hydraulic conductivity and distance from hydrostatic position and is given by:

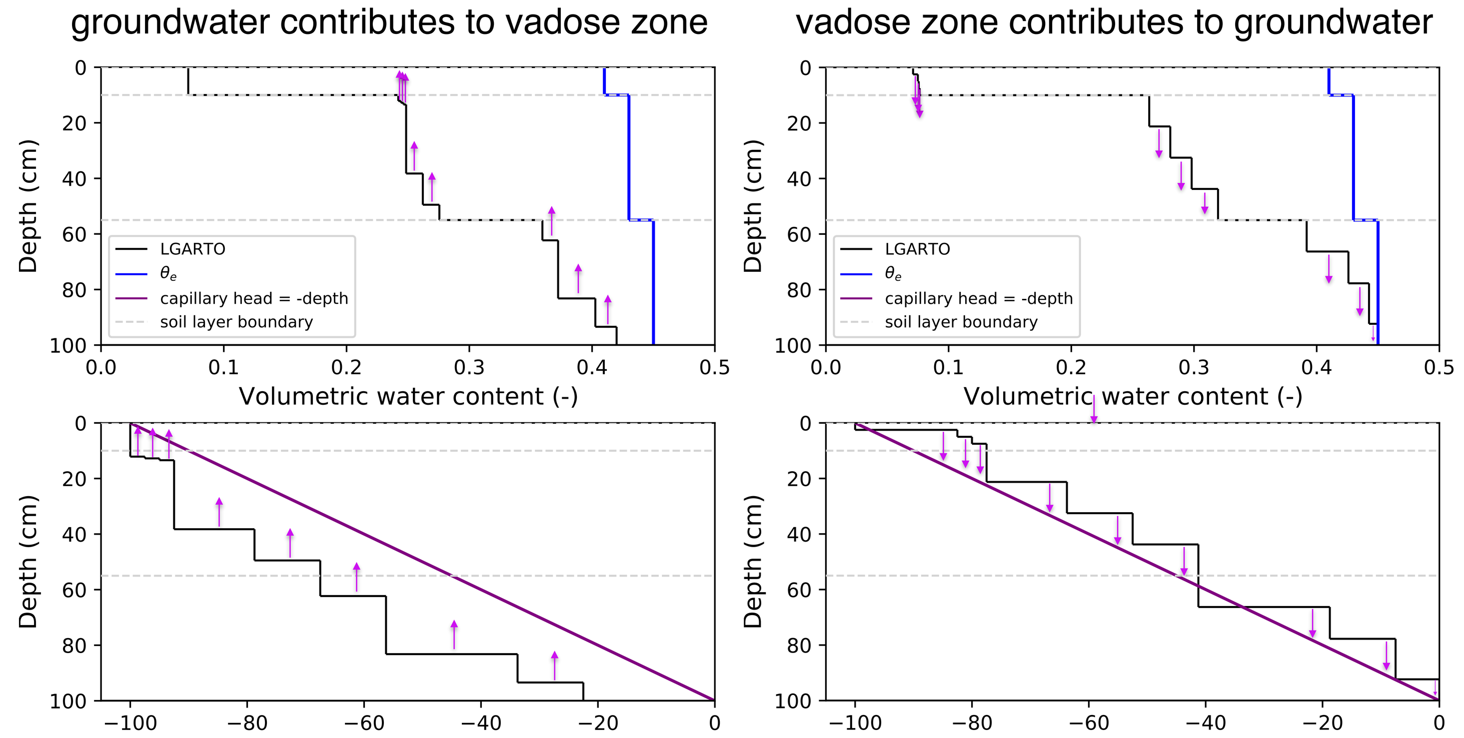
$$\frac{dZ}{dt} = \frac{K_c(\psi(\theta)) - K_c(\psi(\theta_l))}{\theta-\theta_l}\left(1-\frac{|\psi(\theta)|}{D-Z}\right)$$

Where θ_l is the moisture to the left of the wetting front and D is the depth from the soil surface to the water table. GW wetting front velocity directly controls fluxes between the vadose zone and groundwater.

Bi-directional fluxes between vadose zone and groundwater

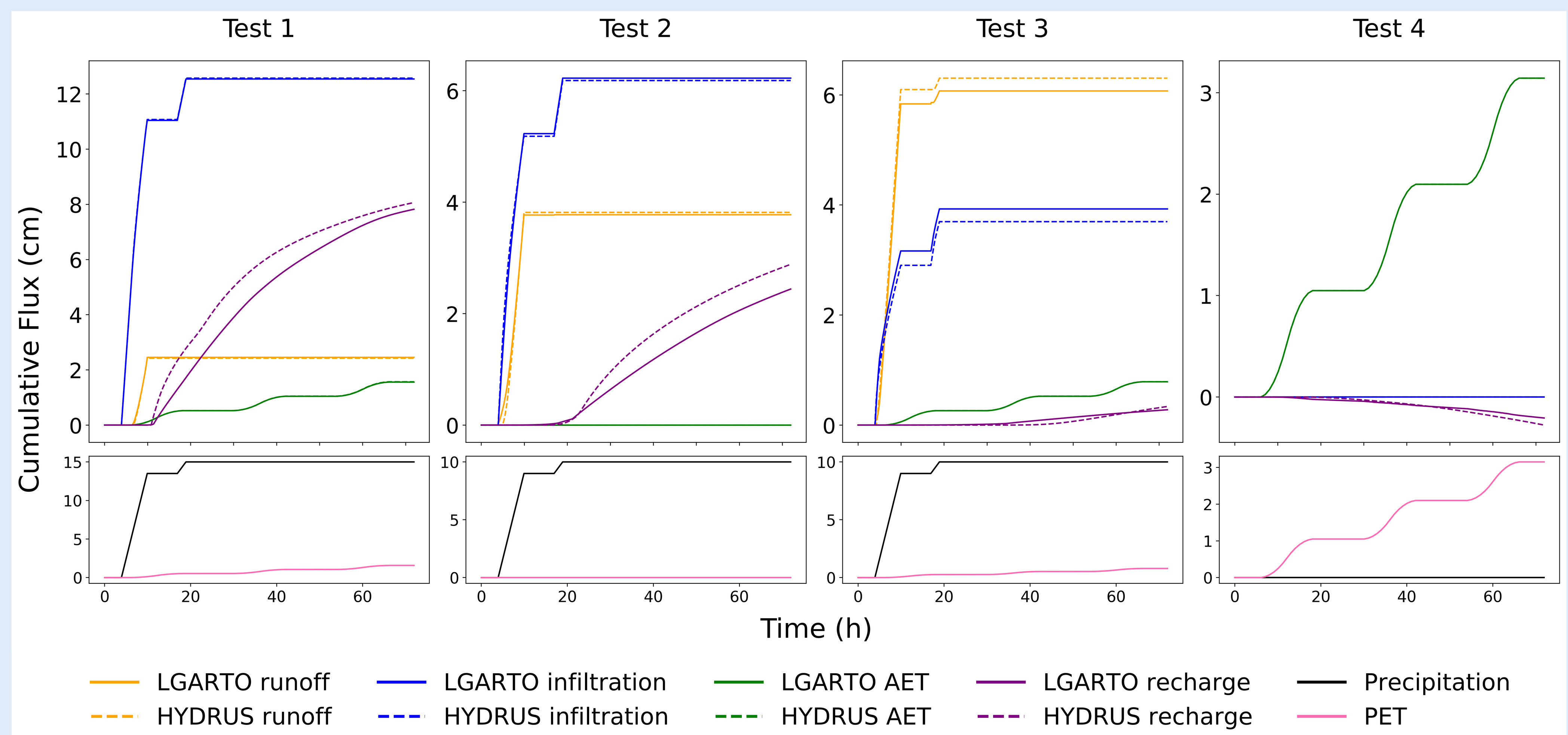
Groundwater wetting fronts move up: groundwater contributes to vadose zone

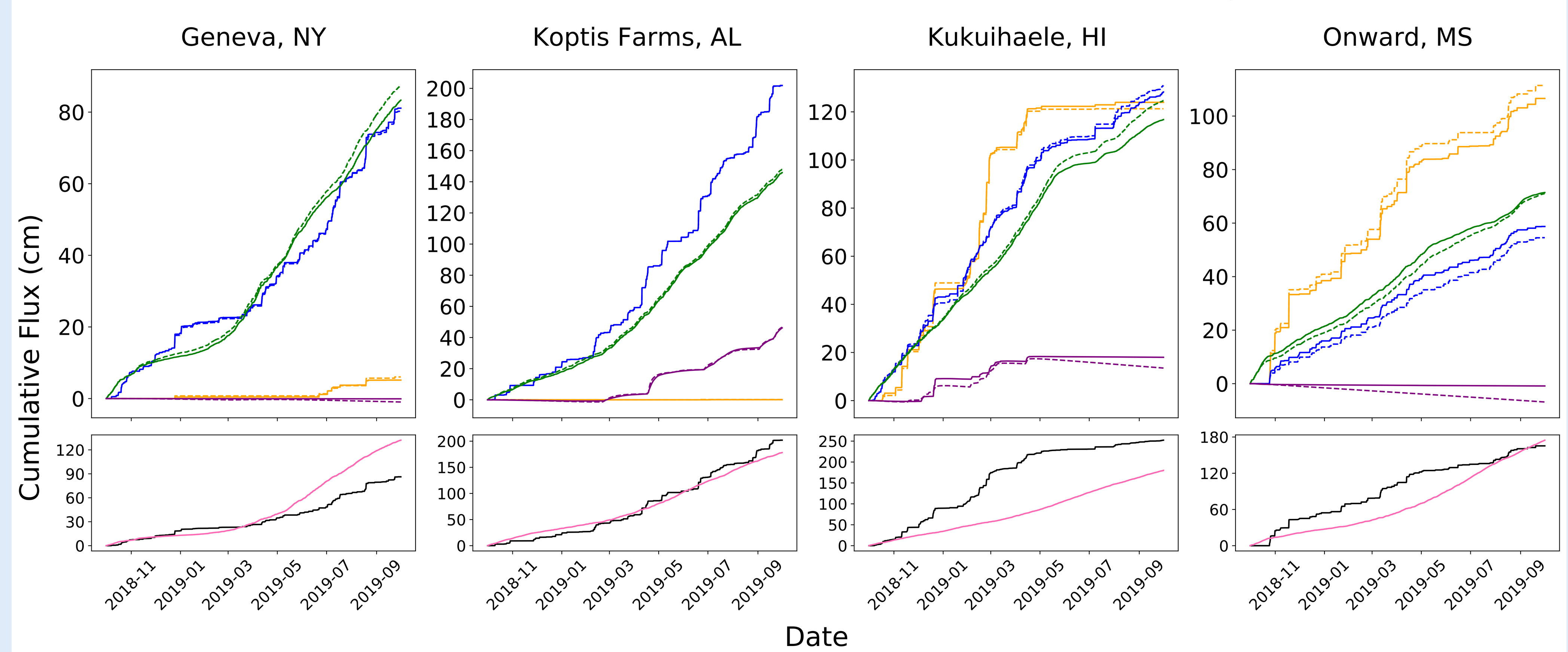
Groundwater wetting fronts move down: vadose zone contributes to groundwater



LGARTO closely mimics Richards equation solver results for a fraction of the computational expense

LGARTO and HYDRUS-1D results were compared for four tests using synthetic forcing data with durations of 72 hours, and for four tests using real forcing and soils data from USDA SCAN sites, with durations of 1 year. Each test used three soil layers, and a broad variety of soil textural classes were incorporated across all simulations.



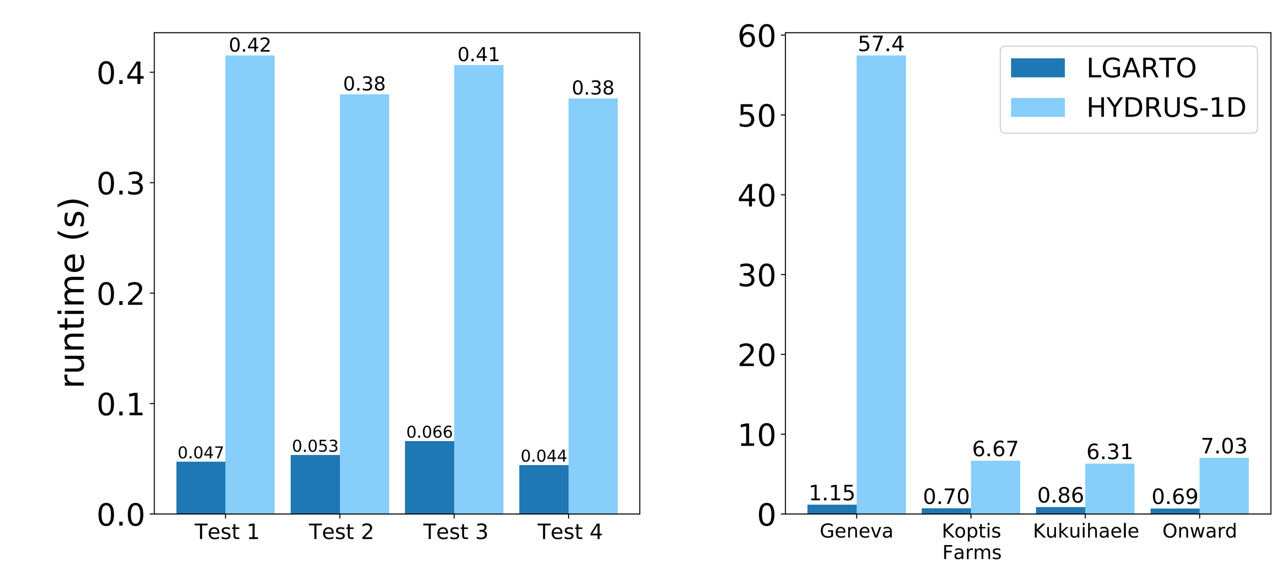


Simulation	Flux	KGE (-)	NSE (-)	PBIAS (%)	RMSE (cm h^{-1})	LGARTO cumulative (cm)	HYDRUS-1D cumulative (cm)	Difference (cm)
Test 1	Infiltration	0.995	0.999	0.24	1.4E-02	12.54	12.58	0.04
	Runoff	0.98	0.99	-1.2	1.4E-02	2.46	2.43	-0.03
	AET	0.99	0.9998	0.66	2.97E-05	1.558	1.569	0.011
	Recharge	0.61	0.64	3.0	5.5E-03	7.82	8.07	0.25
Test 2	Infiltration	0.97	0.98	-0.69	3.4E-03	6.23	6.18	-0.05
	Runoff	0.92	0.96	1.1	3.4E-03	3.77	3.82	0.05
	AET	-	-	0	0	0	0	0
	Recharge	0.63	0.75	15.4	1.3E-03	2.44	2.88	0.44
Test 3	Infiltration	0.89	0.91	-6.3	4.1E-03	3.93	3.70	-0.23
	Runoff	0.95	0.97	3.7	4.1E-03	6.07	6.30	0.23
	AET	0.999	0.99998	0.11	4.4E-06	0.7867	0.7875	0.0008
	Recharge	0.42	0.44	17.6	3.5E-04	0.278	0.338	0.06
Test 4	Infiltration	-	-	0	0	0	0	0
	Runoff	-	-	0	0	0	0	0
	AET	0.99998	0.99997	2.8E-04	2.5E-05	3.143808	3.1438	-8E-06
	Recharge	0.48	0.13	25.3	2.2E-04	-0.207	-0.277	-0.07

Simulation	Flux	KGE (-)	NSE (-)	PBIAS (%)	RMSE (cm h^{-1})	LGARTO cumulative (cm)	HYDRUS-1D cumulative (cm)	Difference (cm)
Geneva	Infiltration	0.98	0.99	-1.1	6.3E-03	81.10	80.22	-0.88
	Runoff	0.84	0.88	14.6	6.3E-03	5.15	6.03	0.88
	AET	0.94	0.99	4.7	1.8E-03	83.34	87.44	4.1
	Recharge	<-0.41	<0	91.9	1.7E-04	-0.08	-0.96	-0.88
Koptis Farms	Infiltration	0.997	0.9998	-0.049	2.1E-03	201.86	201.76	-0.1
	Runoff	-0.28	<0	57.0	1.9E-03	0.072	0.166	0.094
	AET	0.98	0.99	1.4	2.2E-03	145.91	147.96	2.05
	Recharge	0.74	0.76	0.92	6.1E-03	46.17	46.60	0.43
Kukuihaele	Infiltration	0.90	0.85	2.1	2.4E-02	128.24	130.97	2.73
	Runoff	0.97	0.96	-2.2	2.4E-02	123.95	121.29	-2.66
	AET	0.92	0.98	6.3	3.0E-03	116.81	124.72	7.91
	Recharge	<-0.41	<0	-33.0	1.6E-02	18.00	13.53	-4.47
Onward	Infiltration	0.90	0.91	-7.7	1.0E-02	58.74	54.56	-4.18
	Runoff	0.95	0.99	4.3	9.6E-03	106.59	111.44	4.85
	AET	0.95	0.97	-0.6	2.4E-03	71.43	71.04	-0.39
	Recharge	<-0.41	<0	87.4	7.5E-04	-0.86	-6.85	-5.99

Computational advantage of LGARTO

LGARTO offers a substantial increase in speed over Richards equation solvers, owing to the relative simplicity of LGARTO. LGARTO is unconditionally stable, whereas the Richards equation will fail to converge given specific combinations of soil hydraulic parameters, choices in spatial discretization, and forcing data. LGARTO's stability and speed facilitate its use for simulations with large spatial domains, over which diverse parameter and forcing data must be used.



	Test 1	Test 2	Test 3	Test 4	Geneva	Koptis Farms	Kukuihaele	Onward
ratio of HYDRUS 1-D runtime to LGARTO runtime	8.8	7.1	6.2	8.5	49.4	9.6	7.3	10.2

Limitations and future work

- Currently, the water table as represented by LGARTO is fixed. Future developments will include a dynamic water table.
- A catchment scale hydrologic model explicitly designed for humid regions with a shallow water table, incorporating LGARTO, will be developed and broadly evaluated.
- The relationship between runtime and accuracy compared to the Richards equation can be further explored.
- The capacity to model preferential flow will be developed.

Videos and other resources

LGARTO is best explained with videos, showing soil moisture dynamics and simulated fluxes. 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 LGARTO, in C (currently a branch of LGAR-C).

LGARTO Videos

LGARTO code

REFERENCES:

La Follette P., et al. (2023). Layered Green and Ampt Infiltration with Redistribution. Water Resources Research, 59(8).

Talbot, C. A., & Ogden, F. L. (2008). A method for computing infiltration and redistribution in a discretized moisture content domain. Water Resources Research, 44(8).

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