Supplementary Materials for "New insights from fully-integrated surface-subsurface hydrological modeling in high-elevation glaciated environments"

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S1. Snow and discharge performance

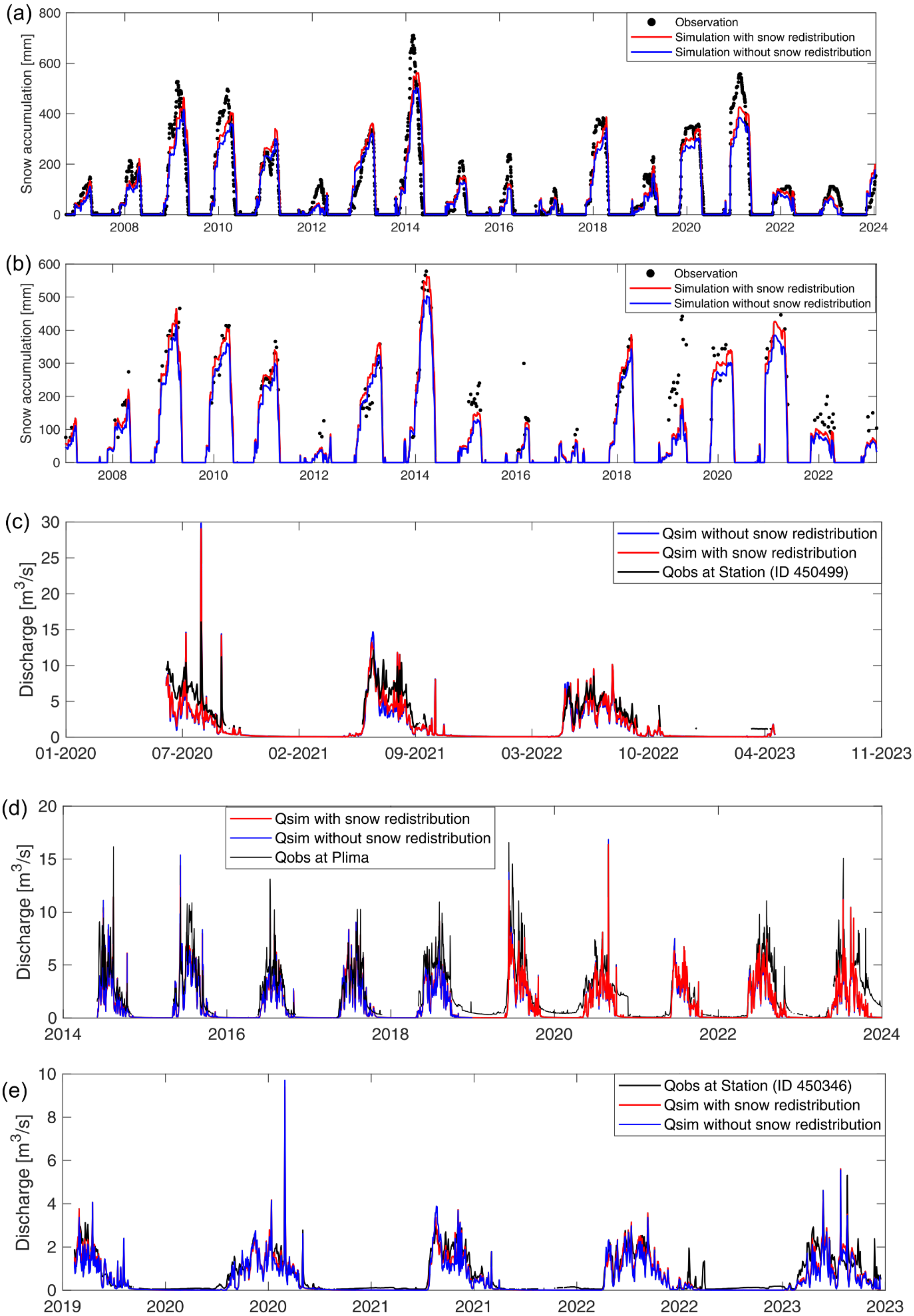


Figure S1. (a-b) The observed and simulated daily snow accumulation by using the energy-balance method with and without snow redistribution algorithms activated in WaSiM. (c-e) The observed and simulated daily discharge with and without snow redistribution algorithms activated for the Subcatchments (c) S2, (d) S7, and (e) S8 (see Fig.1). The model performances of the simulations are summarised in Table S1. The black dot and line denote the observation, the red line denote the simulation with snow redistribution, and the blue line denote the simulation without snow redistribution.

Table S1. The model performance of the simulated snow accumulation and discharge with (Y) and without (N) snow redistribution algorithms activated in WaSiM.

Station	NSE (Y)	NSE (N)	Spearman's correlation coefficient (Y)	Spearman's correlation coefficient (N)
Zufritt (snow in Fig.S1a)	0.87	0.86	0.94	0.93
Zufallhuette (snow in Fig.S1b)	0.76	0.74	0.88	0.88
ID 450499 (discharge in Fig.S1c)	0.50	0.35	0.87	0.84
Plima (discharge in Fig.S1d)	0.63	0.60	0.90	0.89
ID 450346 (discharge in Fig.S1e)	0.76	0.69	0.90	0.87

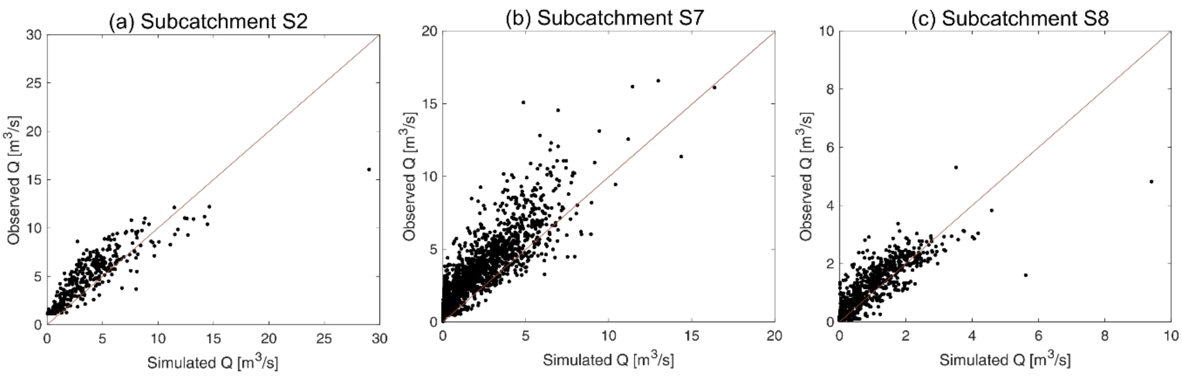
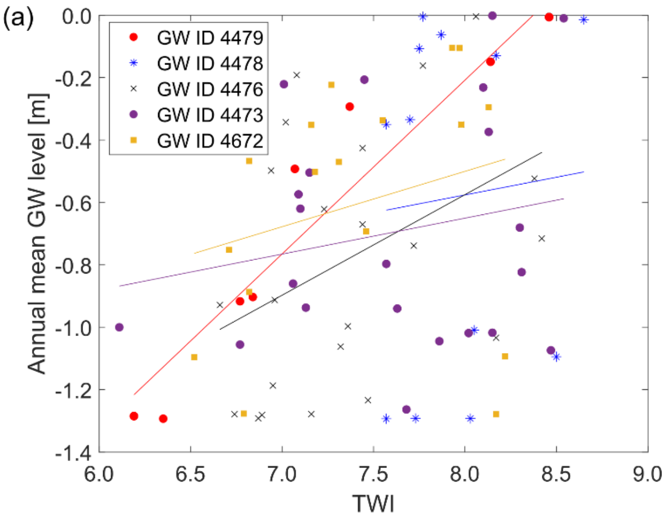


Figure S2. Scatter plots of the observed against simulated discharge (Q) in the Subcatchments S2, S7, and S8 corresponding to Figure 6.

S2. Groundwater heads and Topographic Wetness Index



(b)

	slope	R^2	*p*-value
GW ID4479	0.54	0.94	0.01
GW ID4478	0.18	0.02	0.69
GW ID4476	0.37	0.25	0.02
GW ID4473	0.10	0.03	0.43
GW ID4672	0.17	0.06	0.33

Figure S3. (a) The relationship between the Topographic Wetness Index (TWI) and the simulated annual mean groundwater (GW) level between 2011 and 2023 of the five observed boreholes and their neighboring cells in the model. Each colour represents the data of each borehole. The lines denote the trends quantified for each site with the data at the observed location and their neighboring cells. The slope, the linearity, and the significance level of the trends are provided in (b).

S3. Parametric analysis of soil thickness impact on groundwater hydrographs

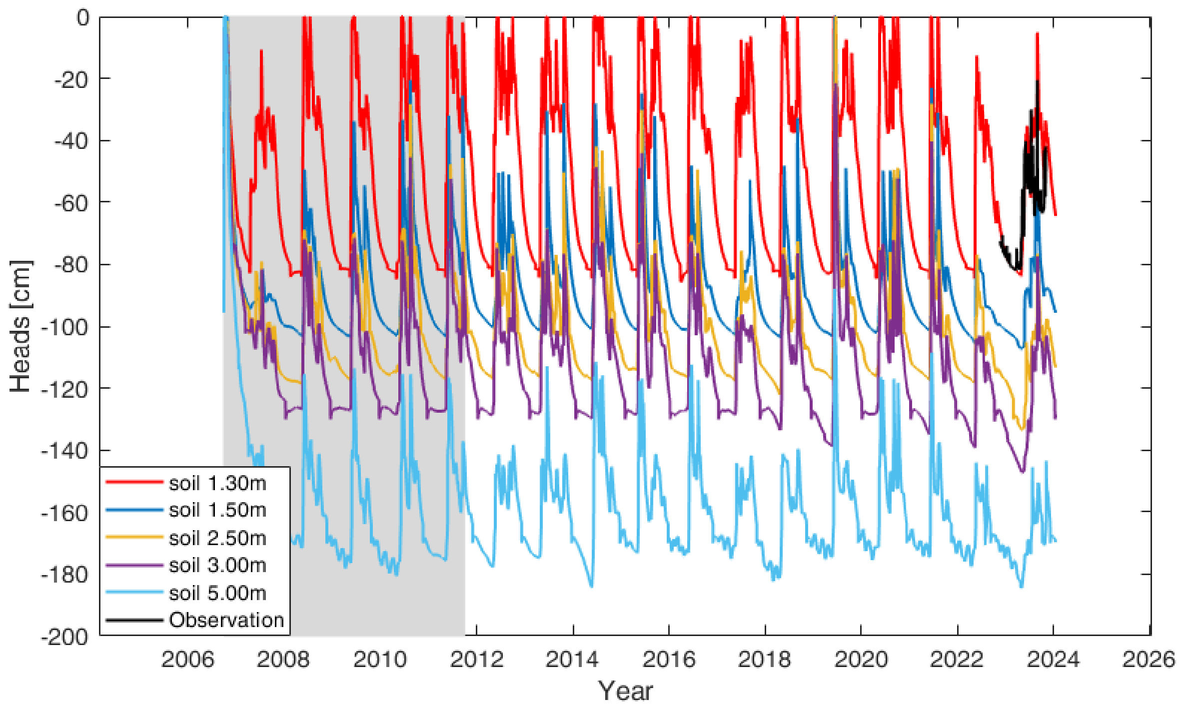


Figure S4. Parametric analysis of soil thickness impact on groundwater hydrographs of bore ID 4479. The grey block denotes the modeling warm-up period between 1 Oct 2006 and 30 Sep 2011 for 5 years.

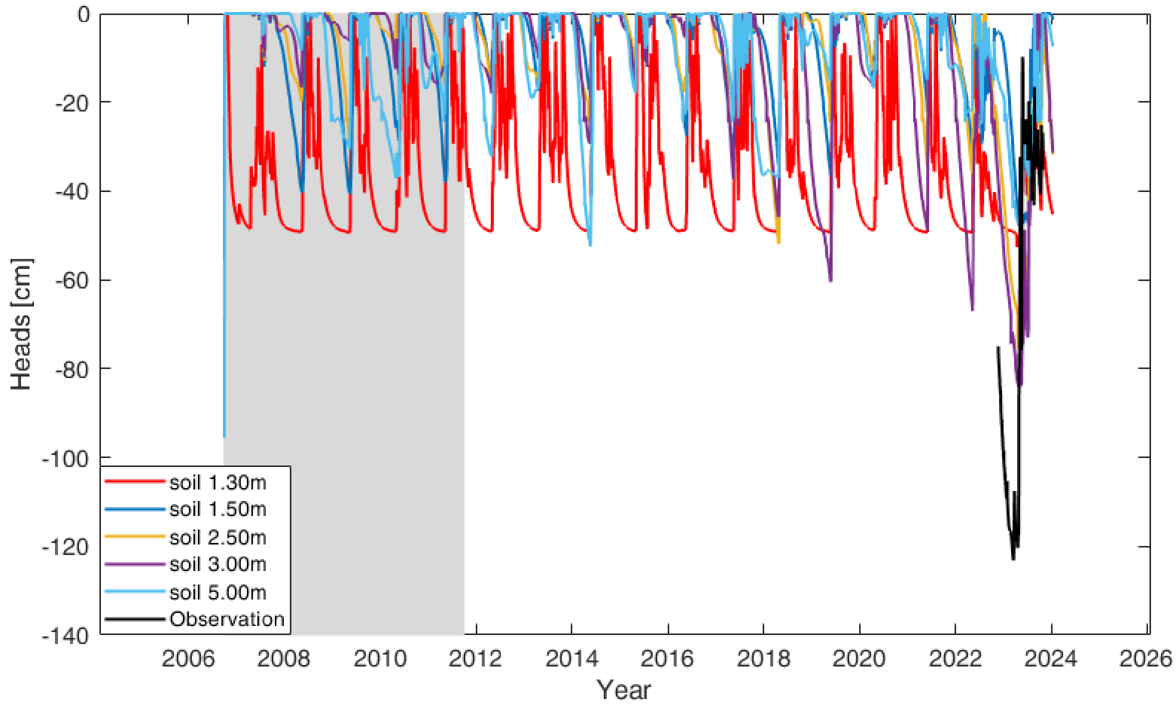


Figure S5. Parametric analysis of soil thickness impact on groundwater hydrographs of bore ID 4478. The grey block denotes the modeling warm-up period between 1 Oct 2006 and 30 Sep 2011 for 5 years.

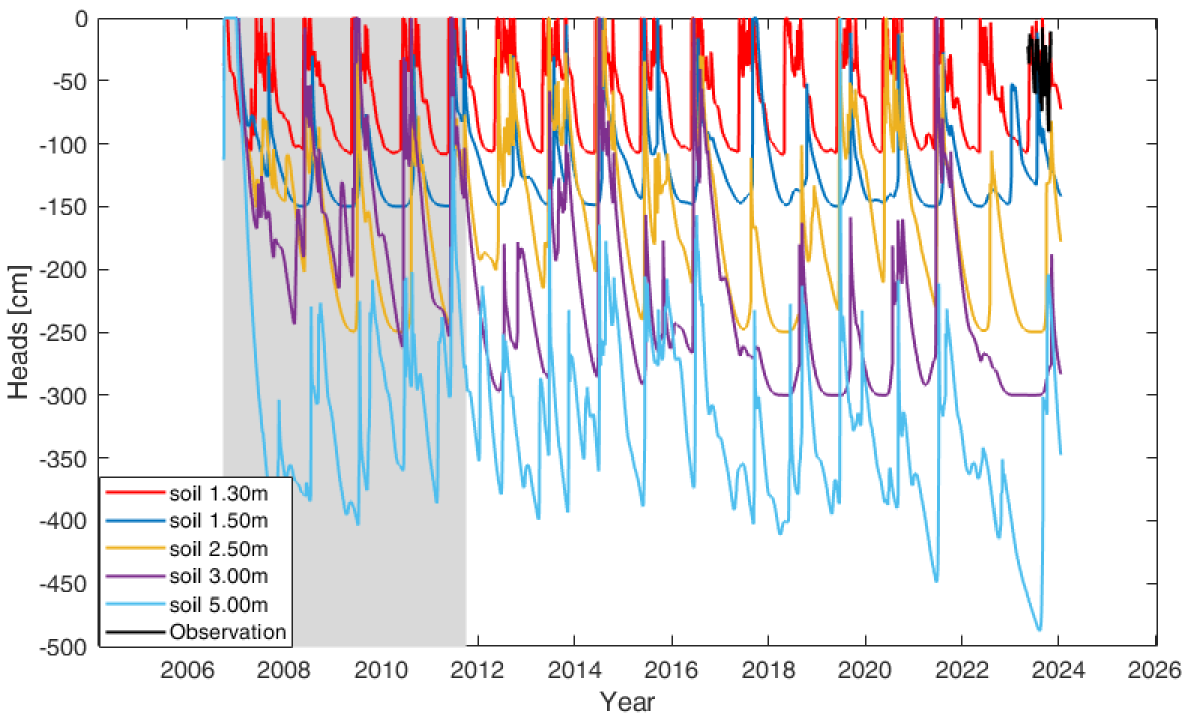


Figure S6. Parametric analysis of soil thickness impact on groundwater hydrographs of bore ID 4476. The grey block denotes the modeling warm-up period between 1 Oct 2006 and 30 Sep 2011 for 5 years.

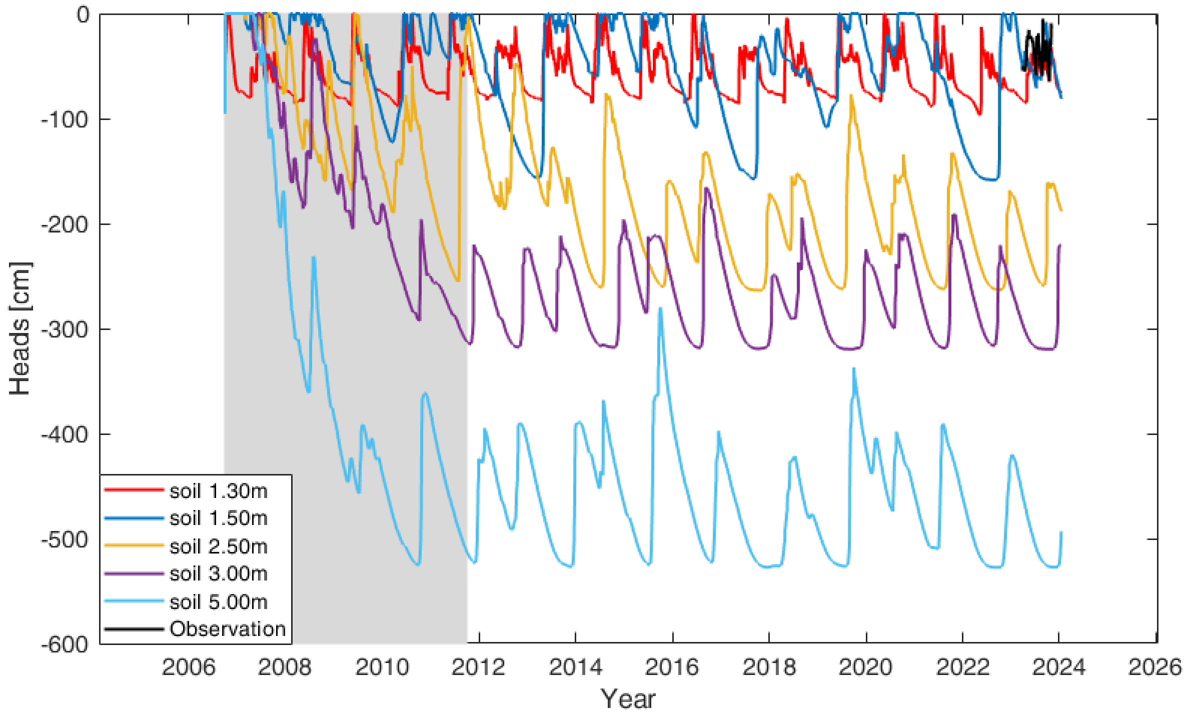


Figure S7. Parametric analysis of soil thickness impact on groundwater hydrographs of bore ID 4473. The grey block denotes the modeling warm-up period between 1 Oct 2006 and 30 Sep 2011 for 5 years.

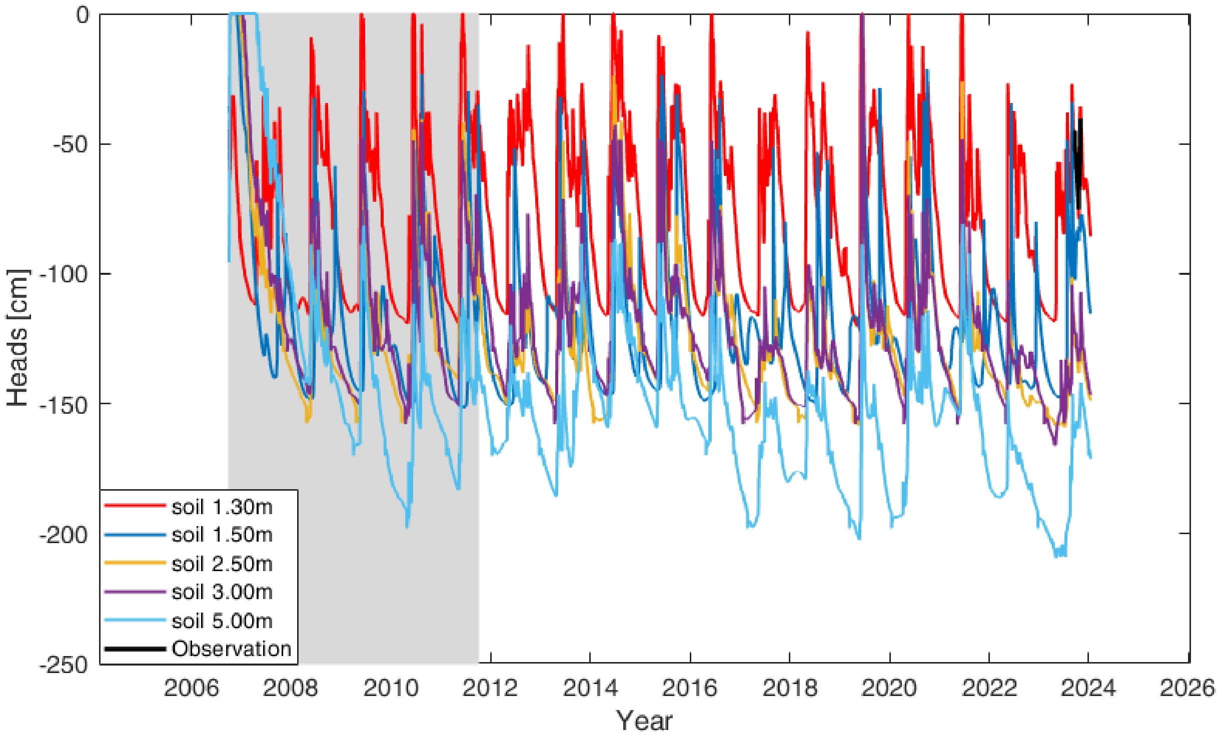


Figure S8. Parametric analysis of soil thickness impact on groundwater hydrographs of bore ID 4672. The grey block denotes the modeling warm-up period between 1 Oct 2006 and 30 Sep 2011 for 5 years.

S4. Parametric analysis of interflow-related parameters (krec, dr) impact on groundwater hydrographs. 500 Monte-Carlo simulations are performed and comprehensively explored the whole parameter spaces. The best groundwater simulations are produced when the interflow is forced to 0 (i.e. dr = 0 and krec = 1). Note, interflow used in WaSiM = subsurface lateral flow.

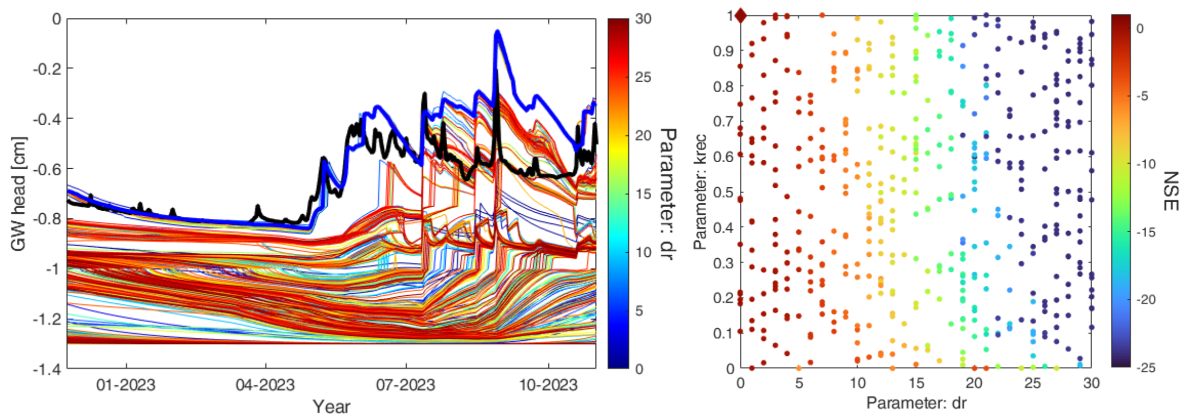


Figure S9. Parametric analysis of interflow-related parameters (krec, dr) impact on groundwater hydrographs of bore ID 4479. The left panel shows the 500 simulated hydrographs with the colorbar representing the Parameter dr value from 0 to 30; black line shows the observed hydrograph; dark blue line shows the best simulated hydrograph achieved when interflow is forced to 0 (dr = 0 and krec = 1). The right panel shows the NSE of all simulated hydrographs with the 500 pairs of dr and krec parameters; the diamond on it indicates the NSE of the best simulated hydrograph with interflow forced to 0.

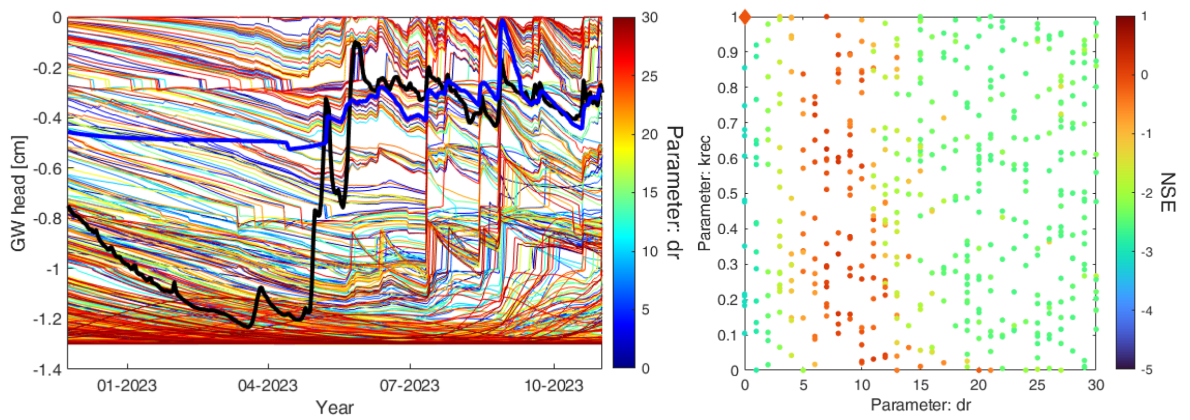


Figure S10. Parametric analysis of interflow-related parameters (krec, dr) impact on groundwater hydrographs of bore ID 4478. The left panel shows the 500 simulated hydrographs with the colorbar representing the Parameter dr value from 0 to 30; black line shows the observed hydrograph; dark blue line shows the best simulated hydrograph achieved when interflow is forced to 0 (dr = 0 and krec = 1). The right panel shows the NSE of all simulated hydrographs with the 500 pairs of dr and krec parameters; the diamond on it indicates the NSE of the best simulated hydrograph with interflow forced to 0.

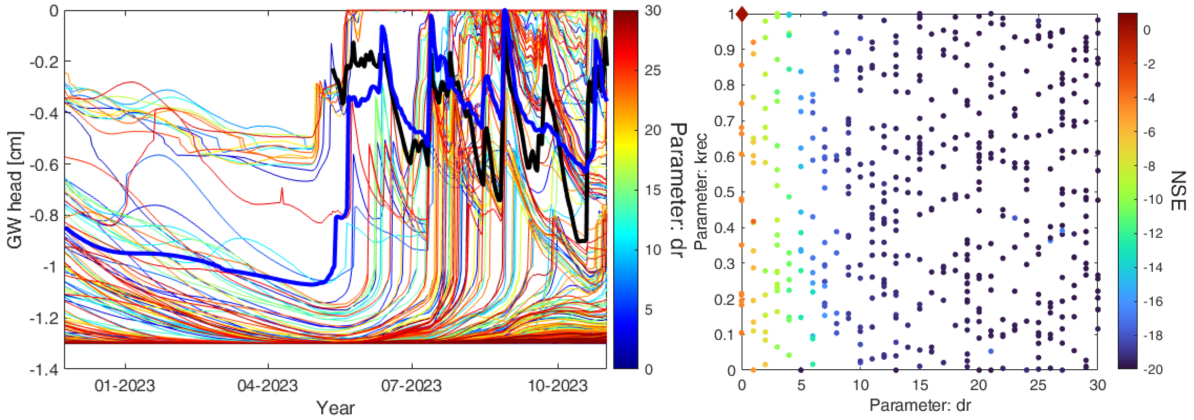


Figure S11. Parametric analysis of interflow-related parameters (krec, dr) impact on groundwater hydrographs of bore ID 4476. The left panel shows the 500 simulated hydrographs with the colorbar representing the Parameter dr value from 0 to 30; black line shows the observed hydrograph; dark blue line shows the best simulated hydrograph achieved when interflow is forced to 0 (dr = 0 and krec = 1). The right panel shows the NSE of all simulated hydrographs with the 500 pairs of dr and krec parameters; the diamond on it indicates the NSE of the best simulated hydrograph with interflow forced to 0.

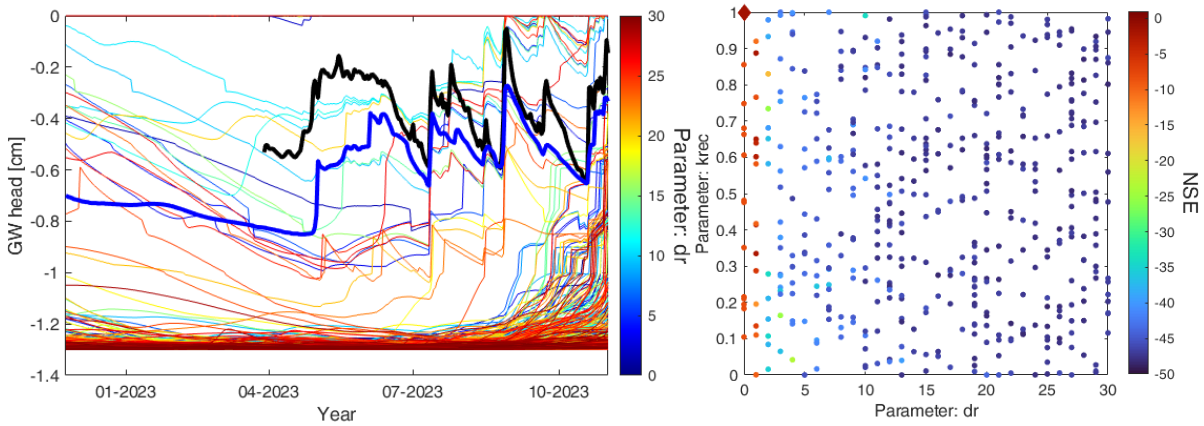


Figure S12. Parametric analysis of interflow-related parameters (krec, dr) impact on groundwater hydrographs of bore ID 4473. The left panel shows the 500 simulated hydrographs with the colorbar representing the Parameter dr value from 0 to 30; black line shows the observed hydrograph; dark blue line shows the best simulated hydrograph achieved when interflow is forced to 0 (dr = 0 and krec = 1). The right panel shows the NSE of all simulated hydrographs with the 500 pairs of dr and krec parameters; the diamond on it indicates the NSE of the best simulated hydrograph with interflow forced to 0.

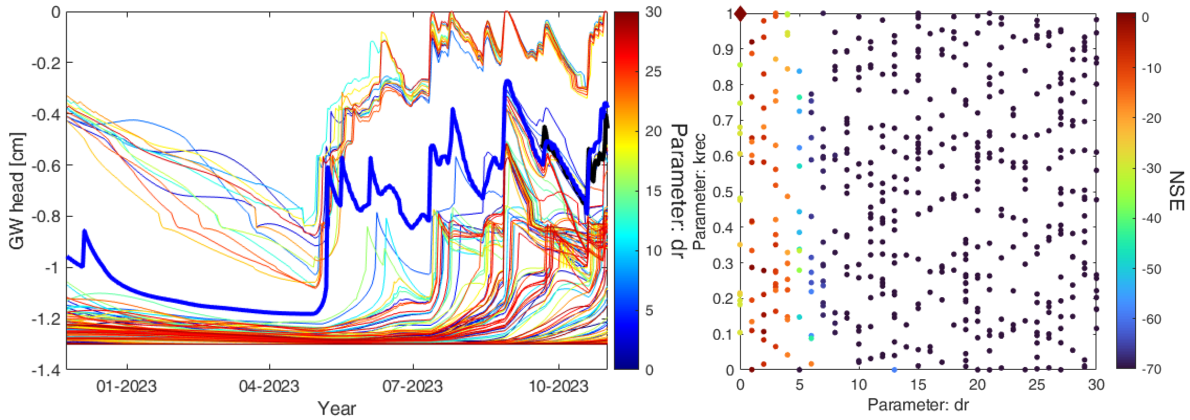


Figure S13. Parametric analysis of interflow-related parameters (krec, dr) impact on groundwater hydrographs of bore ID 4672. The left panel shows the 500 simulated hydrographs with the colorbar representing the Parameter dr value from 0 to 30; black line shows the observed hydrograph; dark blue line shows the best simulated hydrograph achieved when interflow is forced to 0 (dr = 0 and krec = 1). The right panel shows the NSE of all simulated hydrographs with the 500 pairs of dr and krec parameters; the diamond on it indicates the NSE of the best simulated hydrograph with interflow forced to 0.