Improving the simulation of groundwater flow in the Escabas catchment (Spain)

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SWAT Soil & Water Assessment Tool

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Introduction. Groundwater resources

Groundwater →

Accounts for approximately **99% of liquid freshwater**.

Annual withdrawal → 959 km³ (69% agriculture, 22% Domestic, 9% Industry).

Around **50% of the human consumption supply (100% in Denmark)**

United Nations, The United Nation
Groundwater: Making th

ALSO A THREATENED RESOURCE

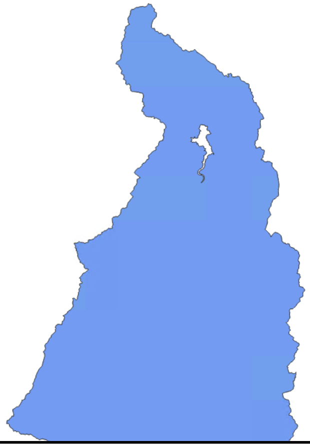
- Overexploitation
- Agricultural and livestock pollution
- Climate change

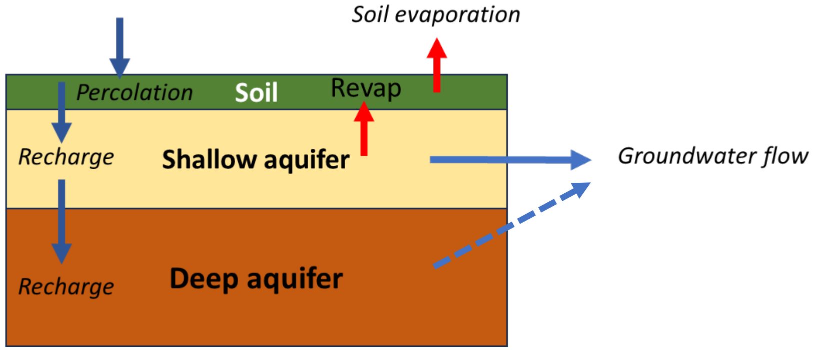
Groundwater → Key resource, espec

- Slow response to precipitation → Maintains the streamflow during dry periods.
- Huge impact on water quality and ecosystems.
- In Spain → Strategic resource for human consumption (reserved for drought periods, but main source in remote locations).

Introduction. Groundwater modelling with SWAT/SWAT+

- Pointed out as one of the model weaknesses.
- SWAT → Lumped model: One single shallow aquifer.
- SWAT+ → 1 shallow aquifer per subbasin





Coupling SWAT/SWAT+ with groundwater models (MODFLOW, GWFLOW) is also an option, but,
can we do it just with SWAT+?

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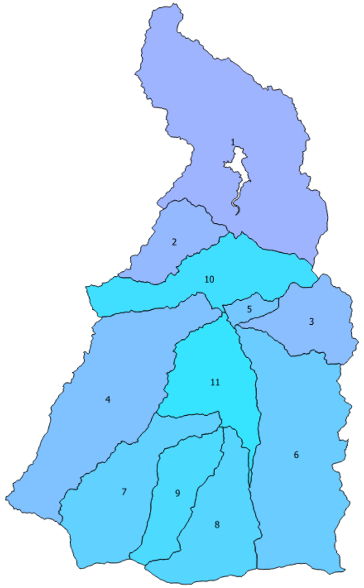
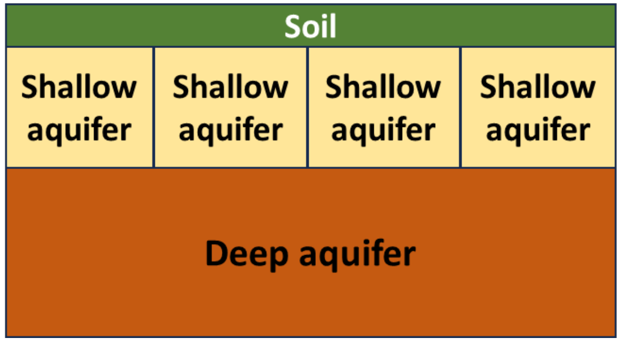
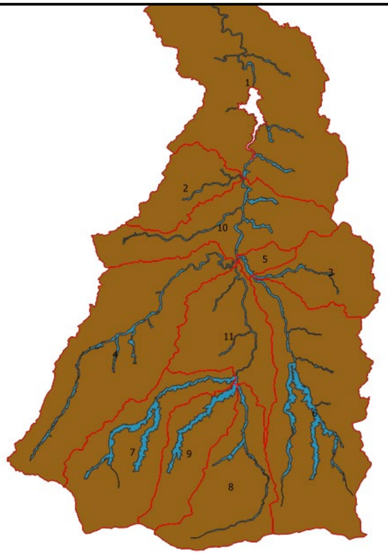
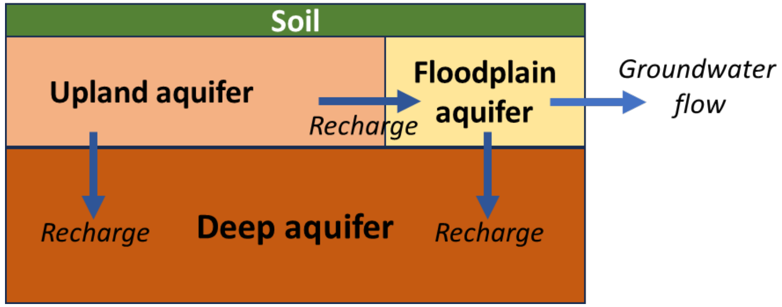


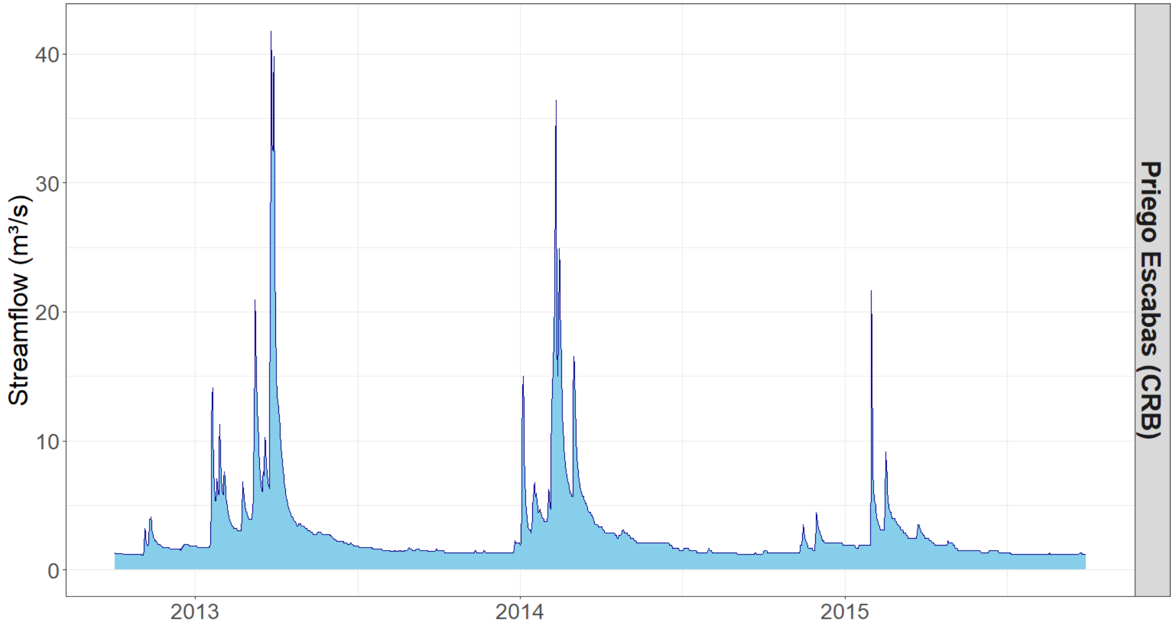


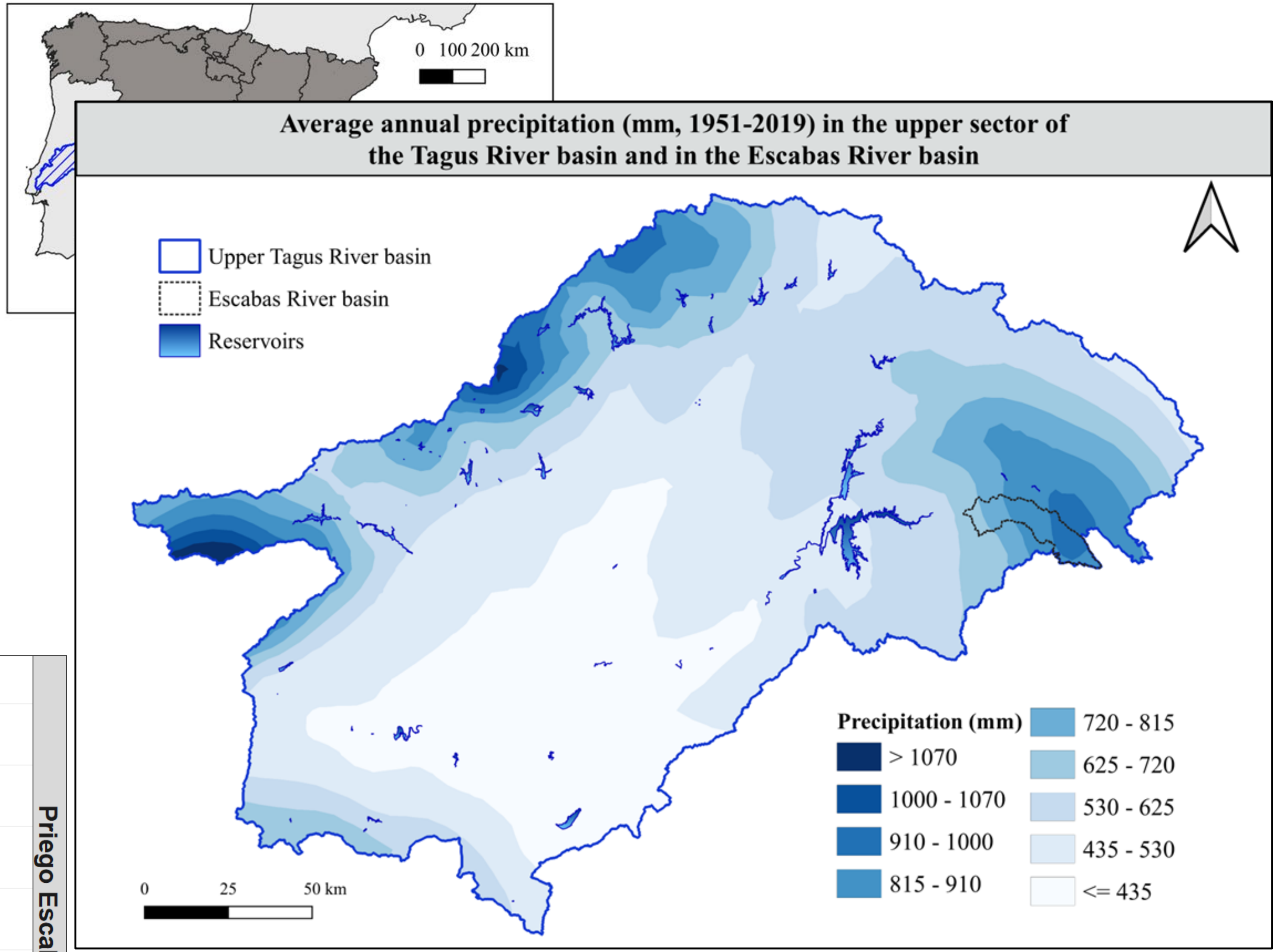




Study area. The Escabas Catchment

- Located in the east of the Tagus River basin, tributary of the Guadiela River.
- Small (330 km²) and undisturbed basin: Low population, no reservoirs or relevant withdrawals.
- Mean precipitation ≈ 850 mm, Mean temperature ≈ 10.2°C (1951-2019), streamflow data from 1972.
- Baseflow maintained during the year.



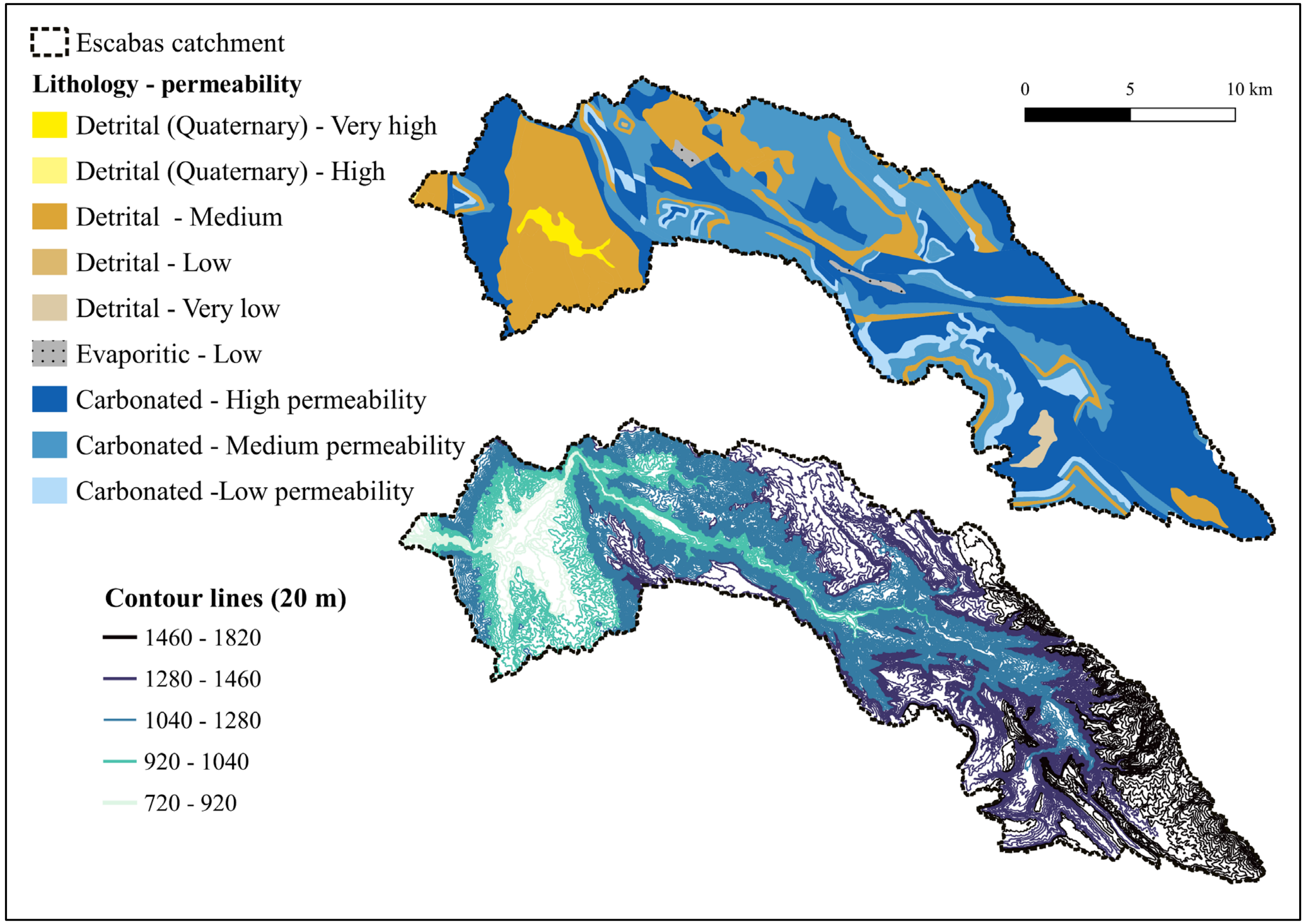


Ideal study case to work on groundwater modelling assessment

Study area. The Escabas Catchment

- Baseflow in this cacthment → Groundwater.

- **Aquifer materials** with high permeability → More than 75% of the catchment → Carbonate materials.



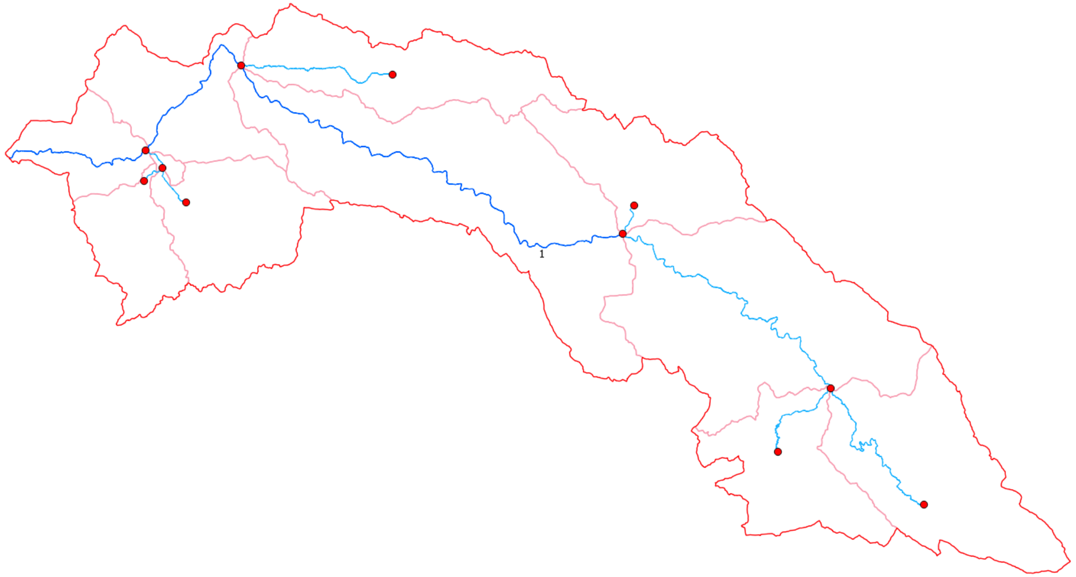
- **Flat areas** over these permeable materials favours recharge.

- **Natural vegetation** is the main land cover (95% of the catchment).

Objectives

- Simulate in a realistic way the streamflow and its components in a aquifer dominated catchment, focusing on the groundwater flow.
- Understand the effect of different parameters on the groundwater simulation in SWAT+.
- Compare two different calibration approaches.

Model setup



As simple as posible:

- 1 subbasin
- No floodplain/upslope LSUs
- No HRUs simplification → Possible coupling with other groundwater model
- 11 channels/LSUs, 364 HRUs
- Time for running 10 years (+5 warm-up) → 40 seconds

Initial aquifers configuration

- Deep aquifer removed (only 1 aquifer).
- **rchrg_deep** and **revap_min** parameters adjusted to 0 → Groundwater flow is the only possible way out of the aquifer.

Type	Area (%)	Landuse	Area (%)
Natural vegetation	90.7	frse	52.8
		frst	20.7
		frsd	1.5
		migs	12.9
		past	2.5
		rngb	0.3
Agricultural lands	7.9	agrl	4.0
		oliv	0.1
		crgr	3.9
Urban	0.4	urmd	0.1
		urhd	0.3
Barren	1	bsvg	1.0

ID	Soil	Area (%)
HWSD9700	Rendzic Leptosols	90.8
HWSD9703	Calcaric Cambisols	9.1
HWSD9707	Calcaric Cambisols	0.1

Slope band	Area (%)
<= 8	14.8
8 - 30	40.0
>= 30	45.3

Model calibration

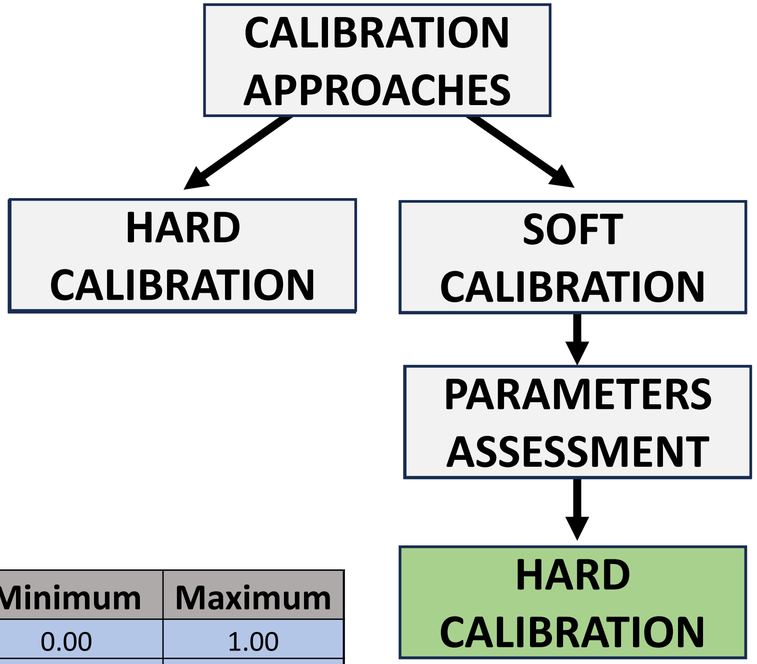
- Calibration period → 2010-2018
- Performed with SWATplusR

Approach 1.

- 3 iterations 1000 simulations, parameters constrain focusing on streamflow simulation performance.

Approach 2:

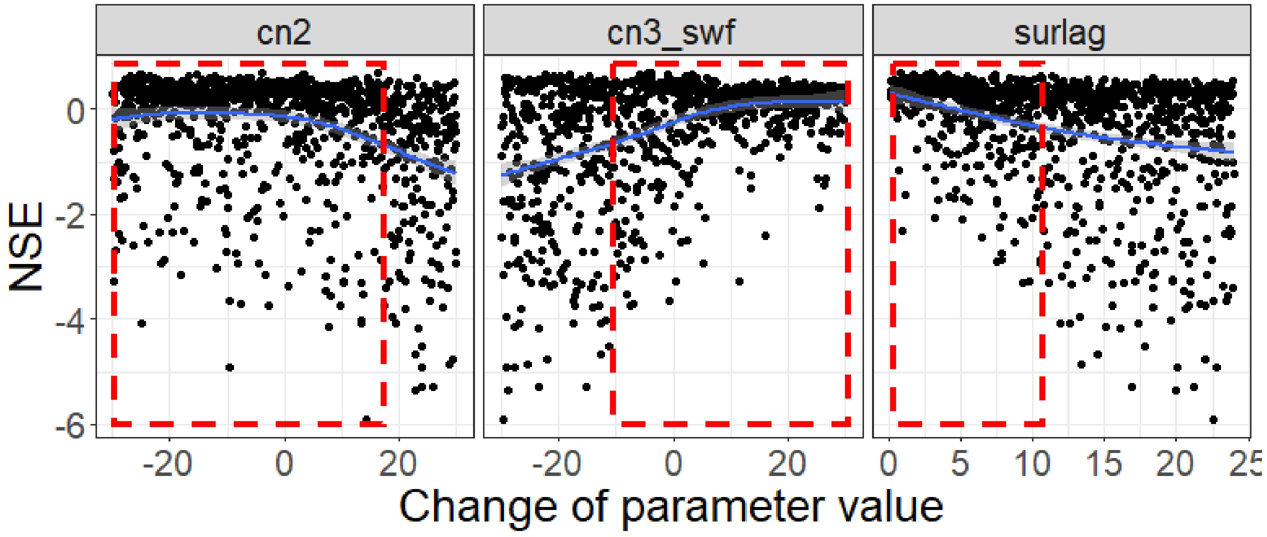
- 4 iterations 1000 simulations, parameters constrain focusing on **runoff coefficient** and **groundwater contribution**.
- Evaluation of parameters effect on groundwater flow simulation.
- Hard calibration: 3 iterations 1000 simulations, parameters constrain focusing on streamflow simulation performance.

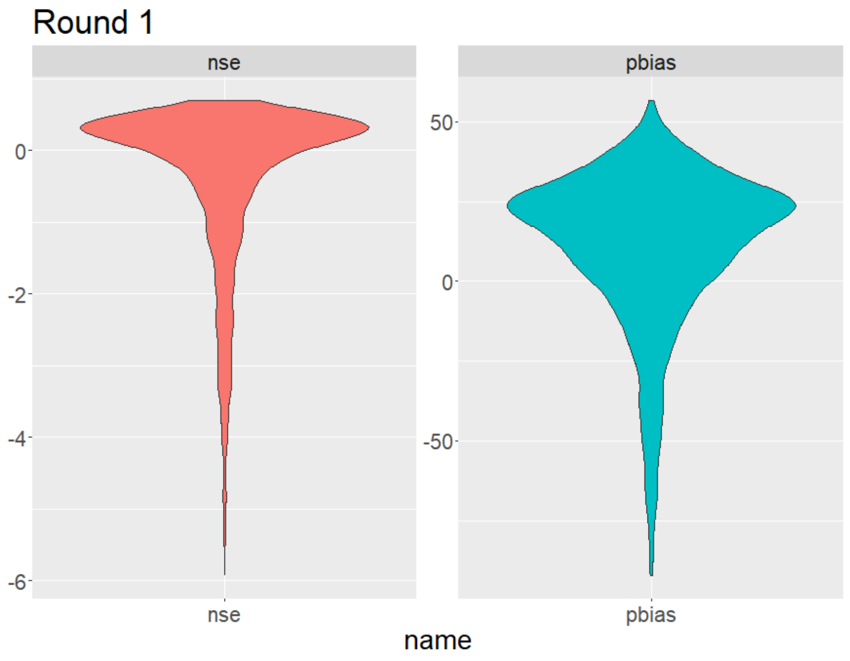


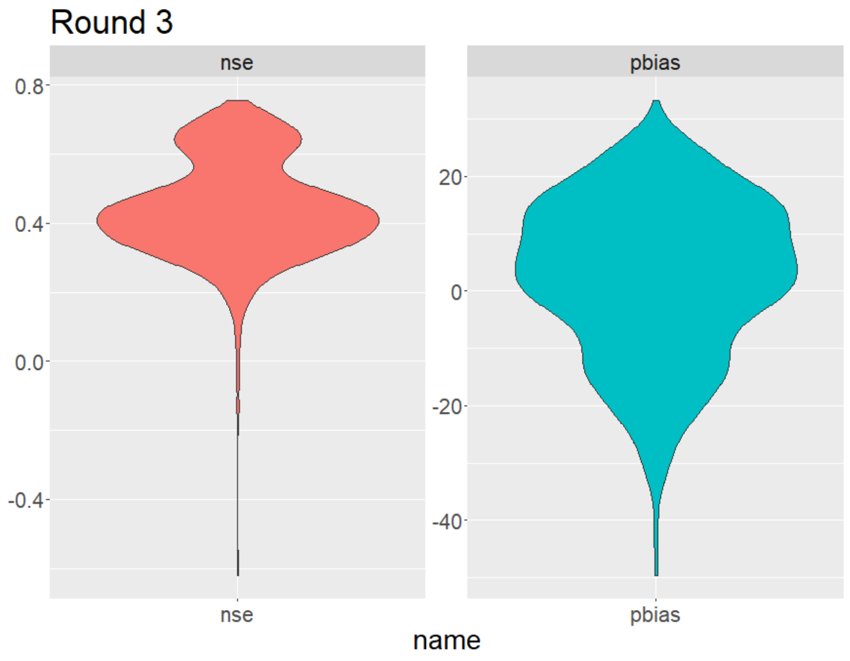
	Parameter	Change	Minimum	Maximum
Soft/Hard calibration	esco.hru	absval	0.00	1.00
	epco.hru	absval	0.00	1.00
	cn2.hru	pctchg	-30.00	30.00
	latq_co.hru	absval	0.00	1.00
	perco.hru	absval	0.00	1.00
	cn3_swf.hru	pctchg	-30.00	30.00
	awc.sol	pctchg	-60.00	60.00
	z.sol	pctchg	-50.00	50.00
	k.sol	pctchg	-80.00	200.00
	bd.sol	pctchg	-30.00	30.00
Hard calibration	ovn.hru	pctchg	-30.00	30.00
	lat_ttime.hru	absval	0.50	180.00
	alpha.aqu	absval	0.00	1.00
	flo_min.aqu	absval	0.00	9.99
	sp_yld.aqu	absval	0.00	0.50
	chn.rte	absval	0.00	0.20
	surlag.bsn	absval	0.05	23.99

Approach I. Hard calibration

- 3 iterations of 1000 simulations
- Parameters constrain based on statistical performance: NSE, R^2, PBIAS, RMSE.





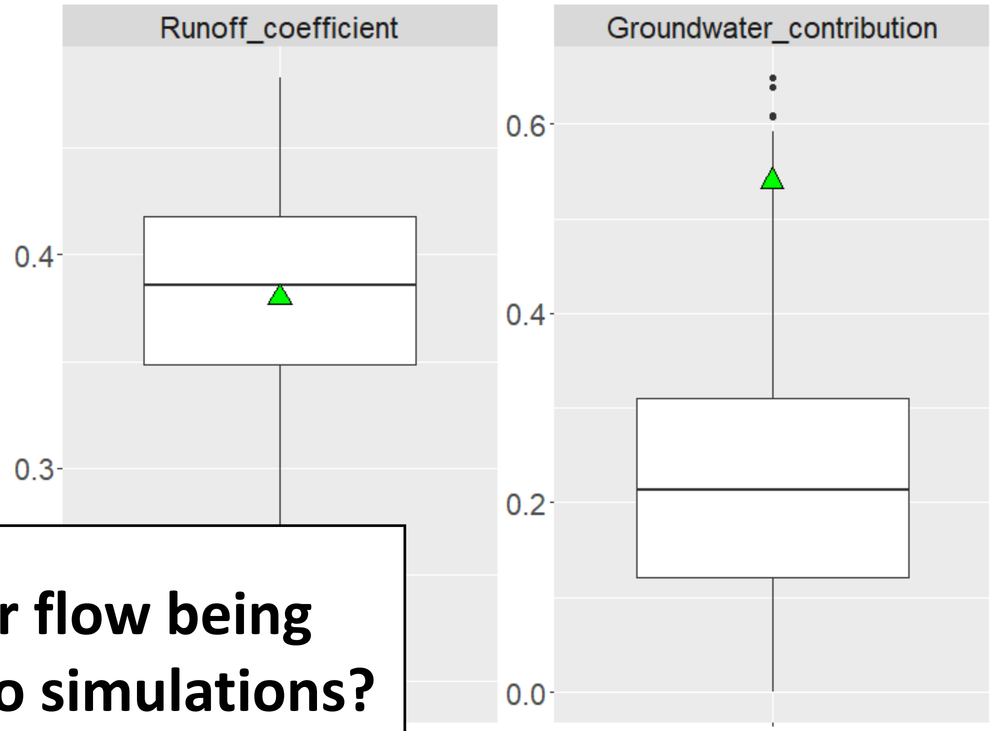


Approach I. Hard calibration

After 3 rounds:

Most of the simulations understimated groundwater.

Best simulation → Very good performance, but **no groundwater**



Runoff_coefficient	Groundwater_contribution	Run	nse_cal	r2_cal	pbias_cal	rmse_cal
0.366	0.000	543	0.748	0.754	-0.8	1.863
0.374	0.070	889				
0.375	0.099	616				
0.376	0.078	605				
0.363	0.000	868				
0.377	0.322	320	0.719	0.725	1.5	1.968

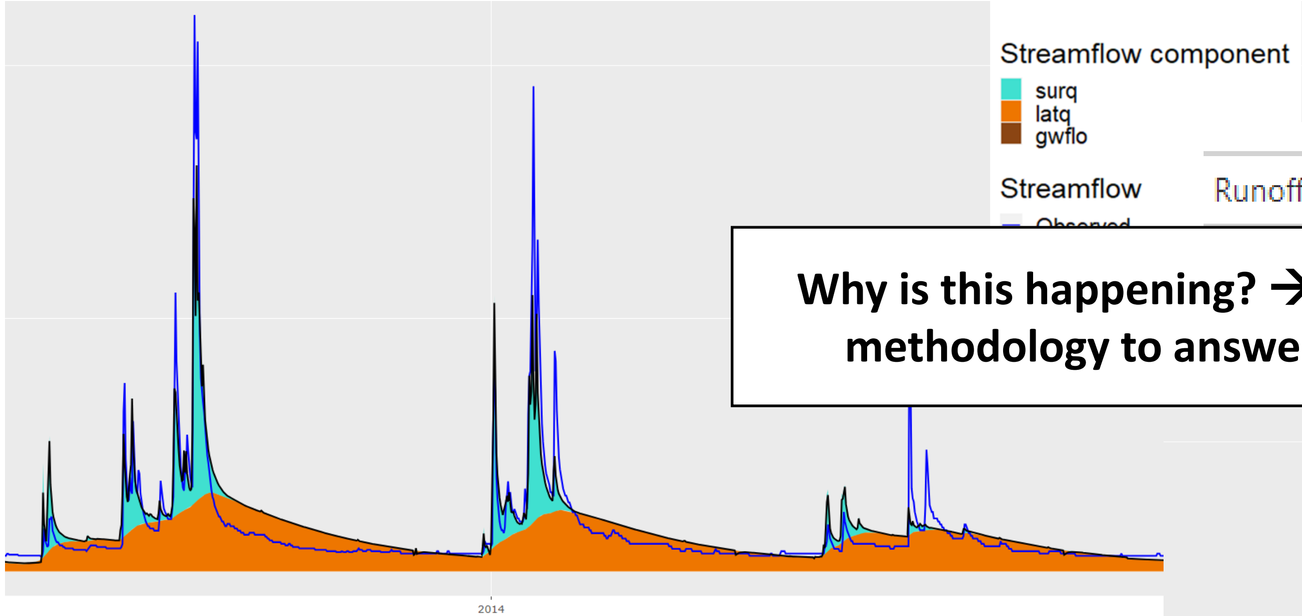
How is groundwater flow being simulated in these two simulations?

Best filtered simulations (Groundwater > 0.5) → Worse (but almost satisfactory) performance, groundwater contribution reasonable.

Runoff_coefficient	Groundwater_contribution	Run	nse_cal	r2_cal	pbias_cal	rmse_cal
0.372	0.649	100	0.477	0.491	1.4	2.685
0.348	0.583	339	0.498	0.502	-5.5	2.629
0.374	0.577	111	0.460	0.460	0.5	2.728
0.383	0.512	441	0.467	0.470	3.6	2.709
0.374	0.505	786	0.449	0.449	0.8	2.756
0.367	0.593	304	0.447	0.448	-1.0	2.761

Approach I. Hard calibration

Runoff_coefficient	Groundwater_contribution	Run	nse_cal	r2_cal	pbias_cal	rmse_cal
0.366	0.000	543	0.748	0.754	-0.8	1.863

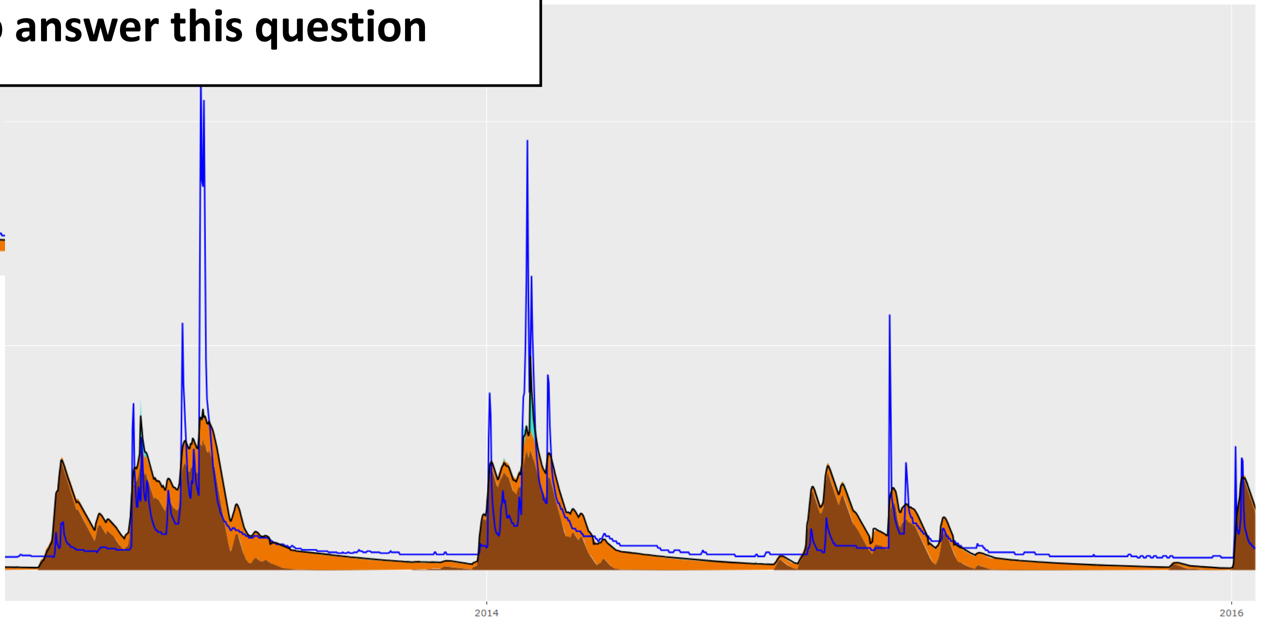


Best statistical simulation → There is no groundwater

Best filtered statistical simulation → Groundwater timing is erroneous, and there is no surface runoff

Runoff_coefficient	Groundwater_contribution	Run	nse_cal	r2_cal	pbias_cal	rmse_cal
[illegible]	0.649	100	0.477	0.491	1.4	2.685

Why is this happening? → Comprehensive methodology to answer this question



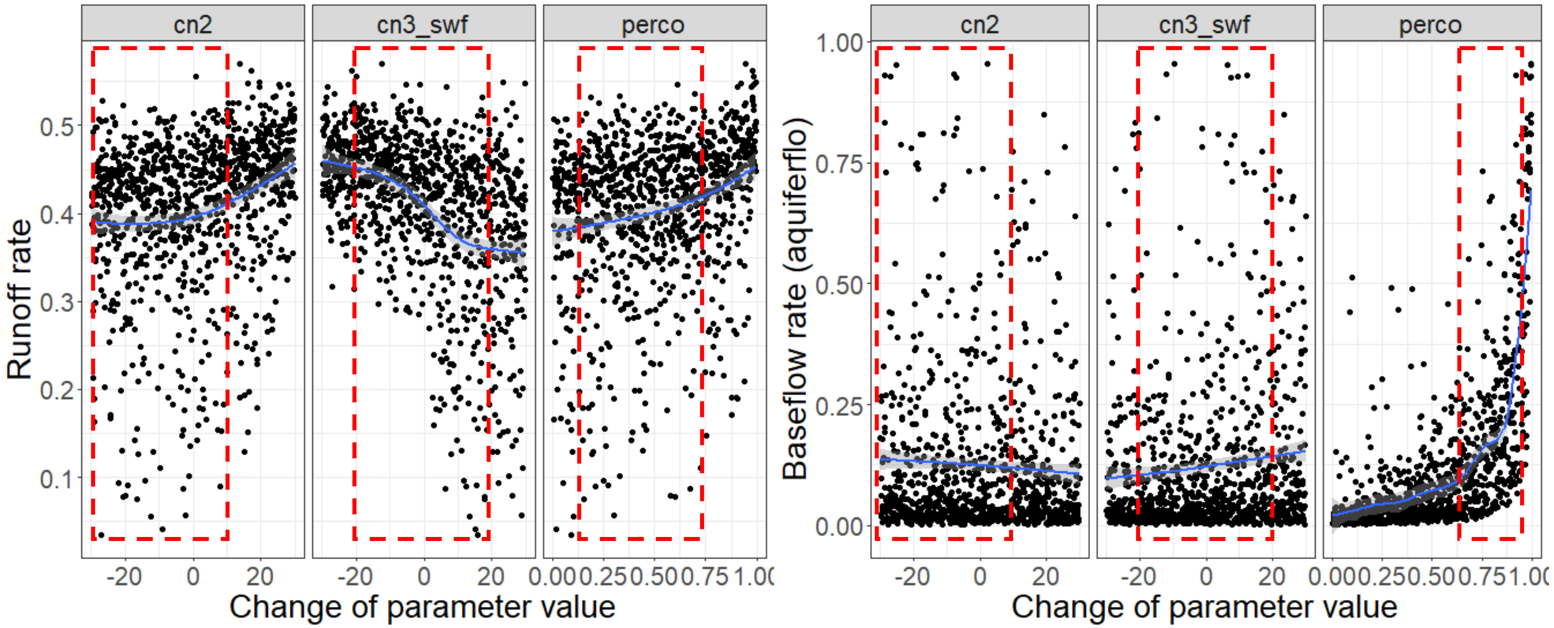
Approach II. Soft calibration

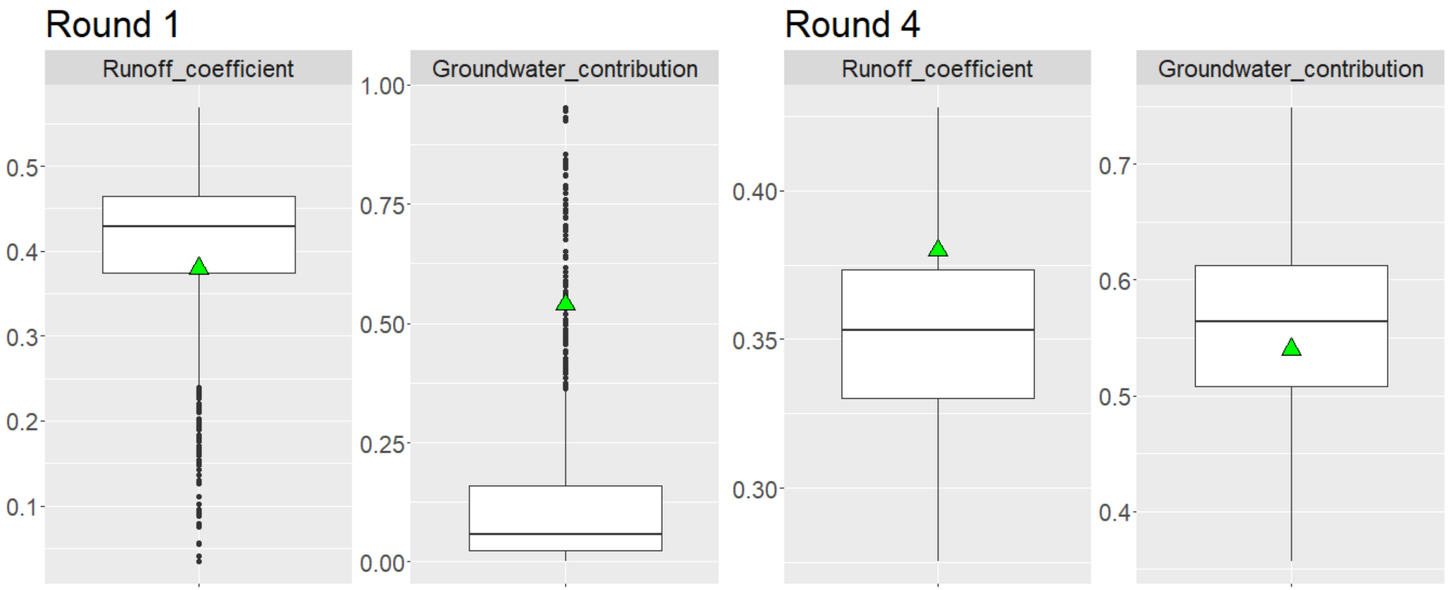
- To ensure that water balance was realistic
- 4 iterations of 1000 simulations
- Parameters constrain based on **runoff coefficient** and **baseflow contribution**

  → Previously estimated (Rc = 0.38, Bc = 0.54)

13:30 - 15:00	**Session I2: Hydrology** Mogens Zieler Stuen, Building 1422
13:30 - 13:50	**Alejandro Sánchez Gómez** Soft data collection for realistic hydrological modelling: a

- Target values matched with round 4 → Low variation in the 1000 simulations.



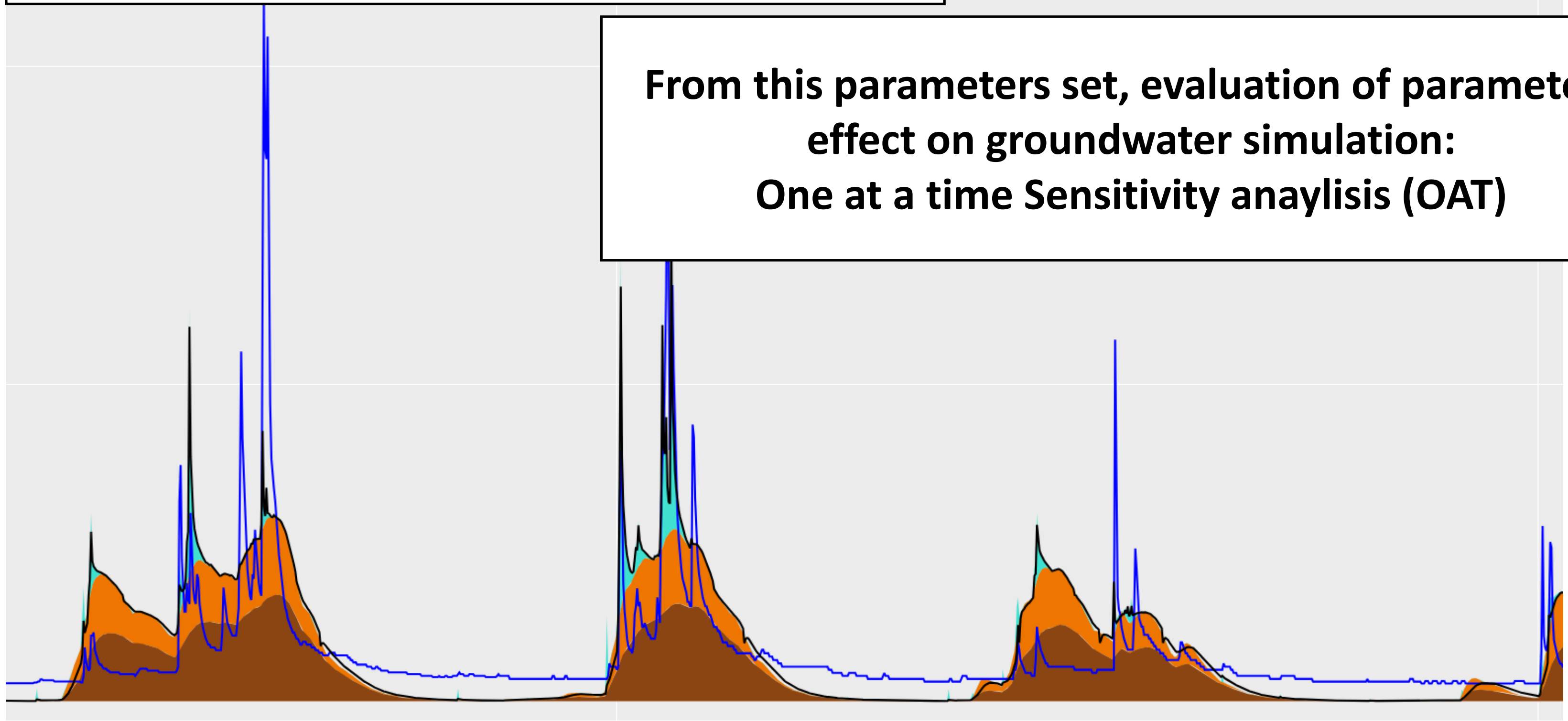


Approach II. Soft calibration

Selection of 1 simulation to assess parameters effect →
Filter (runoff rate within 0.36 and 0.4, baseflow contribution within 0.5 and 0.6) → Ordered by streamflow performance

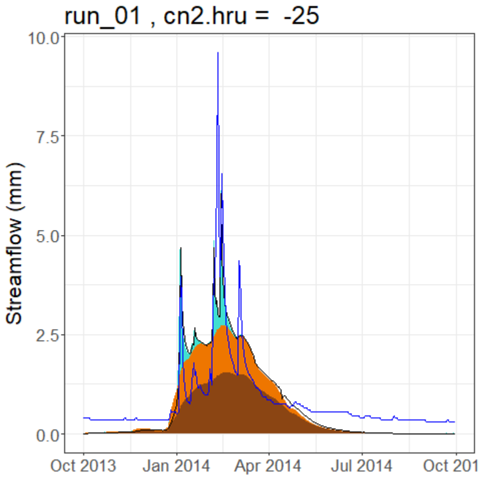
run_cal	runoff_rt	gr_cont	nse_ob	r2_ob	pbias_ob	rmse_ob
run_24	0.370	0.576	0.381	0.451	0.6	2.919
run_208	0.364	0.516	0.380	0.451	-0.7	2.922
run_646	0.371	0.550	0.375	0.436	0.4	2.934
run_973	0.363	0.530	0.372	0.440	-1.0	2.941
run_664	0.368	0.537	0.366	0.430	-0.1	2.954
[illegible]	[illegible]	0.507	0.372	0.444	-1.3	2.942

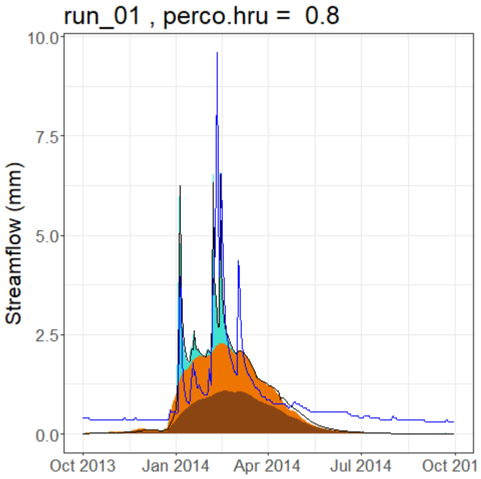
Groundwater simulation sligthly better than in Approach 1, but still unrealistic

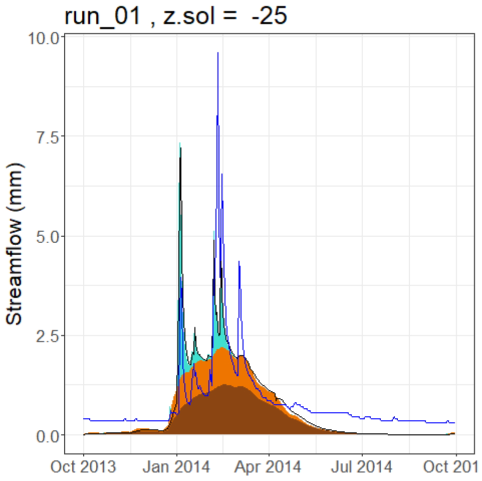


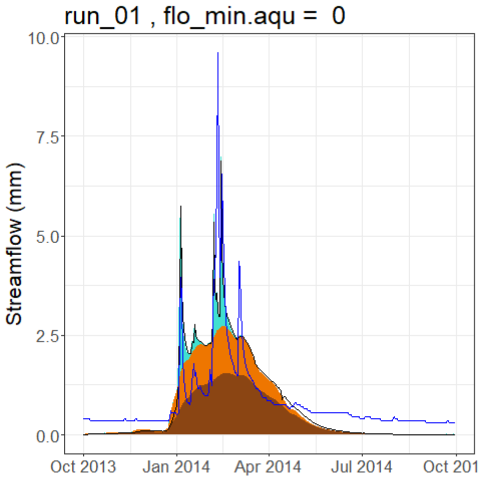
From this parameters set, evaluation of parameters effect on groundwater simulation: One at a time Sensitivity anaylisis (OAT)

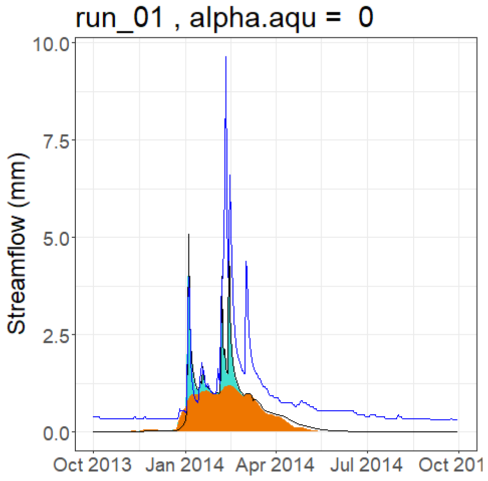
Approach II. Parameters assessment







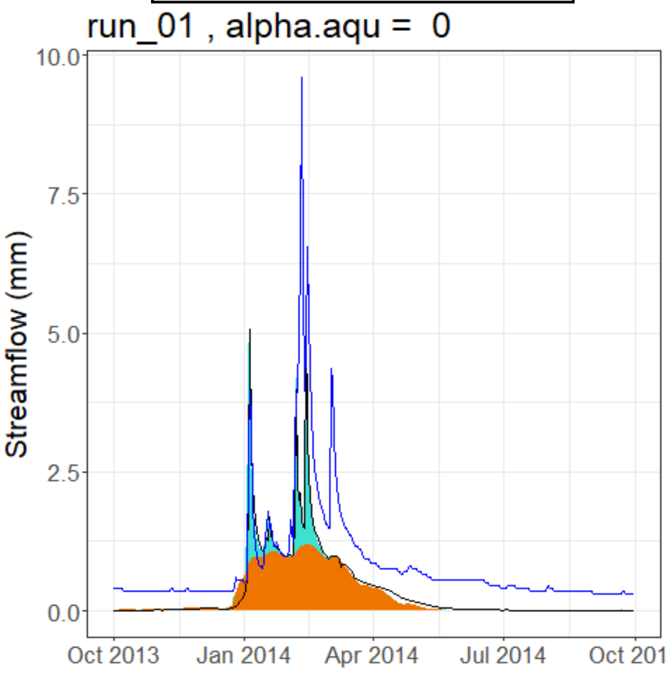


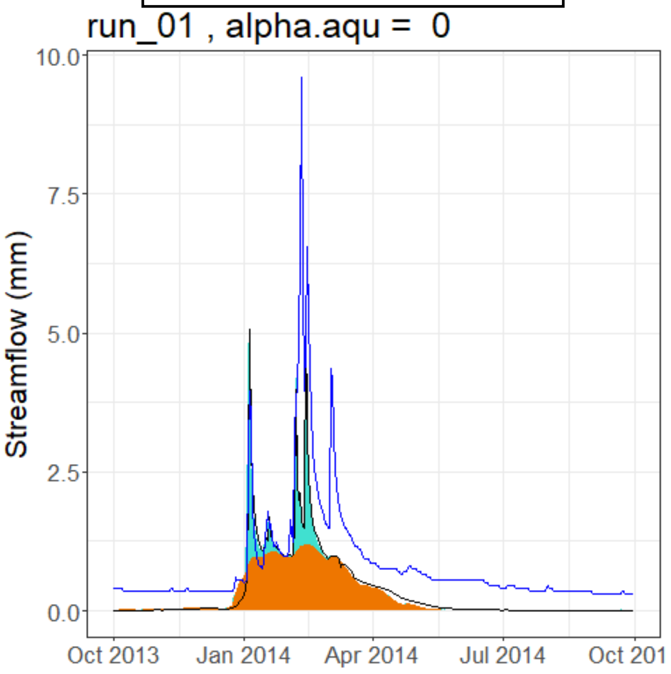


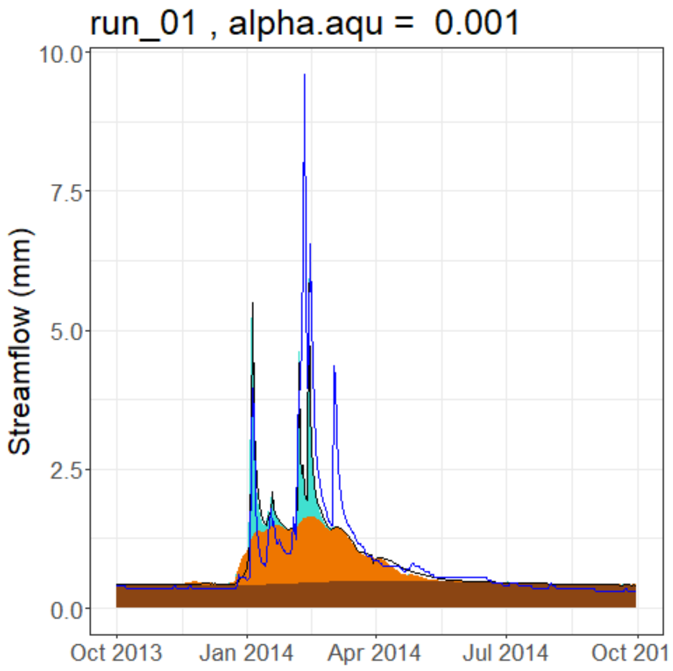
alpha → 0 – 0.2

alpha → 0 – 0.05

alpha → 0 – 0.01



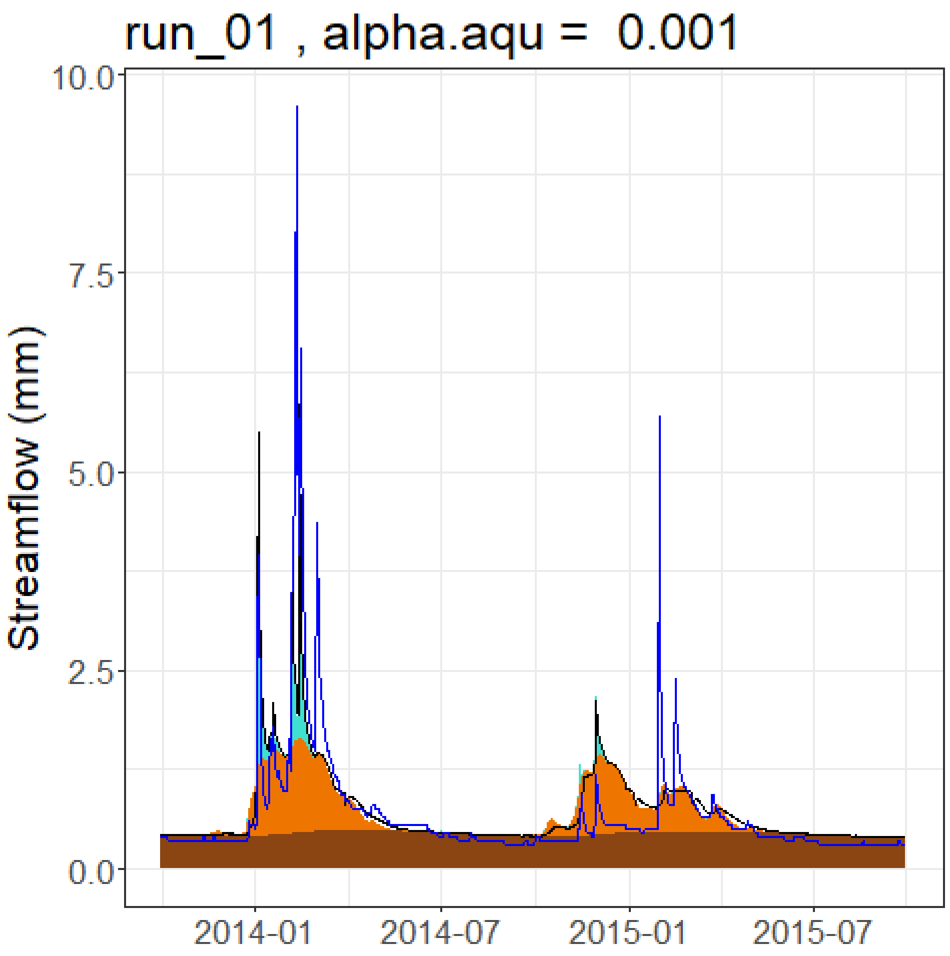




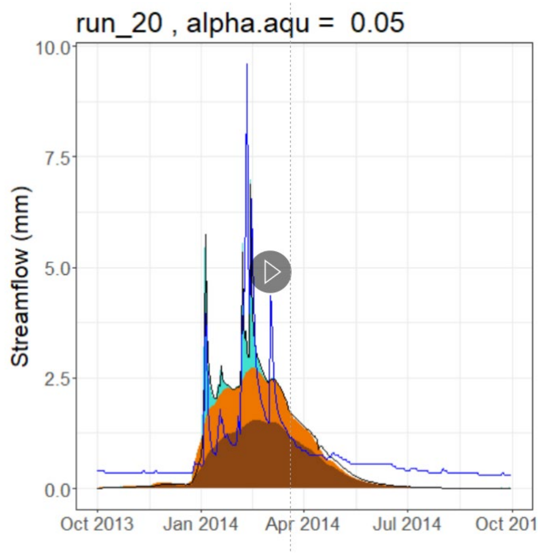
Approach II. Parameters assessment

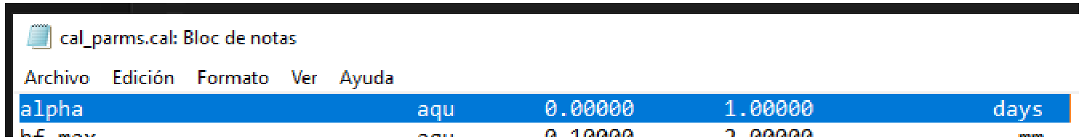
Very small variations of alpha → Huge impact on baseflow simulation

alpha → 0 – 0.01



- Default value (SWAT+) → 0.05
- Range of variation for calibration → 0 – 1 → **Very low probability of using a suitable value.**





cal_parms.cal: Bloc de notas

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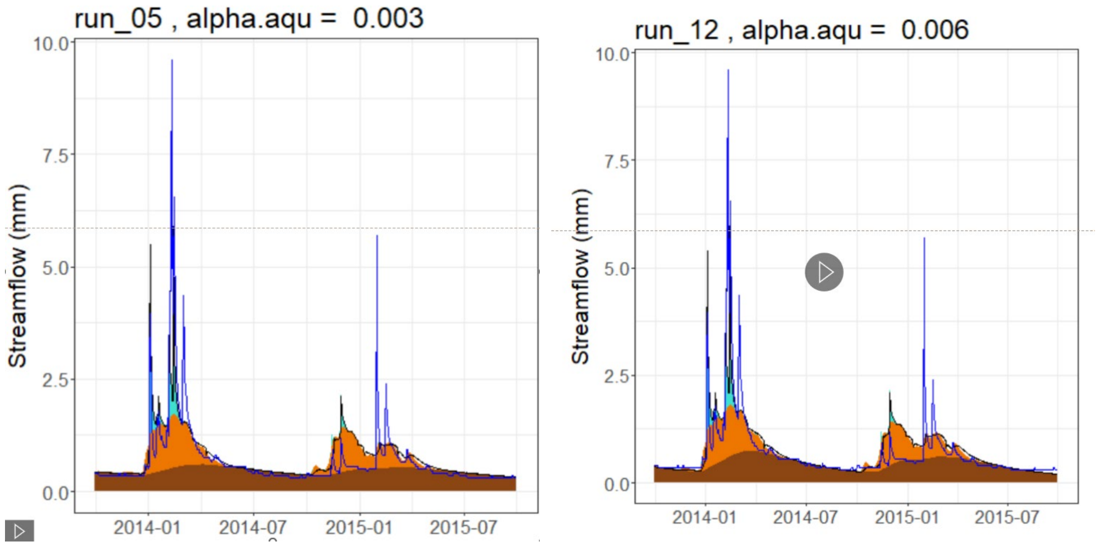
```
alpha                                   aqu     0.00000      1.00000         days
```

- Range of variation recommended after noticing this → Depends on the basin, but ≈ 0 – 0.02

Approach II. Hard calibration

From the parameters obtained on the Soft calibration:

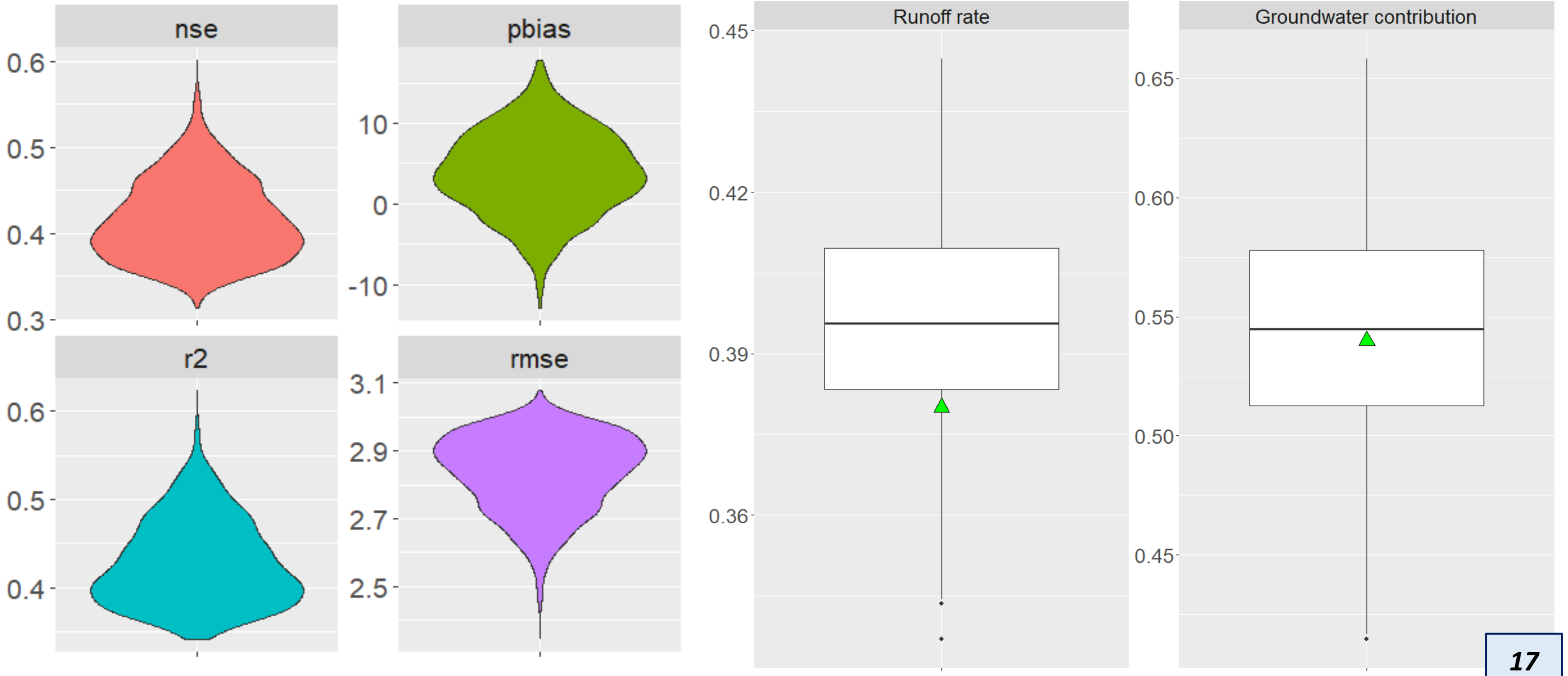
- The other parameters were included.
- alpha range of variation was changed to 0.004 – 0.005.
- Three iterations of 1000 simulations, parameters constrain considering streamflow simulation. Runoff coefficient and groundwater contribution were checked in these iterations.



After these iterations →

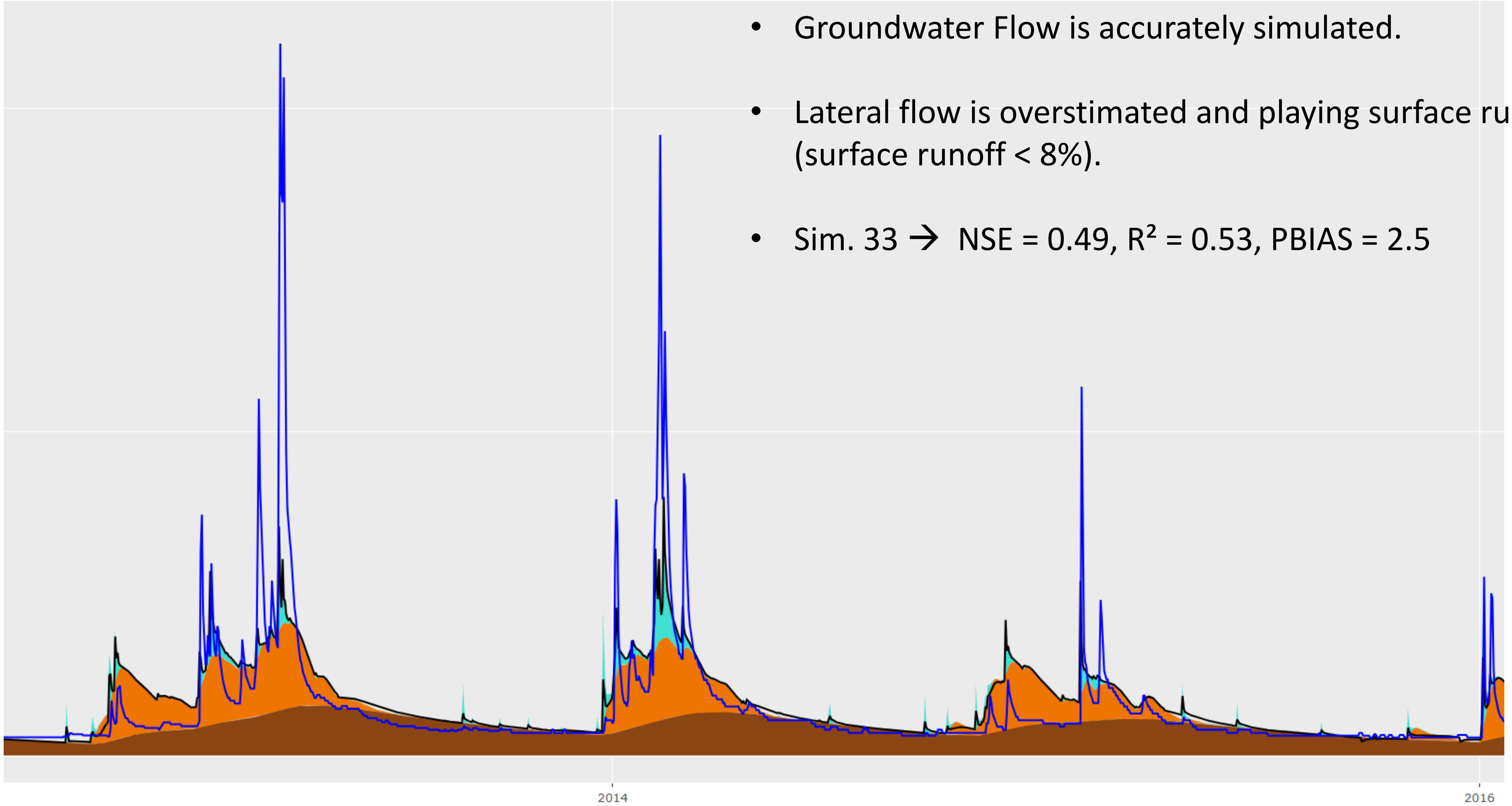
Filtered → baseflow within 0.55 and 0.6, Runoff within 0.36 and 0.4

sim_number	nse_ob	r2_ob	pbias_ob	rmse_ob	runoffrt	basflow_cont
run_33	0.4864032	0.5255271	2.5	2.659761	0.3917552	0.5601704
run_195	0.4967665	0.5115009	5.0	2.632790	0.3964373	0.5503809
run_787	0.4602244	0.4811987	0.4	2.726705	0.3825573	0.5580747
run_241	0.4626814	0.4900950	1.4	2.720492	0.3872701	0.5698946
run_362	0.4539371	0.4896565	0.2	2.742539	0.3831918	0.5578793
run_844	0.4813915	0.5082917	4.2	2.672706	0.3967454	0.6079336



Final adjustment and further work

- Groundwater Flow is accurately simulated.
- Lateral flow is overstimated and playing surface runoff rol (surface runoff < 8%).
- Sim. 33 → NSE = 0.49, R^2 = 0.53, PBIAS = 2.5

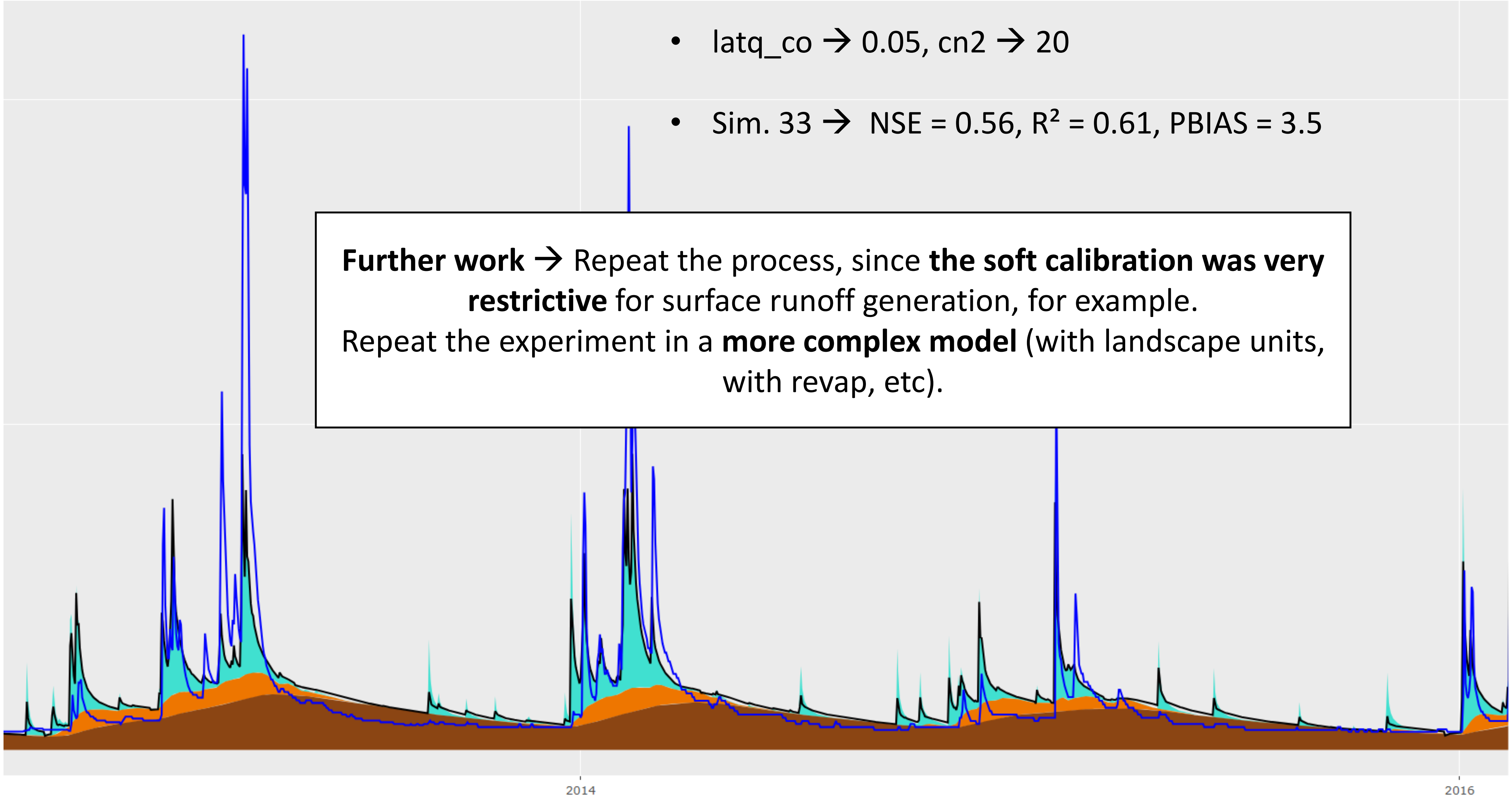


A tibble: 1 x 17

	esco	epco	cn2	latq_co	cn3_swf	perco	awc	z	k	bd	alpha	flo_min	sp_yld	ovn	lat_ttime	surlag	chn
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
1	0.278	0.801	6.41	0.177	7.94	0.844	8.71	-3.51	14.6	-24.5	0.00430	6.34	0.316	6.19	4.92	1.17	0.178

Final adjustment and further work

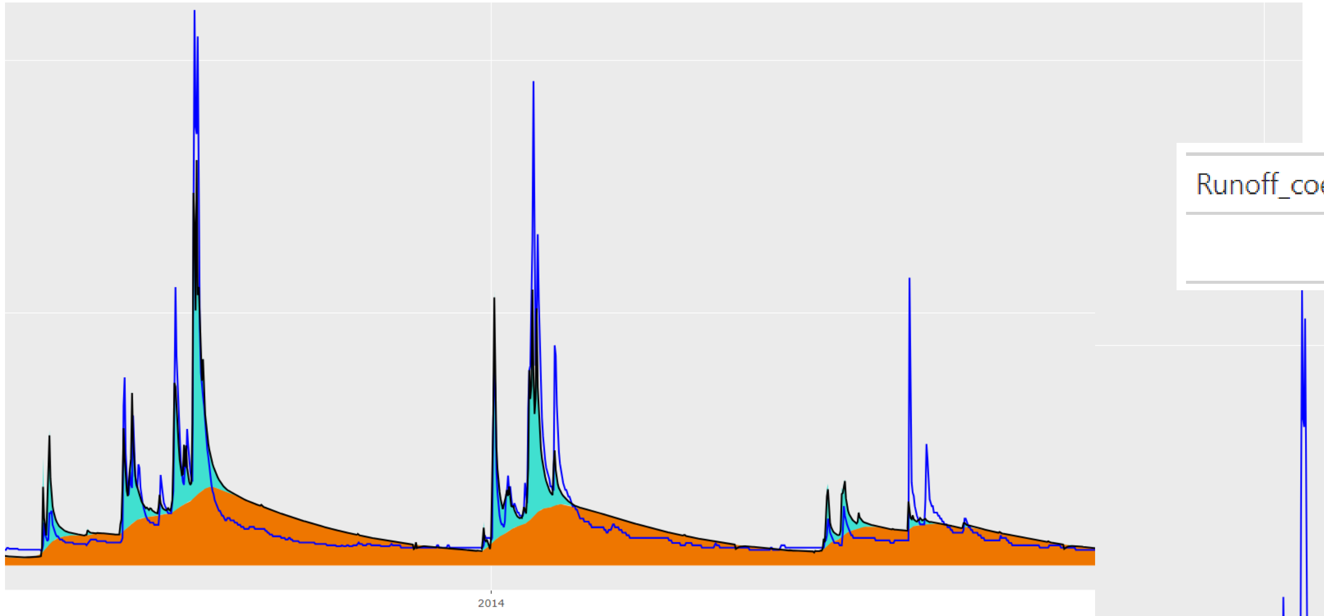
- Changing latq_co and cn2 to obtain more surface runoff.
- latq_co → 0.05, cn2 → 20
- Sim. 33 → NSE = 0.56, R^2 = 0.61, PBIAS = 3.5



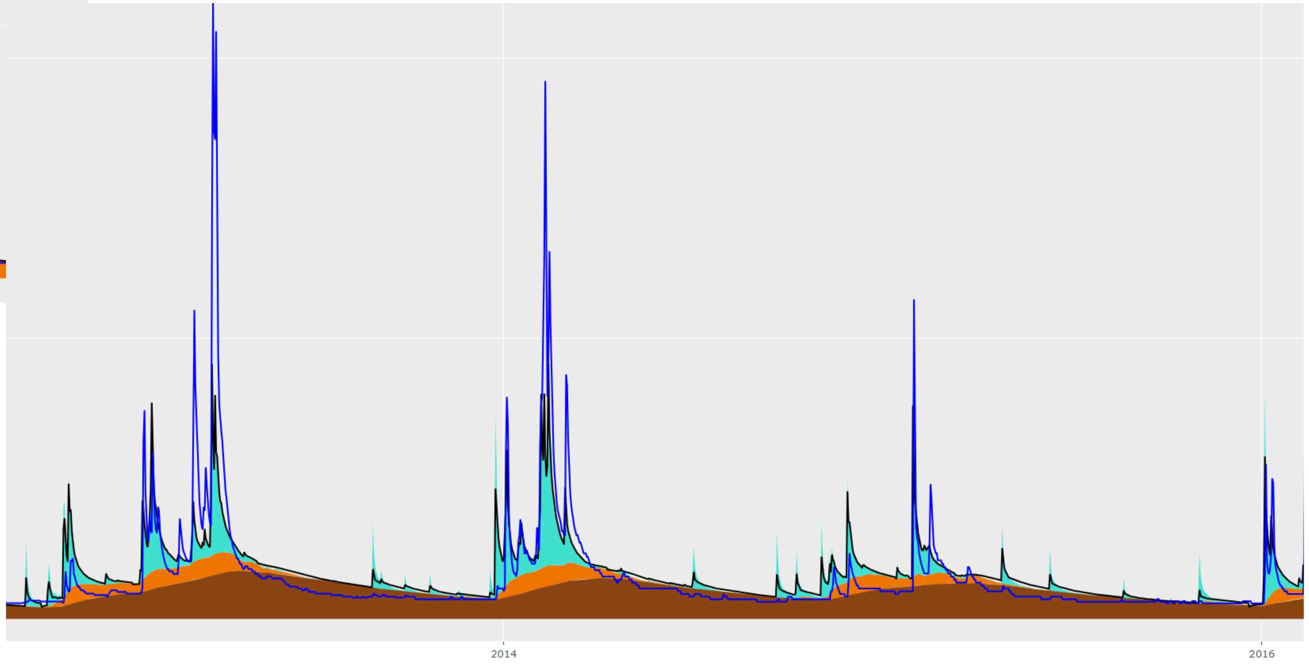
Further work → Repeat the process, since **the soft calibration was very restrictive** for surface runoff generation, for example.
Repeat the experiment in a **more complex model** (with landscape units, with revap, etc).

Results and conclusions

Runoff_coefficient	Groundwater_contribution	Run	nse_cal	r2_cal	pbias_cal	rmse_cal
0.366	0.000	543	0.748	0.754	-0.8	1.863



Runoff_coefficient	Groundwater_contribution	NSE	R^2	PBIAS	RMSE	Surface_rt	lateral_rt
0.397	0.638	0.568	0.611	3.5	2.43	0.247	0.119



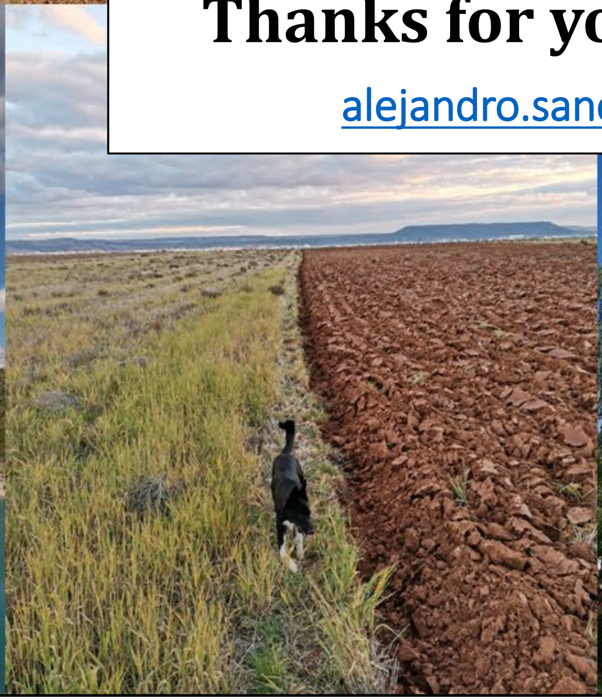
Results and conclusions

- The groundwater flow simulation in SWAT+ has been comprehensively analysed.
- A realistic simulation for this variable has been achieved through the analysis of the parameters on it.
- Some key guidelines for reaching a realistic simulation have been established: a soft calibration process to ensure runoff coefficient and baseflow contribution are realistic, and a suitable range of variation for alpha parameter.
- Modellers should piroritize a realisitc simulation of different variables rather than just performance metrics.



Thanks for your attention!

alejandro.sanchezg@uah.es

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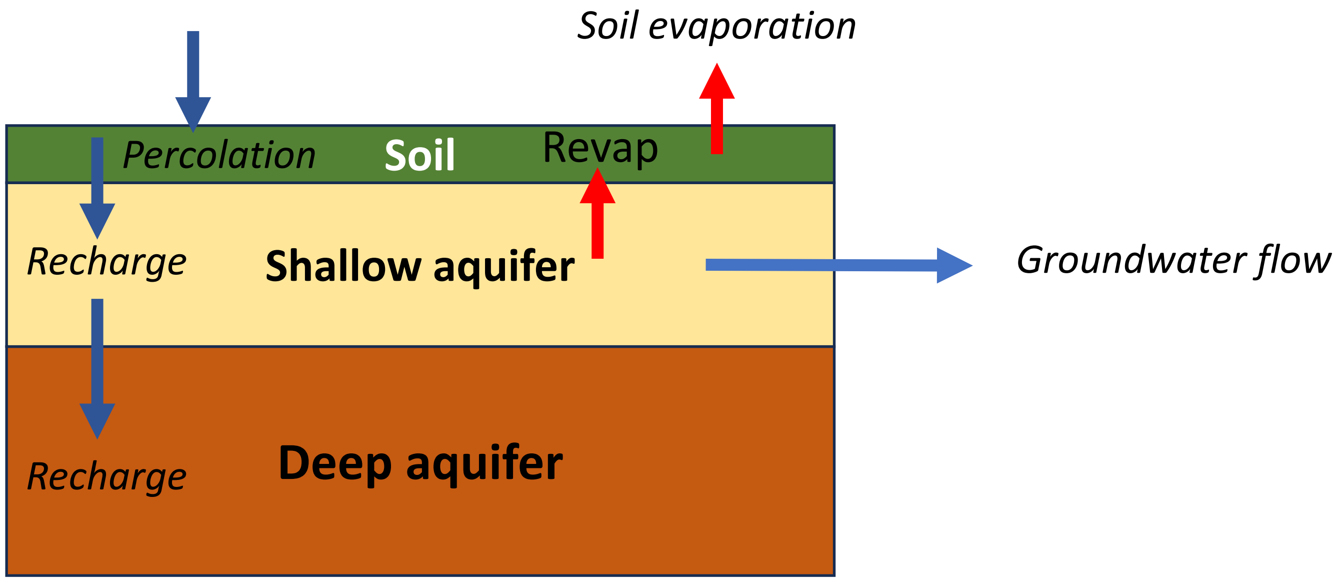
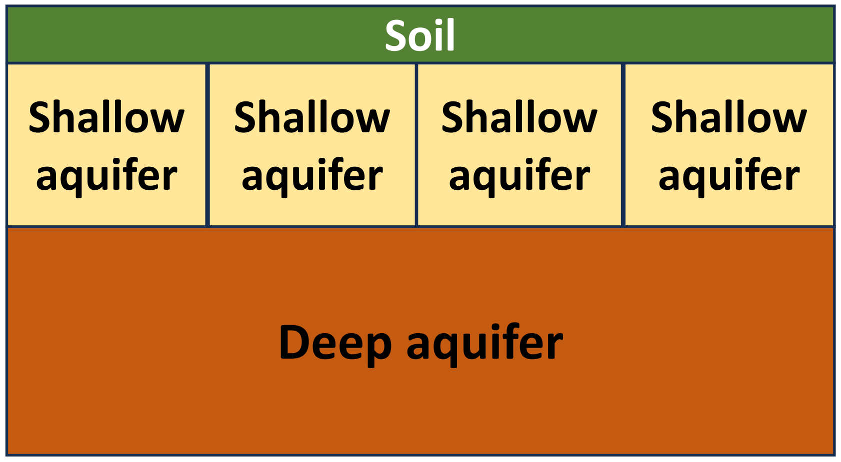
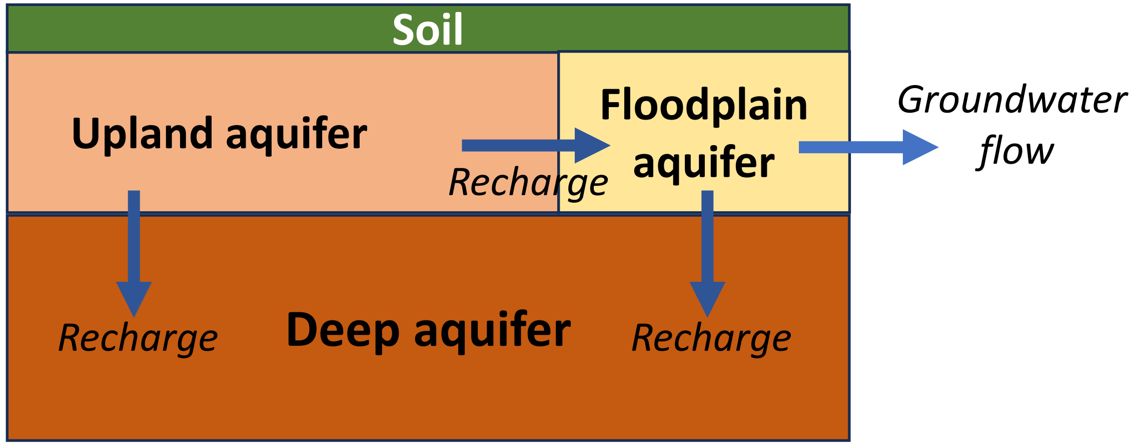

Soil evaporation
Percolation
Soil
Revap
Recharge
Shallow aquifer
Groundwater flow
Recharge
Deep aquifer


Soil
Shallow aquifer
Shallow aquifer
Shallow aquifer
Shallow aquifer
Deep aquifer


Soil
Upland aquifer
Floodplain aquifer
Recharge
Groundwater flow
Recharge
Deep aquifer
Recharge