Christian-Albrechts-Universität zu Kiel

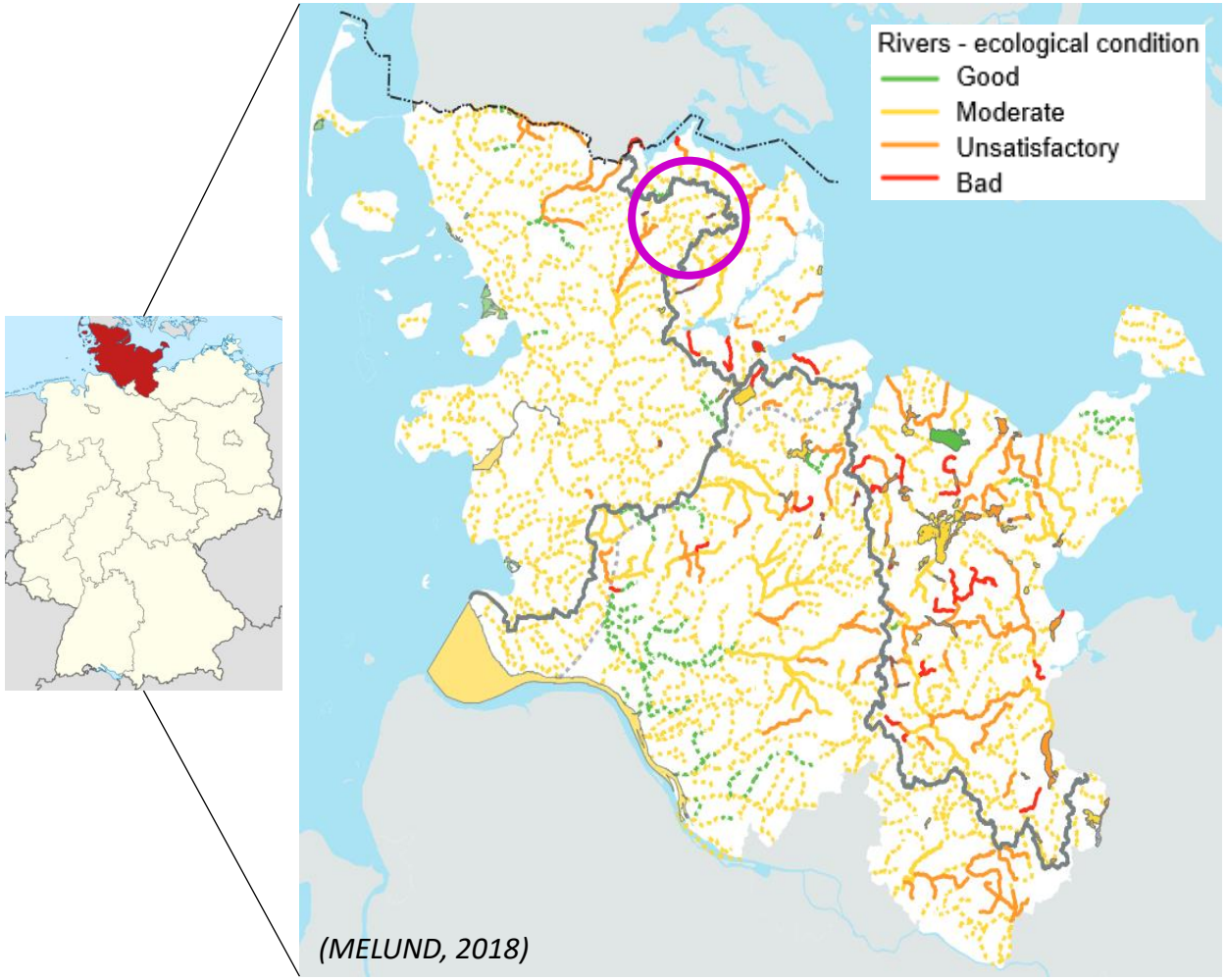
Evaluation of Sediment and Phosphorus Dynamics with SWAT+: Experiences from a German lowland catchment

Henrike T. Risch, Paul D. Wagner, Nicola Fohrer

Hydrology and Water Resources Management, Kiel University

Motivation: Water Framework Directive

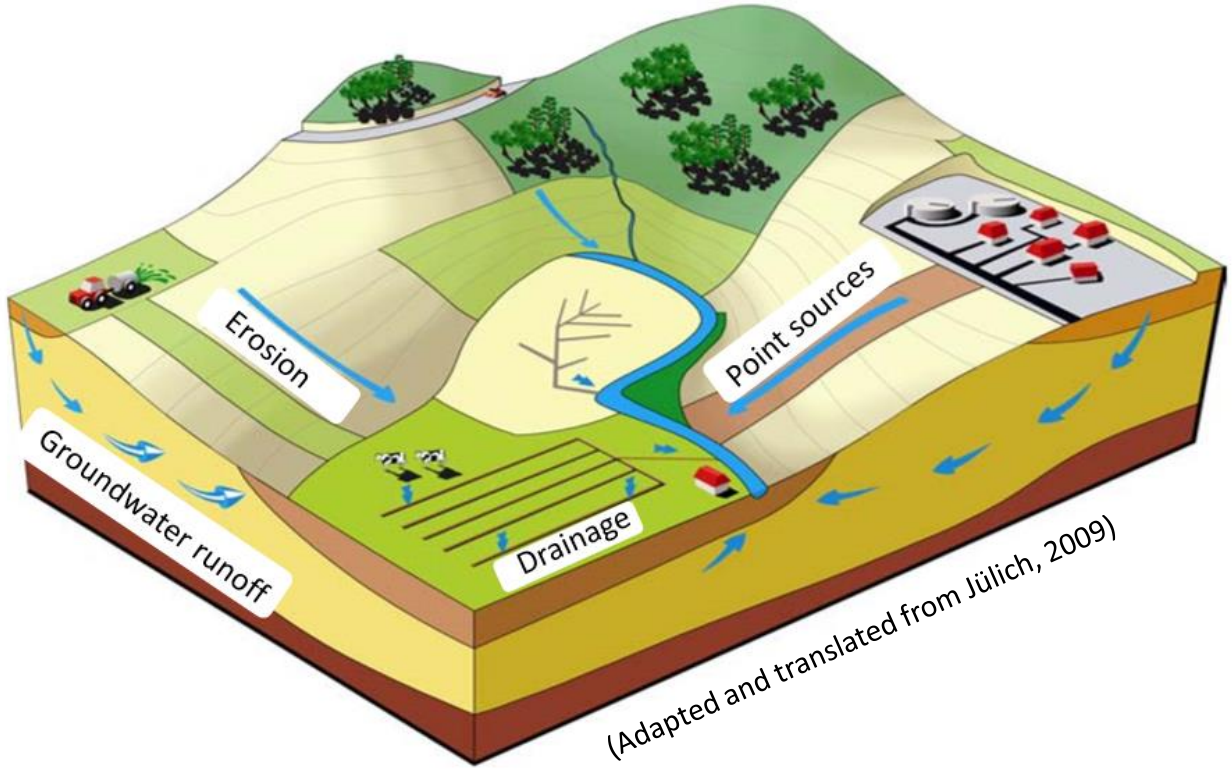
Surface water according to WFD



"Good status" is not yet achieved in most German surface waters

Motivation: Phosphorus pollution

- Phosphorus ➡ growth limiting element
- Entry from diffuse sources & point sources
- Erosion ➡ influencing factor for phosphorus input

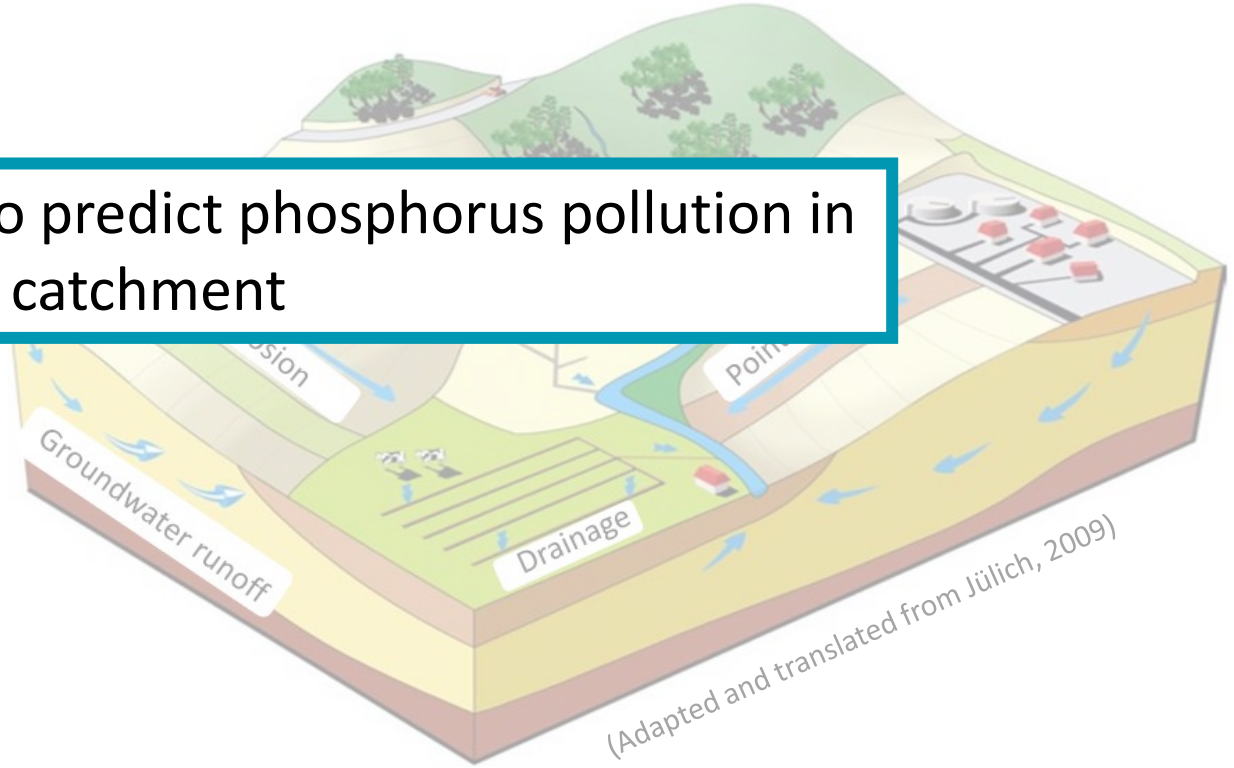


(Adapted and translated from Jülich, 2009)

Motivation: Phosphorus pollution

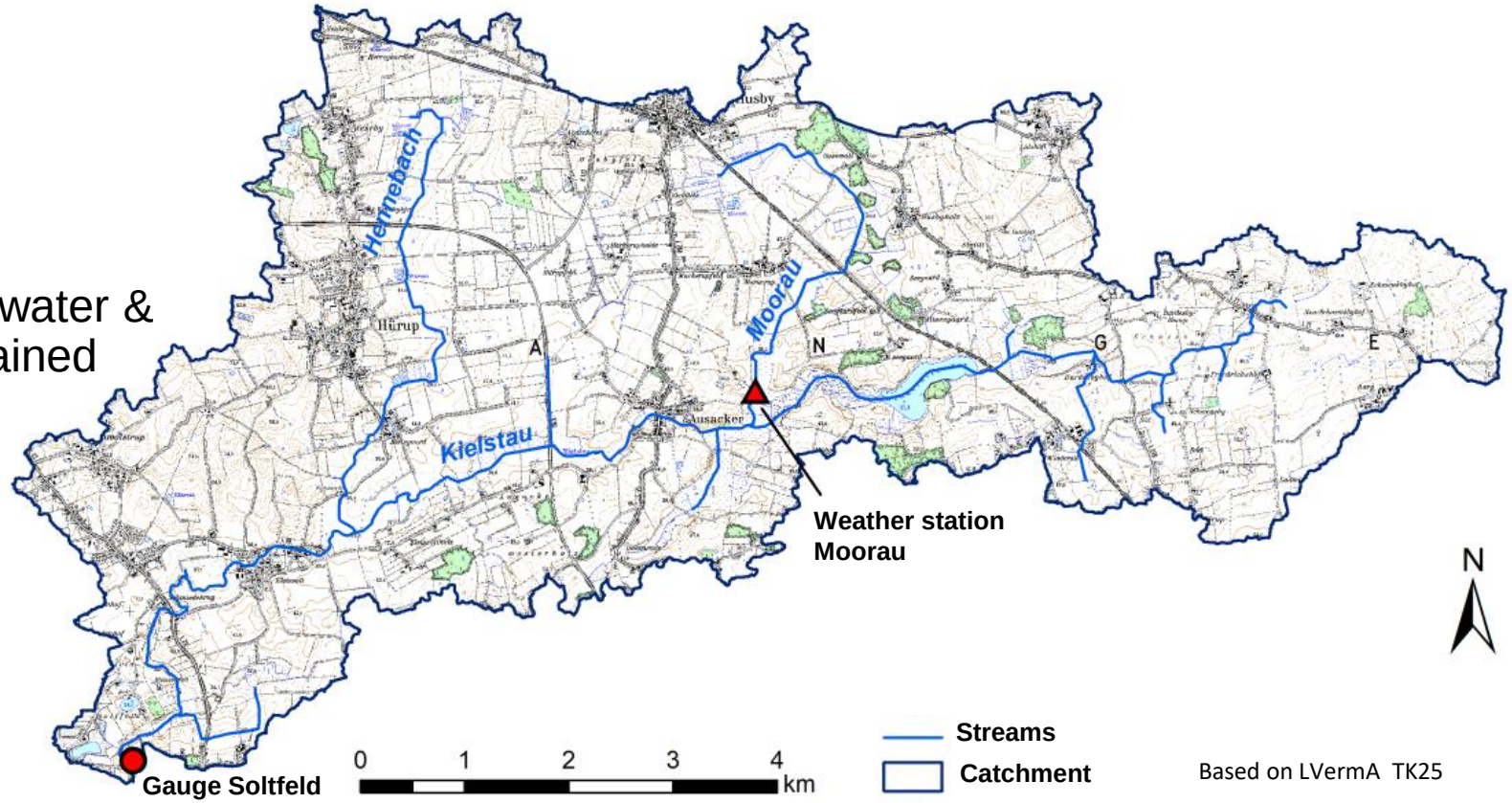
- Phosphorus ➡
- Erosion ➡
- Entry from diffuse sources & point sources

Development of a SWAT+ model to predict phosphorus pollution in the Kielstau catchment



Study area: Kielstau catchment

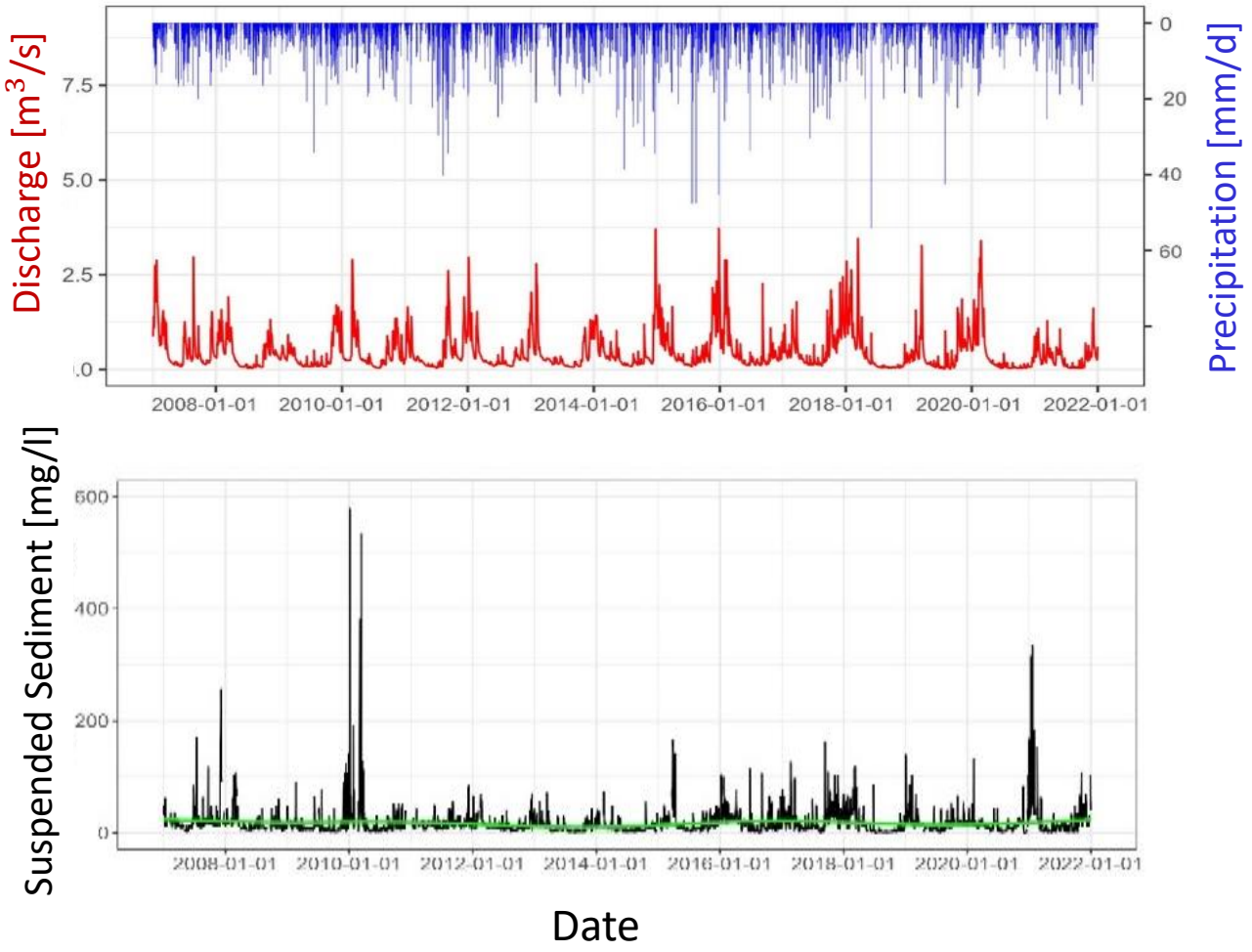
- UNESCO demonstration site for ecohydrology
- Area: 50 km²
- Length of river: 17 km
- Mean temperature: 8.2°C
- Precipitation: 919 mm/a
- Agriculture dominated
- Characterized by near-surface groundwater & around 38% of agricultural land tile drained

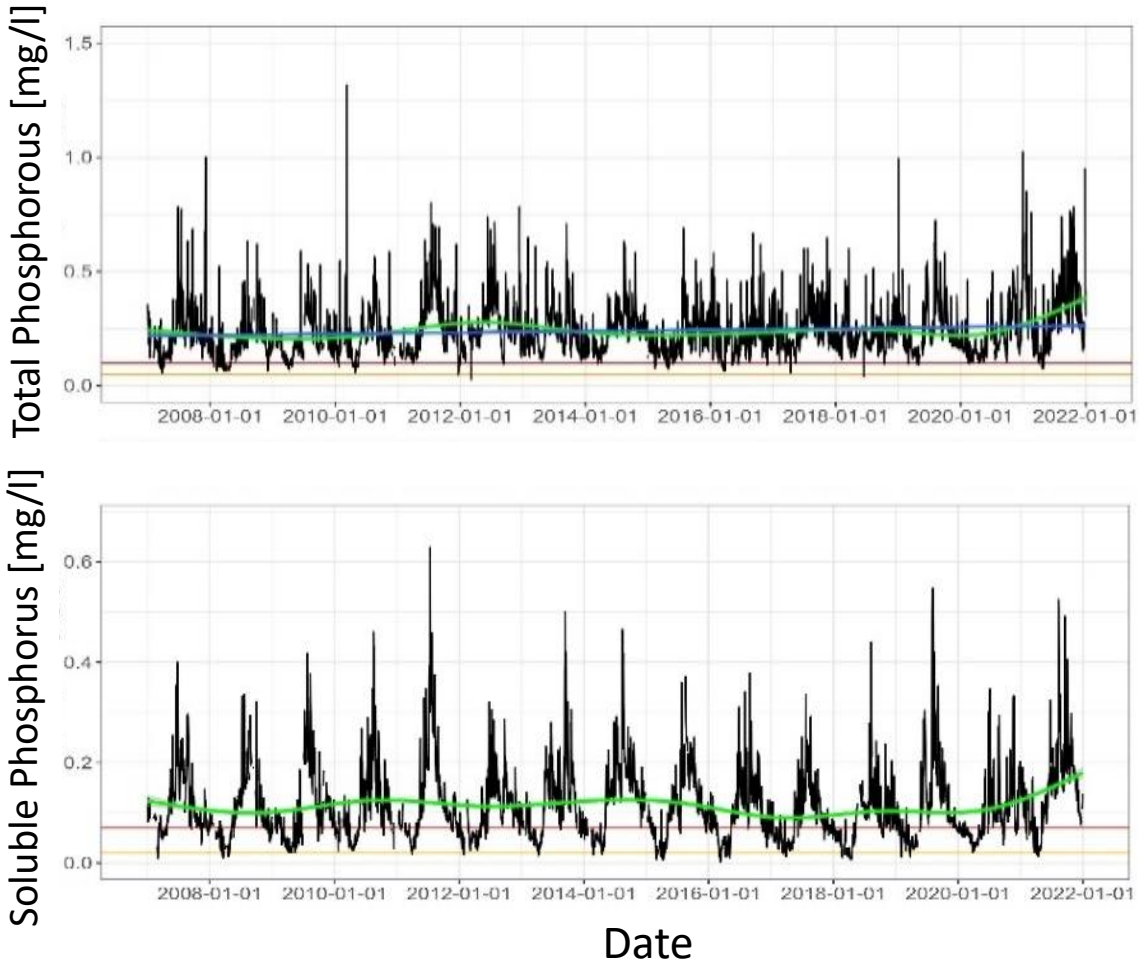


Measurements at the Outlet

(Risch et al. 2024)

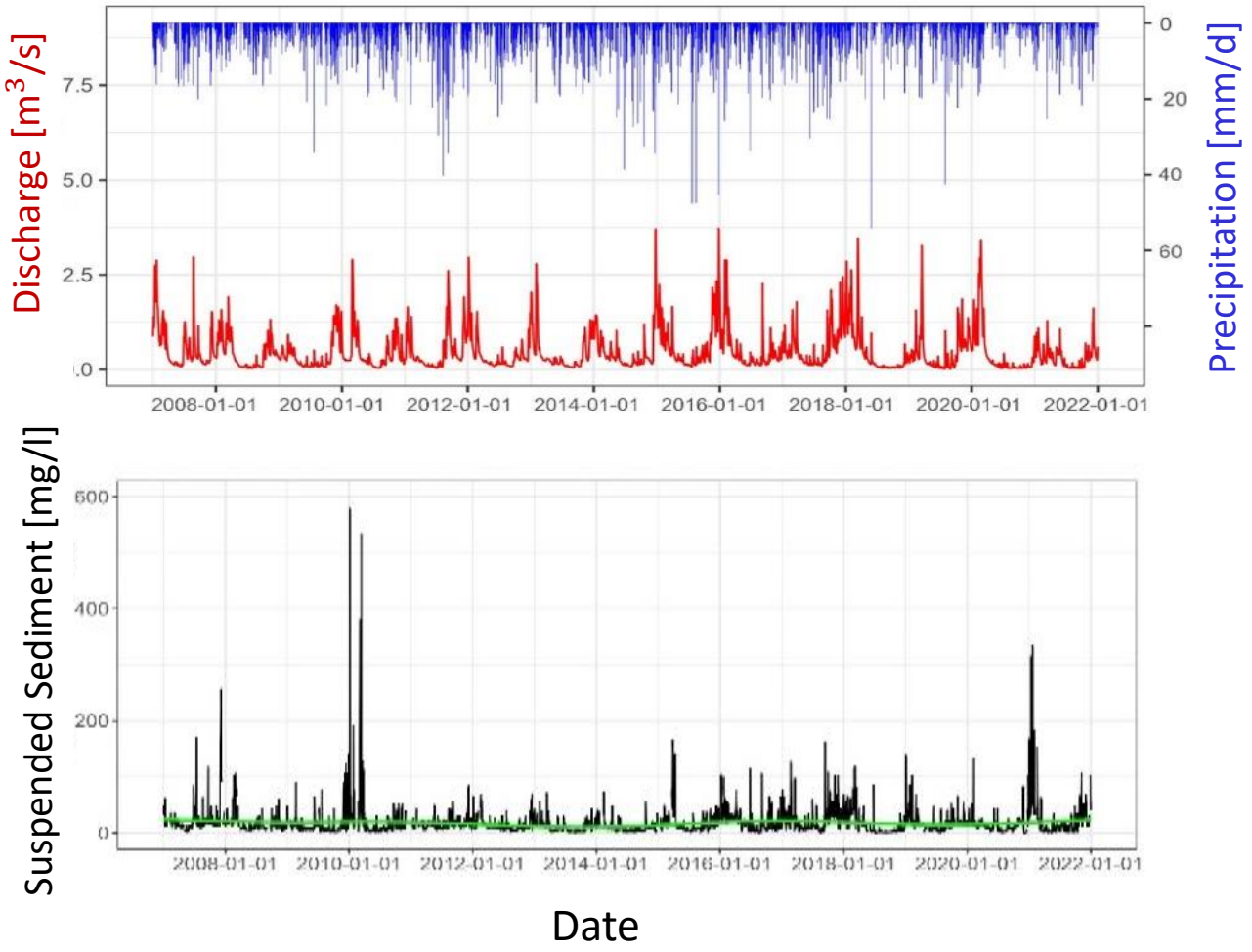
Measurements at the Outlet





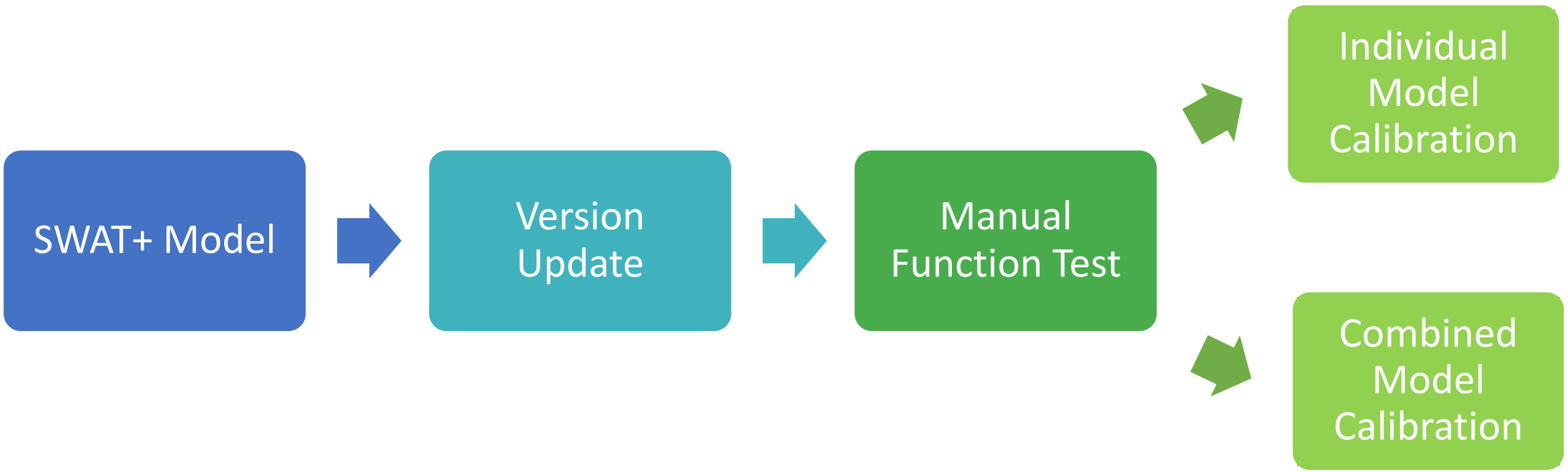
(Risch et al. 2024)

Measurements at the Outlet



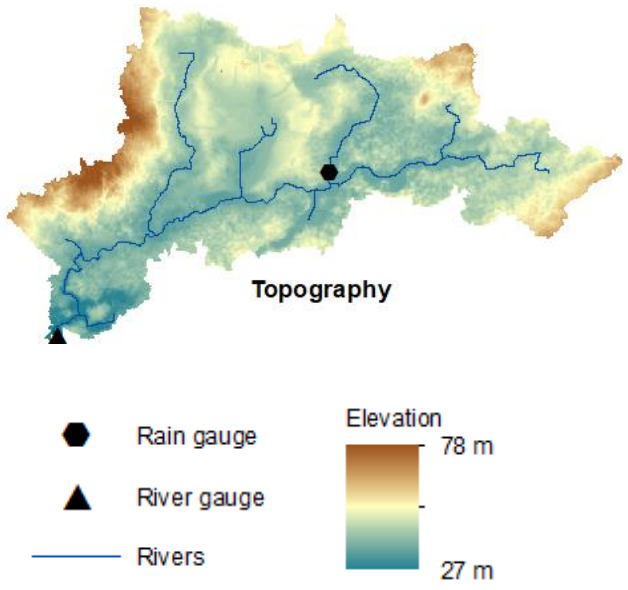
(Risch et al. 2024)

Materials and Methods

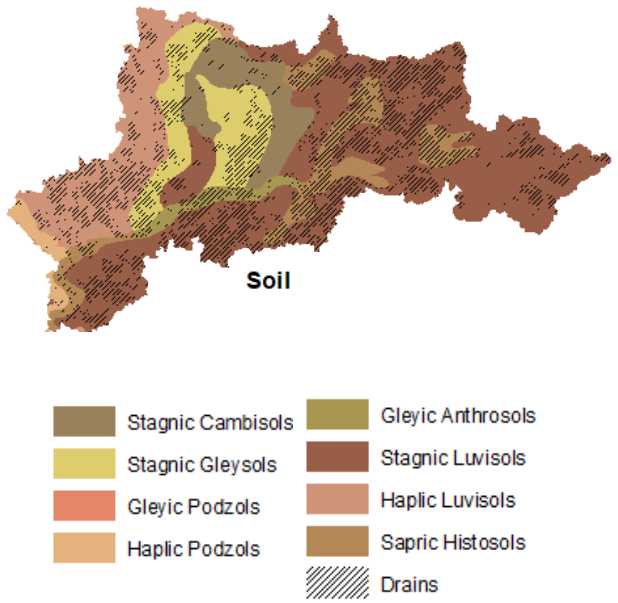


Model Setup

DEM (LVA, 2004)

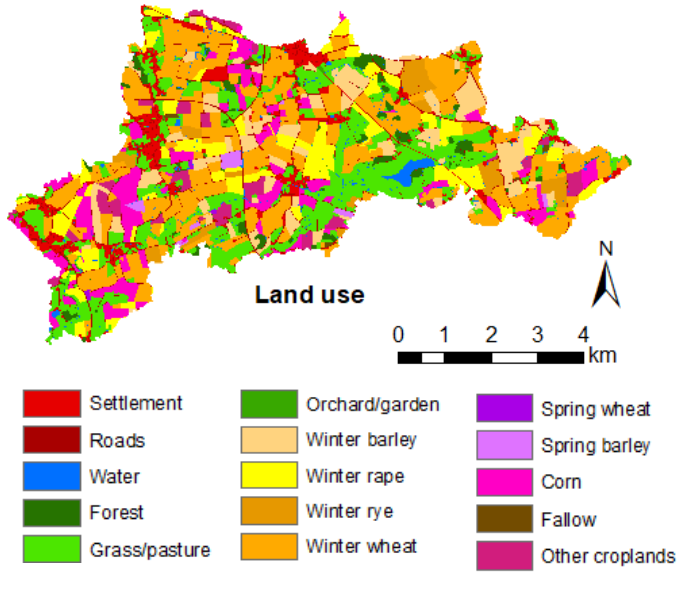


Soil map (BGR, 1999)



Land use 2016 (survey)

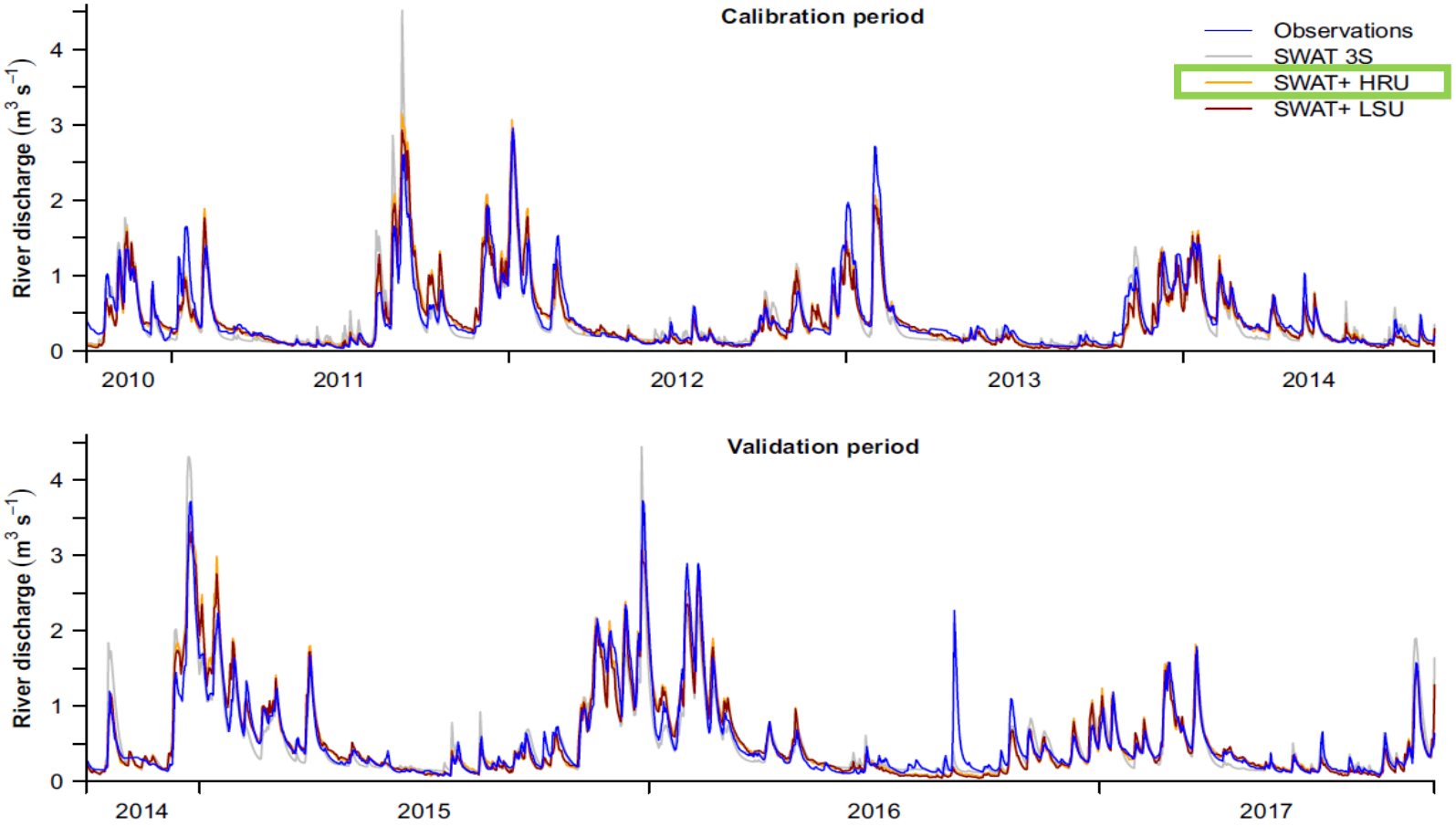
(Lei et al. 2019)



Weather data: since 2010 precipitation measured within the catchment, other variables from a weather service station outside the catchment

(Wagner et al. 2022, Hydrological Processes, 36(5))

SWAT+ Model



Comparison of modelled and measured hydrographs at the Soltfeld outlet of the Kielstau catchment

SWAT+ (60.5.3) model calibrated for discharge

NSE	PBIAS	KGE
0.82	-1.9	0.91

(Wagner et al. 2022, Hydrological Processes, 36(5))

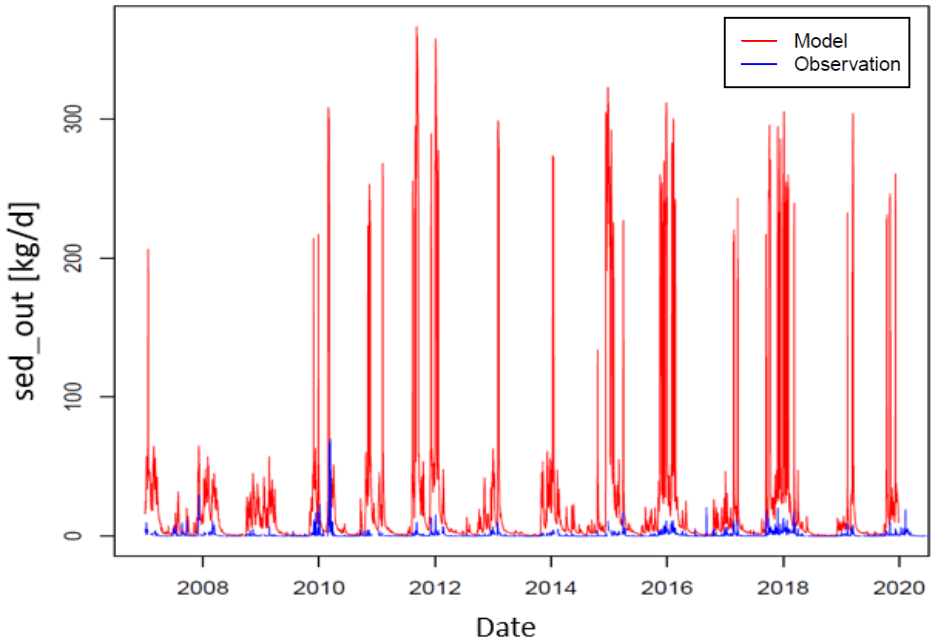
Significant Changes

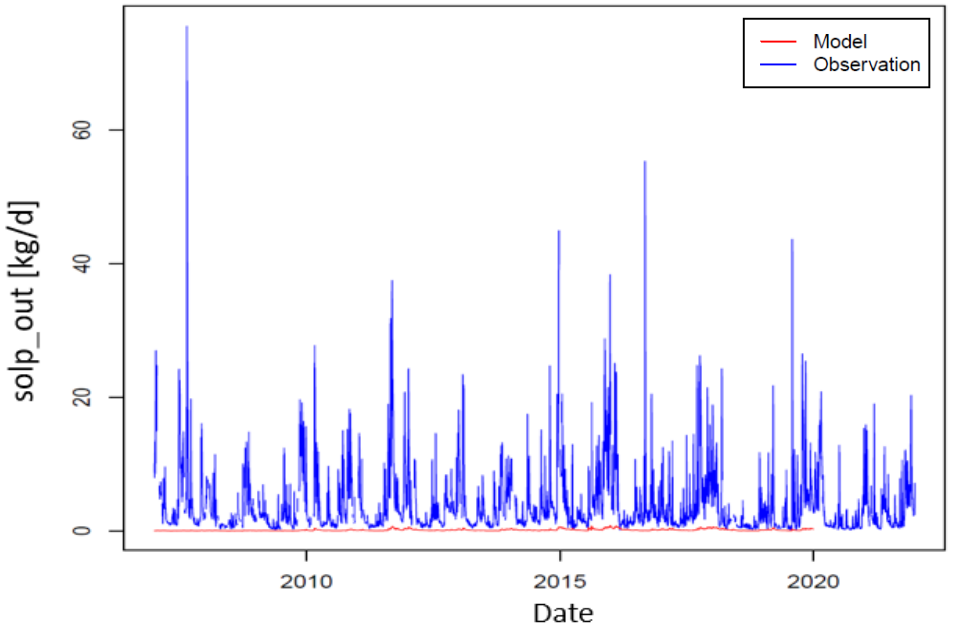
Updates or adjustments to focus on phosphorus and sediment:

- management schedule (in management.sch)
- min_p & org_p content and added new fertilizers (in fertilizer.frt)
- days_mat, bm_e, harv_idx & lai_pot of crops to conditions in north Germany (in plants.plt)
- harv_idx & harv_eff (in harv.ops)
- 6 WWTP with discharge and phosphorus concentrations (in pt001.rec – pt006.rec)

Significant Changes

First Result: Sediment and phosphorus estimations
do not match observations in version 60.5.3





Changes to the SWAT+ Model

Updat

- mana
- min_p & org_p content and added new fertilizers (in fertilizer.frt)
- days_mat, bm_e, harv_idx & lai_pot of c to conditions in north Germany (in plants.plt)
- harv_idx & harv_eff (in harv.ops)
- 6 WWTP with discha rec – pt006.rec)
- weather data until end of 2021

First Result: Sediment and Phosphorus estimations
do not match observations in 60.5.3

61.0 => updated erosion routine

Transfer between Model Versions

SWAT+ 60.5.3 file format changes to version 61.0

- aquifer.aqu
- chandeg.con
- channel-lte.cha
- codes.bsn
- fertilizer.frt
- file.cio
- hru-data.hru
- hyd-sed-lte.cha
- hydrology.hyd
- initial.aqu
- initial.cha
- initial.res
- irr.ops
- ls_unit.def
- lum.dtl
- nutrients.res
- nutrients.sol
- om_water.ini
- ovn_table.lum
- parameters.bsn
- pesticide.pes
- plants.plt
- print.prt
- recall.swf
- res_rel.dtl
- reservoir.res
- rout_unit.def
- rout_unit.ele
- sediment.res
- soil_plant.ini
- weather-sta.cli

Manual Function Test

- Manual one parameter at a time (OAT) analysis to test basic functionality

Parameter	Location	Calibration Range	Primarily related to
alpha_bf	calibration.cal	0.5 to 1	Discharge
alpha_bf2	**aquifer.aqu**	0.01 to 0.02	Discharge
cn2	calibration.cal	-15 to 5 (-15 to 10)	Discharge
cn3	calibration.cal	-20 to 20	Discharge
epco	calibration.cal	0.05 to 0.5	Discharge
esco	calibration.cal	0.05 to 1.0	Discharge
latq_co	calibration.cal	-20 to 20	Discharge
perco	calibration.cal	-20 to 5	Discharge
rchrg_dp	calibration.cal	0.01 to 0.1	Discharge
sol_awc	calibration.cal	0.04 to 0.2	Discharge
surlag	calibration.cal	0.2 to 0.75 (0.2 to 0.5)	Discharge
orgp_enrich	**hydrology.hyd**	0.8 to 4.8	Phosphorus
p_updis	calibration.cal	30 to 100	Phosphorus
phoskd	calibration.cal	100 to 140 (115 to 190)	Phosphorus
pperco	calibration.cal	10 to 16	Phosphorus
psp	calibration.cal	0.01 to 0.7 (0.01 to 0.5)	Phosphorus
sol_p_aqu	**aquifer.aqu**	0.04-0.15 (0.04 to 0.4)	Phosphorus
watersol_p	**nutrients.sol**	30 to 90	Phosphorus
adj_pkr	**parameters.bsn**	0.5 to 2	Sediment
adj_pkr_sed	**parameters.bsn**	0.5 to 1.5 (0.5 to 2)	Sediment
cov_fact	**sediment.cha**	0.4 to 0.7	Sediment
erod_fact	**sediment.cha**	0.1 to 0.5	Sediment
hru_slp	**topography.hyd**	-20 to 20	Sediment
lat_sed	calibration.cal	1-60 (55 to 140)	Sediment
slp_len	**topography.hyd**	-20 to 20	Sediment
usle_c	**plants.plt**	-20 to 20	Sediment
usle_k	calibration.cal	0.01 to 0.15 (0.06 to 0.2)	Sediment
usle_p	**cons_practice.lum**	-10 to 10 (-20 to 5)	Sediment
z	calibration.cal	-20 to 10	Sediment

Model calibration

Latin Hypercube Sampling with 3000 runs

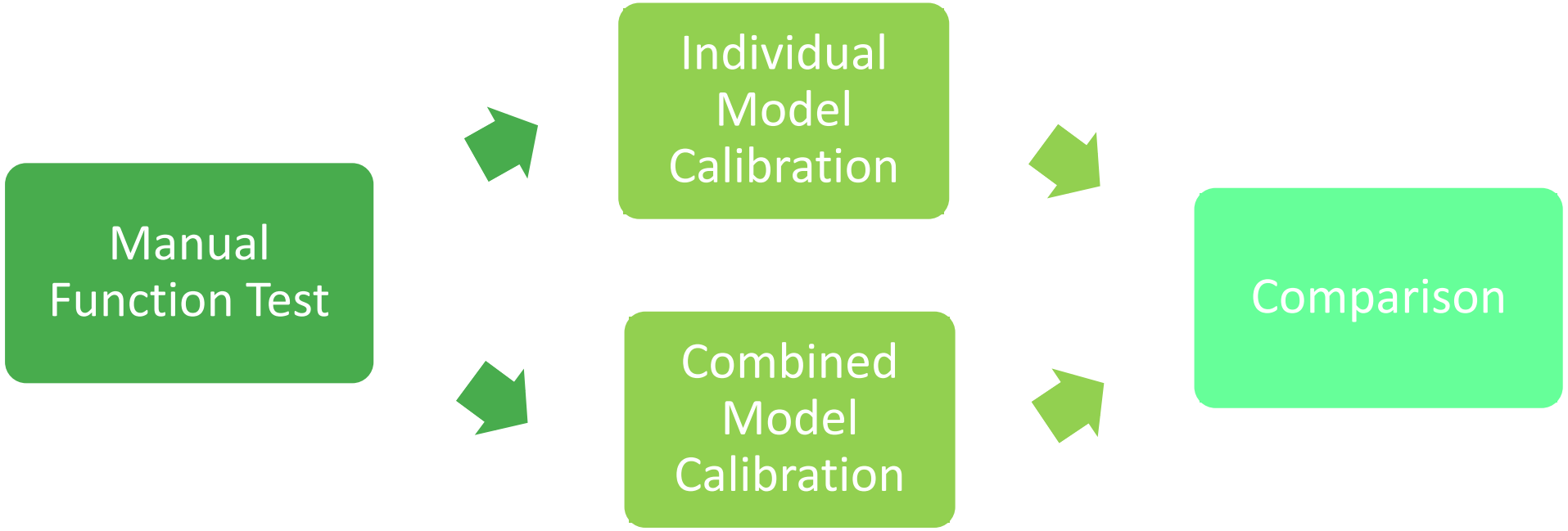
Individual Model Calibration

Select best parameterization for **each variable** (e.g., discharge) **separately** based on KGE.

Combined Model Calibration

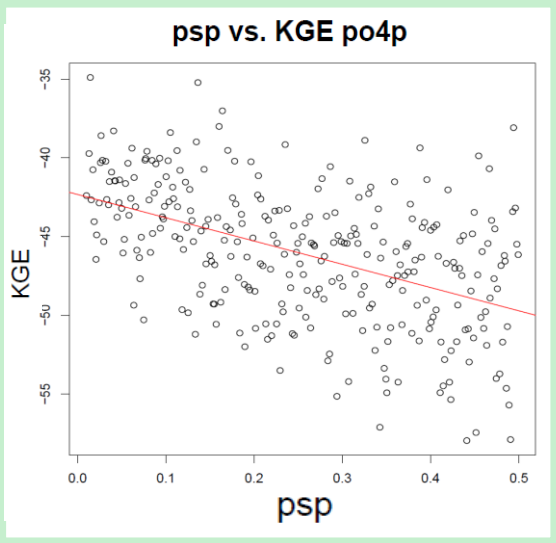
Select best parameterization for **all variables** (discharge, suspended sediment, soluble phosphorus, sediment-bound phosphorus) **together** based on mean KGE.

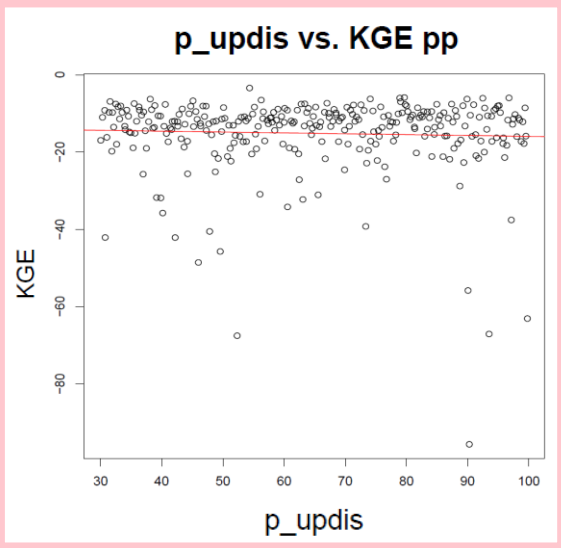
Results


Manual Function Test
Individual Model Calibration
Combined Model Calibration
Comparison

Function Test & Sensitivity Analysis

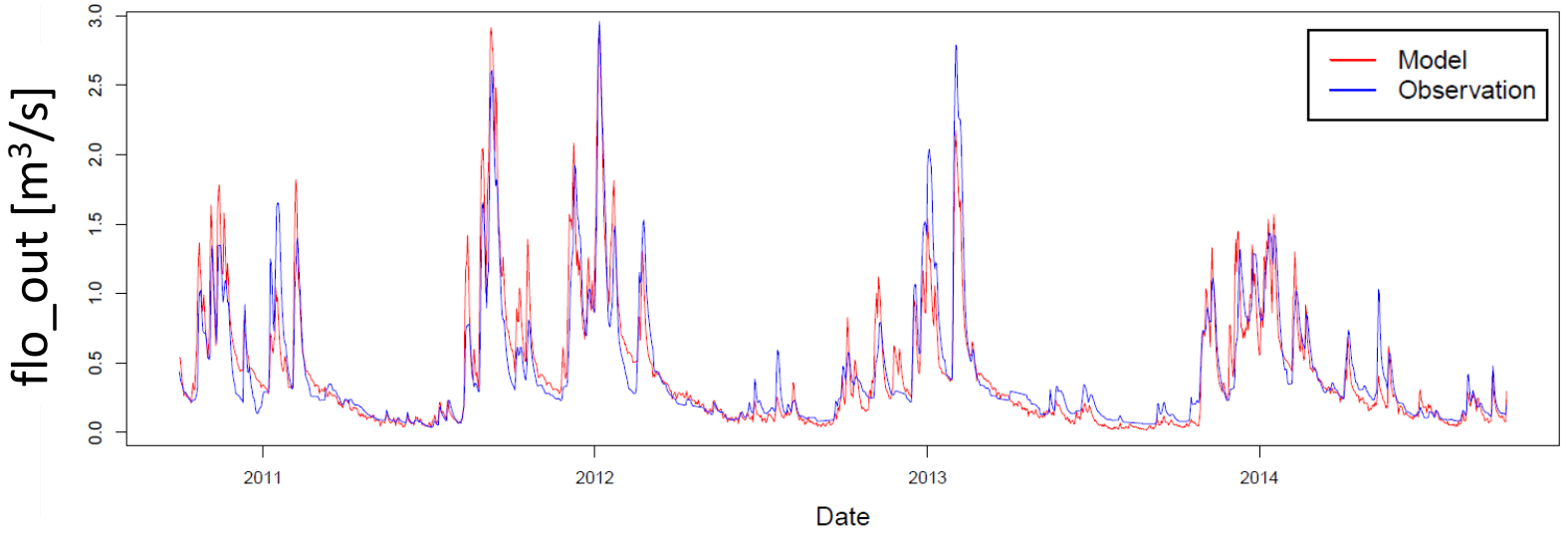
- Manual one parameter at a time (OAT) sensitivity analysis
- Automated model runs to test the effect on KGE, PBIAS & NSE

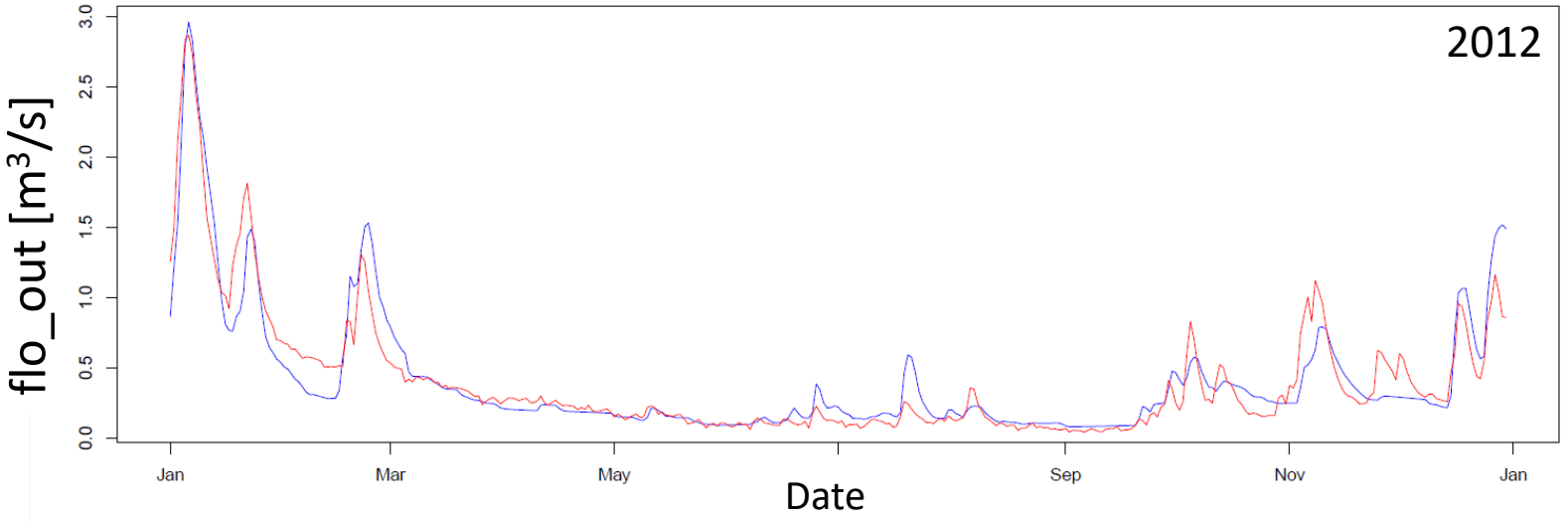




Parameter	Location	Calibration Range	Primarily related to	Sensitive
alpha_bf	calibration.cal	0.5 to 1	Discharge	y
alpha_bf2	**aquifer.aqu**	0.01 to 0.02	Discharge	y
cn2	calibration.cal	-15 to 5 (-15 to 10)	Discharge	y
cn3	calibration.cal	-20 to 20	Discharge	y
epco	calibration.cal	0.05 to 0.5	Discharge	n
esco	calibration.cal	0.05 to 1.0	Discharge	y
latq_co	calibration.cal	-20 to 20	Discharge	y
perco	calibration.cal	-20 to 5	Discharge	y
rchrg_dp	calibration.cal	0.01 to 0.1	Discharge	n
sol_awc	calibration.cal	0.04 to 0.2	Discharge	y
surlag	calibration.cal	0.2 to 0.75 (0.2 to 0.5)	Discharge	y
orgp_enrich	**hydrology.hyd**	0.8 to 4.8	Phosphorus	n
p_updis	calibration.cal	30 to 100	Phosphorus	y
phoskd	calibration.cal	10 to 140 (115 to 190)	Phosphorus	y
pperco	calibration.cal	10 to 16	Phosphorus	y
psp	calibration.cal	0.01 to 0.7 (0.01 to 0.5)	Phosphorus	y
sol_p_aqu	**aquifer.aqu**	0.04-0.15 (0.04 to 0.4)	Phosphorus	y
watersol_p	**nutrients.sol**	30 to 90	Phosphorus	n
adj_pkr	**parameters.bsn**	0.5 to 2	Sediment	n
adj_pkr_sed	**parameters.bsn**	0.5 to 1.5 (0.5 to 2)	Sediment	y
cov_fact	**sediment.cha**	0.4 to 0.7	Sediment	n
erod_fact	**sediment.cha**	0.1 to 0.5	Sediment	n
hru_slp	**topography.hyd**	-20 to 20	Sediment	y
lat_sed	calibration.cal	1-60 (55 to 140)	Sediment	y
slp_len	**topography.hyd**	-20 to 20	Sediment	n
usle_c	**plants.plt**	-20 to 20	Sediment	n
usle_k	calibration.cal	0.01 to 0.15 (0.06 to 0.2)	Sediment	y
usle_p	**cons_practice.lum**	-10 to 10 (-20 to 5)	Sediment	y
z	calibration.cal	-20 to 10	Sediment	y

Individual Calibration: Discharge

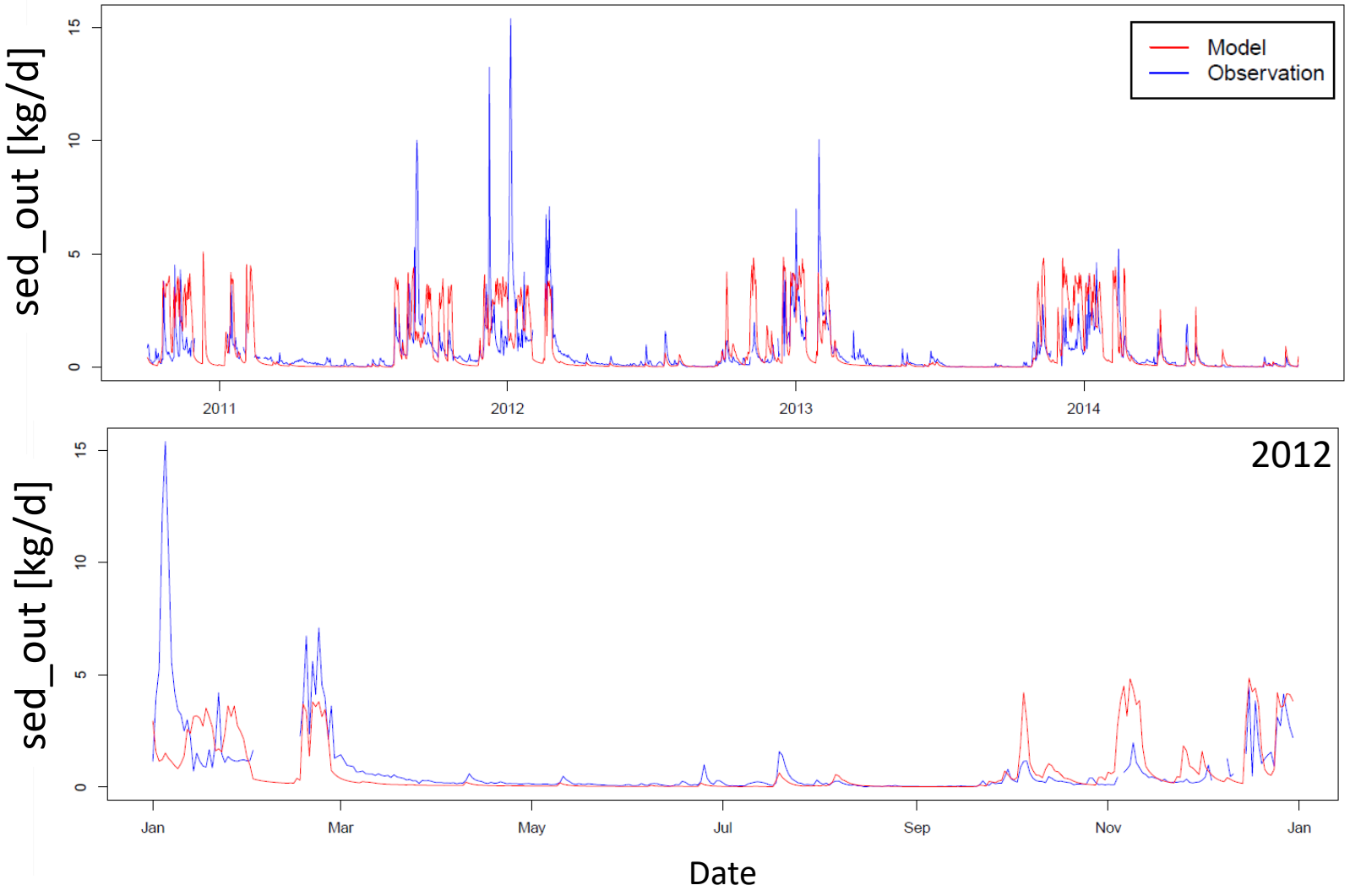




run	NSE	PBIAS	KGE
725	0.82	-1	0.91

Good model fit for discharge

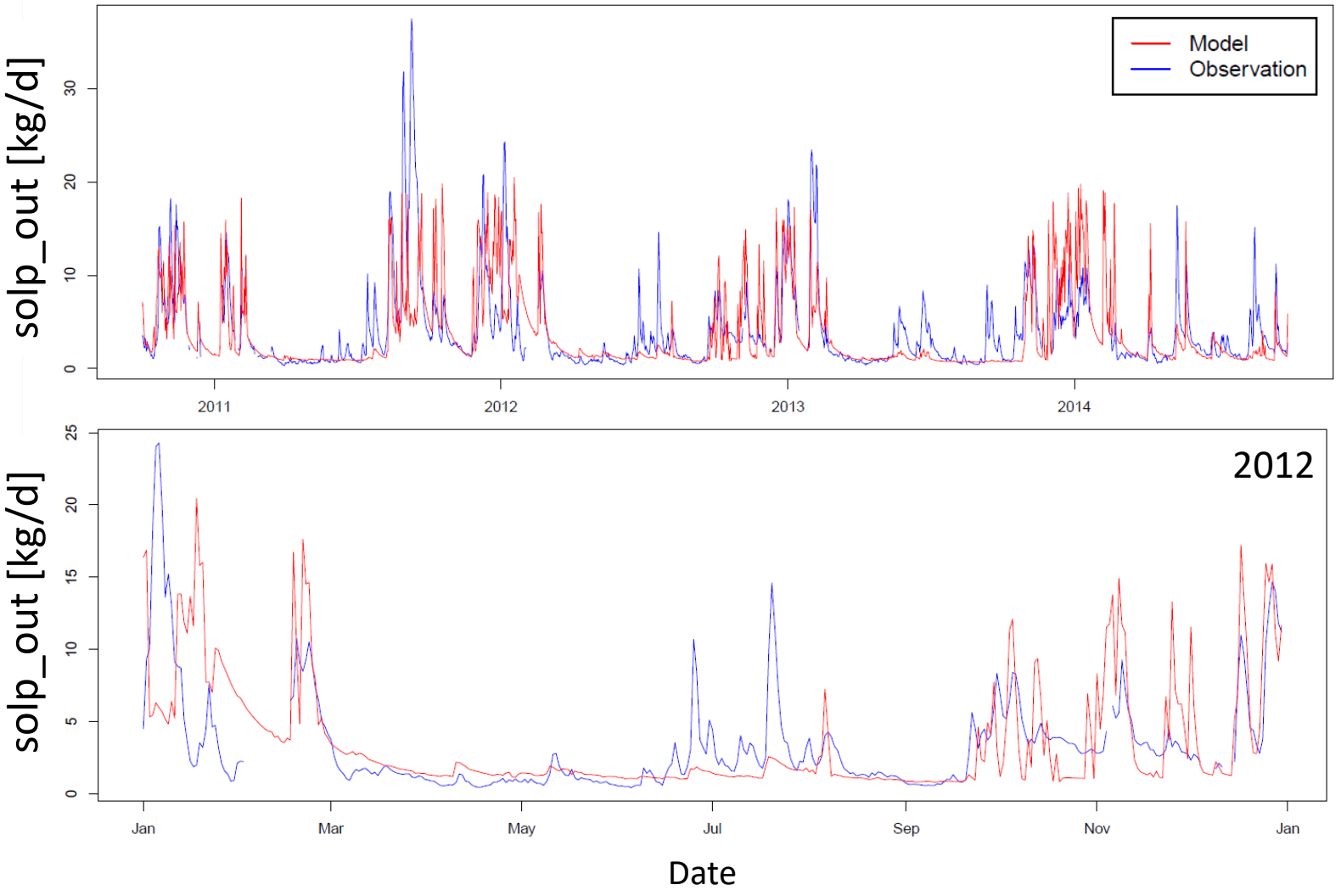
Individual Cal.: Suspended Sediment



run	NSE	PBIAS	KGE
597	-0.03	15.3	0.47

- negative NSE
- Missed Peaks

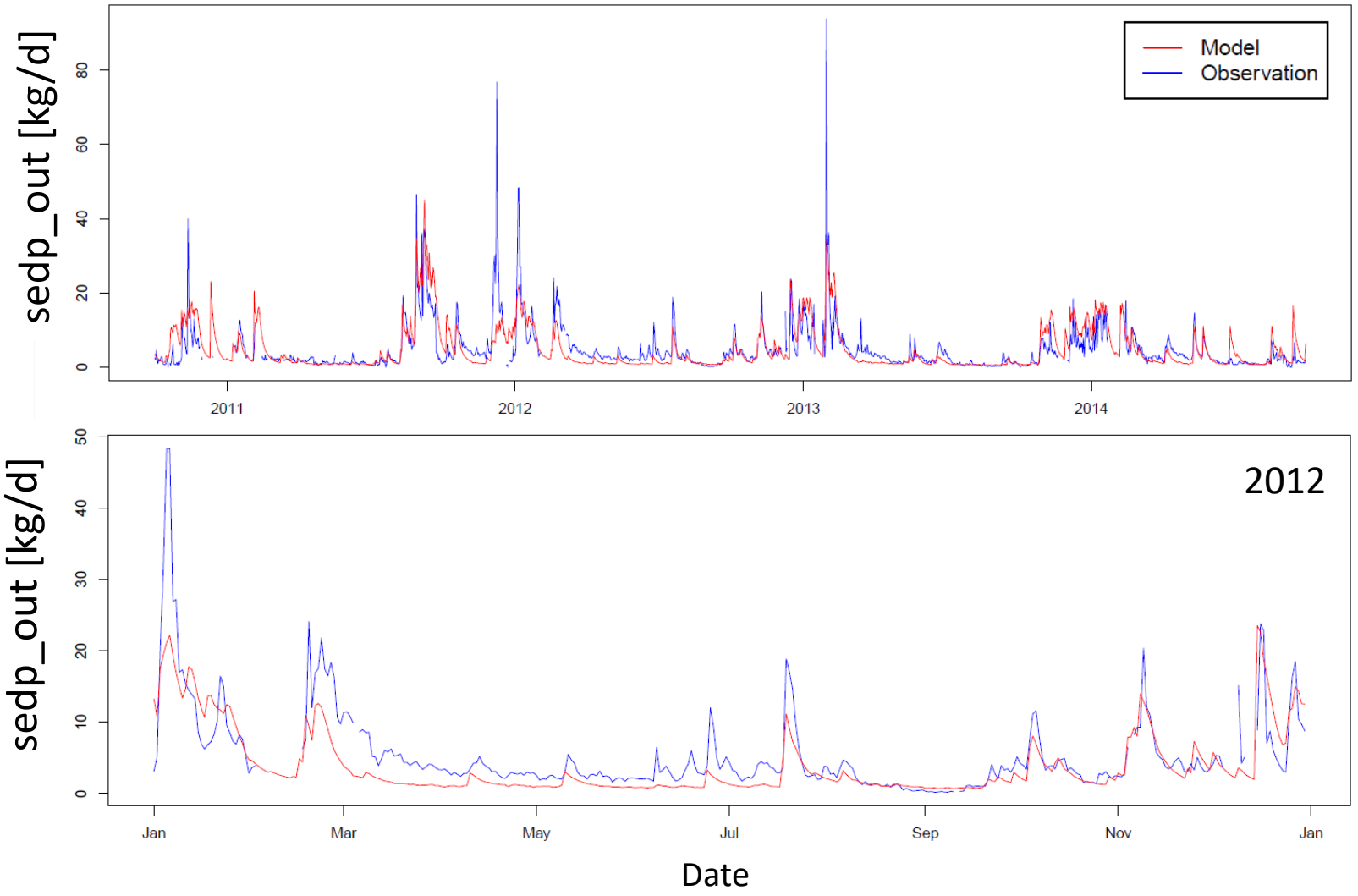
Individual Cal.: Soluble Phosphorus



run	NSE	PBIAS	KGE
216	0.13	-6.3	0.53

- Low positive NSE
- Missed peaks

Individual Cal.: Sediment-bound Phosphorus

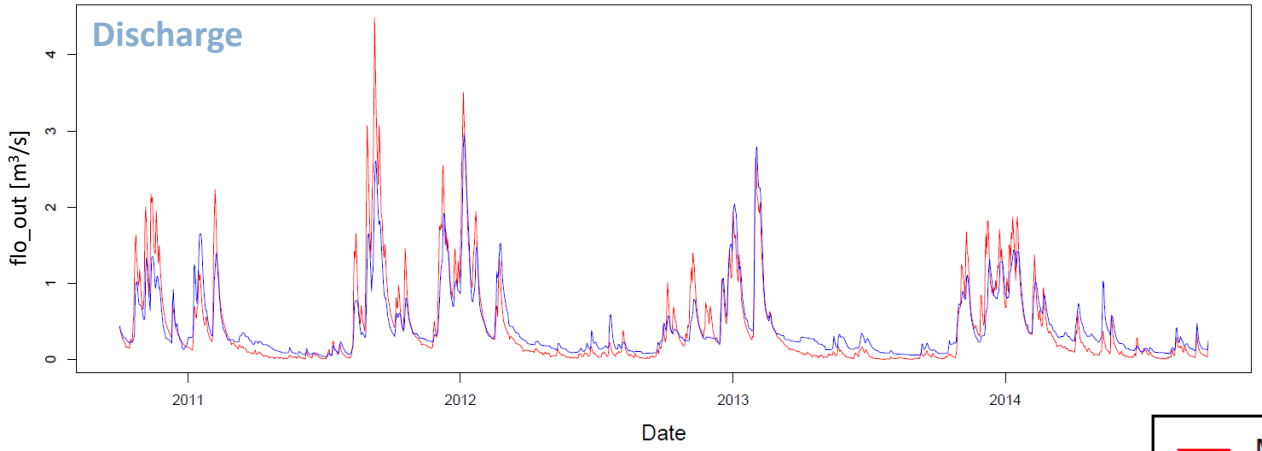


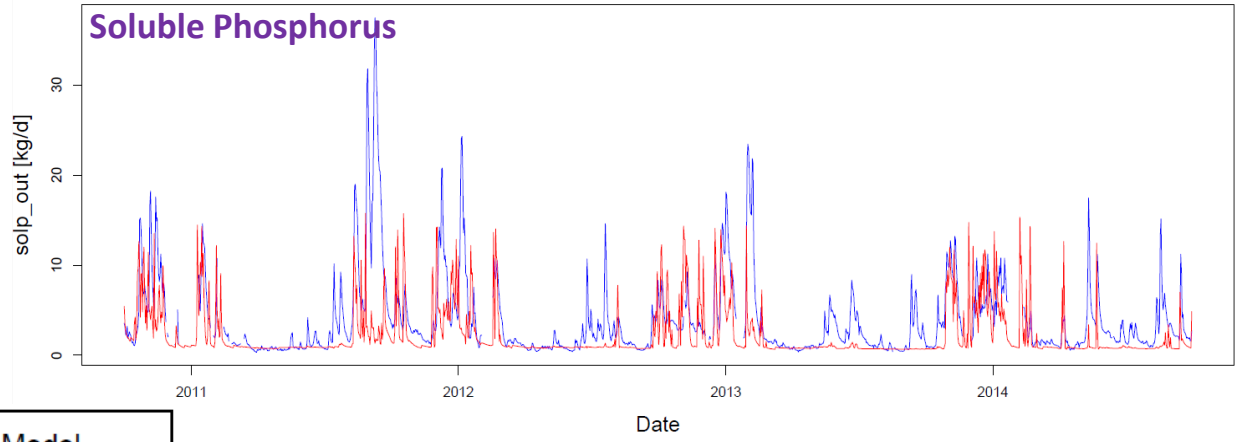
run	NSE	PBIAS	KGE
1206	0.46	0.6	0.70

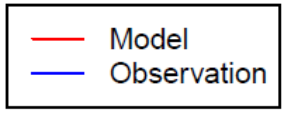
- satisfactory positive NSE
- very good PBIAS

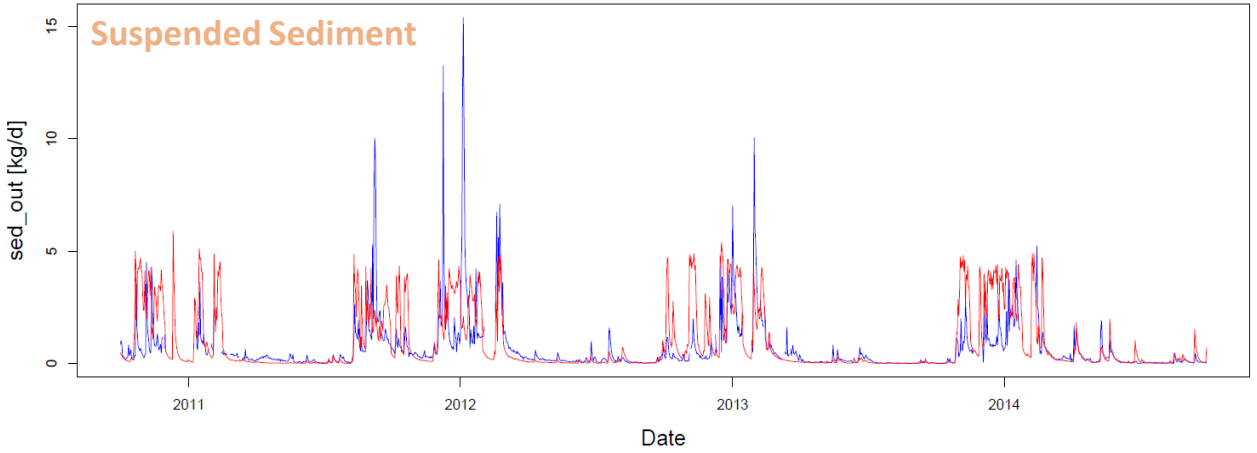
Combined Calibration

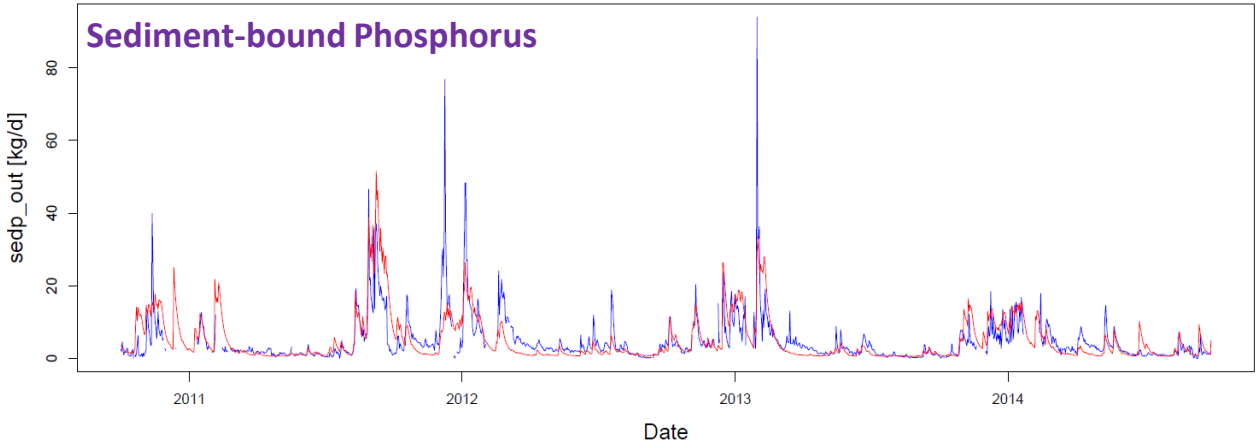
Highest mean KGE over all variables in run 2264: mean KGE 0.48







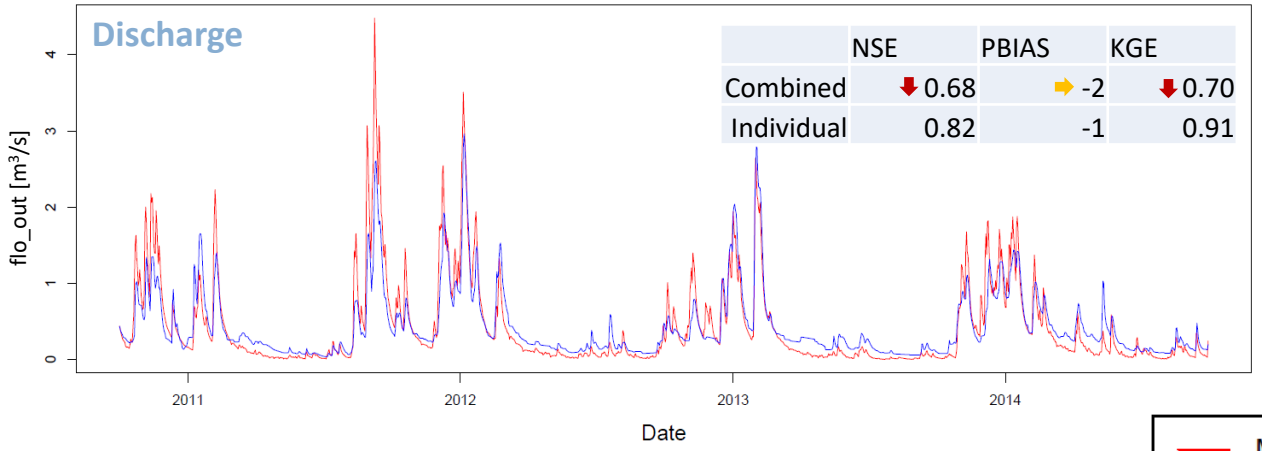


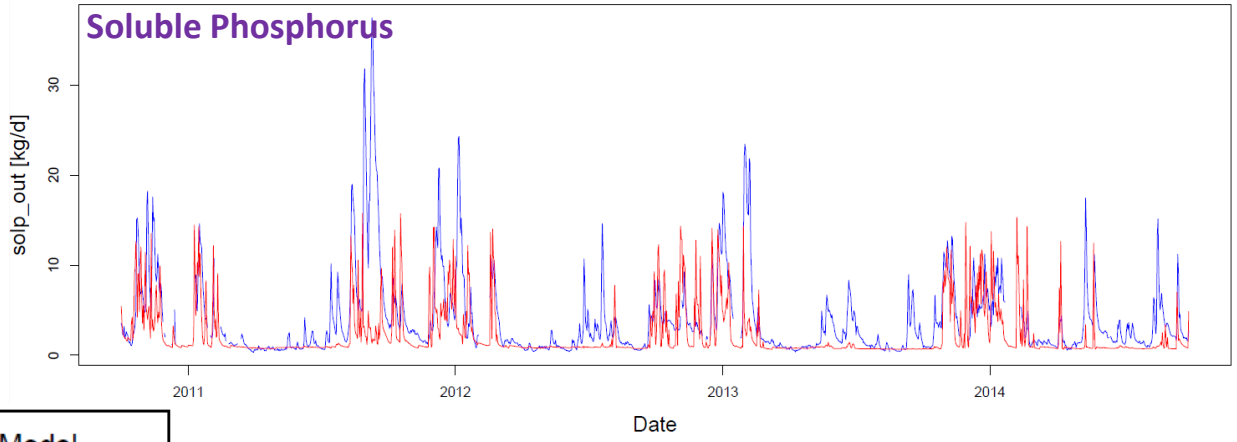


Combined Calibration

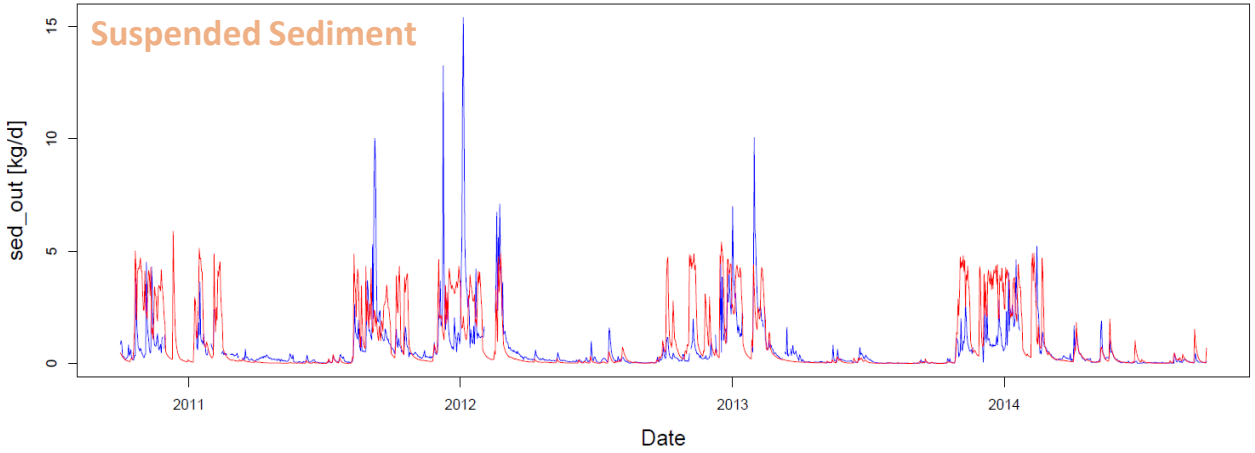
slightly worse | much worse

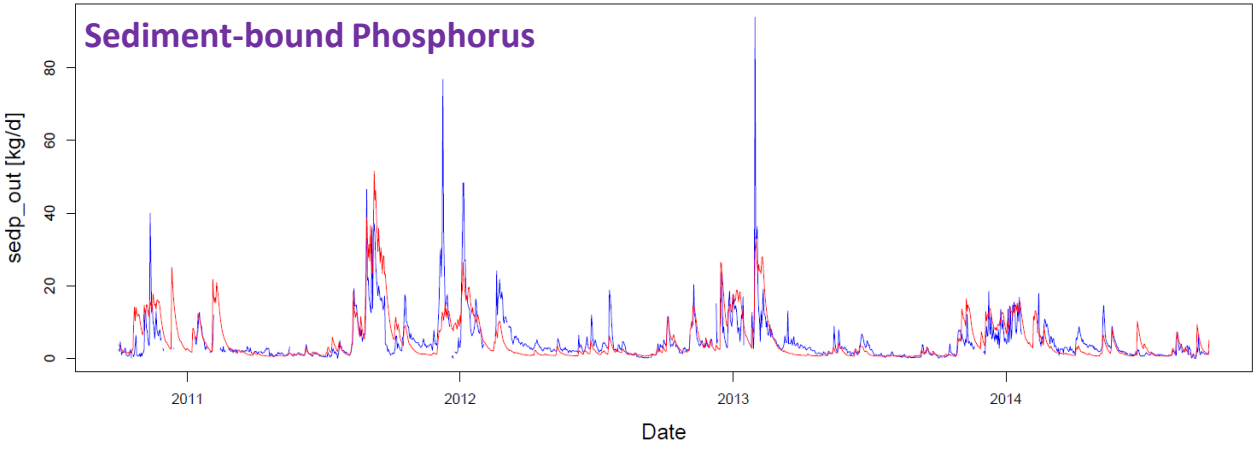
Highest mean KGE over all variables in run 2264: mean KGE 0.48





Model
Observation

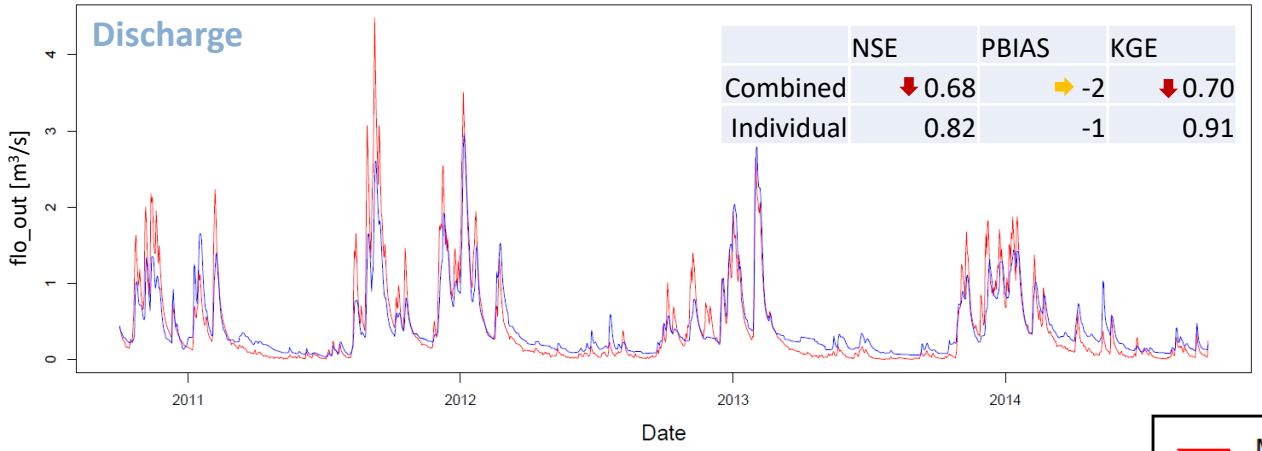


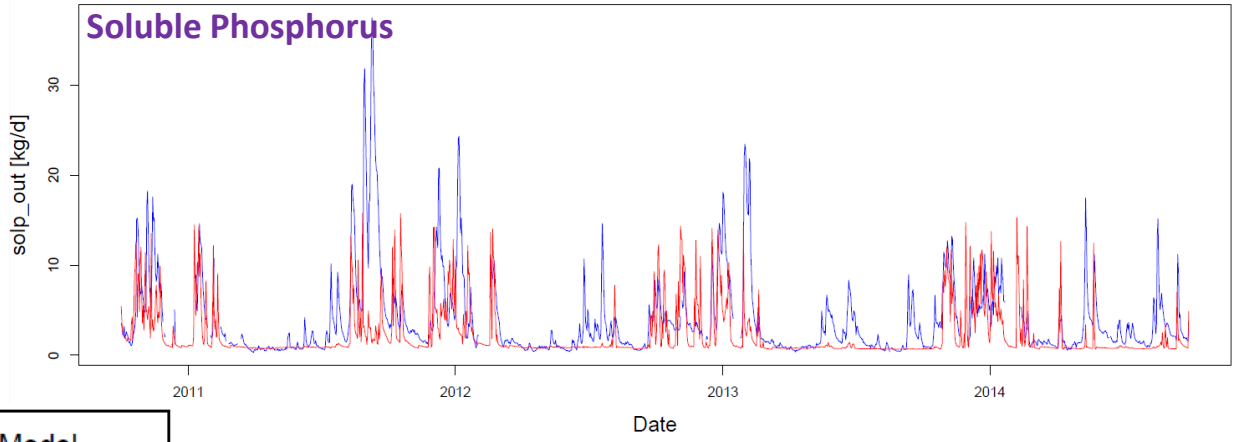


Combined Calibration

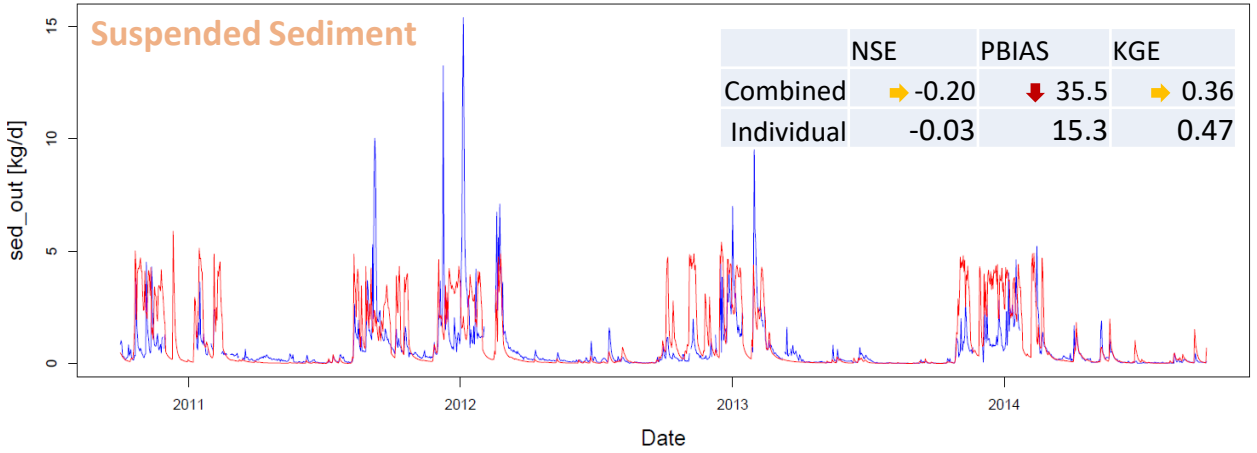
slightly worse much worse

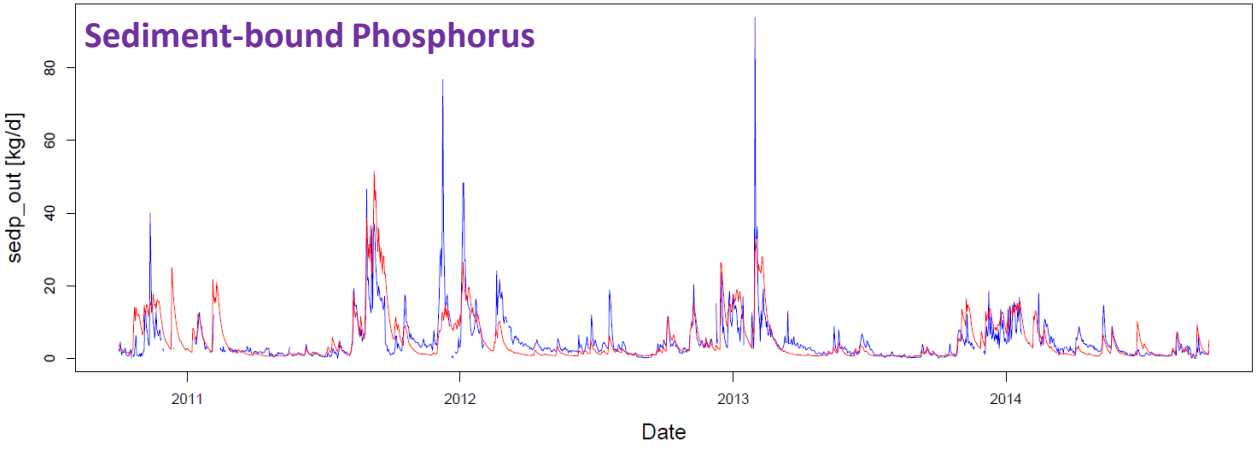
Highest mean KGE over all variables in run 2264: mean KGE 0.48





Model
Observation

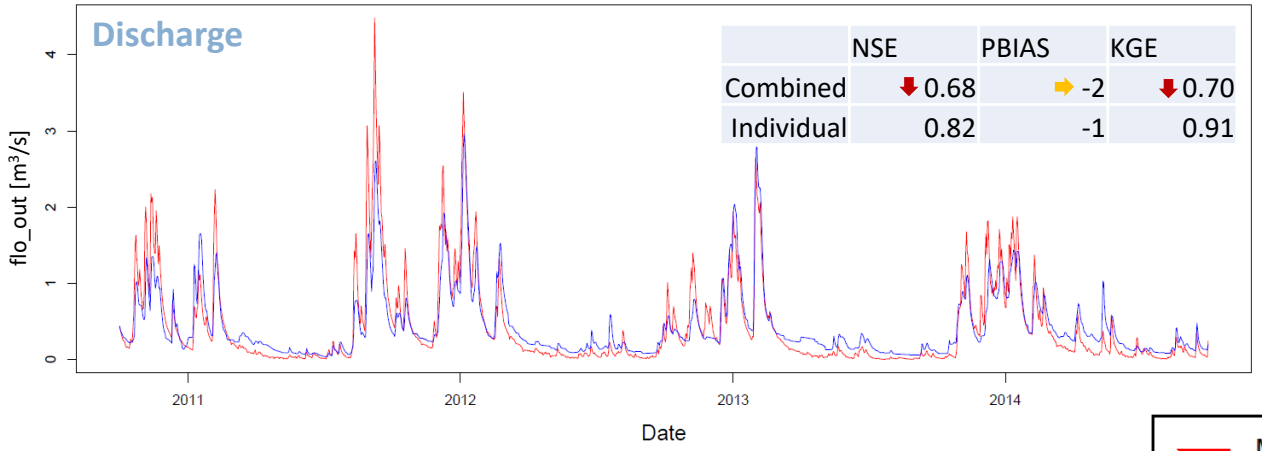


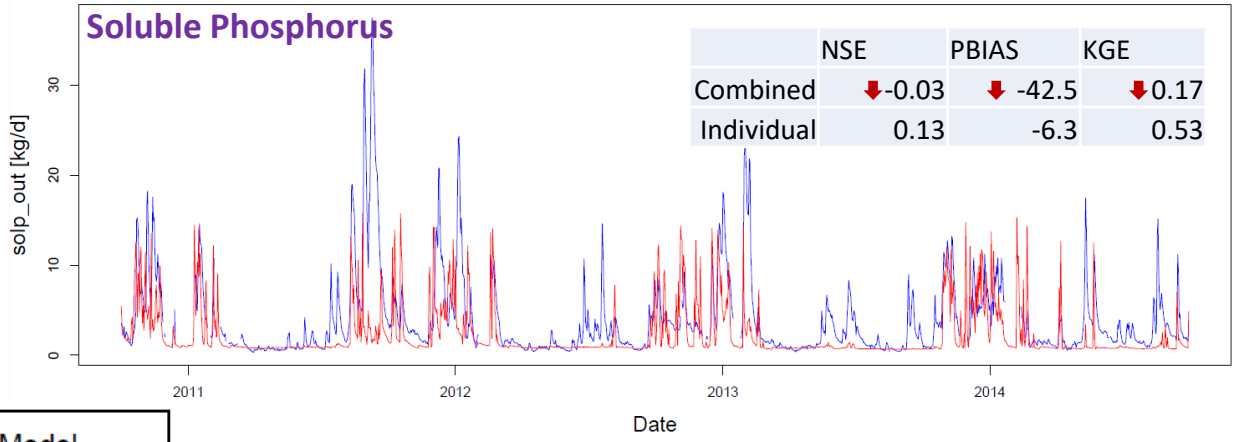


Combined Calibration

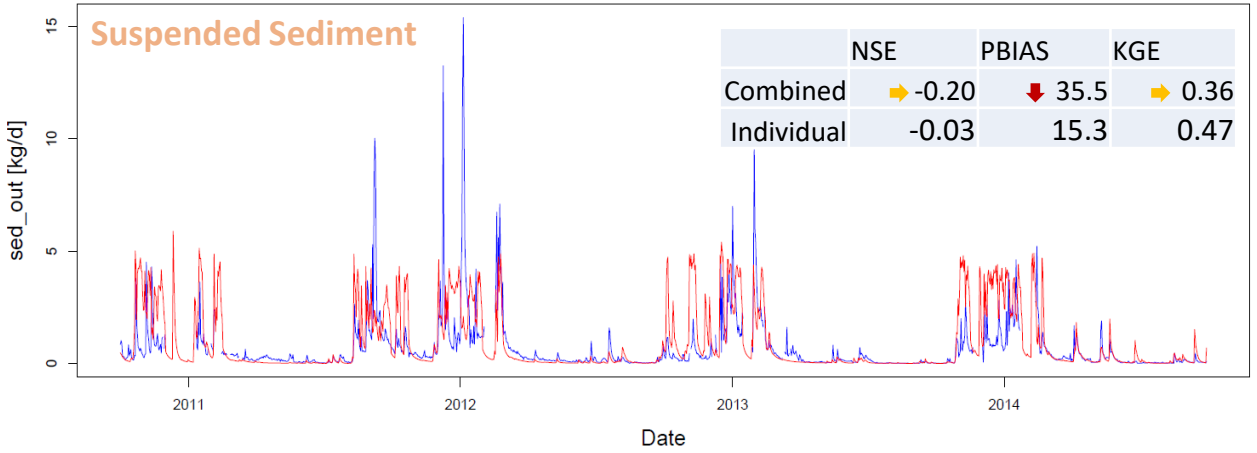
slightly worse much worse

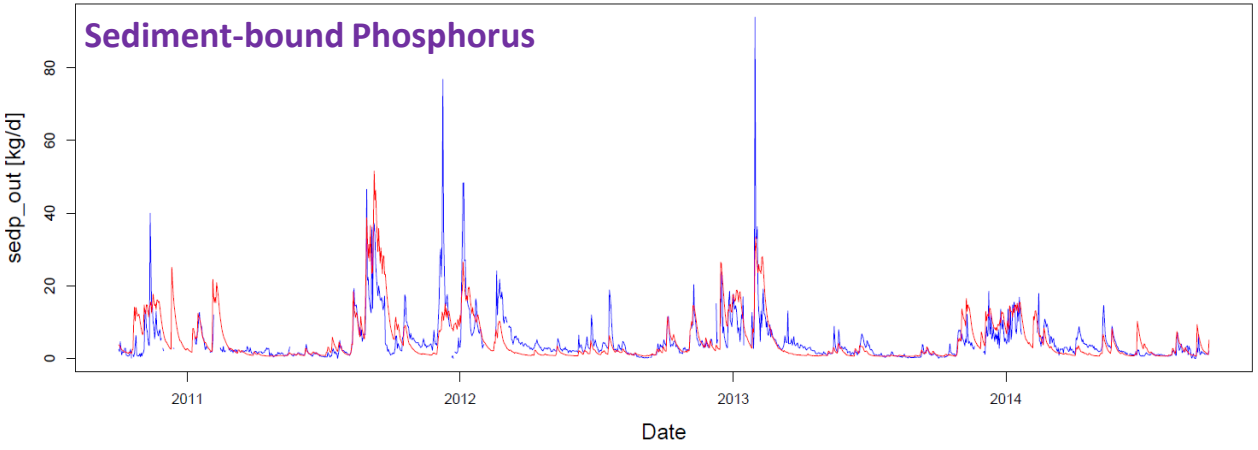
Highest mean KGE over all variables in run 2264: mean KGE 0.48





Model
Observation

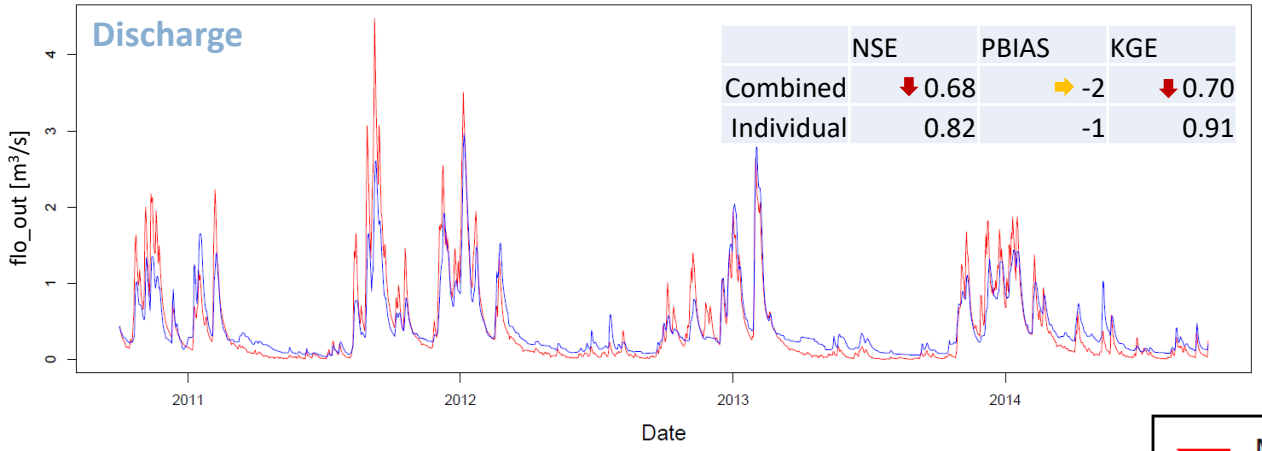


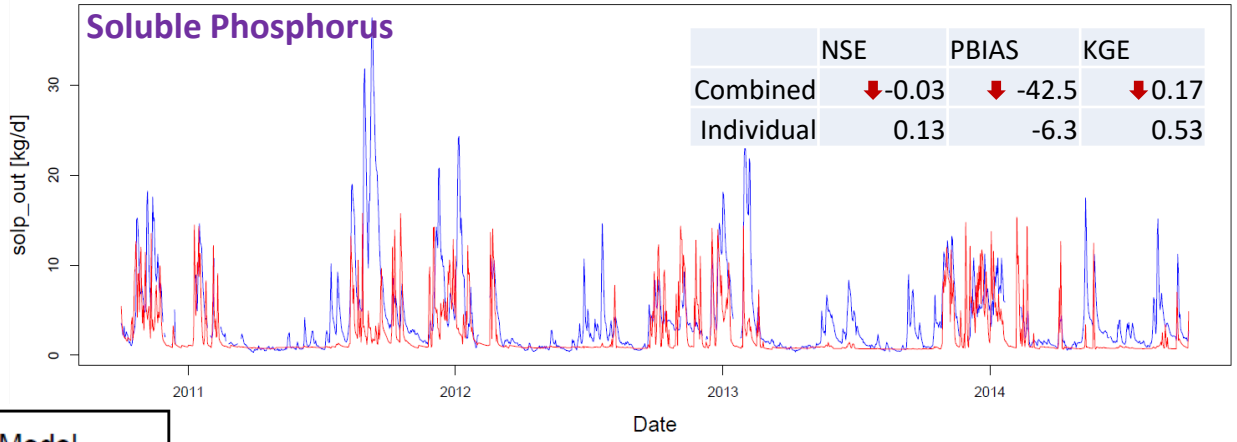


Combined Calibration

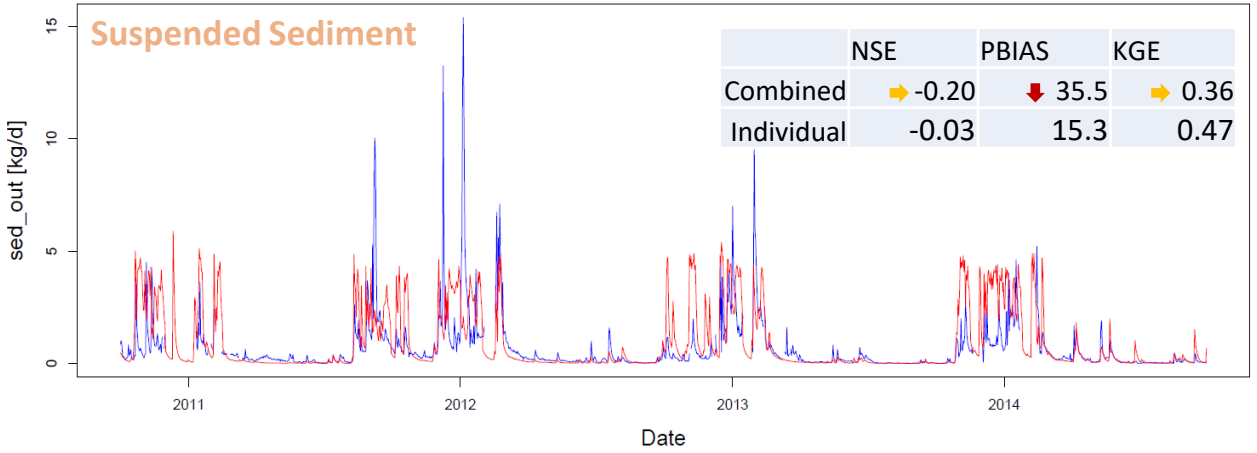
slightly worse much worse

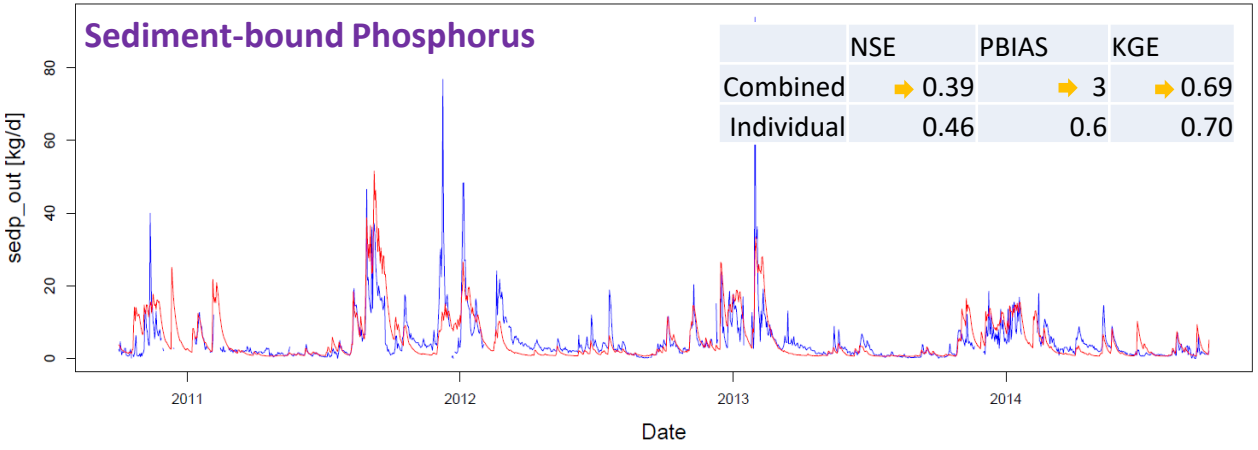
Highest mean KGE over all variables in run 2264: mean KGE 0.48





Model
Observation





Conclusion

Phosphorus and Sediment Modeling with SWAT+ ➡ Use Version 61.0

Functionality & Sensitivity Analysis:

- Not all relevant parameters are included or active in calibration.cal.

Individual Calibration:

- Achieved acceptable performance regarding PBIAS.
- Dynamics, especially for sediment, need improvement.

Combined Calibration:

- Results indicate trade-off in combined calibration.

Outlook

- Future work will follow Haas et al. (2016) using flow, sediment, and phosphorus duration curves for a more comprehensive calibration.
- Parameter ranges will be optimized, and more model runs will be conducted.

Thank you for your attention !

hrisch@hydrology.uni-kiel.de

(Risch, 2022)