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Supplement of

A framework for parameter estimation, sensitivity analysis, and uncertainty analysis for holistic hydrologic modeling using SWAT+

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Table S1. Description and hydrological process of **23** selected parameters for the standalone SWAT+ model.

Parameters	Description	Hydrologic Processes
CN2 #	SCS runoff curve number for moisture condition II	Surface runoff processes (cn)
ESCO #	Soil evaporation compensation factor	Potential and actual evapotranspiration processes (hydro)
EPCO #	Plant uptake compensation factor	
gw_flo #	Initial depth of water in the shallow aquifer (mm H_2O)	Groundwater flow processes (aqu)
dep_bot #	Initial depth of water in the deep aquifer (mm H_2O)	
dep_wt #	Initial groundwater height (m)	
flo_max #	The delay time	
alpha_bf #	Baseflow alpha factor (1/days)	
revap #	Groundwater "revap" coefficient	
rchg_dp #	Deep aquifer percolation fraction	
spec_yld #	Specific yield of the shallow aquifer (m^3/m^3)	
revap_min #	Threshold depth of water in the shallow aquifer for "revap" (mm H_2O)	
Ftmp	Snowfall temperature (°C)	Snow processes (sno)
Mtmp	Snowmelt base temperature (°C)	
Mmax	Melt factor for snow on June 21 (mm H_2O/°C– day)	
Mmin	Melt factor for snow on December 21 (mm H_2O/°C– day)	
Tmplag	Snowpack temperature lag factor	
Snowd	Minimum snow water content (mm H_2O)	
COV50	Fraction of COVMX	
perco #	Percolation coefficient	Soil water processes (sol)
SOL_AWC ()	Available water capacity of the soil layer (mm H_2O/mm soil)	
SOL_BD ()	Moist bulk density (g/cm^3 or Mg/m^3)	
SOL_K ()	Saturated hydraulic conductivity (mm/h)	

Table S2. Monthly streamflow performance statistics for the base SWAT+ simulations.

| River Basin	Station	Calibration				Validation			
		NSE	R^2	PBIAS	KGE	NSE	R^2	PBIAS	KGE
Nanticoke River	USGS 01488500	0.67	0.73	19.60	0.68	0.78	0.79	7.10	0.78
	USGS 01487000	0.72	0.78	16.00	0.77	0.66	0.67	6.80	0.72
Winnebago River	USGS 05459500	0.89	0.89	–0.60	0.93	0.82	0.87	15.20	0.71
Cache River	USGS 07077380	0.81	0.81	–7.20	0.82	0.71	0.72	6.10	0.77
	USGS 07077700	0.68	0.74	14.70	0.61	Not enough observations			
	USGS 07077555	0.78	0.85	–0.70	0.66	0.79	0.88	7.70	0.64
Arkansas Headwaters River	USGS 07087050	0.62	0.76	30.60	0.59	0.66	0.83	31.40	0.54
	USGS 07091200	0.62	0.79	30.20	0.63	0.61	0.79	32.60	0.53
	USGS 07094500	0.64	0.66	9.40	0.76	0.50	0.53	12.40	0.63
	USGS 07096000	0.65	0.67	4.70	0.80	0.54	0.56	10.80	0.69
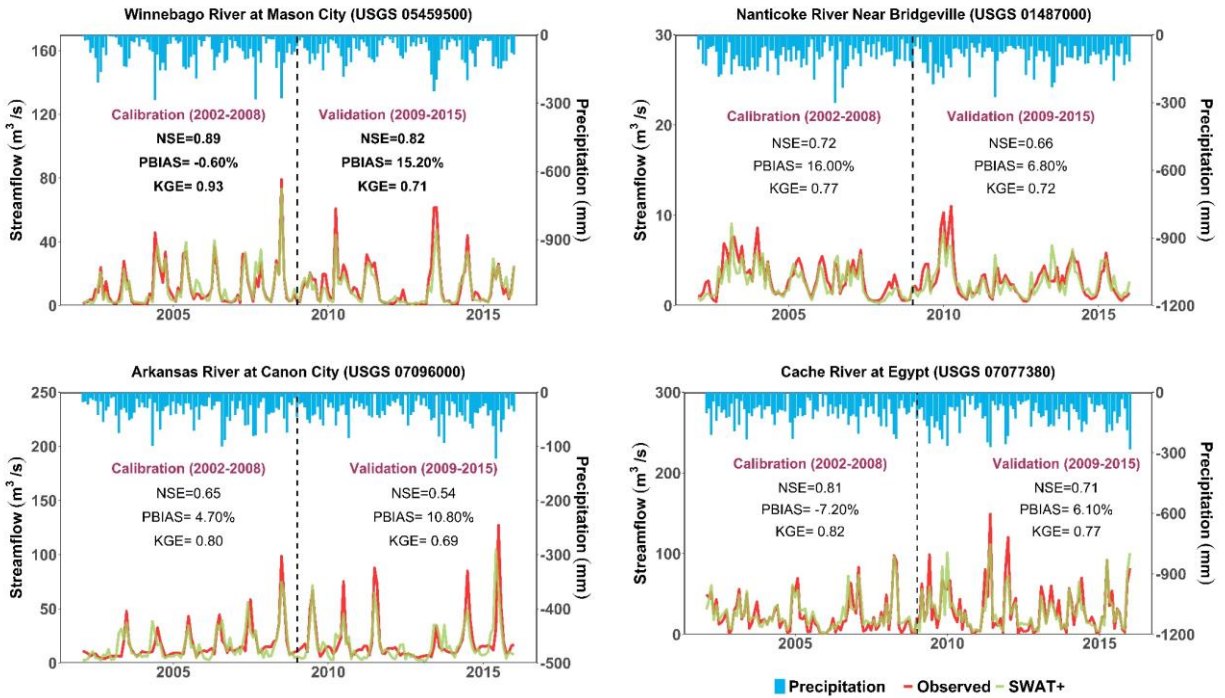
Figure S1. Measured and simulated monthly streamflow for SWAT+ models for selected USGS stream gaging sites within the four study watersheds. Performance statistics (NSE, PBIAS, KGE) are shown for each gage site.
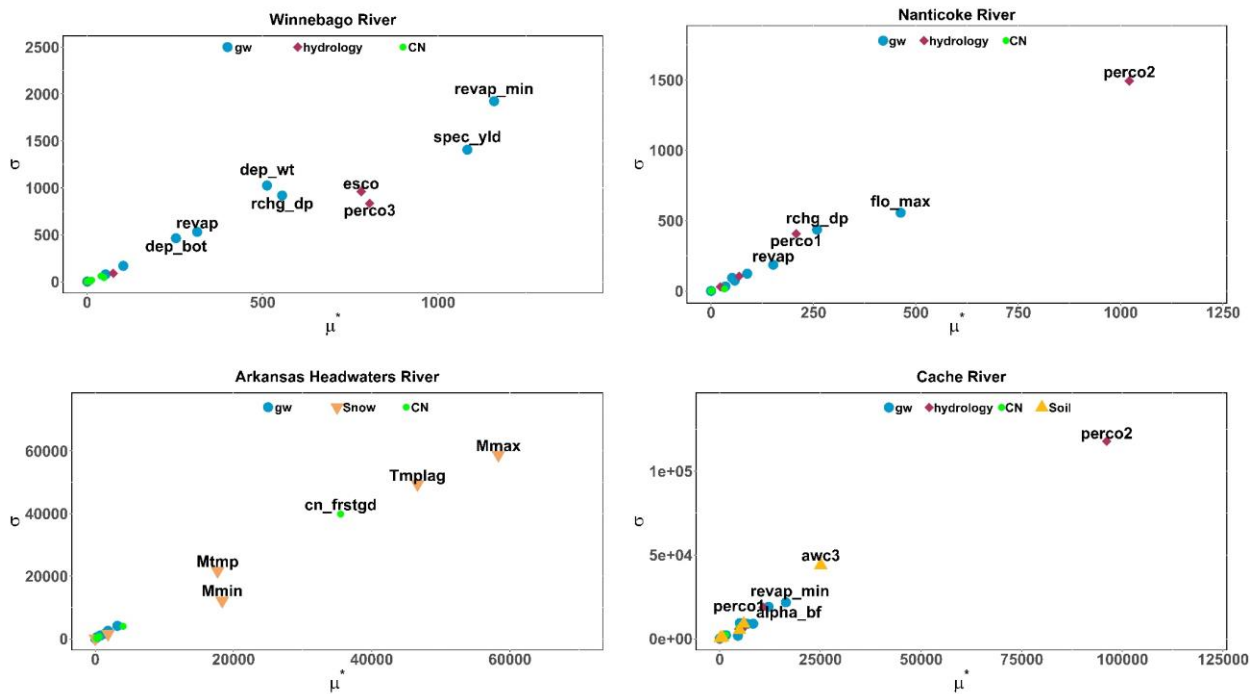

Figure S2. Parameters sensitivity analysis based on the Morris screening method for minimizing streamflow for base SWAT+. Only the most sensitive parameters are labelled. μ^* is the sensitivity measure, and σ reveals the degree of nonlinearity or factor interaction.
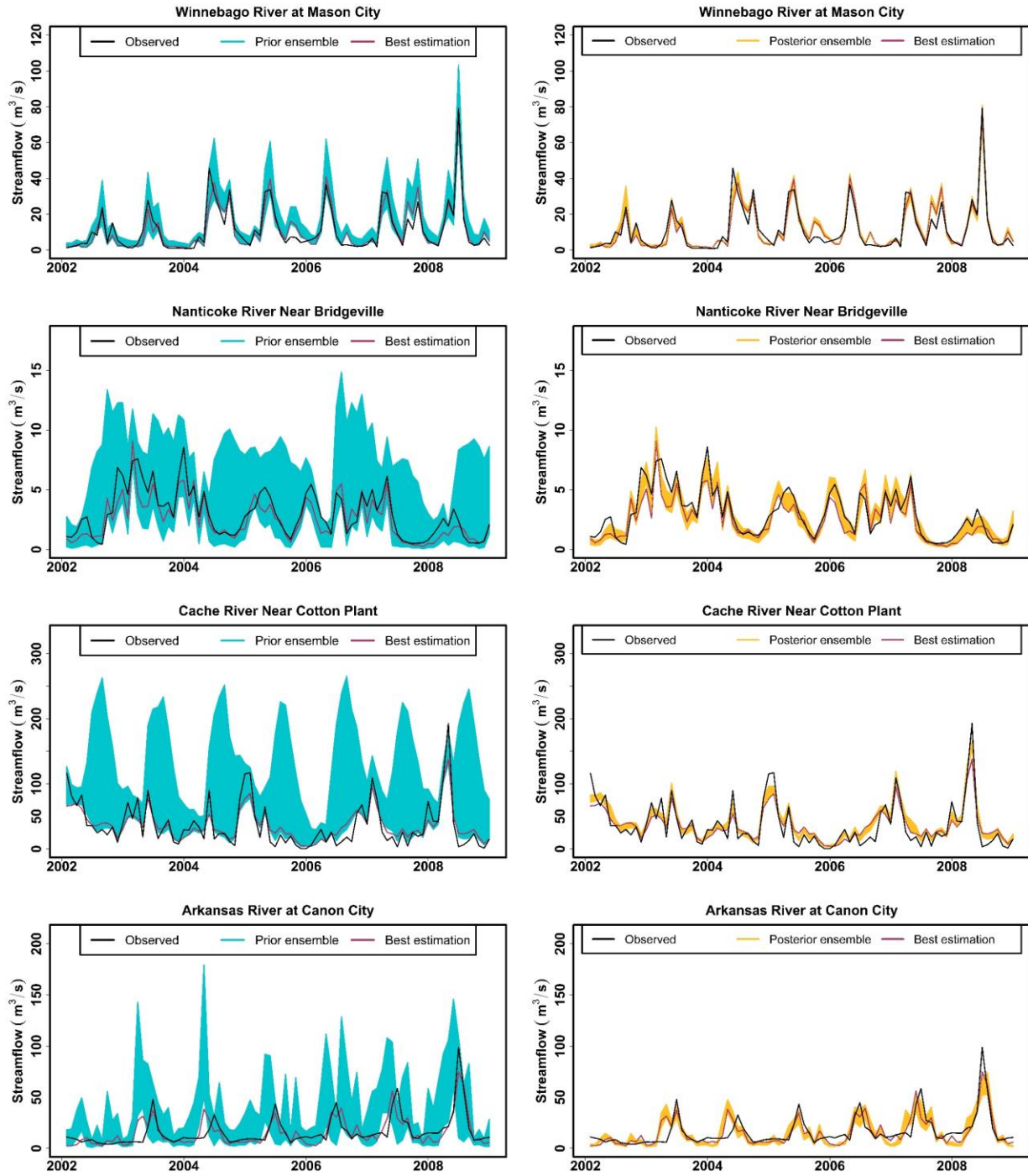
Figure S3. Prior (left column) and Posterior (right column) prediction uncertainty bounds for streamflow estimation using SWAT+ in four study watersheds.