

Comparing Single-Site and Multi-Site Calibration of SWAT+ in a Moroccan Semi-Arid watershed

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Summary

- Introduction
- Swat+ Toolbox capabilities
- Watershed description
- Input data
- Model verification
- Soft calibration
- Set Calibration/Validation periods
- Sensitivity analysis
- Single-site calibration
- Multisite one step calibration
- Multisite multistep calibration
- Comparing results
- Conclusion



Introduction

- The calibration phase is a crucial step in any hydrological modeling process;
- In engineering, the main challenge lies in data collection, processing, and establishing the rainfall-runoff relationship;
- When multiple hydrological stations are present, calibration is performed basin by basin, without the possibility of processing the entire network simultaneously;
- This is where a tool like the SWAT+ Toolbox becomes essential, as it enables processing of the entire hydrometric network and improves the regionalization of the calibration process
- Here we have a sophisticated tool. The current question is how to leverage this tool to Improve the calibration model at the outlet level of a watershed ?



Parallel Processes
4 Multi-Site
CalibrationObjective Function
NSECalibration Algorithm Selection
DiffeRential Evolution Adaptive Metropolis (DREAM)Observation
Channel 01 Monthly River Flow

Stop

CALibration by Latin-Hypercube Sampling Iterations [CALS]

Dynamically Dimensioned Search [DDS]

DiffeRential Evolution Adaptive Metropolis [DREAM]

Name	Change Type	Value	
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000

Best NSE: 0.683477619103829

Channel 01 Monthly River Flow

NSE

0.519



Status

Progress

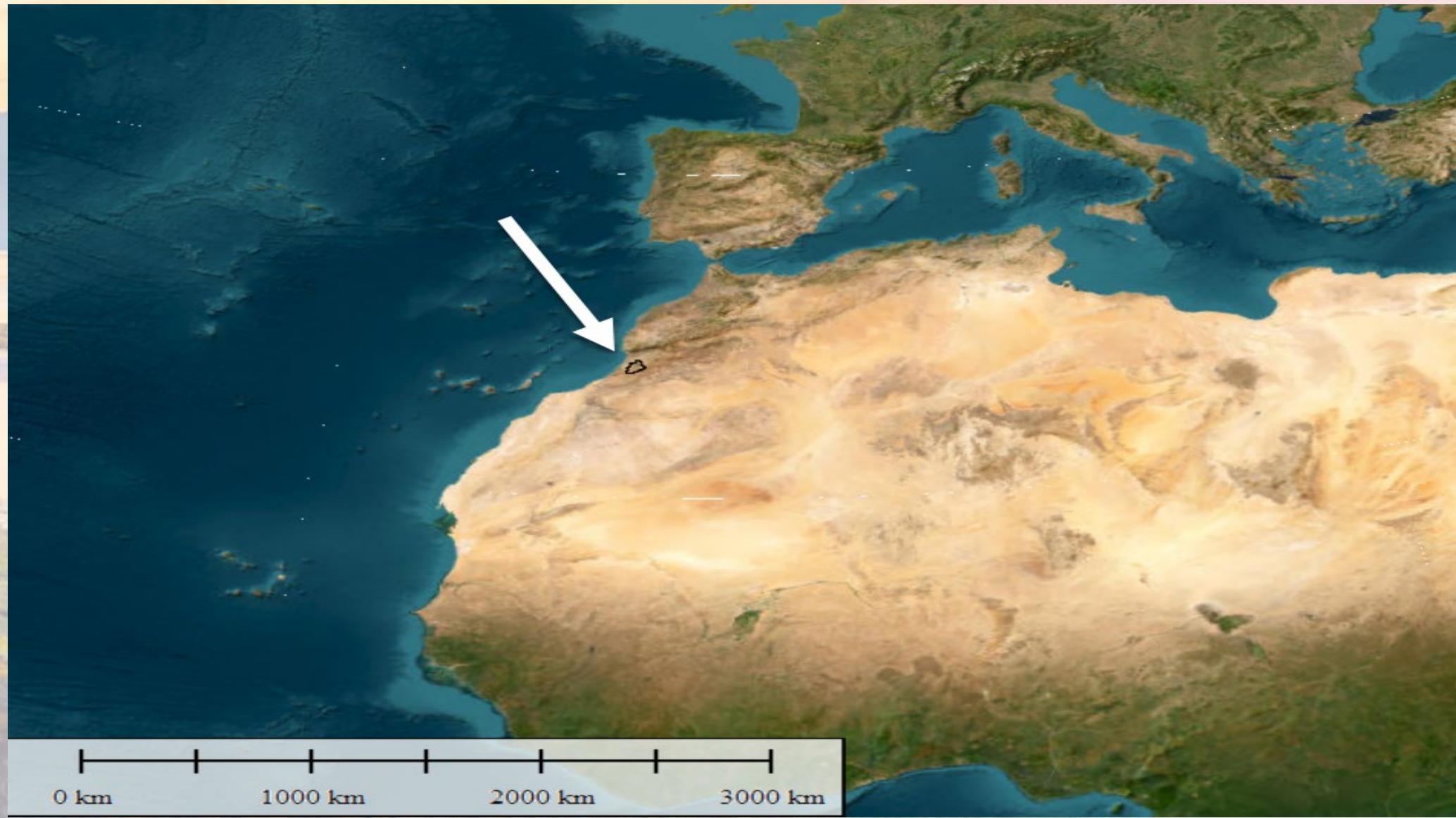
Charts

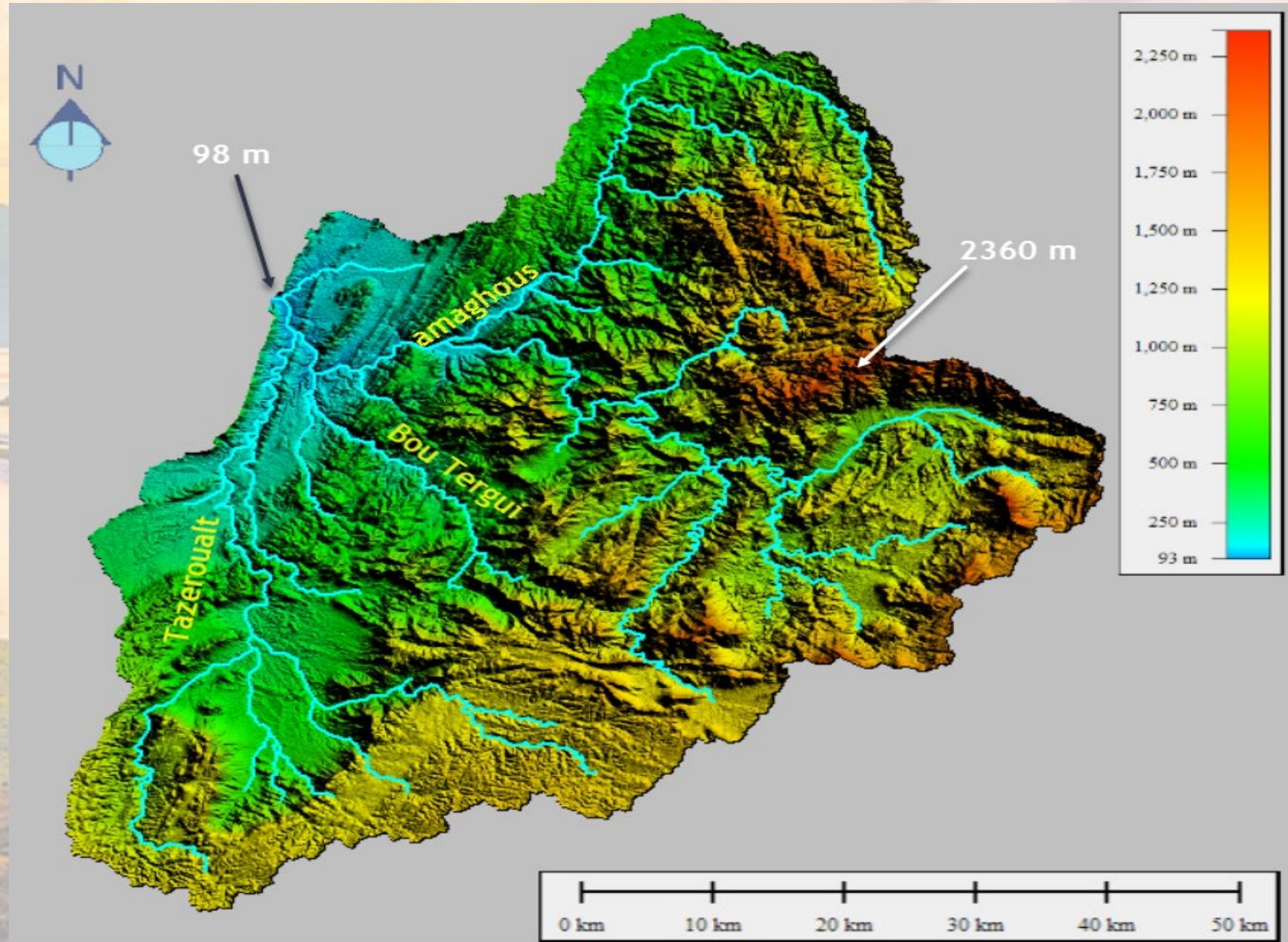
Dotty Plots

Manual Automatic

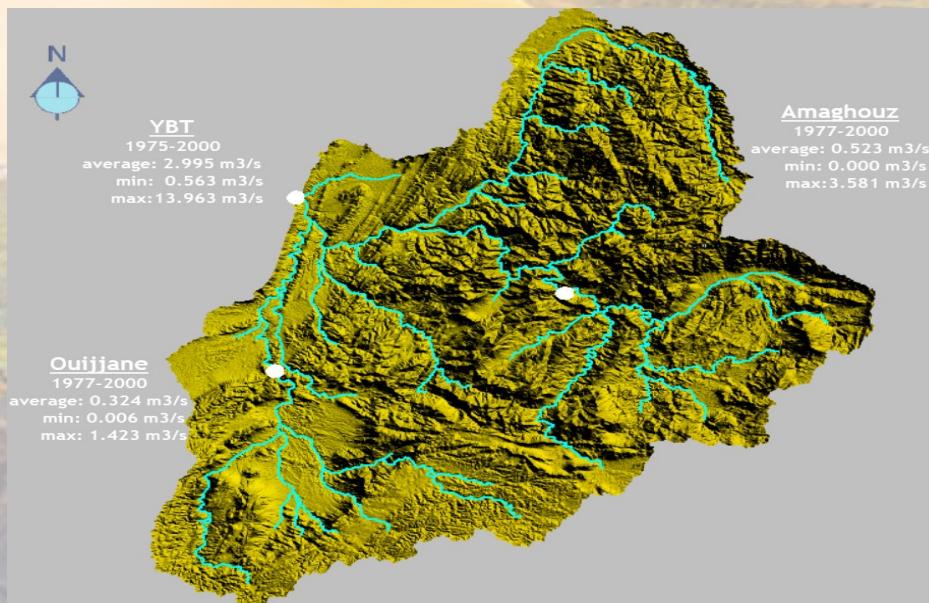
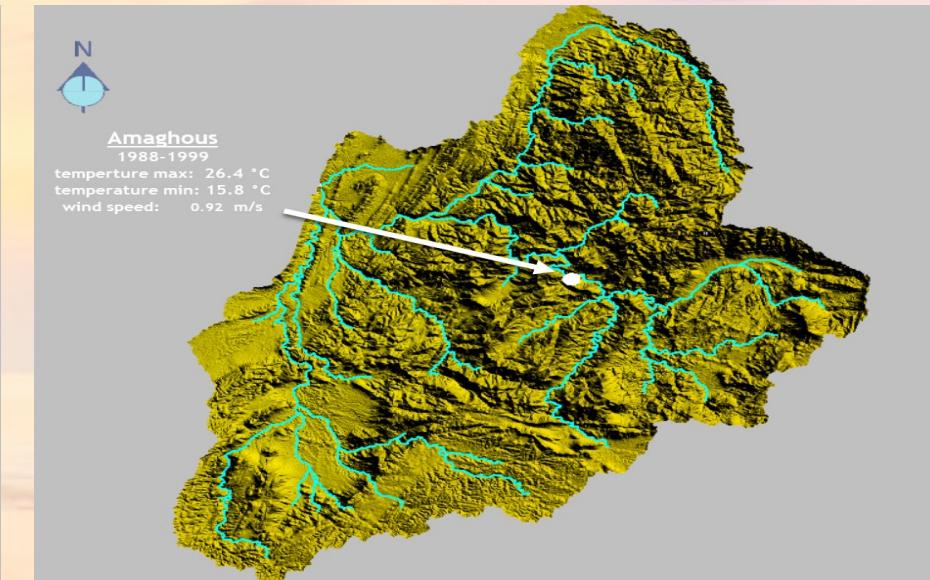
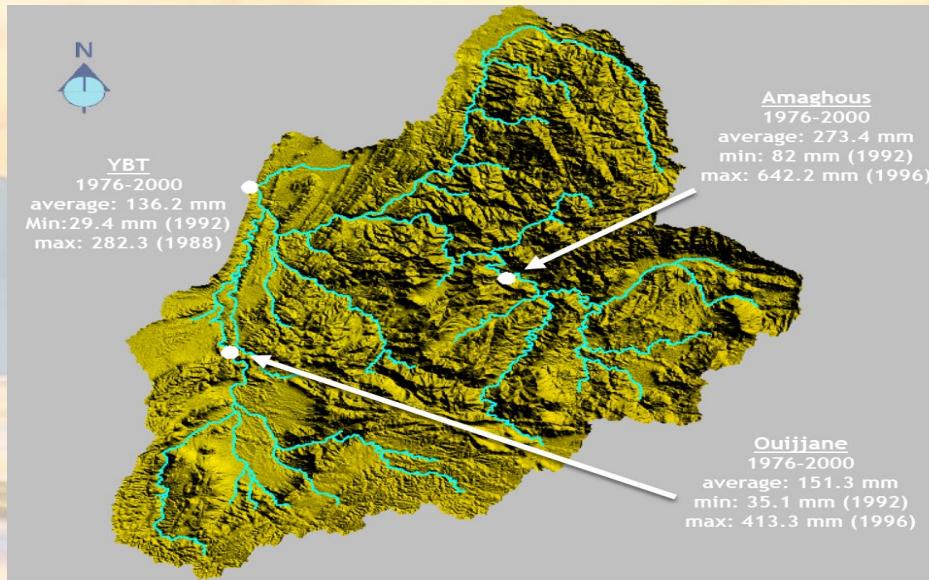


Watershed description

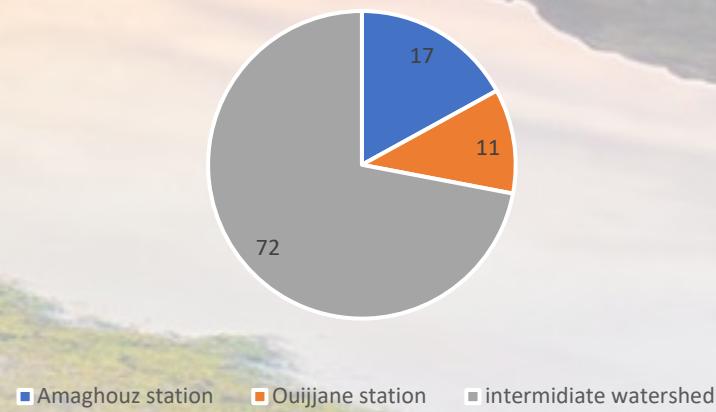


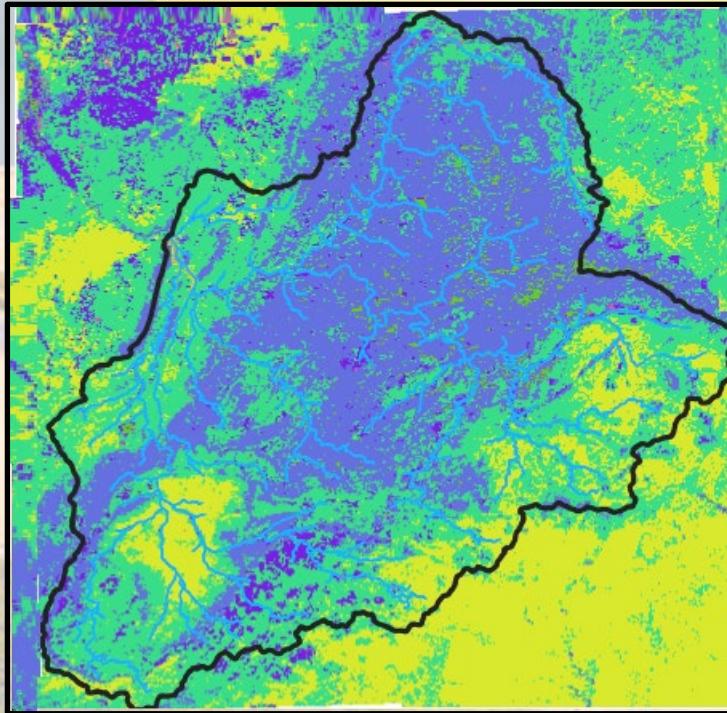


Input data

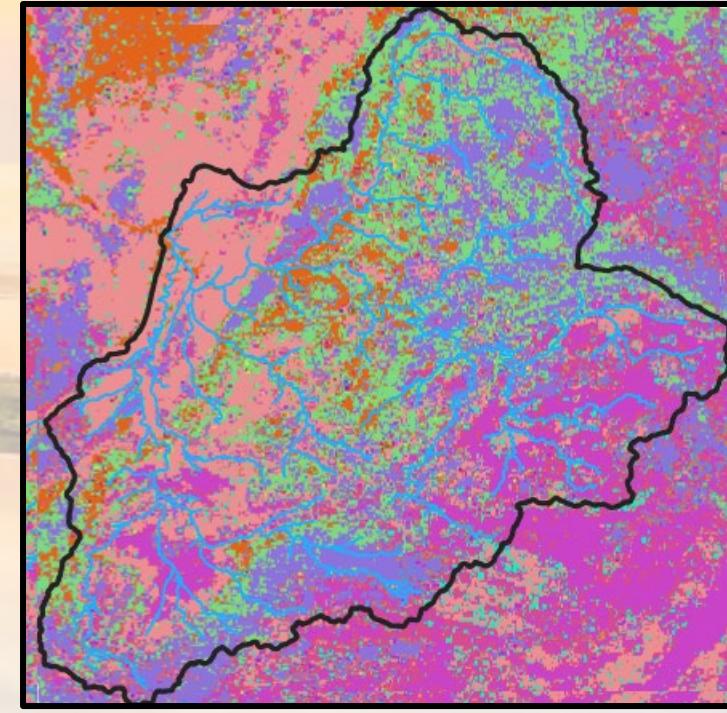


flow distribution in percent





Copernicus global land cover (**100 m**)



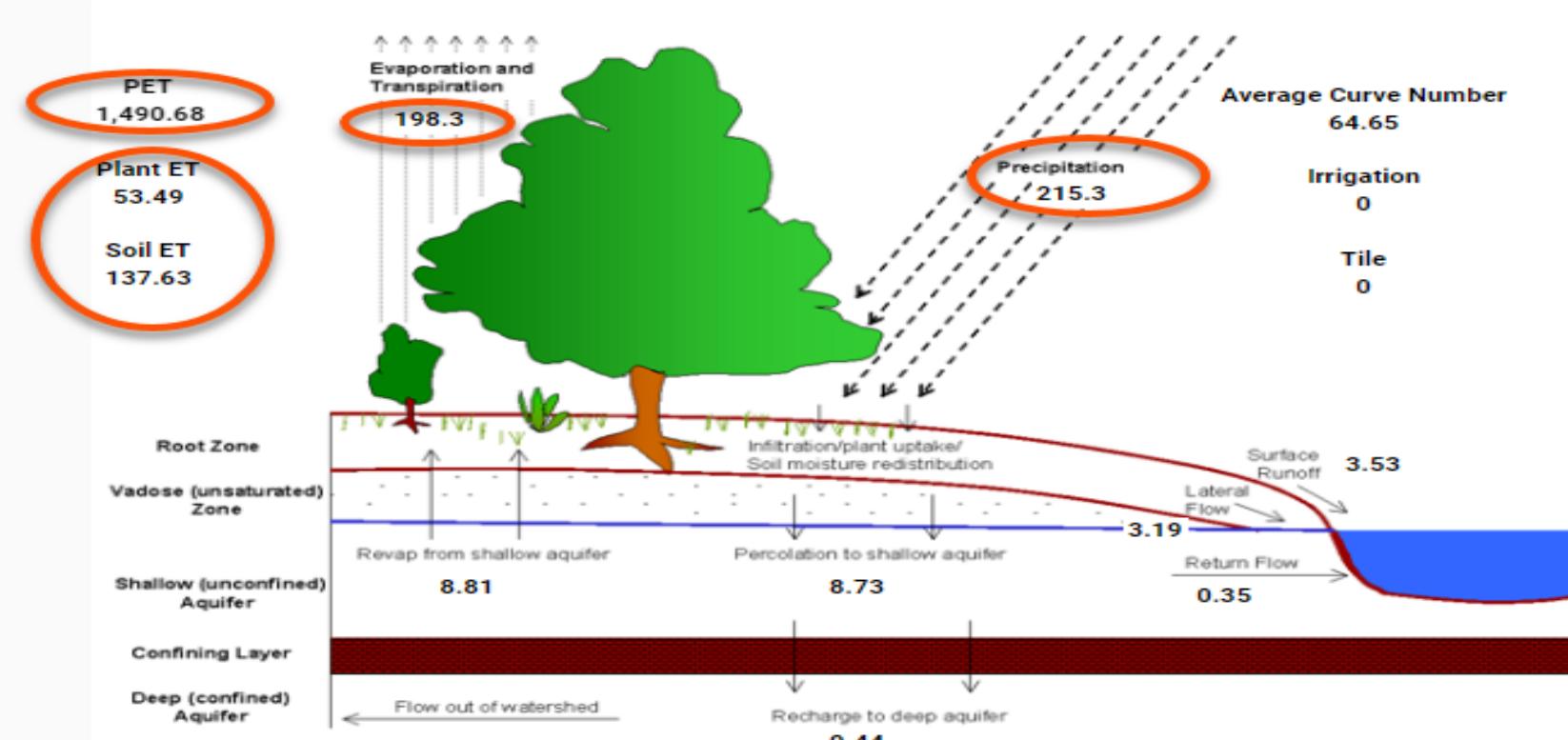
DSOL map: Digital Soil Open Land map (**250 m**)



Model verification

Parameter	Measured values in the watershed
PT	180 mm
PET	1410 mm

Amaghous	Ouigjane	YBT
273.4 mm	151.3	136.2



Soft calibration

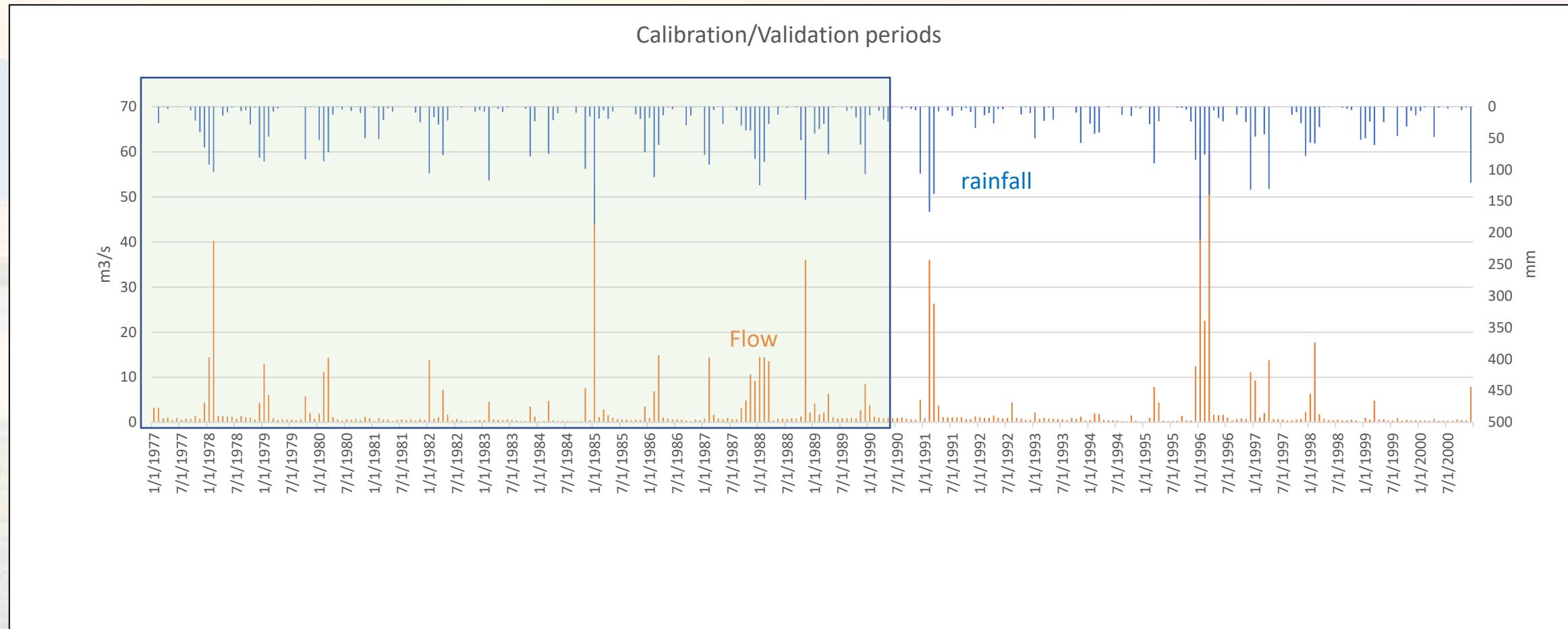
Water yield ratio = $\frac{\text{total water yield}}{\text{precipitation}}$ = **0.119**

BFI = $\frac{\text{base flow}}{\text{total flow}}$ = **0.0437**

BFI: base flow index



Calibration/Validation periods



Sensitivity Analysis

File Home Model Parameters Observations Sensitivity Analysis Calibration Management Model Check Export About test01

Sensitivity Analysis Method: Sobol Use Observations: Yes Observation: Channel 1 Monthly River Flow Seed: 50 Parallel Processes: 3 1600 Samples ▶ Analyse

1st Order Sensitivity	Name	Group	Change Type	
0.2620420056	esco	hru	Replace	null
0.1685973833	cn2	hru	Percent	null
0.1595372117	canmx	hru	Replace	mm/H ₂ O
0.0165098200	awc	sol	Percent	mm ₋ H ₂ O/mm
0.0032599903	revap_min	aqu	Replace	m
0.0017778589	k	sol	Percent	mm/hr
0.0006172111	alpha	aqu	Replace	days
0.0000046663	lat_ttime	hru	Percent	days
0.0000000000	epco	hru	Percent	null
0.0000000000	bf_max	aqu	Replace	mm/H ₂ O
0.0000000000	chk	rte	Percent	mm/hr
-0.0006824624	revap_co	aqu	Replace	null
-0.0025869343	flo_min	aqu	Percent	m
-0.0040548773	perco	hru	Replace	fraction
-0.0067552651	cn3_swf	hru	Replace	null

NSE

epco (Percent) Parameter Space

Export as Image

Status : Finished Analysis
Progress : 100.00 %

Start Generating Parameter Samples Preparing Working Directories Running Parameter Samples Aggregating Results Analysing Sensitivity Finished

ESCO	Soil evaporation compensation factor
CN2	initial's runoff SCS curve number for moisture condition II
CANMX	Maximum canopy storage (mm H ₂ O)
SOL_AWC	available water capacity of the soil layer (mm H ₂ O/mm soil)



Single site calibration

S₄ CALSI: CAlibration by Latin-hypercube Sampling Iterations

Parallel Processes: 4 | Multi-Site Calibration | Objective Function: NSE | Calibration Algorithm Selection: Calibration by Latin-hypercube Sampling Iterations (CALSI)

Iteration 5/5 | Range Refining Threshold: 5 | Range Expansion Factor (%): 4.5 | Global Step: 10

Channel 01 Monthly River Flow | Selection Count: recommended is less than 10% | recommended < 40%

Name	Change Type	Min	Max	Group	Min Adj.	Curr. Best	Max Adj.	Value
cn2	Percent	-20.00000	20.00000	hru	13.505	13.640	19.788	13.640 null
esco	Replace	0.00000	1.00000	hru	0.020	0.996	1.000	0.996 null
canmx	Replace	1.00000	100.00000	hru	5.717	23.817	24.215	23.817 mm/H2O
awc	Percent	-10.00000	10.00000	sol	-4.981	-3.684	-2.547	-3.684 mm_H2O/mm

Best NSE: 0.5192572120205154 | Channel 01 Monthly River Flow | NSE: 0.519

95ppu | Observed | Simulated

Status | Progress | Charts | Dotty Plots

Manual | Automatic

S₄ DREAM: DiffeRential Evolution Adaptive Metropolis

Parallel Processes: 4 | Multi-Site Calibration | Objective Function: NSE | Calibration Algorithm Selection: Differential Evolution Adaptive Metropolis (DREAM)

Max Repetition: 500 | Chain Count: 4 | Crossover Probability: 3.0 | Perturbation Threshold: 0.00001 | Gamma: 0.1 | Delta: 0.1

Channel 01 Monthly River Flow

Name	Change Type	Min	Max	Group	Curr. Best	Value
cn2	Percent	-20.00000	20.00000	hru	9.318	9.318 null
esco	Replace	0.00000	1.00000	hru	0.000	0.000 null
canmx	Replace	1.00000	100.00000	hru	88.451	88.451 mm/H2O
awc	Percent	-10.00000	10.00000	sol	5.742	5.742 mm_H2O/mm

Best NSE: 0.683477619103829 | Channel 01 Monthly River Flow | NSE: 0.519

95ppu | Observed | Simulated

Status | Progress | Charts | Dotty Plots

Manual | Automatic

S₄ DDS: Dynamically Dimensioned Search

Parallel Processes: 4 | Multi-Site Calibration | Objective Function: PBIAS | Calibration Algorithm Selection: Dynamically Dimensioned Search (DDS)

Observation: Channel 01 Monthly River Flow | Max Iterations: 50 | Global Search Batch: 10 | Initial Solution Probability: 1 | Final Solution Probability: 0.1

Running Iteration: 50 of 50 | Calibrate

Name	Change Type	Min	Max	Group	Curr. Best	Value
cn2	Percent	-20.00000	20.00000	hru	10.698	10.698 null
esco	Replace	0.00000	1.00000	hru	0.000	0.000 null
canmx	Replace	1.00000	100.00000	hru	84.417	84.417 mm/H2O
awc	Percent	-10.00000	10.00000	sol	0.936	0.936 mm_H2O/mm

Best Abs. PBIAS: 19.962077766439076 | Channel 01 Monthly River Flow | PBIAS: 0.010

95ppu | Observed | Simulated

Status | Progress | Charts | Dotty Plots

Manual | Automatic

method	NSE
CALSI	0.614
DREAM	0.669
DDS	0.686



Multisite-one step- calibration

Home Run Model Parameters Observations Sensitivity Analysis Calibration Management Model Check Export About

Add by Sets No Yes Select Predefined Parameter Set Group: Common Used HRU Parameters Attach Objects All Specific Add: Map Selection Selected Objects on Map Show Map No Yes

Currently Adding Parameter Names: cn2, esco, epco, canmx, perco, lat_ltime, cn3_swf

Absolute Range : [Multiple Values] Change Type : [Multiple Values] Current Value : [Multiple Values] Parameter Group : [Multiple Values] Applies to : All

Name	Change Type	Minimum	Maximum
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000

Common Used HRU Parameters

cn2 (percent; min: -20; max: 20); esco (replace; min: 0; max: 1); epco (percent; min: 0; max: 1); canmx (replace; min: 0; max: 1); lat_ltime (percent; min: -10; max: 20); cn3_swf (replace; min: 0; max: 1)

To change this list, you can modify the file at

Home Run Model Parameters Observations Sensitivity Analysis Calibration Management Model Check Export About

Add by Sets No Yes Select Predefined Parameter Set Group: Common Used HRU Parameters Attach Objects All Specific Add: Map Selection Selected Objects on Map Show Map No Yes

8 added parameters

Name	Change Type	Minimum	Maximum
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000

Home Run Model Parameters Observations Sensitivity Analysis Calibration Management Model Check Export About

Add by Sets No Yes Select Predefined Parameter Set Group: Common Used HRU Parameters Attach Objects All Specific Add: Map Selection Selected Objects on Map Show Map No Yes

Selected Parameter: awc Absolute Range : Absolute Minimum: 0.01 - Absolute Maximum: 1 Change Type : Percent Current Value : 0 Parameter Group : sol Applies to : 560-565 431-434 566-569 570-572 626-629 630-633 573-576 577-578

Name	Change Type	Minimum	Maximum
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000
cn2	Percent	-20.00000	20.00000
esco	Replace	0.00000	1.00000
canmx	Replace	1.00000	100.00000
awc	Percent	-10.00000	10.00000

AWC
AWC(layer #) Available water capacity of the soil layer (mm H2O/mm soil).
The plant available water is calculated by subtracting the fraction of water present at permanent wilting point from that present at field capacity. Available water capacity is estimated by determining the amount of water released between in situ field capacity (the

Home Run Model Parameters Observations Sensitivity Analysis Calibration Management Model Check Export About

Parallel Processes: 4 Multi-Site Calibration Objective Function: NSE Calibration Algorithm Selection: Dynamically Dimensioned Search (DDS)

Observation	Max Iterations	Global Search Batch	Initial Solution Probability	Final Solution Probability
Channel 01 Monthly River Flow	50	10	1	0.1
Channel 01 Monthly River Flow	Part of Max Iterations	Initial Perturbation Probability	Final Perturbation Probability	

Running Iteration: 50 of 50 Calibrate

Name	Change Type	Min	Max	Group	Curr. Best	Value	
cn2	Percent	-20.00000	20.00000	hru	7.370	7.370	null
esco	Replace	0.00000	1.00000	hru	0.020	0.020	null
canmx	Replace	1.00000	100.00000	hru	71.666	71.666	mm/H2O
awc	Percent	-10.00000	10.00000	sol	-1.599	-1.599	mm_H2O/mm
cn2	Percent	-20.00000	20.00000	hru	7.556	7.556	null
esco	Replace	0.00000	1.00000	hru	0.000	0.000	null
canmx	Replace	1.00000	100.00000	hru	86.336	86.336	mm/H2O
awc	Percent	-10.00000	10.00000	sol	-9.153	-9.153	mm_H2O/mm
cn2	Percent	-20.00000	20.00000	hru	20.000	20.000	null
esco	Replace	0.00000	1.00000	hru	0.000	0.000	null

Status Progress Charts Dotty Plots

Best Weighted Objective FX: 0.6038986824308585 NSE Weight

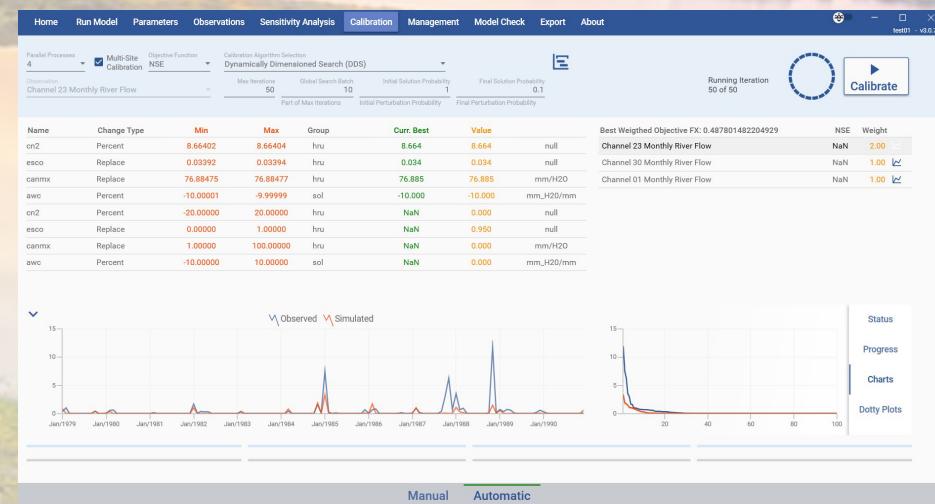
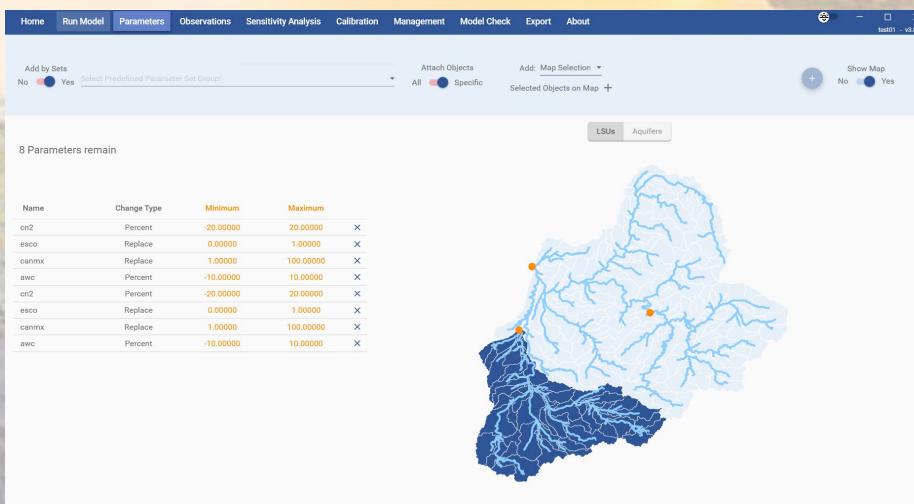
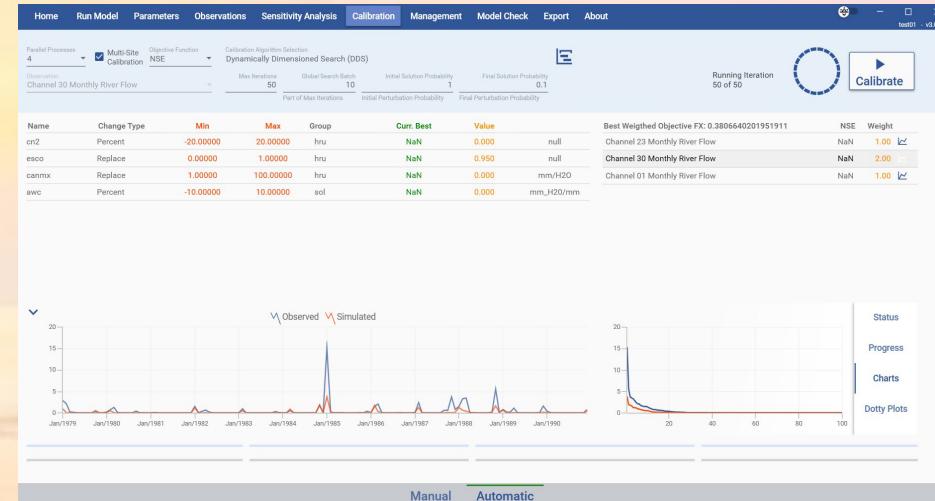
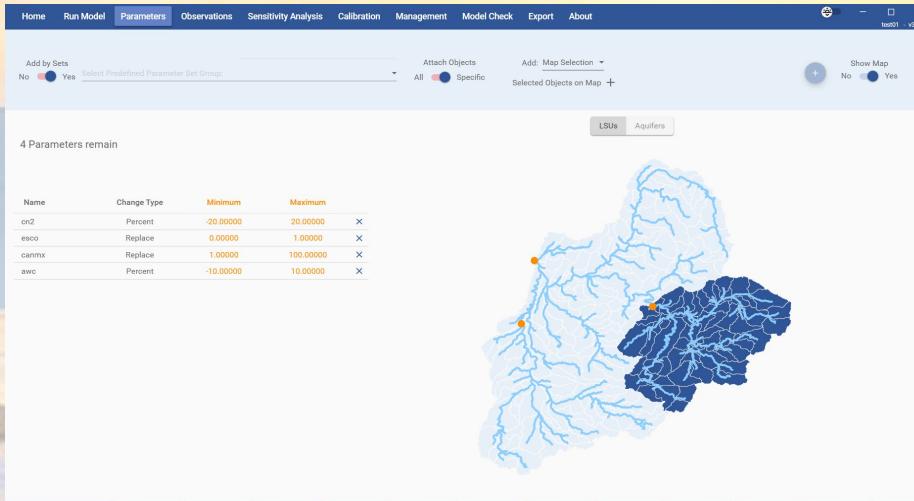
Channel 01 Monthly River Flow 0.519 2.00 ↗
Channel 30 Monthly River Flow NaN 1.00 ↗
Channel 23 Monthly River Flow NaN 1.00 ↗

Start Preparing Working Directories Running Initial Samples Searching Solutions Cleaning Up Running Proposed Solution Finished

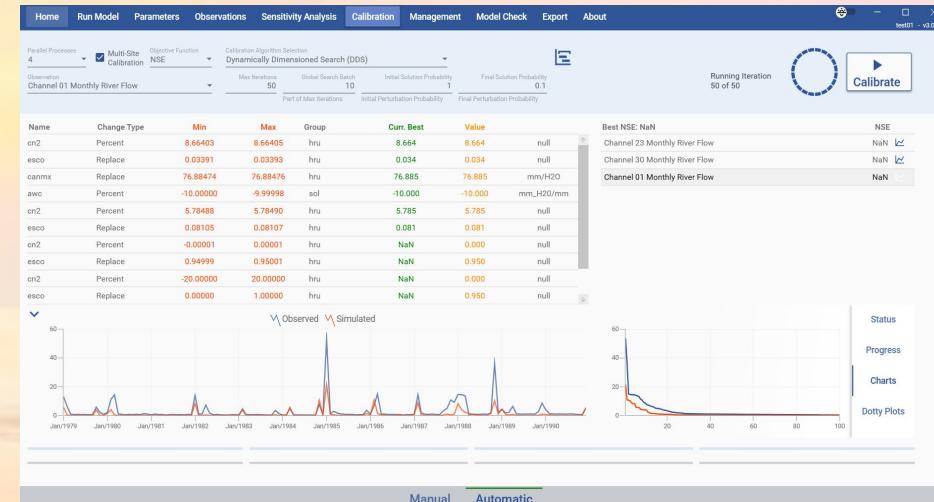
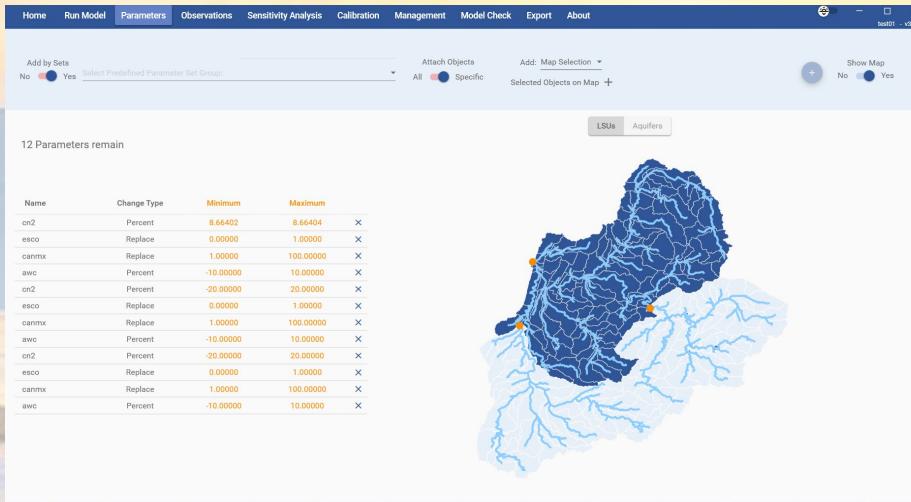
Manual Automatic



Multisite-Multistep- calibration



Multisite-Multistep- calibration



Results analysis

	Amaghous		Ouijjane		YBT	
calibration	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
single-site	0.66	-6.93	0.41	8.77	0.52	36.07
multisite-one-step	0.65	2.80	0.39	21.21	0.69	18.15
multisite-multi-step	0.66	-2.02	0.40	15.80	0.69	2.16

	Amaghous		Ouijjane		YBT	
validation	NSE	PBIAS	NSE	PBIAS	NSE	PBIAS
single-site	0.49	23.17	-0.06	-34.74	0.52	36.07
multisite-one-step	0.47	26.96	-0.10	-13.53	0.53	33.83
multisite-multi-step	0.50	17.49	0.01	-16.72	0.55	23.71

Regarding calibration, we observe a clear improvement in the Nash-Sutcliffe Efficiency (NSE) when shifting from single-site to multi-site calibration at the YBT station. For validation, a slight improvement is noted at the YBT station, which is not the case for the Amaghous and Ouijjane stations. This limited improvement at YBT station can be explained by: (1) the low flow contribution of Amaghous and Ouijjane stations to the total watershed discharge (28%), and (2) the poor model performance at Ouijjane station.



Conclusion

- The results indicate that SWAT+Toolbox significantly enhances hydrological model performance at the outlet of a multi-station watershed systems;
- Calibration efficiency showed substantial gains ($\Delta\text{NSE} = +0.17$), while validation exhibited incremental improvements ($\Delta\text{NSE} = +0.03$);
- These outcomes are contingent upon: (i) the relative discharge contributions of secondary stations, and (ii) the calibration accuracy achieved at intermediate monitoring points.

