Uncertainty analysis of nonpoint source pollution modeling:

An important implication for Soil and Water Assessment Tool

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Contents

Background

Soil & Water Assessment Tool | SWAT

The SWAT model accounts for most of the key processes of NPS pollution at basin scale.




Uncertainty in NPS modeling

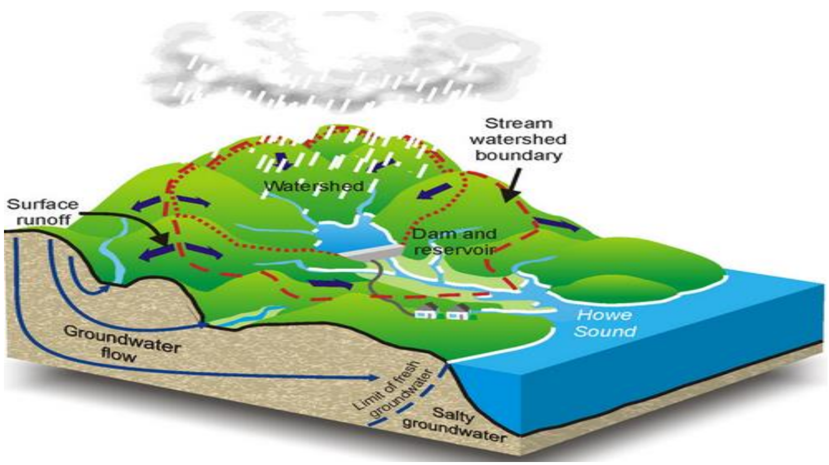
Meteorological processes

Complexity of watersheds

Ecological processes

Natural randomness

Insufficient knowledge



Sources of uncertainty

- **Input data uncertainty**

  (1)Changes in natural conditions

  (2)Limitations of measurement

  (3)Lack of data

- **Structural uncertainty**

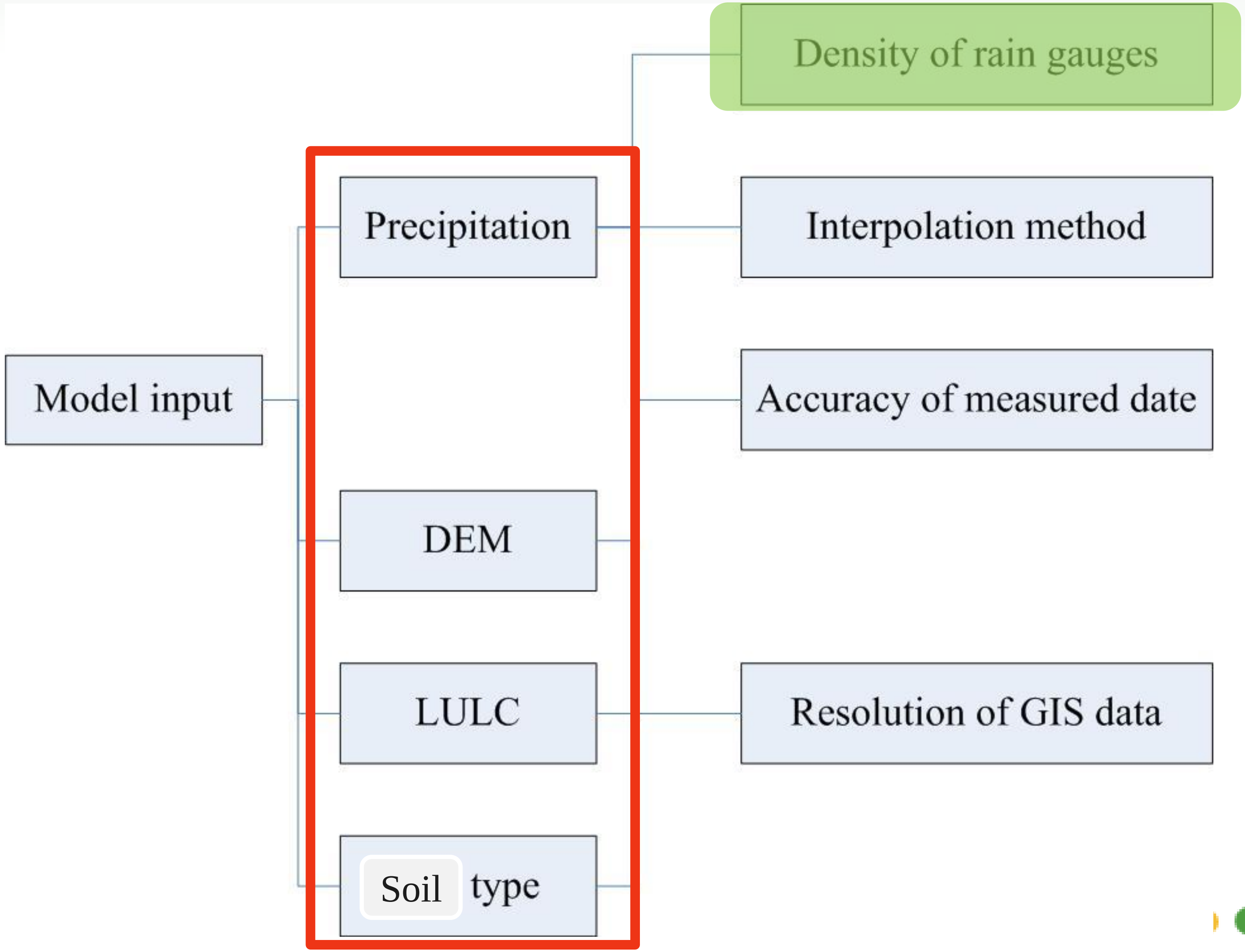
  (1) The assumptions and simplification in the model

  (2) Application of the model under conditions that are not quite consistent with the model design

- **Parameter uncertainty**

  Parameters attained through empirical estimation and optimization of observed data cannot ensure the precision and reliability of the predicted results

Model input


Density of rain gauges
Precipitation
Interpolation method
Model input
Accuracy of measured date
DEM
LULC
Resolution of GIS data
Soil type

Density of rain gauges

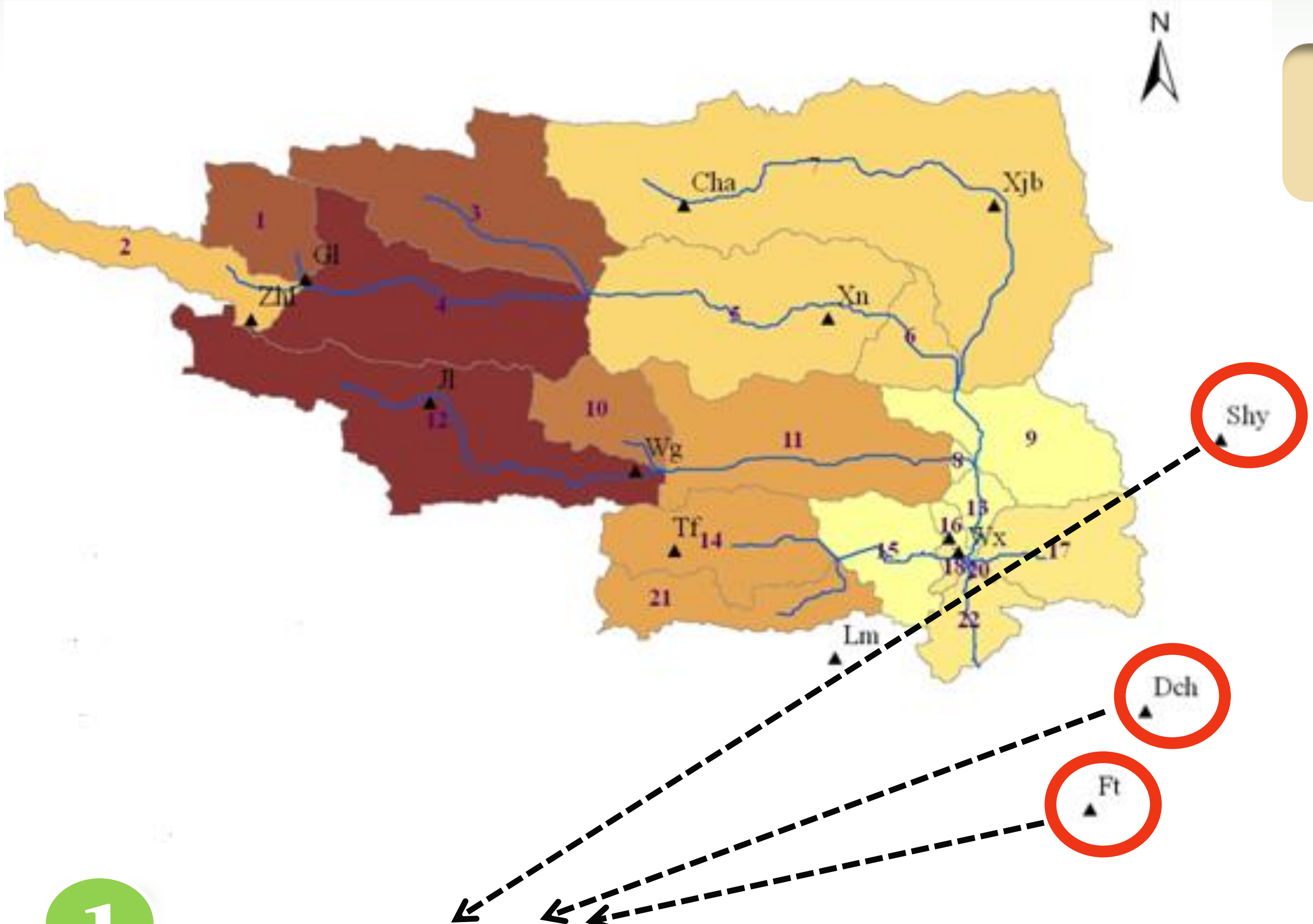
Intensively distributed rain gauges are usually recommended

Single- and multi-gauge calibrations exhibited no apparent differences

50ha→one well-located station
20km→the threshold distance between stations

Watershed characteristics

Interpolation method



Centroid method

Elevation

1 Those rain gauges far from the centroids will be neglected.

2 Variation of elevation is not considered.

Interpolation method

Selection of an appropriate interpolator

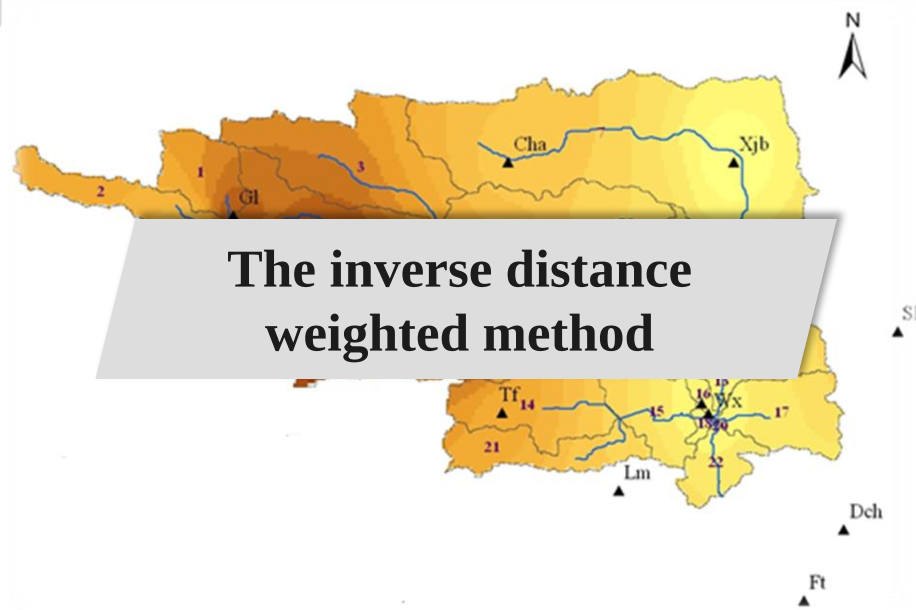
1

Global interpolators with more precise description of rainfall spatial variability for large watersheds

2

The centroid method can provide adequate accuracy in small watersheds

The Kriging method



The inverse distance weighted method

Interpolation method

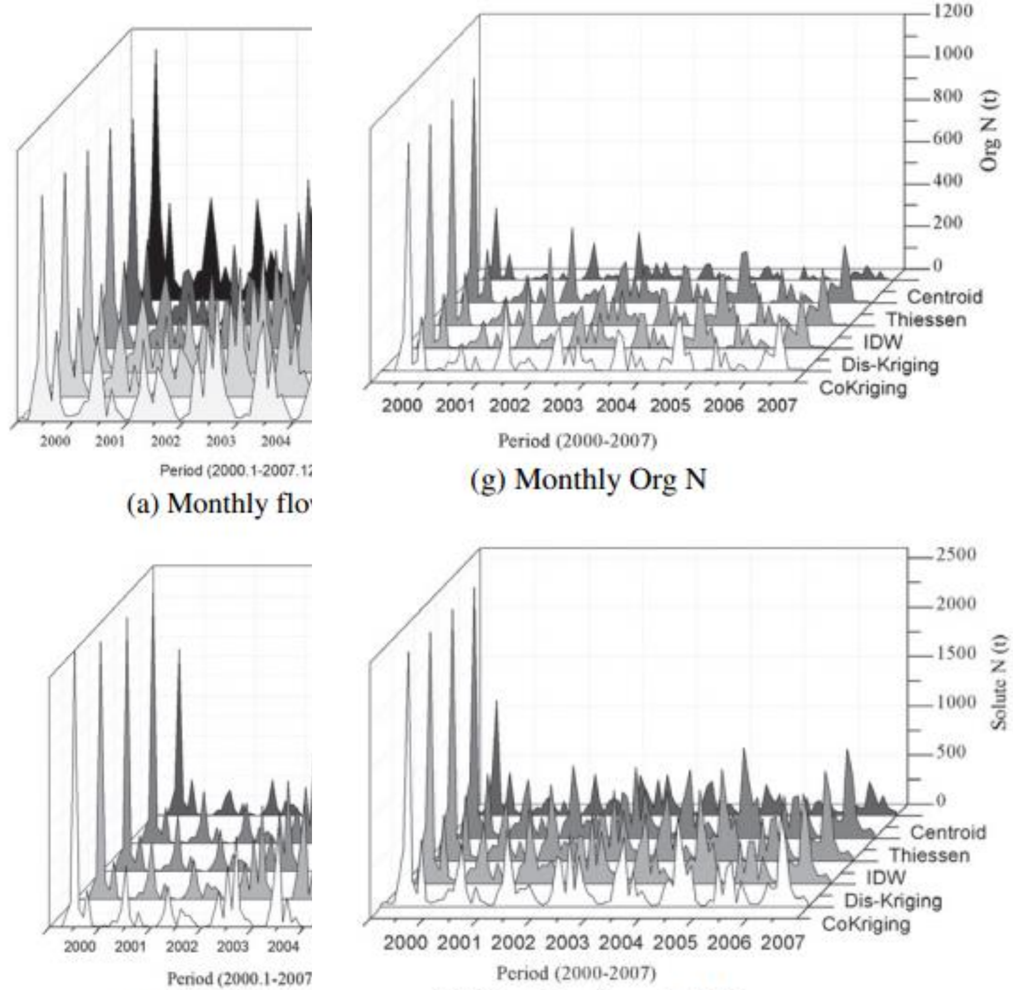
Input uncertainty

↓

Hydrologic modeling

↓

NPS simulation



(a) Monthly flo

(g) Monthly Org N

(c) Monthly sedi

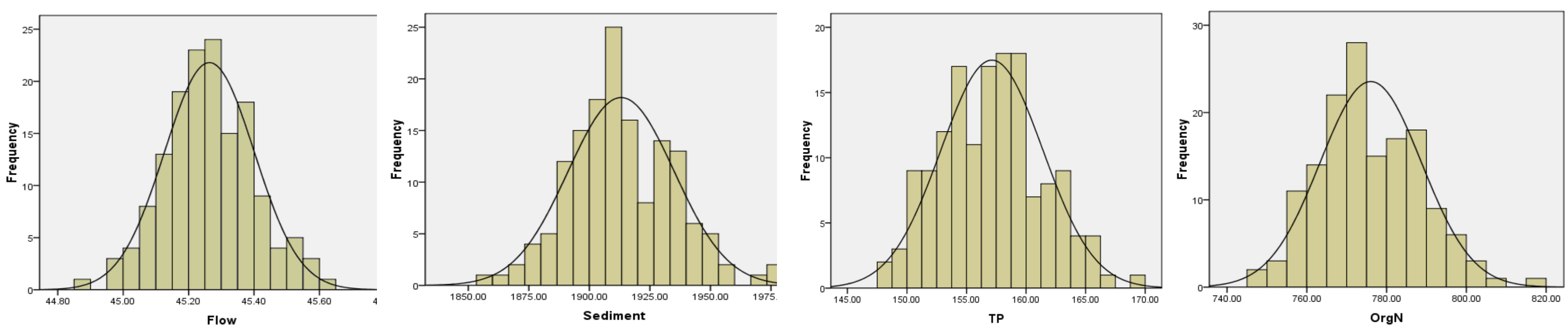
(i) Monthly dissovled N

Measurement errors

Rain measurement involves complicated processes

Complexity of the environment	Constrains of tools	Lack of calibration

Measurement errors



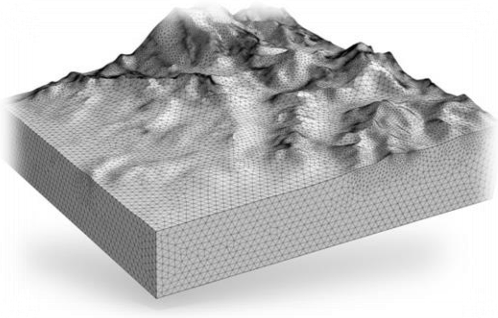
GIS data

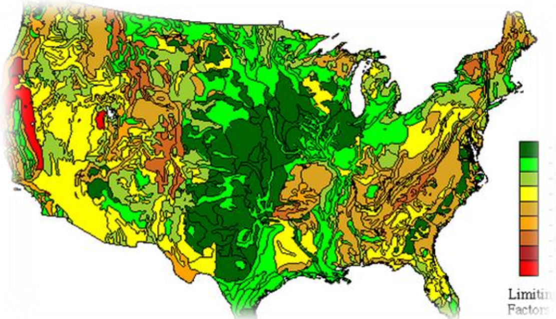
Land characteristics

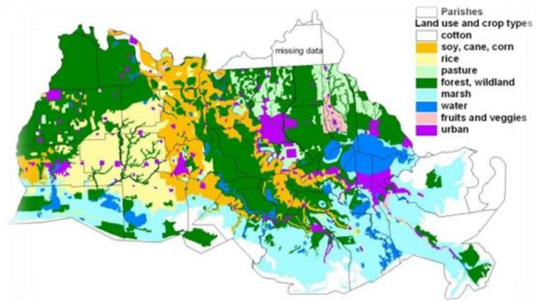
Digital elevation model (DEM)

Soil type

Land use-land cover (LULC)

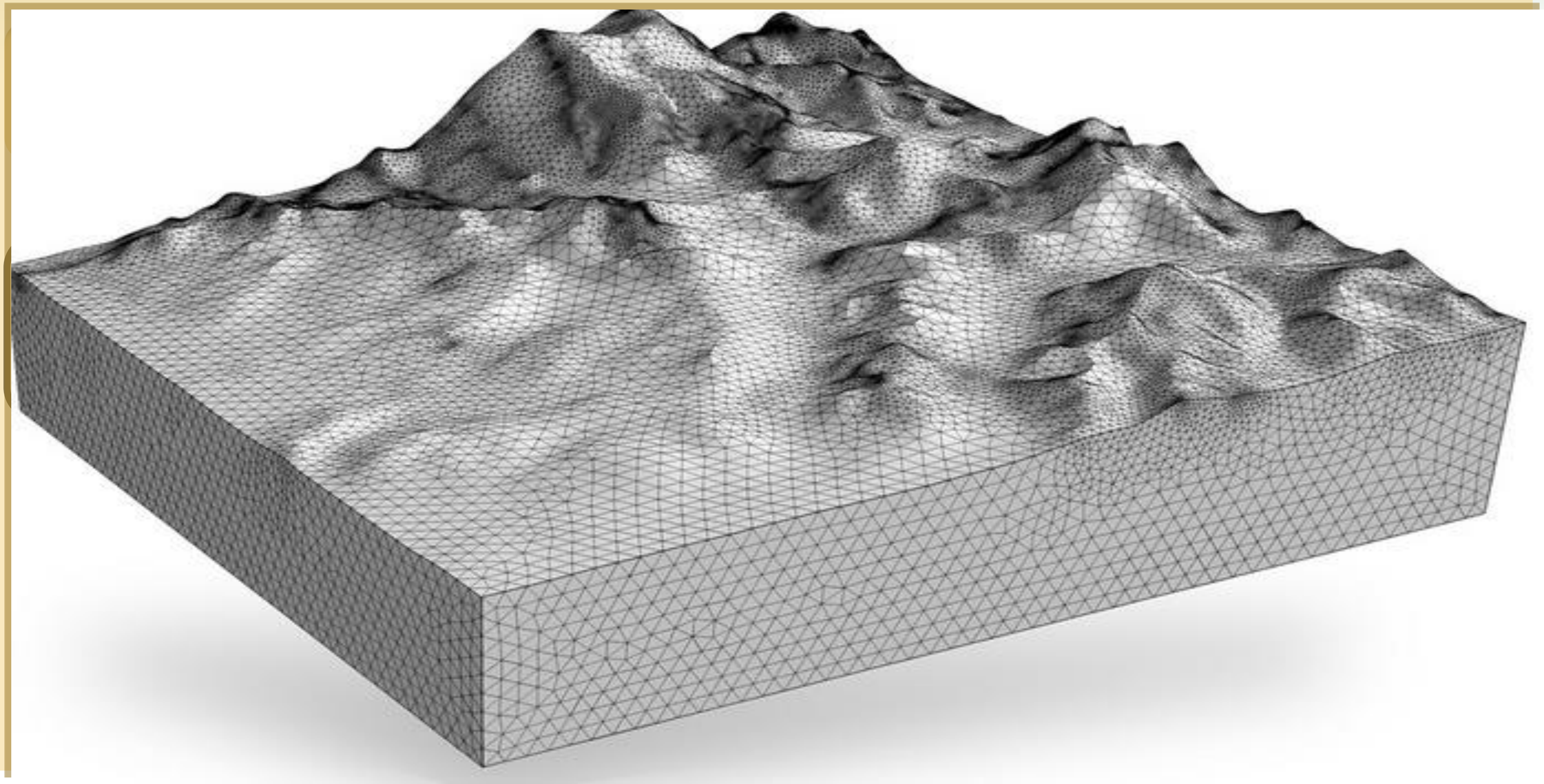






Geographic Information System (GIS)

GIS data



DEM was identified as a determining role in the selection of the appropriate combination of resolutions.

Model parameter

Name	Definition	Process
ALPHA_BF	α_{gw}: Baseflow recession constan	
BIOMIX	Biological mixing efficiency	
CANMX	can_{mx}: Maximum canopy storag	
CN2	CN_p: SCS moisture condition II c for pervious areas	
ESCO	*esco*: Soil evaporation compensation coefficient	Evaporation
SLOPE	*slp*: Average slope steepness (m/m)	Geomorphology
SOL_AWC	AWC_{ly}: Available water capacity of the soil layer	Soil
S	nductivity of first	Soil
S	hor	
S	ntrat	
S	anic	
S	nic phosphorus in soil layer (mg/kg or ppm)	Soil
SOL_Z	*z*: Depth from soil surface to bottom of layer (mm)	Soil
SPCON	c_{sp}: Linear parameter for calculating the chan l sediment routing	Channel
SPEXP	*spexp*: Exponent parameter for calculating the channel sediment routing	Channel
USLE_C	$C_{USLE,mn}$: Minimum value for the cover and management factor for land cover	Erosion
USLE_P	P_{USLE}: USLE support practice factor	Erosion

✓Large number
✓Model structure

Conceptual group

Calibration

Physical group

✓Measured
✓Estimated

UNCERTAINTY

Model parameter

Uncertainty of model outputs

Only a few parameters significantly affected the uncertainty of the outputs

Parameter	Runoff		Sediment		Organic N		Nitrate		TP	
	CV	Contribution	CV	Contribution	CV	Contribution	CV	Contribution	CV	Contribution
CN2	1.428	19.378	11.409	11.498	5.593	5.417	8.711	30.353	25.481	16.099
USLE_P	0.000	0.000	25.865	26.067	32.042	31.029	0.077	0.268	30.581	19.321
ESCO	4.009	54.404	12.220	12.315	2.446	2.369	6.023	20.987	32.648	20.627
SOL_Z	0.045	0.611	1.118	1.127	1.204	1.166	3.239	11.286	1.693	1.070
SOL_AWC	1.877	25.472	2.852	2.874	2.851	2.761	1.018	3.547	1.753	1.108
SPCON	0.000	0.000	23.665	23.849	0.000	0.000	0.000	0.000	0.000	0.000
SPEXP	0.000	0.000	21.574	21.742	0.000	0.000	0.000	0.000	0.000	0.000
SOL_ORGN	0.003	0.041	0.044	0.044	58.960	57.097	9.617	33.510	3.919	2.476
SOL_ORGP	0.007	0.095	0.480	0.484	0.142	0.137	0.012	0.042	50.788	32.087
SOL_LABP	0.000	0.000	0.000	0.000	0.025	0.024	0.002	0.007	11.417	7.213

Model parameter

Parameter range

Small adjustments may derive significant uncertainty especially near the upper and lower limits of parameter range.

It is preferable to obtain a confidence range of each parameter within which models can be well-calibrated.

Model parameter

Parameter	Flow			Sediment		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
r__CN2.mgt	0.0203	−0.1027	−0.0085	0.1363	0.0217	0.0643
v__ALPHA}BF.gw	0.4048	0.0087	0.4896	0.3411	0.0191	0.0324
v__GW_DELAY.gw	36.0475	24.2712	39.5298	35.3257	13.4576	13.2559
v__CH_N2.rte	0.4176	0.3761	0.2179	0.2947	0.2024	0.2178
v__CH_K2.rte	32.1141	89.7282	16.4653	10.1802	38.9954	18.0410
v__ALPHA_BNK.rte	0.3616	0.4323	0.3980	0.4089	0.9418	0.4505
v[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]196
r[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]082
a[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]136
v[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]027
v[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]640
v[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]153
v[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]050
v__REVAPMN.gw	137.0420	129.2090	434.2130	390.4860	71.2840	34.4314
v__USLE_P.mgt	0.5067	0.2462	0.4990	0.1085	0.6628	0.6285
r__SLSUBBSN.hru	0.0402	−0.0759	−0.0946	−0.0771	0.0011	0.0481
v__CH_Cov.rte				0.8376	0.3398	0.1628
v__CH_EROD.rte				0.8894	0.6481	0.5564
v__SPCON.bsn				0.0326	0.0391	0.0358
v__SPEXP.bsn				1.4285	1.2595	1.3446
E_{NS}	0.6915	0.6917	0.6919	0.6997	0.6999	0.7000

Model users should check if any information related to the watershed characteristics and its underlying hydrologic Processes.

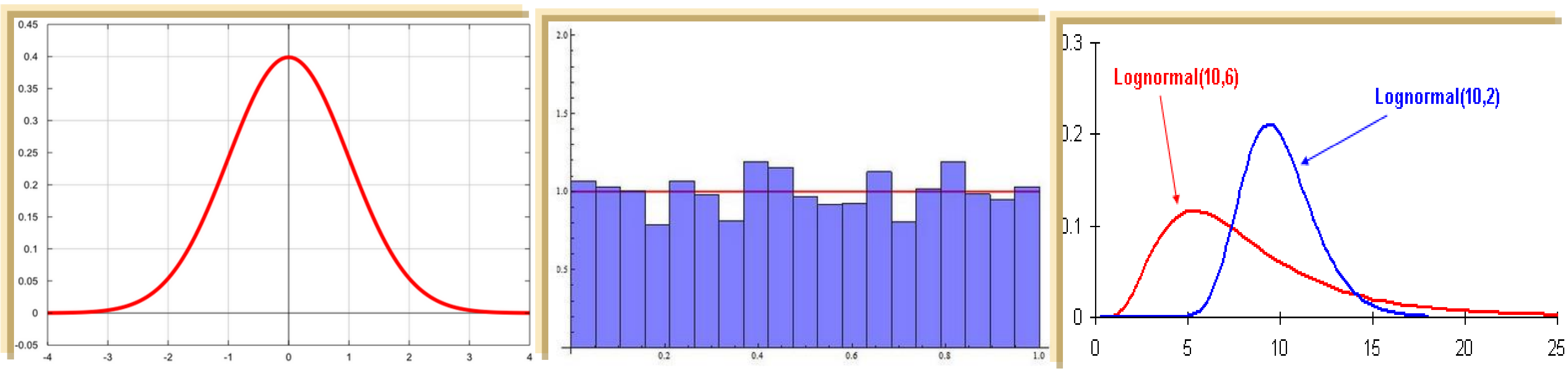
Equifinality

Different parameter groups may introduce the similar results

Model parameter

Probability distribution function (PDF)

Determining the PDF of each parameter is a critical step when uncertainty analysis is conducted.

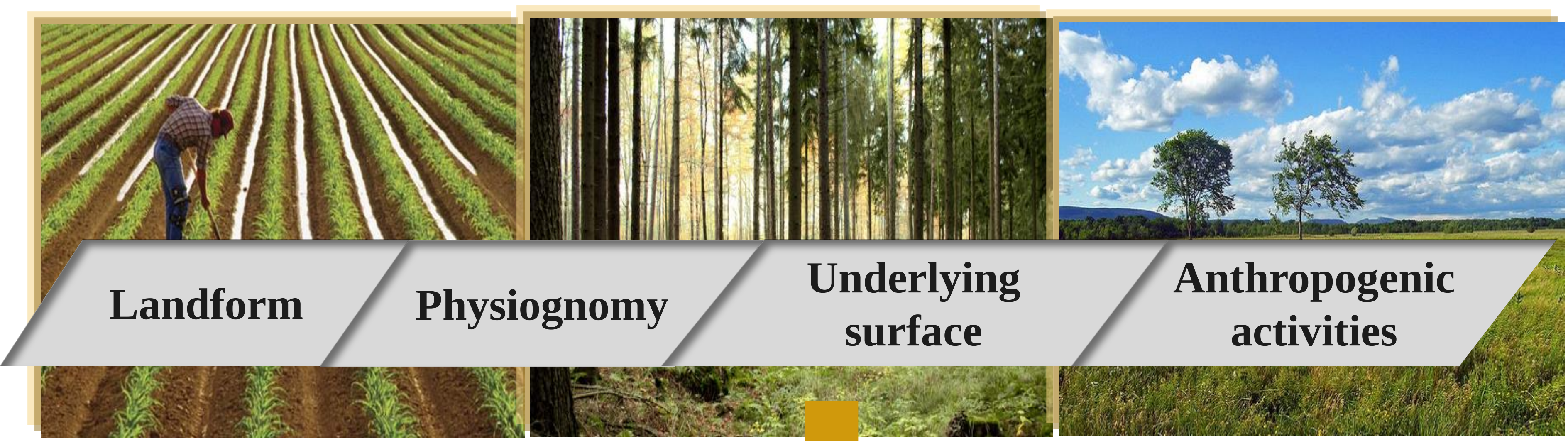


- ✓ **Sufficient number of simulation is required to satisfy the convergence precision.**
- ✓ **A proper sampling method is recommended.**

Model parameter

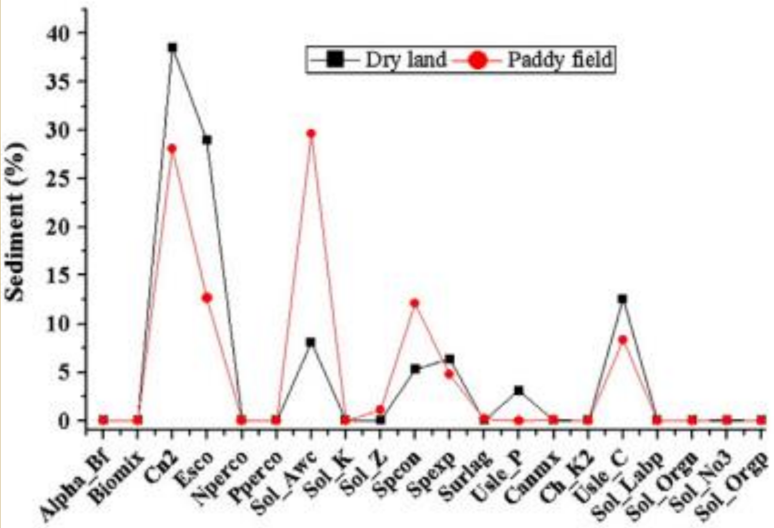
Targeted management

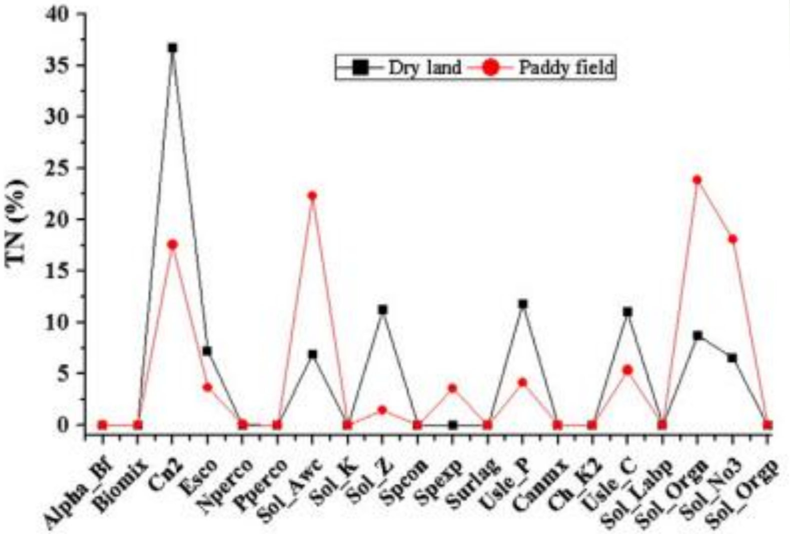
Uncertainty of NPS outputs displayed apparent variation among different land use types.

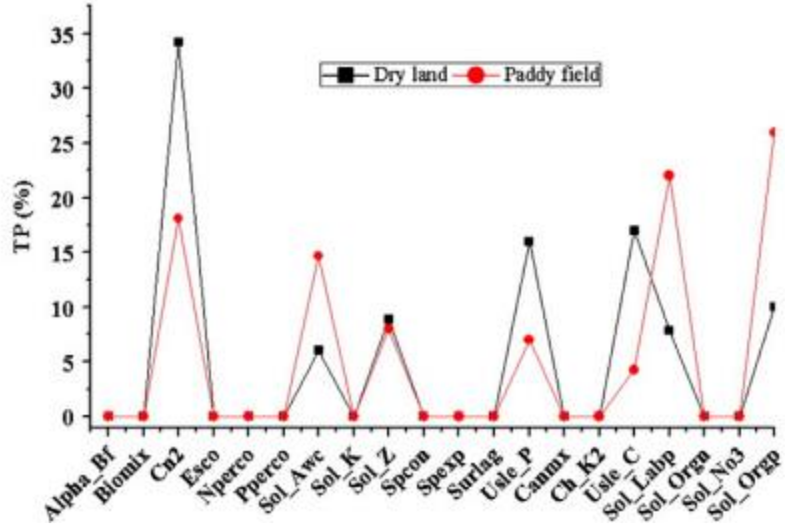


UNCERTAINTY

Model parameter







Model parameter

Dry land

- Conservation practices
- Proper land cover

Paddy

- Nutrient management

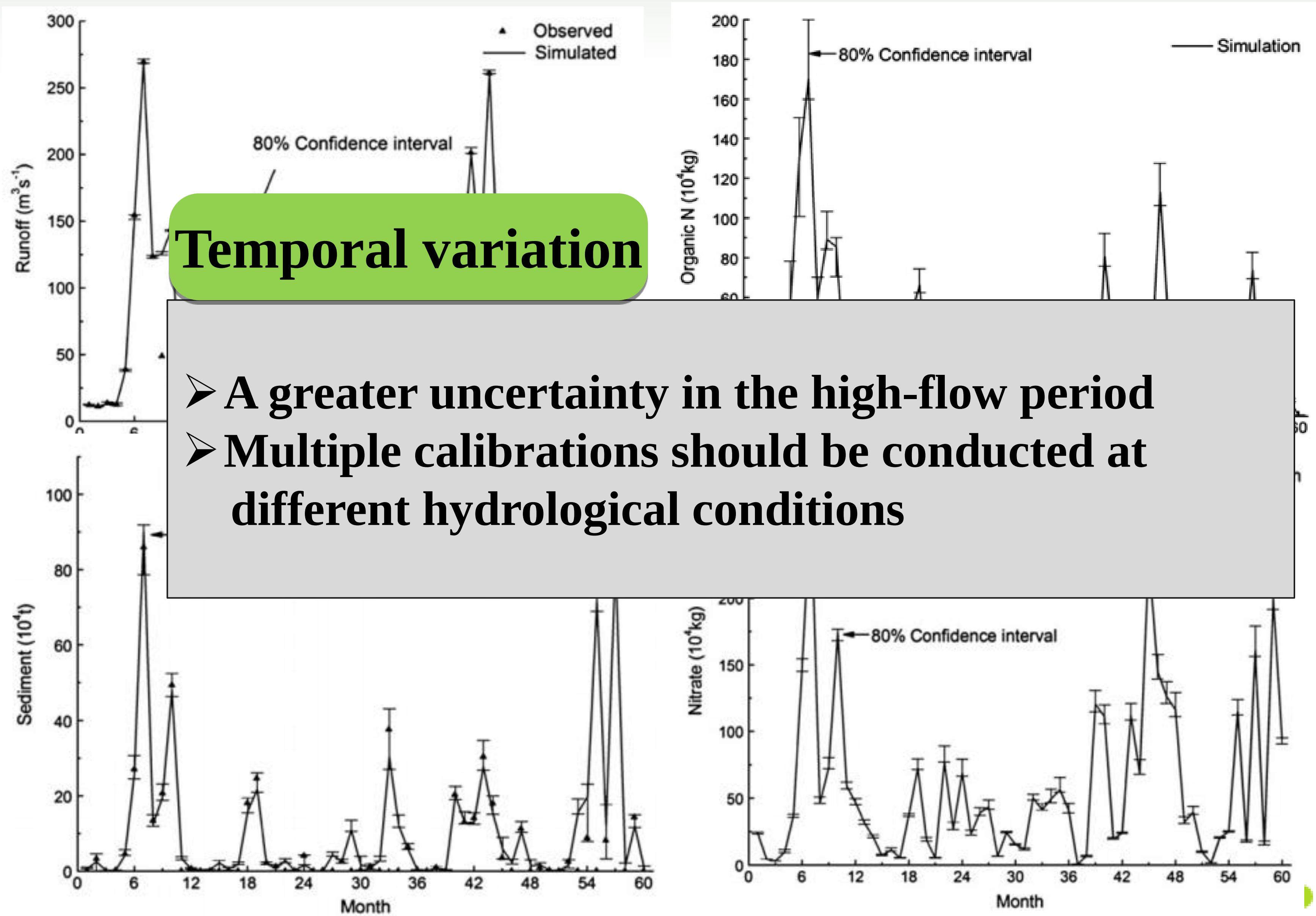
Yellow earth

- Grazing practices

Purple soil

- Vegetation density

Model parameter

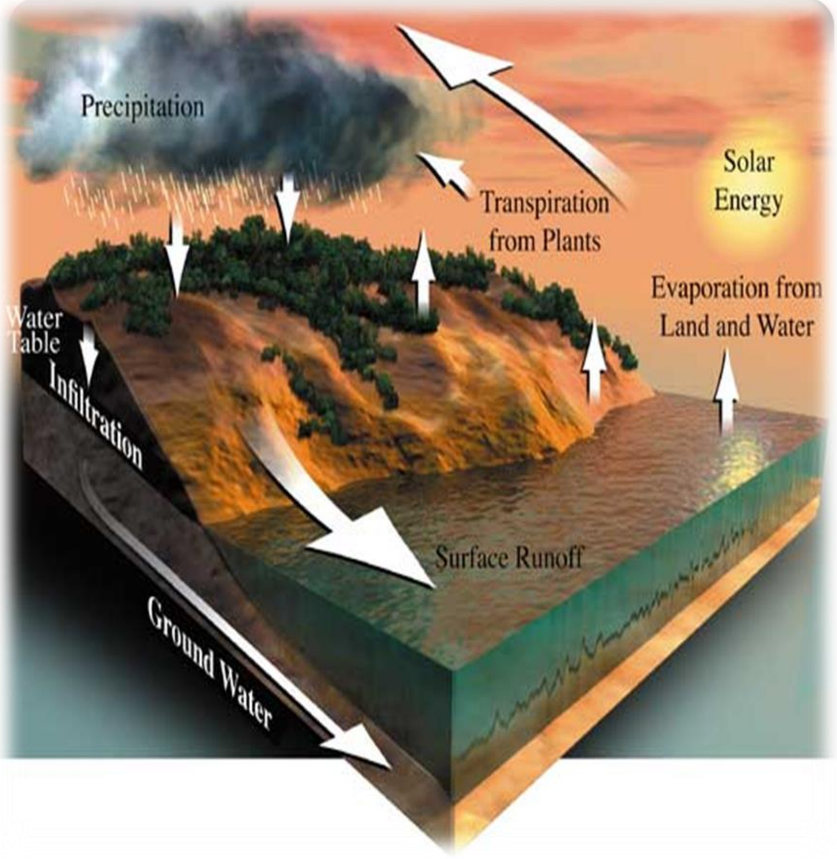


Temporal variation

- ➢ **A greater uncertainty in the high-flow period**
- ➢ **Multiple calibrations should be conducted at different hydrological conditions**

Model structure

Inaccurate description of watershed system



Soil & Water Assessment Tool | SWAT

Evapotranspiration

Flow routing

Snow accumulation and melt

Ensemble prediction

Methods of uncertainty analysis

Method	Critical considerations		
	System nonlinearity	Correlation of elements	Assumption of PDFs
OTA			√
SUFI-2	√	√	√
FOEA			
MC	√	√	√
GLUE	√	√	√
Bayesian inference	√	√	
Bootstrap			

Methods of uncertainty analysis

One factor at a time (OTA)

✓Easy to program; low computational requirements.

Sequential Uncertainty Fitting, ver. 2 (SUFI-2)

✓Semi-automated; all sources of uncertainty are accounted for.

First-order error analysis (FOEA)

✓Simple but with much hypothesis adopted.

Monte Carlo

✓Flexible; abundant simulation times are required to achieve reliable prediction.

Methods of uncertainty analysis

Generalized Likelihood Uncertainty Estimation (GLUE)

✓Huge sampling quantity; all sources of uncertainty are accounted for.

Bayesian inference

✓Strong dependence on the formulation of likelihood function.

Bootstrap

✓High dependency on original samples; wide scope of application.

Implication

SWAT | Soil & Water Assessment Tool

EPIC & APEX Models

HSPF Model

AGNPS & AnnAGNPS models

Other H/NPS models sharing much similarity

Implication

- **Input and structural uncertainty should be paid more emphasis.**

- **The interaction effect between these three sources of uncertainty deserves more attention.**

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