Integration of TUSLE in SWAT model for sediment prediction at a small mountainous catchment, Chenyulan watershed, Taiwan

Presenter : Chih-Mei Lu

Authors : Chih-Mei Lu, Li-Chi Chiang*

Department of Civil and Disaster Prevention Engineering, National United University, Miaoli, Taiwan.

Corresponding author : L. Chiang (lchiang@nuu.edu.tw)

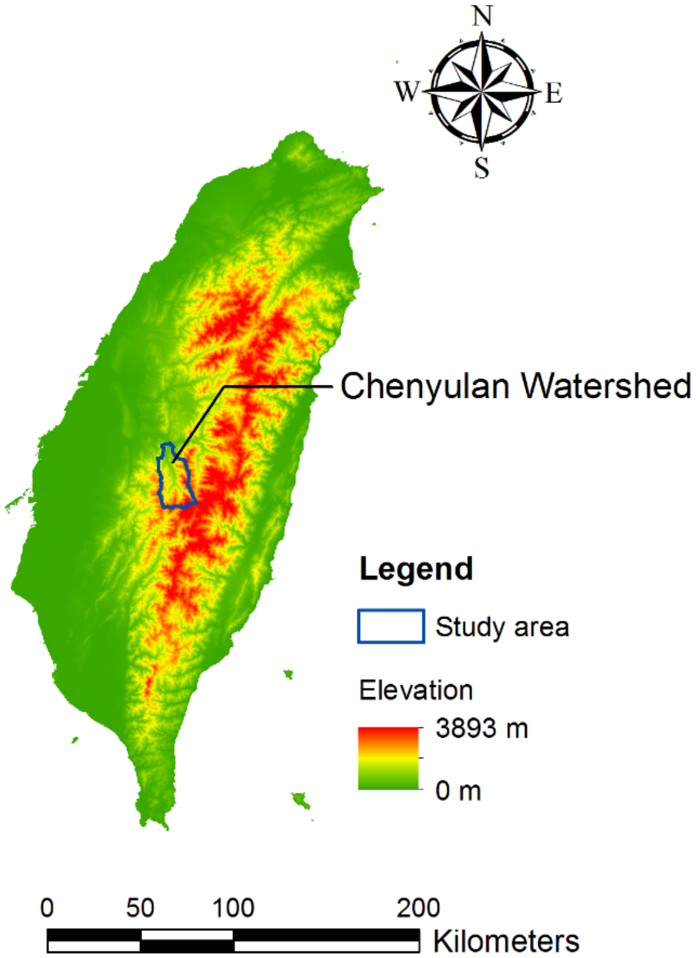
Introduction

- Climate change becomes more severe due to global warming. In Taiwan, it has been observed that increasing rainfall intensity results in more landslides, debris flows, and flooding at mountainous regions.
- In SWAT, MUSLE is used to estimate soil erosion. However, it is not suitable for Taiwan, mainly because of slope steepness factor (S).
- Moreover, sediment routing method needs to be carefully selected for streams of different geomorphologic characteristics and bed materials.

Objectives

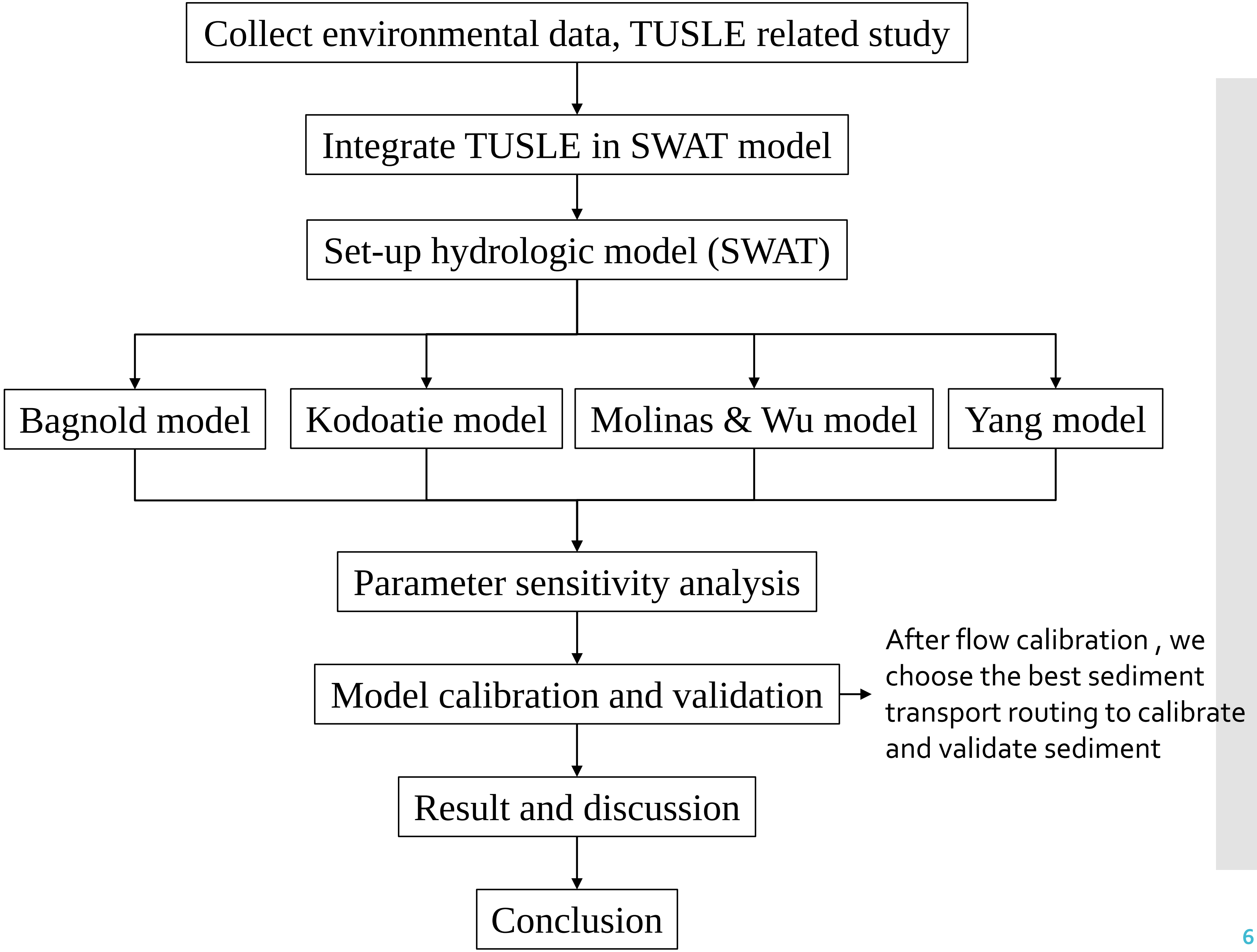
- Integrate TUSLE in SWAT model as SWAT-TUSLE model
- Compare the simulation results by using different sediment transport routing
- Evaluate the suitability of SWAT-TUSLE model for simulating sediment exports in the Chanyulan watershed

Study area: Chenyulan watershed

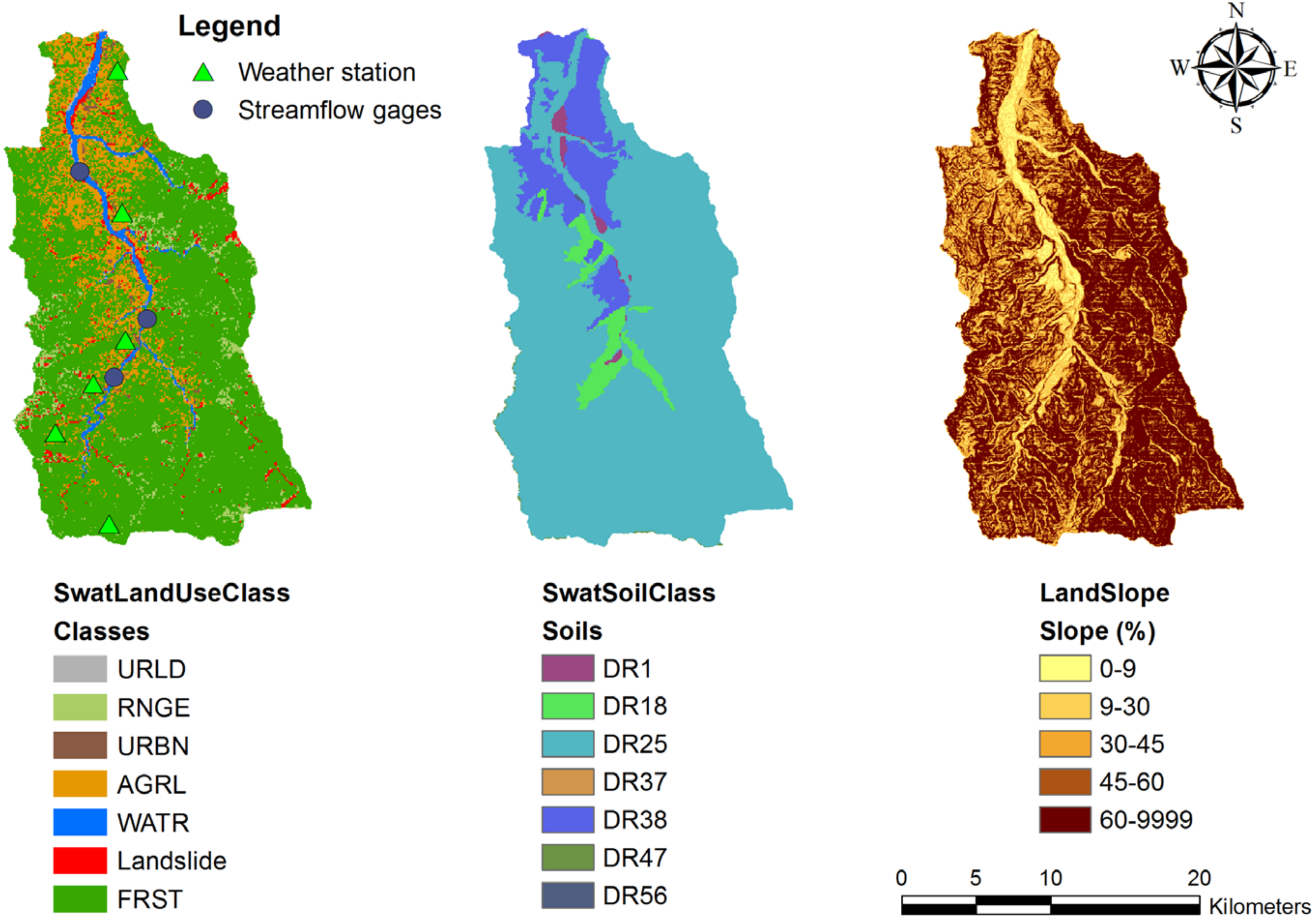


Study method

Research Flow



Study area: Chenyulan watershed



Taiwan Universal Soil Loss Equation (TUSLE)

- Taiwan Universal Soil Loss Equation (TUSLE) was revised from Universal Soil Loss Equation (USLE) by Chen *et al.*(2009).
- Key modified factors:
  - Soil erodibility factor (K): Based on the soil survey in Taiwan conducted by Wan and Huang (1989) and Hsieh and Wang (1991).

Soil	DR1	DR18	DR25	DR37	DR38	DR47	DR56
K	0.4	0.3	0.36	0.13	0.19	0.2	0.29

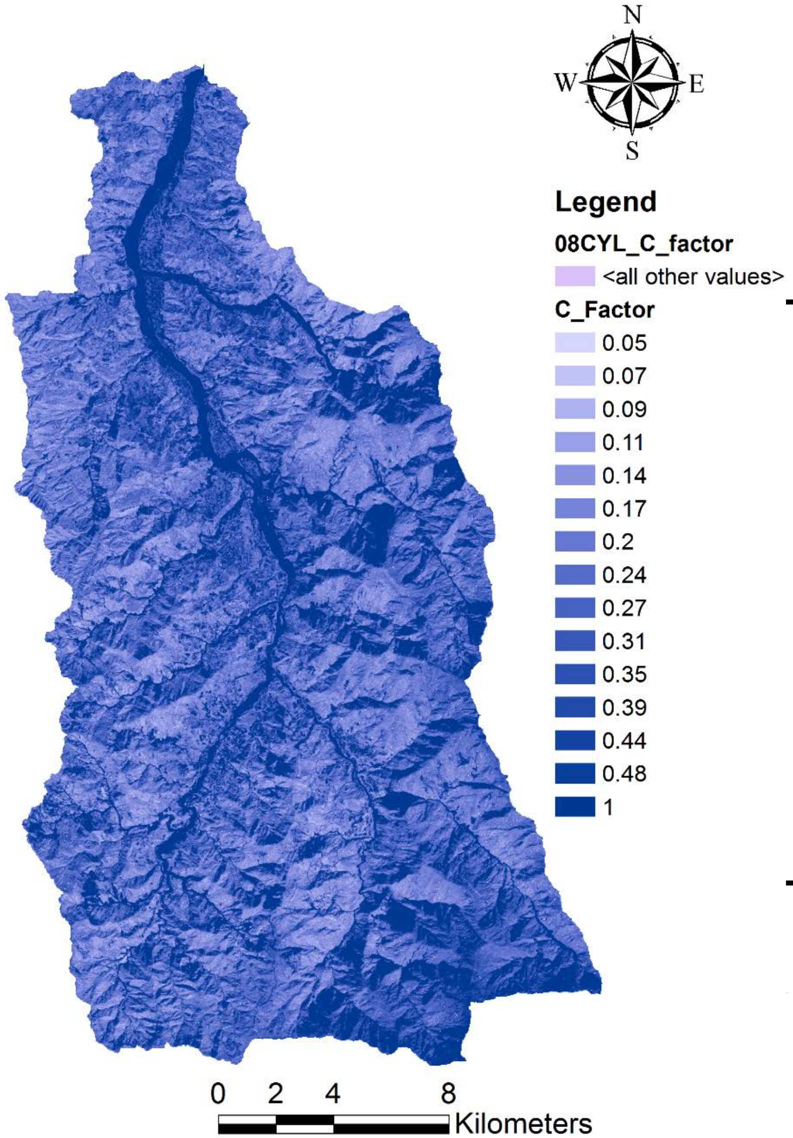
TUSLE- Cover and management factor (C)

- Cover and management factor (C) : The C factor was estimated by non-linear equation from Normalized Difference Vegetation Index (NDVI) to avoid overestimating the C values of area with low soil erosion rate.

$$NDVI \geq 0, \qquad C = \left(\frac{1 - NDVI}{2}\right)^{1+NDVI}$$

$$NDVI < 0, \qquad \begin{cases} Building\ or\ non-exposed\ ground, C = 0.01 \\ Barren, \qquad C = 1.0 \end{cases}$$

TUSLE- Cover and management factor (C)



C	Grid Numbers			
	WATR	RNGE	FRST	AGRL
0.01	13429	3914	61334	0
0.1	117	3049	67819	8463
0.2	678	8417	153468	26007
0.3	538	4120	59365	14141
0.4	1195	4084	56689	17422
1	0	0	0	9205
Weighted C	0.1	0.2	0.2	0.4

TUSLE- Slope steepness factor (S)

- Topographic factor (LS) : The Wischmeier and Smith (1978) equation would overestimate LS factor in area of steeper slope.

Wischmeier and Smith (1978) equation:

$$LS = \left(\frac{X}{22.13}\right)^m (0.0654 + 4.56\sin\theta + 65.4\sin^2\theta)$$

- Many studies indicated that Wischmeier and Smith (1978) topography factor equation could only suitable for the slope form 0.1% to 18%, while the S factor equation revised by McCool *et al*. (1987) could more reasonably predict soil loss at steep topography.

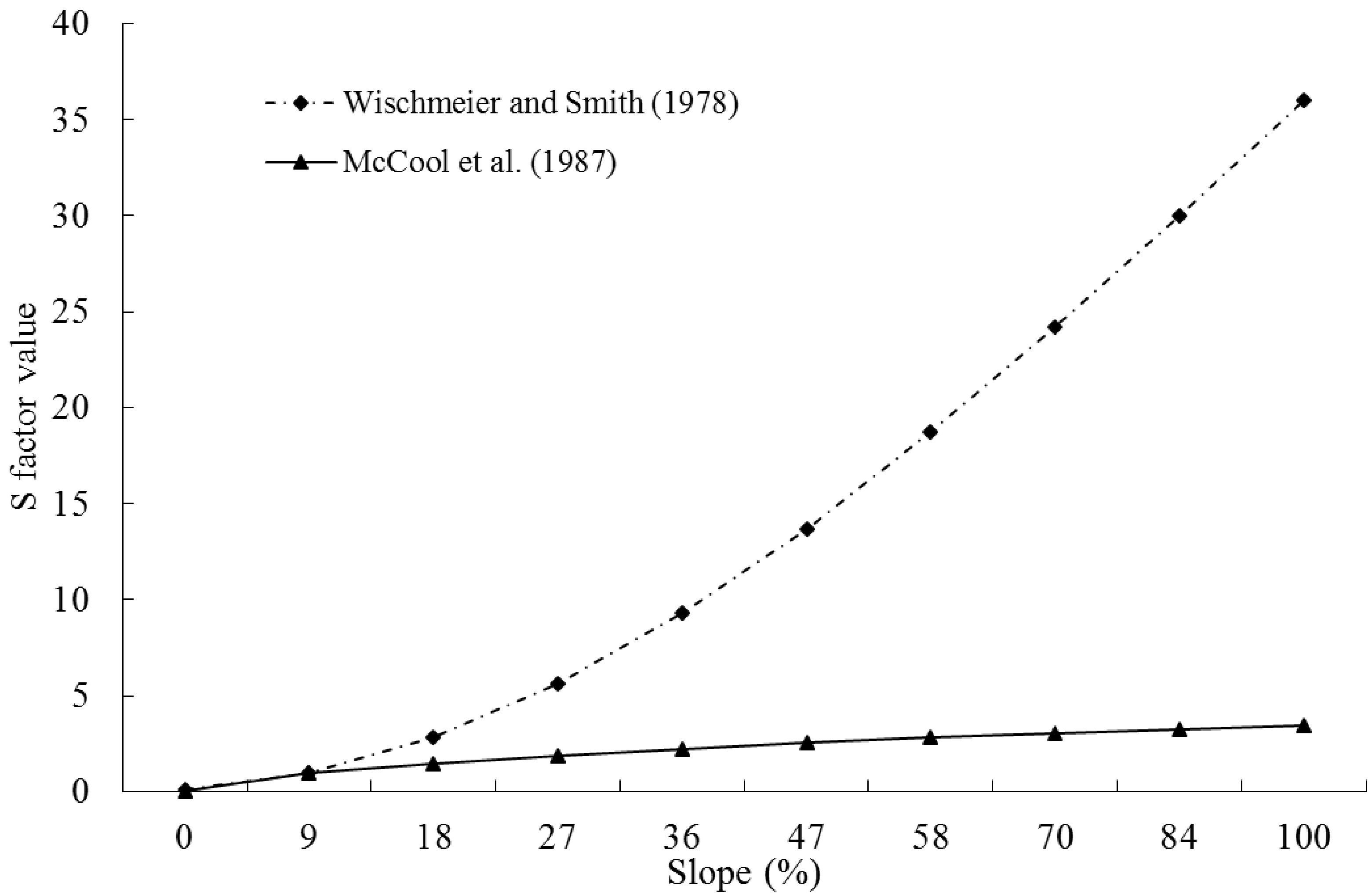
McCool *et al*.(1987) equation:

$$S = 10.8\sin\theta + 0.03, \qquad \theta < 9\%$$

$$S = \left(\frac{\sin\theta}{0.0896}\right)^{0.6}, \qquad \theta \geq 9\%$$

TUSLE-Slope steepness factor (S)

- Thus, the S factor estimated by McCool *et al*.(1987) equation is suggested to be more suitable for steep topography area.



TUSLE- Slope length factor (L)

- Slope length factor (L):

Wischmeier and Smith (1978) equation:

$$L = \left(\frac{X}{22.13}\right)^m$$

where X = slope length (m), m = exponential factor.

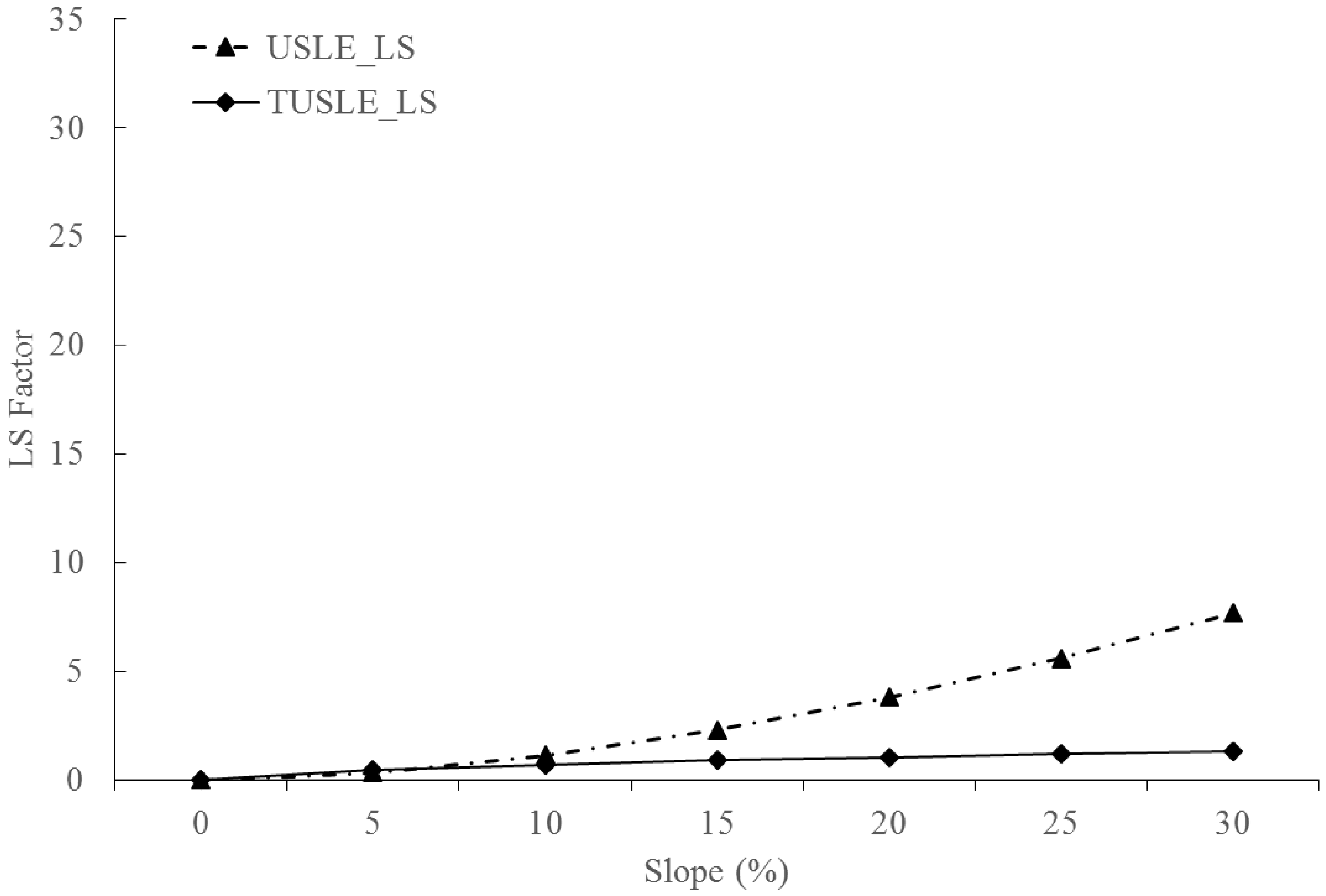
- In MUSLE: $m = 0.6 \times (1 - e^{-35.835*S})$

where s is the slope of HRU

- In TUSLE, m = 0.5 for the average slope greater than 5%; m=0.4 for the average slope between 3%-5%; m=0.3 for slope between 1%-3%; m=0.2 for slope less than 1%.

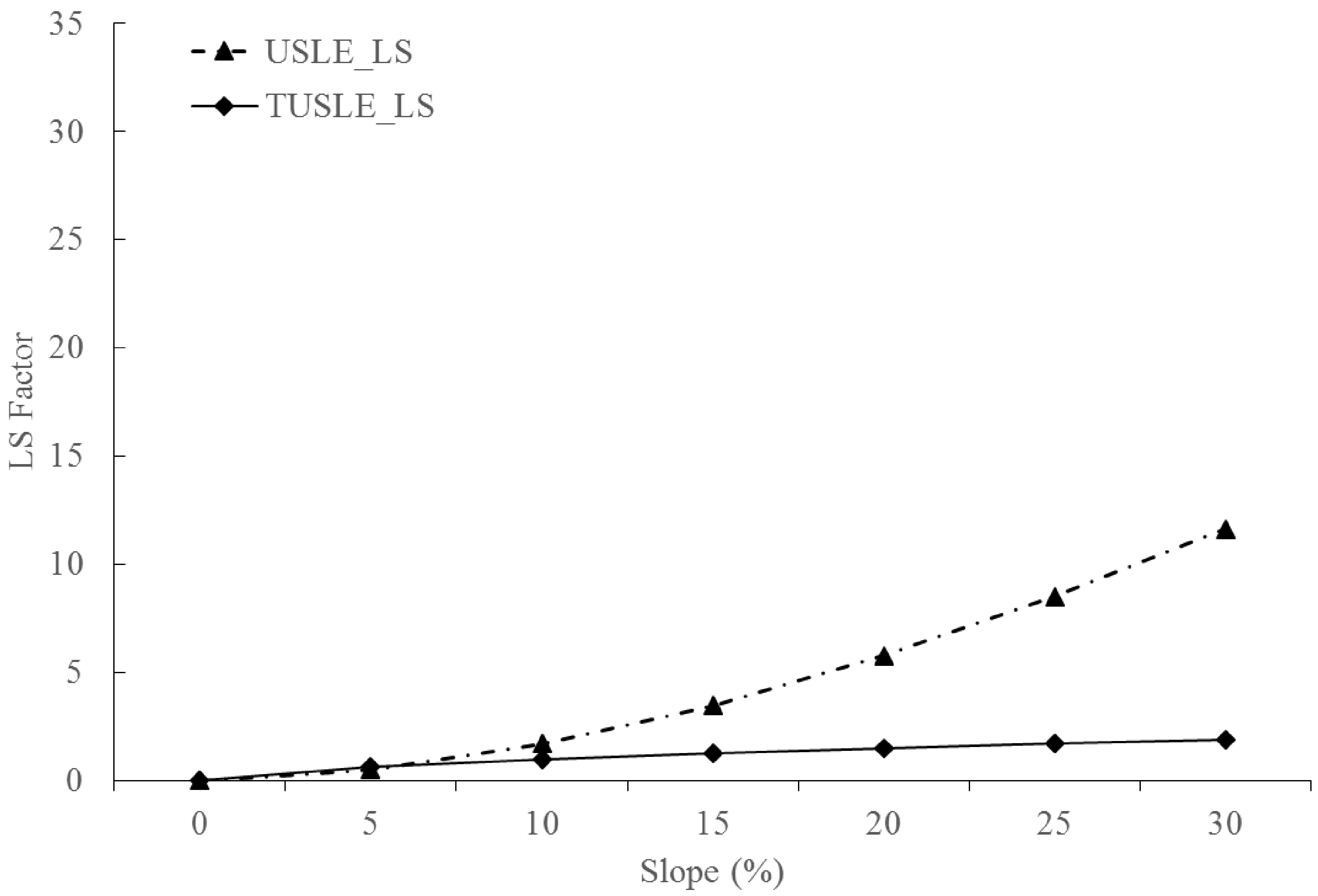
TUSLE-Topography factor (LS)

- Slope Length = 5 m



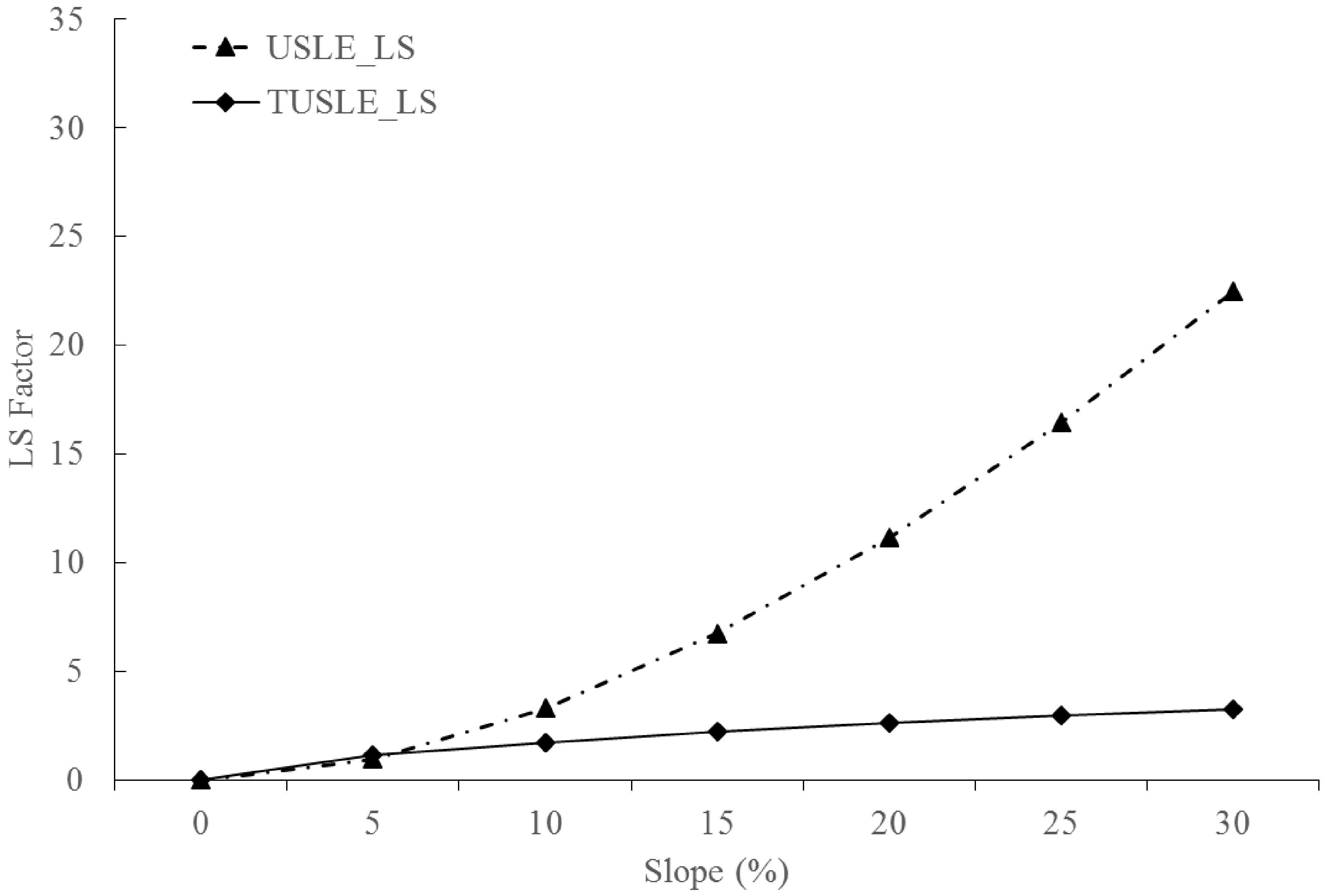
TUSLE- Topography factor (LS)

- Slope Length = 10 m



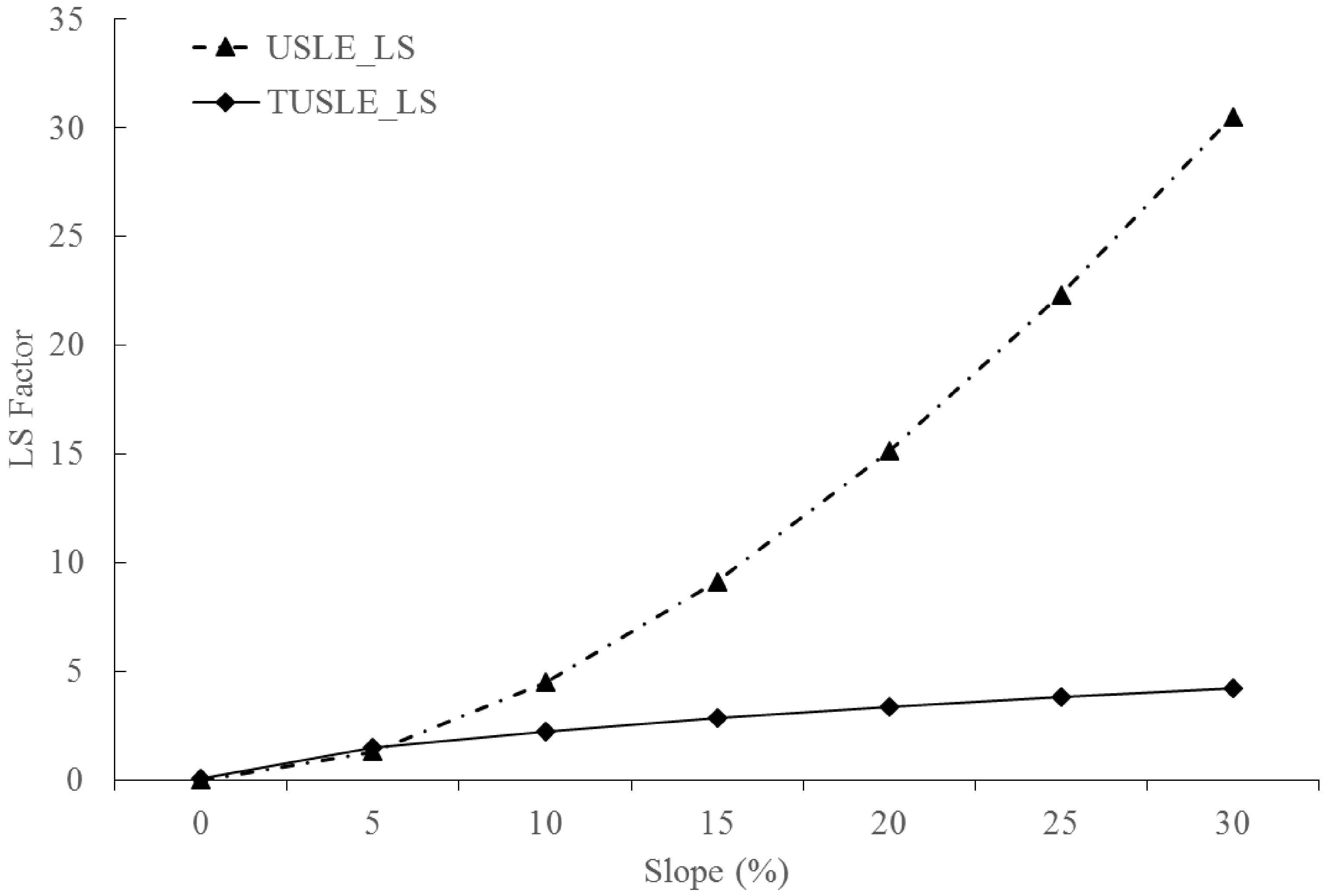
TUSLE- Topography factor (LS)

- Slope Length = 30 m



TUSLE-Topography factor (LS)

- Slope Length = 50 m



Result and discussion

Sensitivity analysis for flow-related parameters

- Based on sensitivity analysis results, we selected 10 parameters that P-value < 0.5 for flow calibration.

Rank	Parameter Name	File name	Method	P-value
1	CN2	*.mgt	Relative	0.00
2	SOL_AWC	*.sol	Relative	0.00
3	GW_REVAP	*.gw	Replace	0.25
4	GW_DELAY	*.gw	Replace	0.26
5	RCHRG_DP	*.gw	Replace	0.34
6	CANMX	*.hru	Replace	0.36
7	CH_K2	*.rte	Relative	0.42
8	ESCO	*.hru	Replace	0.45
9	SURLAG	basin.bsn	Replace	0.49
10	CH_N2	*.rte	Relative	0.49

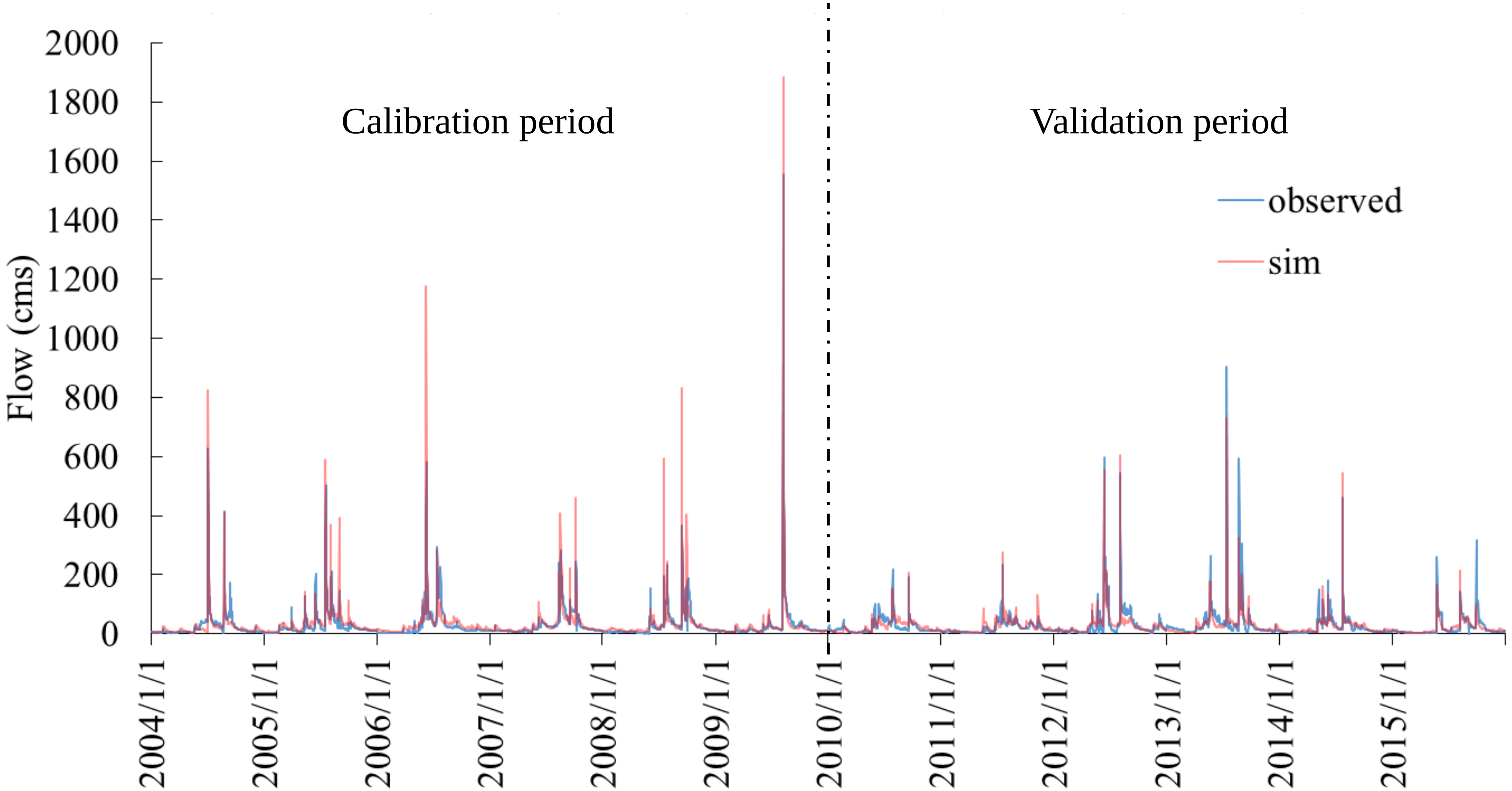
Daily flow calibration and validation result

- As steeper areas might have different hydrological characteristics, we separated subbasins into two group by average subbasin slope > 60% and <60% for calibration.

Parameter Name		File name	Method	Range	Fitted Value
CN2		*.mgt	Relative	-0.6 ~ -0.51	-0.59
ESCO		*.hru	Replace	0.48 ~ 0.95	0.69
SURLAG		basin.bsn	Replace	0.05 ~ 8.7	7.4
SOL_AWC	Slope < 60 %	*.sol	Relative	-0.4 ~ -0.2	-0.29
	Slope > 60 %			-0.14 ~ 0.26	0.19
GW_REVAP	Slope < 60 %	*.gw	Replace	0.16 ~ 0.2	0.18
	Slope > 60 %			0.04 ~ 0.08	0.07
GW_DELAY	Slope < 60 %	*.gw	Replace	31.4 ~ 52.2	44.2
	Slope > 60 %			8.6 ~ 16	10.6
RCHRG_DP	Slope < 60 %	*.gw	Replace	0.24~0.51	0.45
	Slope > 60 %			0.2 ~ 0.5	0.3
CANMX	Slope < 60 %	*.hru	Replace	9 ~ 40	18.7
	Slope > 60 %			20 ~ 60	32.5
CH_K2	Slope < 60 %	*.rte	Relative	445 ~ 500	496
	Slope > 60 %			217 ~ 317	307
CH_N2	Slope < 60 %	*.rte	Relative	0.15 ~ 0.58	0.32
	Slope > 60 %			0.4 ~ 0.73	0.64

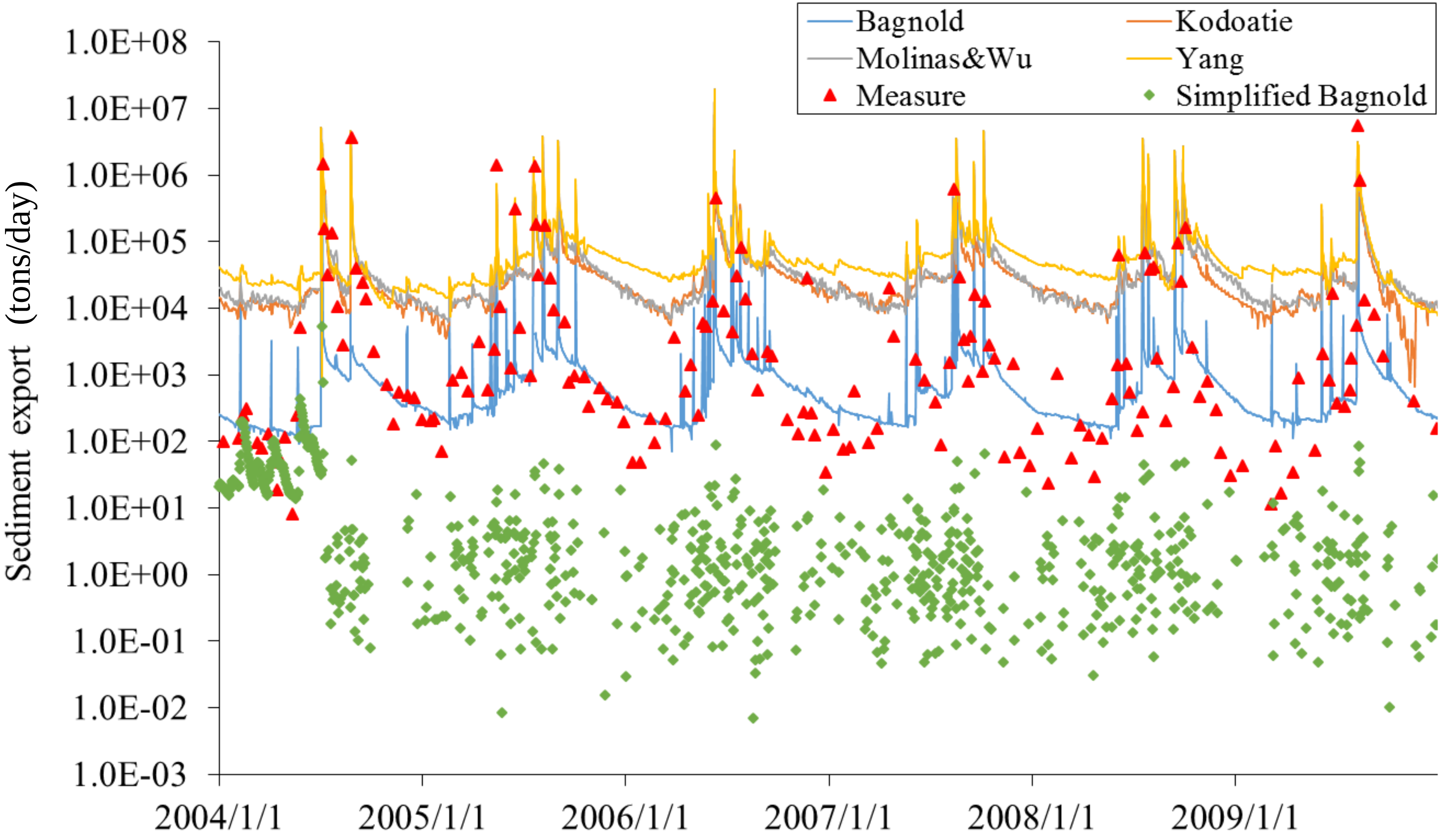
Daily flow calibration and validation result

	Period	R^2	NSE	PBIAS	RSR	Simulation Average	Measured Average	Result
Calibration	2004~2009	0.79	0.64	-16.4%	0.6	34.42 cms	29.57 cms	Satisfactory
Validation	2010~2015	0.75	0.75	0.6%	0.5	26.44 cms	26.60 cms	Very Good



Comparison of sediment routing methods

- After flow calibration and validation and before sediment calibration, we used SWAT2016 model (ver. 644) to simulate sediment exports by using 5 different sediment routing methods.
- Visually, Bagnold equation (CH_EQN = 1) performed better than other 4 routing methods.



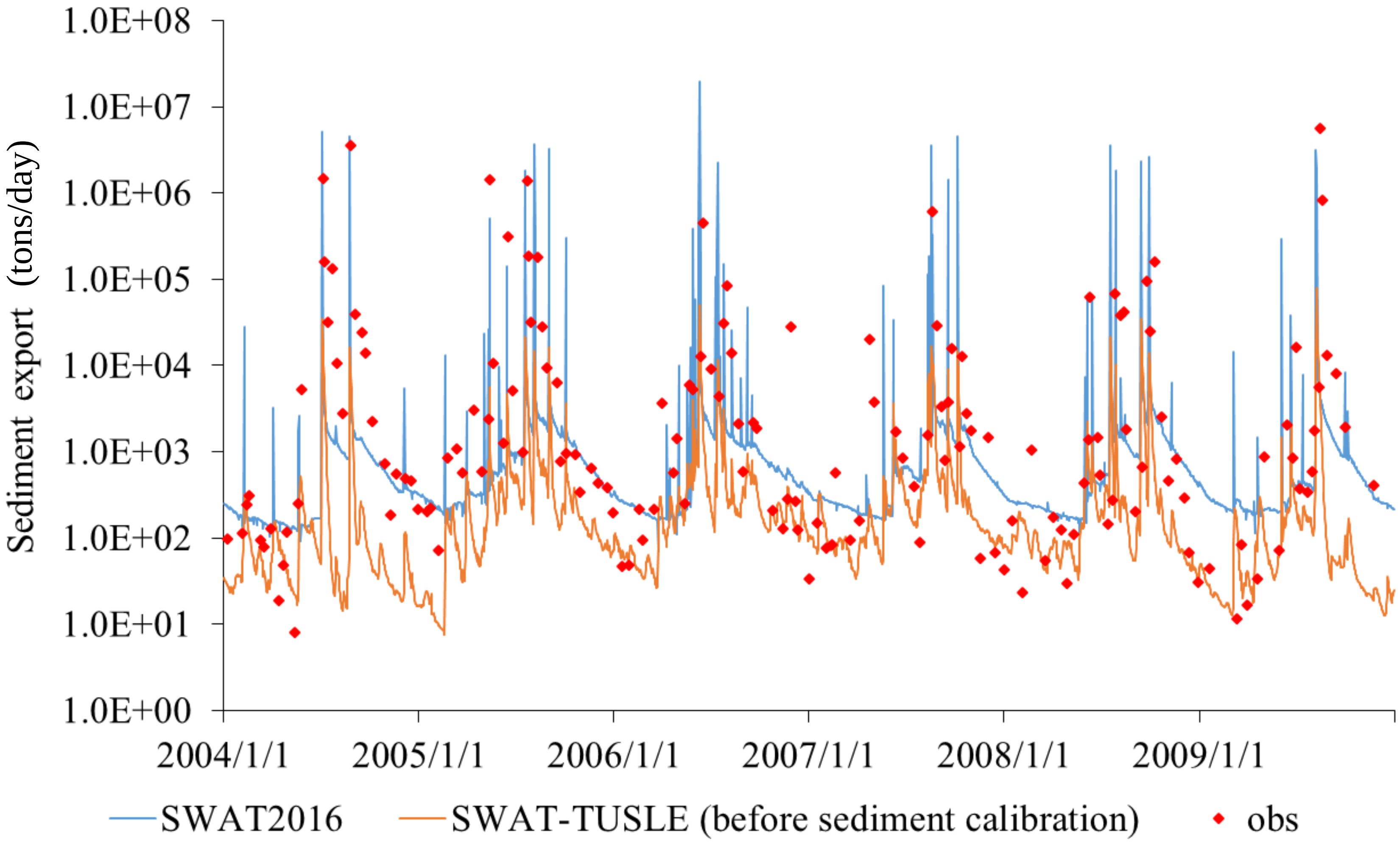
Comparison of sediment routing methods

	Bagnold	Kodoatie	Molinas&Wu	Yang	Simplified Bagnold
CH_EQN	1	2	3	4	0 (default)
R^2	0.75	0.73	0.68	0.74	0.04
NSE	0.48	0.56	0.53	0.61	-0.03
PBIAS	70.08	-9.45	-20.09	-58.20	99.98
RSR	0.72	0.66	0.69	0.62	1.01

- Generally, the model performed well for 4 routing methods in terms of the R^2 value (0.68-0.75) and NSE value (0.48-0.61); however, most of the sediment exports were underestimated for peak flow and overestimated for low flow conditions.
- Lots of zero values were generated when using Simplified Bagnold equation (CH_EQN=0), thus its R^2 value and NSE value were very poor.

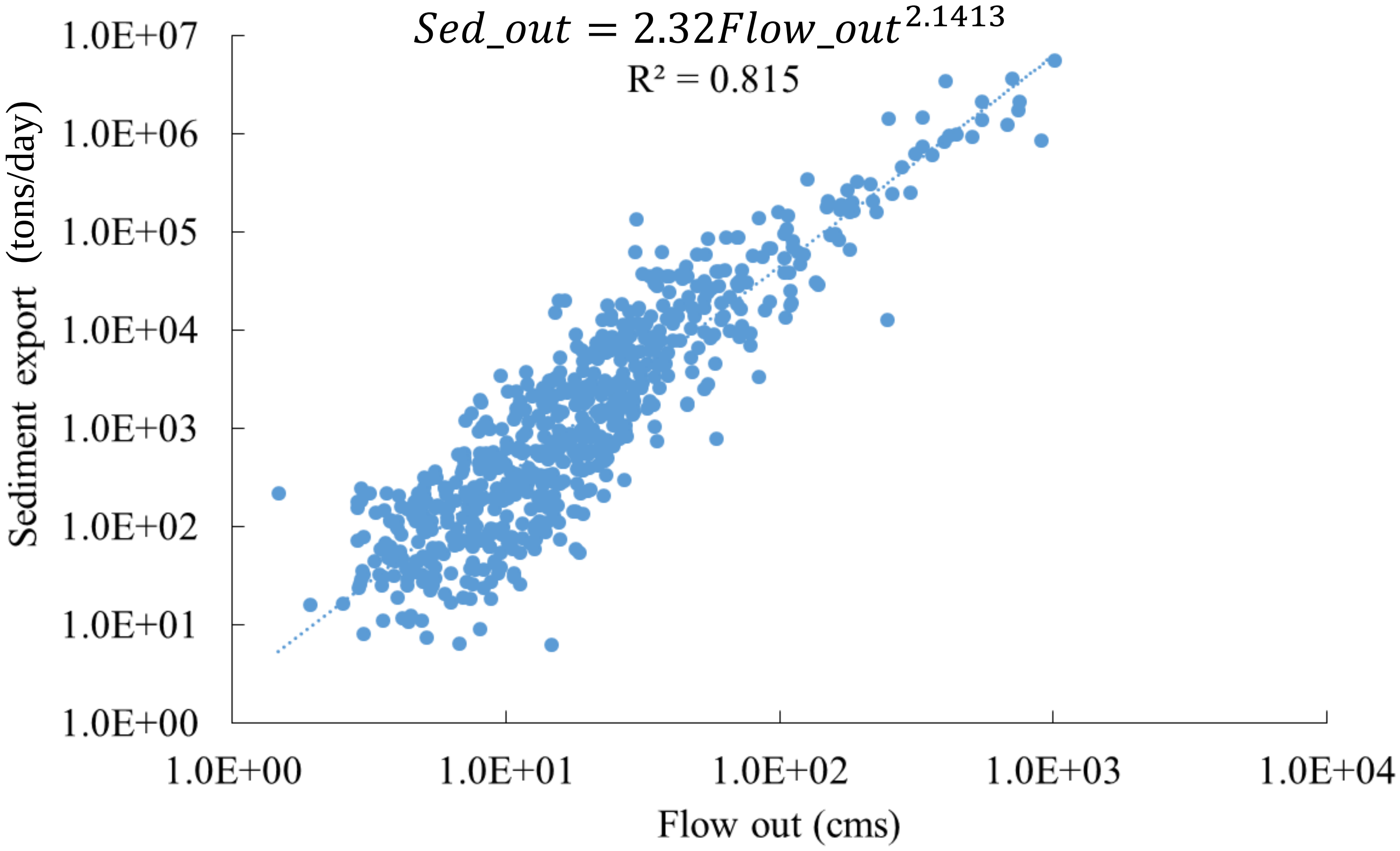
Comparison of SWAT-TUSLE and SWAT2016

- SWAT-TUSLE performed better than SWAT2016 in low flow conditions.
- SWAT-TUSLE could reflect the fluctuation of sediment exports and match the trend of observed sediment export.



Estimation of observed daily sediment data

- Due to availability of limited observed sediment data (2-5 times per month), we used the fitting curve between daily discharge and daily sediment transport in the records of 2004-2015 to estimate continuous daily sediment data for 2004-2015.



Sensitivity analysis for sediment-related parameters

- A total of 9 parameters that P-value < 0.5 were selected to calibrate sediment export.

Rank	Parameter Name	File name	Method	P-value
1	PRF_BSN	basin.bsn	Repalce	0.00
2	SPEXP	basin.bsn	Repalce	0.00
3	SPCON	basin.bsn	Repalce	0.00
4	CH_BED_TC	*.rte	Repalce	0.01
5	CH_BED_D50	*.rte	Repalce	0.03
6	ADJ_PKR	basin.bsn	Repalce	0.10
7	CH_BNK_D50	*.rte	Repalce	0.17
8	CH_BNK_TC	*.rte	Repalce	0.35
9	CH_COV2	*.rte	Repalce	0.47

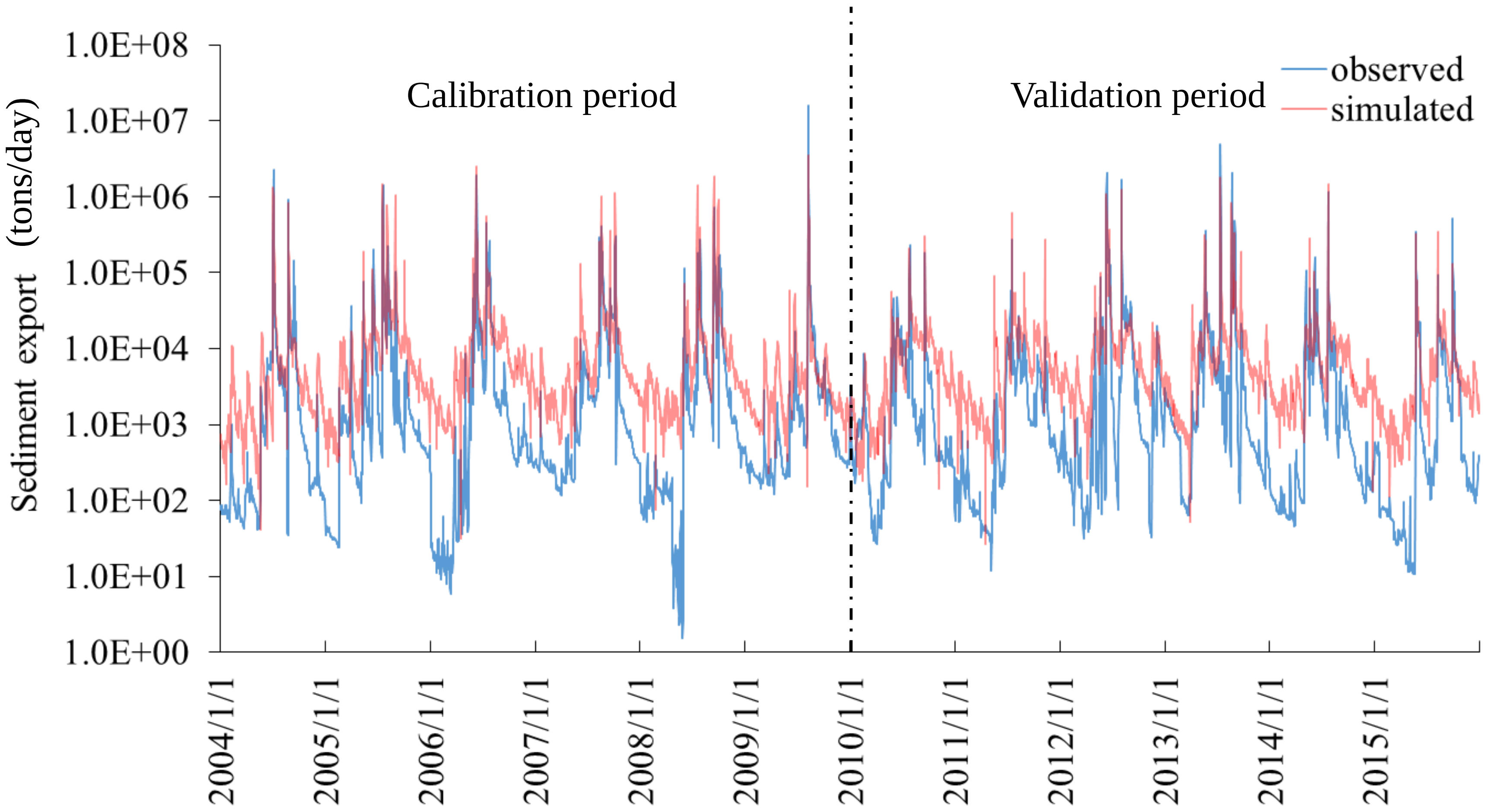
Daily sediment export calibration and validation result

- CH_COV2(channel bed vegetation coefficient), CH_D50 (median particle size) and TC (critical shear stress) were calibrated separately for subbasins with slope > 60% and <60%.

Parameter Name		File name	Method	Range	Fitted Value
ADJ_PKR		basin.bsn	Replace	0.5 ~ 1	0.93
PRF_BSN		basin.bsn	Replace	0.4 ~ 0.5	0.45
SPCON		basin.bsn	Replace	0.02 ~ 0.06	0.03
SPEXP		basin.bsn	Replace	1.3 ~ 1.5	1.49
CH_COV2	Slope < 60 %	*.rte	Replace	0.7 ~ 1	0.72
	Slope > 60 %			0.3 ~ 0.8	0.77
CH_BNK_D50	Slope < 60 %	*.rte	Replace	5500 ~ 7500	6049
	Slope > 60 %			3500 ~ 7300	5559
CH_BED_D50	Slope < 60 %	*.rte	Replace	6500 ~ 10000	8051
	Slope > 60 %			6500 ~ 10000	9377
CH_BNK_TC	Slope < 60 %	*.rte	Replace	50 ~ 280	211
	Slope > 60 %			150 ~ 350	301
CH_BED_TC	Slope < 60 %	*.rte	Replace	150 ~ 290	274
	Slope > 60 %			30 ~ 250	143

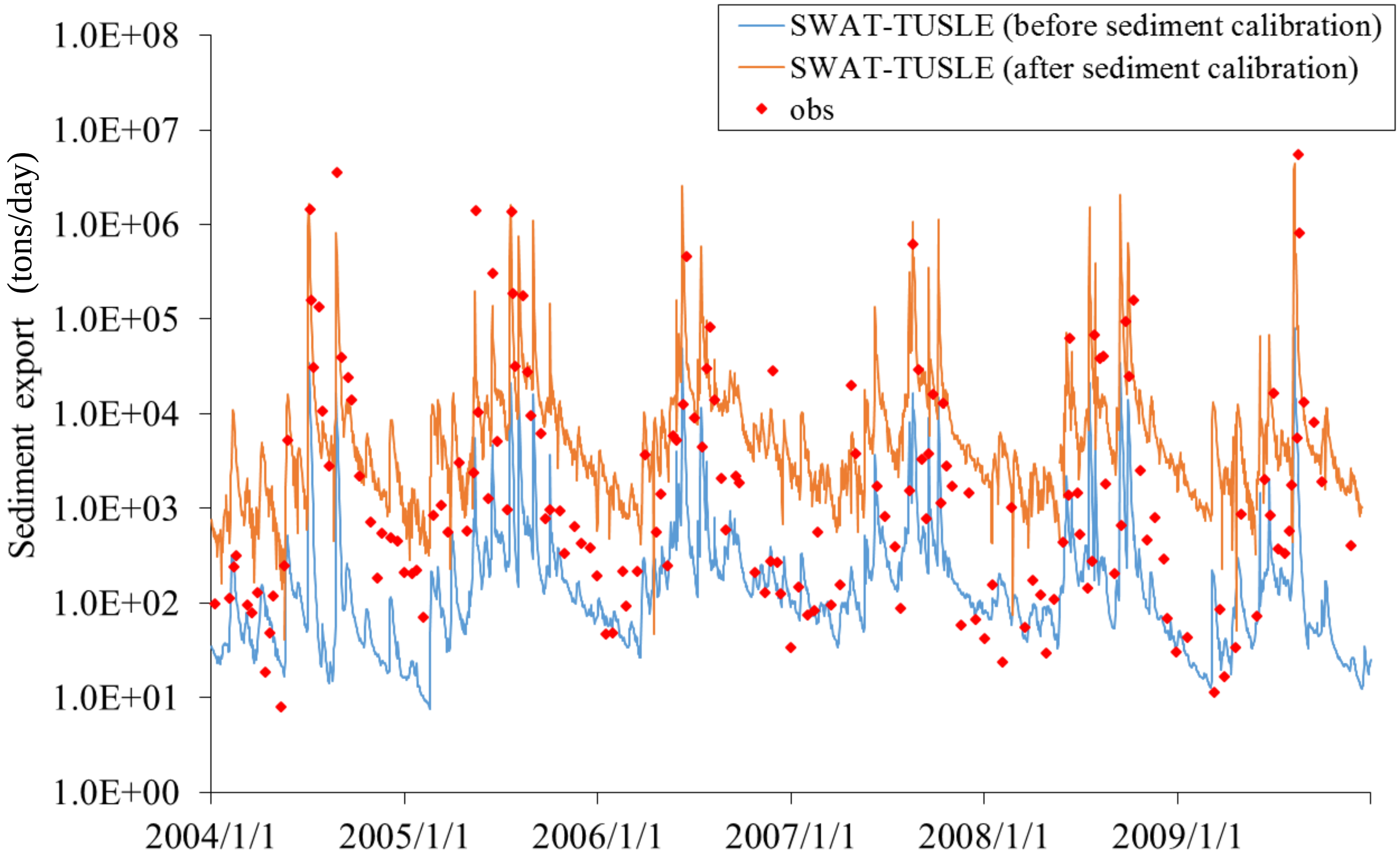
Daily sediment export calibration and validation result

	Period	R^2	NSE	PBIAS	RSR	Simulation Average	Measured Average	Result
Calibration	2004~2009	0.54	0.52	-40.7%	0.69	36315 tons	25817 tons	Satisfactory
Validation	2010~2015	0.64	0.62	-17.3%	0.62	16664 tons	14201 tons	Satisfactory



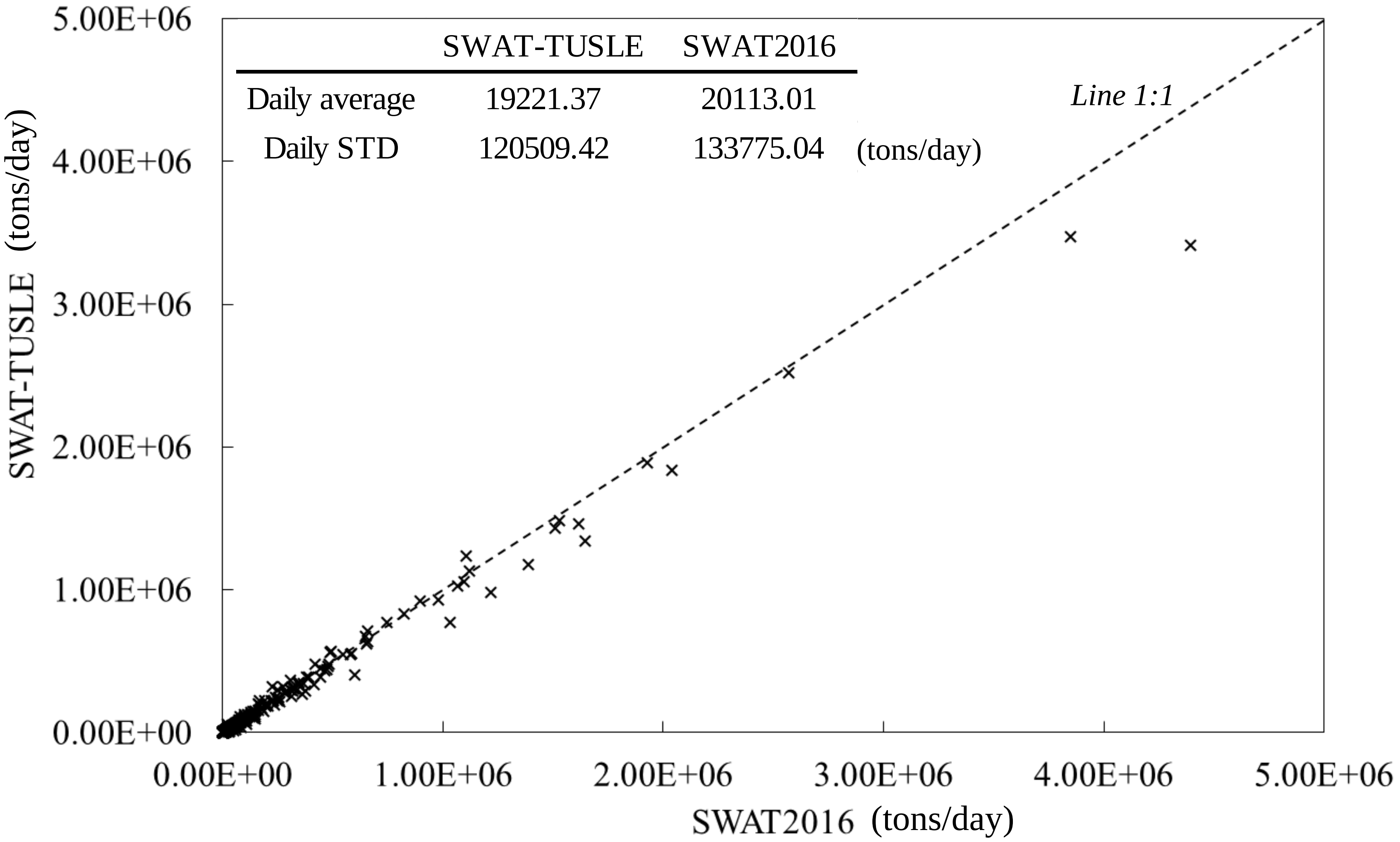
SWAT-TUSLE: Before-calibration and after-calibration

- The calibrated SWAT-TUSLE significantly improved the sediment export at the peak flow, but it also overestimated the sediment export at the low flow condition.



Comparison of SWAT-TUSLE and SWAT2016

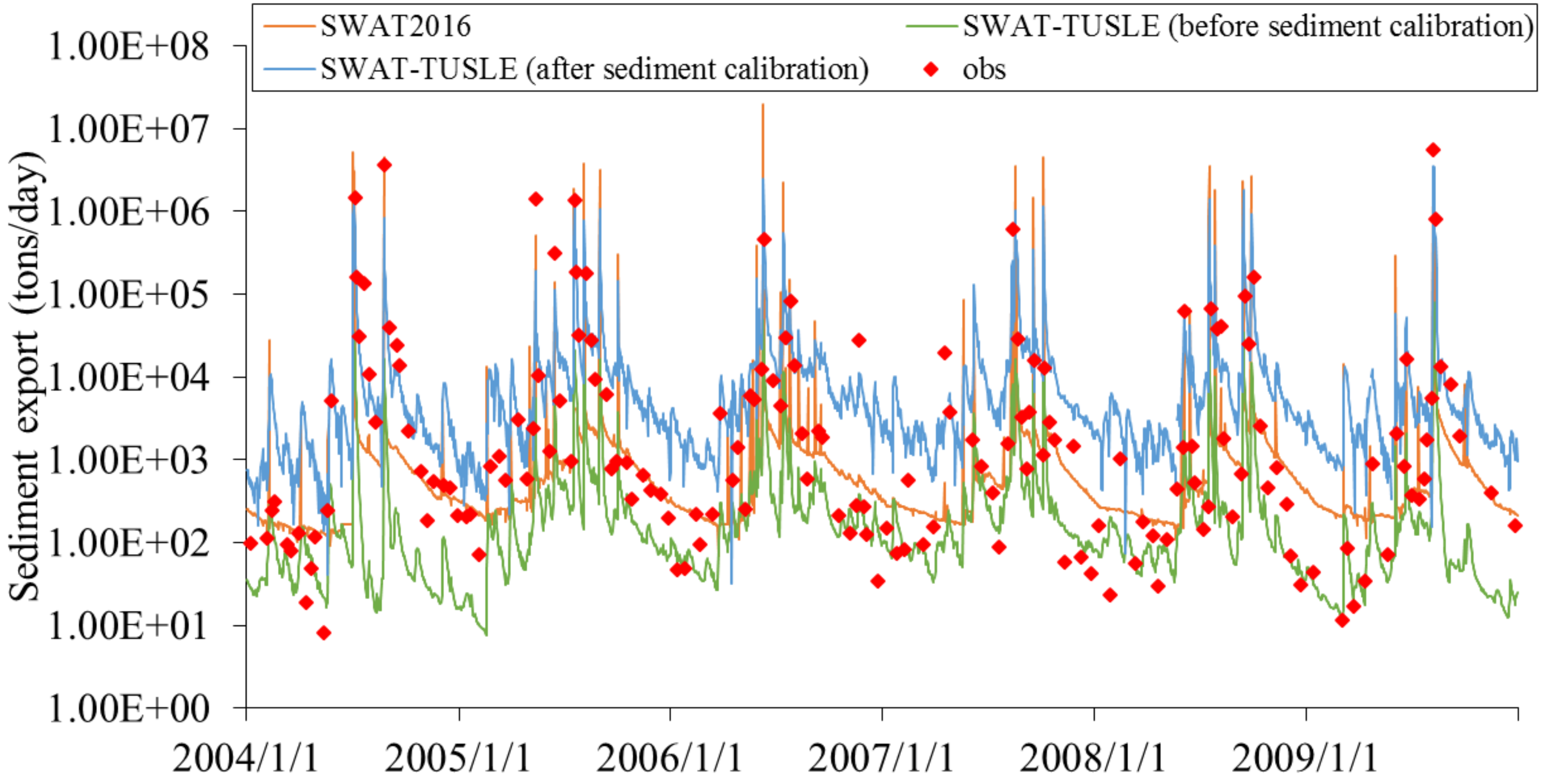
- Relative to SWAT-TUSLE, SWAT2016 has predicted higher sediment export after calibration, especially at high sediment condition.



Comparison of SWAT-TUSLE and SWAT2016

- SWAT-TUSLE had better R-square value (0.94) than SWAT2016 (0.75), but had bad NSE (0.00), PBAIS (98.42), and RSR (1.00) before sediment calibration.
- Although all statistical parameter seems performed well at sediment simulation after SWAT-TUSLE calibration, we could visually see that model over-predicted at low sediment condition.

	SWAT2016	SWAT-TUSLE (before cal.)	SWAT-TUSLE (after cal.)
R^2	0.75	0.94	0.95
NSE	0.48	0.00	0.81
PBIAS	70.08	98.42	35.96
RSR	0.72	1.00	0.44



Conclusion and future work

- TUSLE calculated less sediment at steep area that make model reasonably predict sediment export at low flow condition.
- Chenyulan watershed has been suffered by serious landslide and debris flow when heavy rain occurred (i.e. typhoon) that will increase huge amount of sediment, but it was not considered in this study, that result in sediment parameters might over-fitted to match the peak sediment export to get better statistical parameters value.
- The sediment parameters over-fitted problem might be solved if we could integrate both of landslide volume prediction and TUSLE in SWAT model, that might predict better result at high flow condition.

Thanks for attention !
Question?