Soil & Water Assessment Tool | SWAT

The Uncertainty Analysis of SWAT Simulated Streamflow and Water Quality Applied to Chungju Dam Watershed of South Korea

15 June 2011

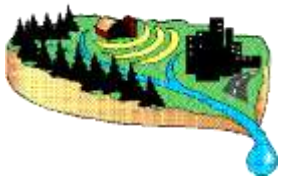
JOH, Hyung-Kyung[1]
[1]Graduate Student

PARK, Jong-Yoon[2] / JUNG, Hyun-Kyo[2] / SHIN, Hyung-Jin[3] / KWON, Hyung-Joong[3]
[2] Ph. D. Candidate / [3]Ph. D.

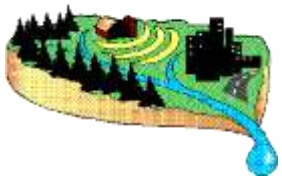
KIM, Seong-Joon[4]
[4]Professor, Corresponding Author

Dept. of Civil and Environmental System Eng.,
Konkuk University, Seoul, **South Korea**

Contents

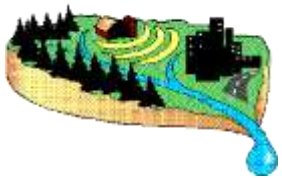


Purpose of this study

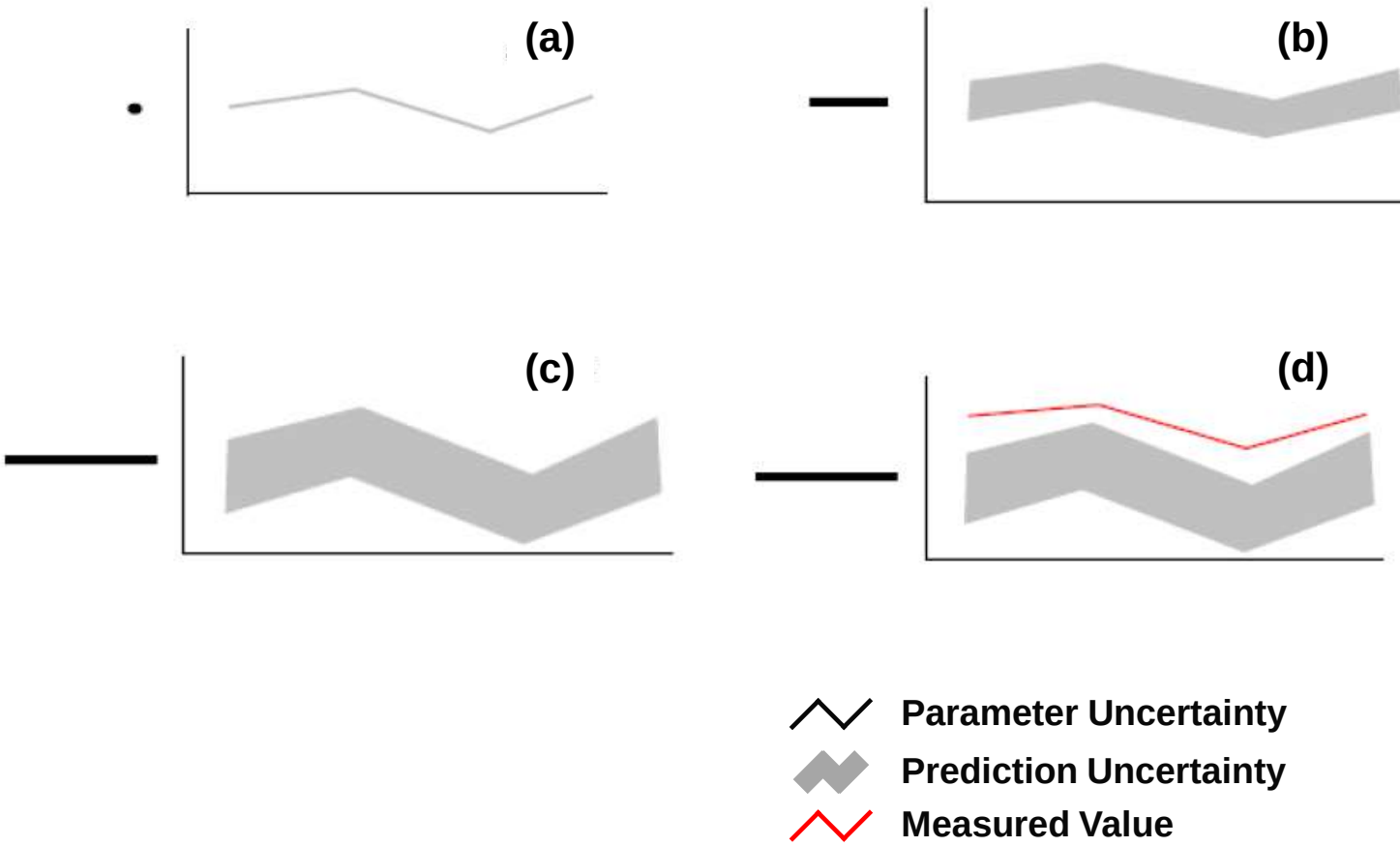


- ✓ SWAT (Soil and Water Assessment Tool, Arnold et al., 1998) model is a very useful tool for both making decisions and research purposes of watershed management .
- ✓ To fulfill this applicability, the model should pass through a careful & well-done calibration.
- ✓ If the model is calibrated using streamflow data at the watershed outlet, can the model be called as calibrated one? What about the case of multisite calibration?
- ✓ What if we add streamflow data from stations inside the watershed? Will the new model give correct results from various parameter set in the watershed? → **Perhaps NOT** (Abbaspour et al., 2007).
- ✓ **Thus, we need to assess and understand the model uncertainty occurred by parameter set. This is possible through SWAT-CUP (Soil and Water Assessment Tool-Calibration Uncertainty Program) Modeling.**

Prediction Uncertainty

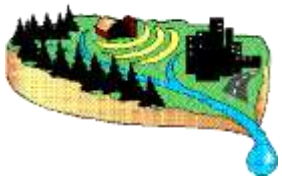


- **Parameter Uncertainty vs. Simulation Uncertainty**



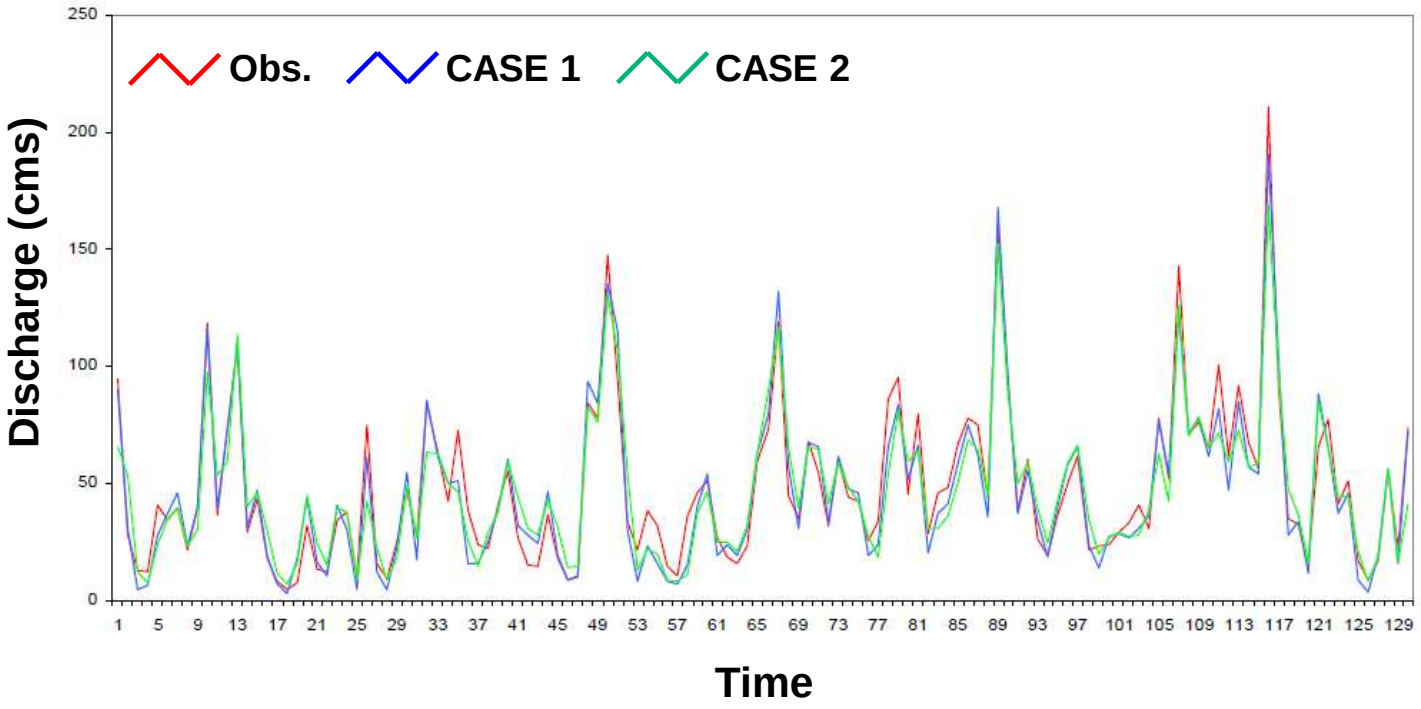
(Karim C. Abbaspour, 2009, SWAT-CUP User manual)

Prediction Uncertainty



- **Combination of Non-unique Parameter Uncertainty vs. Simulation Uncertainty**

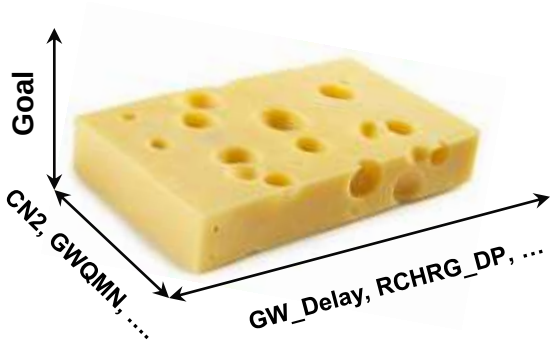
	GW_DELAY	CH_N2	CN2	REVAPMN	SOL_AWC
CASE 1	3.46	0.0098	50	0.8	0.11
CASE 2	0.34	0.131	20	2.4	0.23

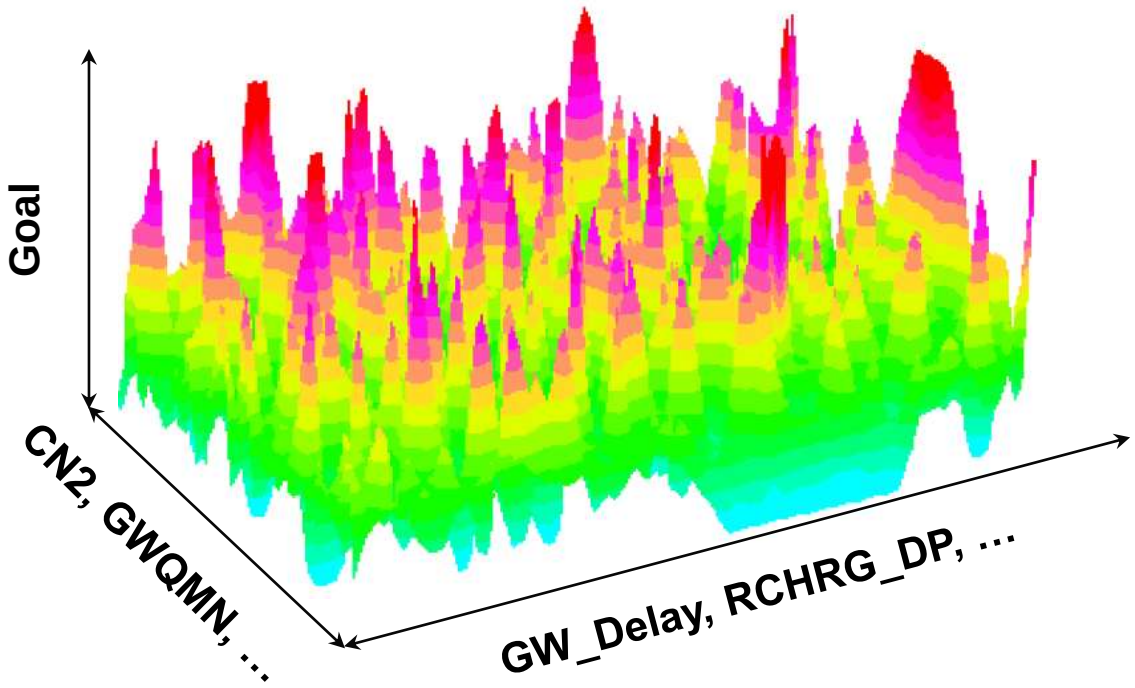


(Karim C. Abbaspour, 2009, SWAT-CUP User manual)

Prediction Uncertainty

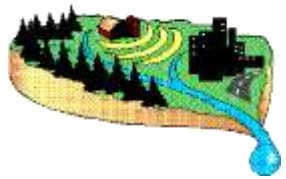
- **Swiss Cheese Effect**

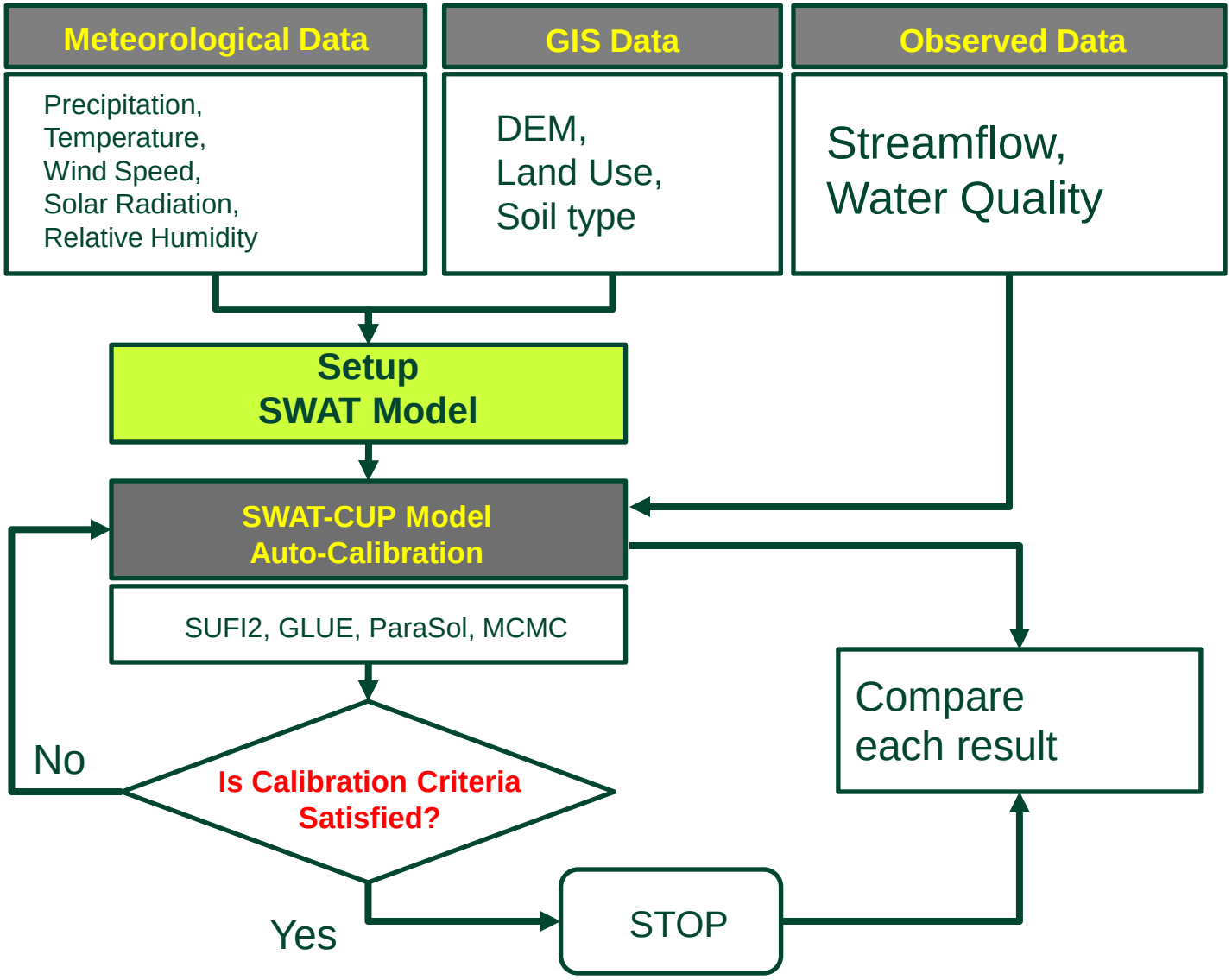




(Karim C. Abbaspour, 2009, SWAT-CUP User manual)

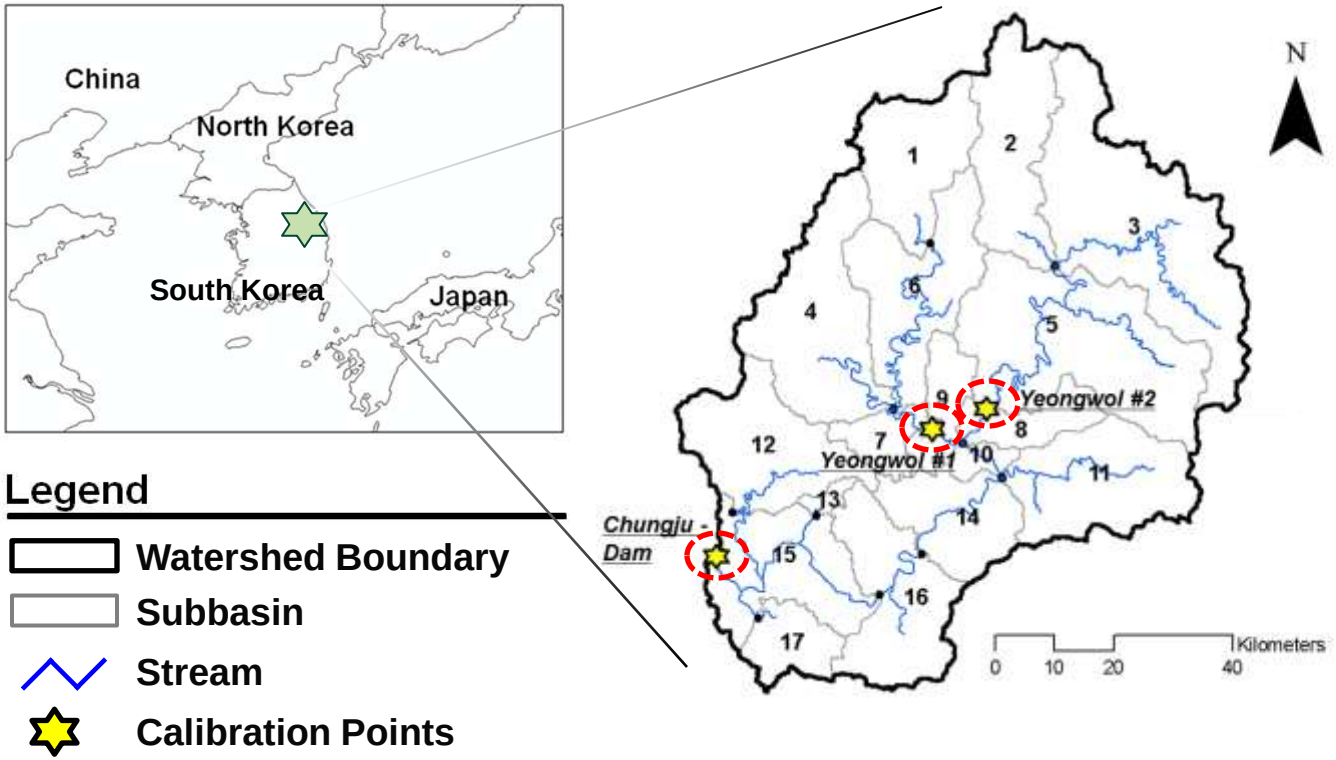
Study Procedure





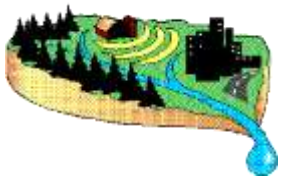
Study Area

Chungju-Dam Watershed



- ✓ Watershed Area : 6,661.3 km^2
- ✓ Annual Average Precipitation : 1,359.5 mm
- ✓ Forest Area : 82.2 %
- ✓ Annual Average Temperature : 9.4 ℃

Input and Measured Data

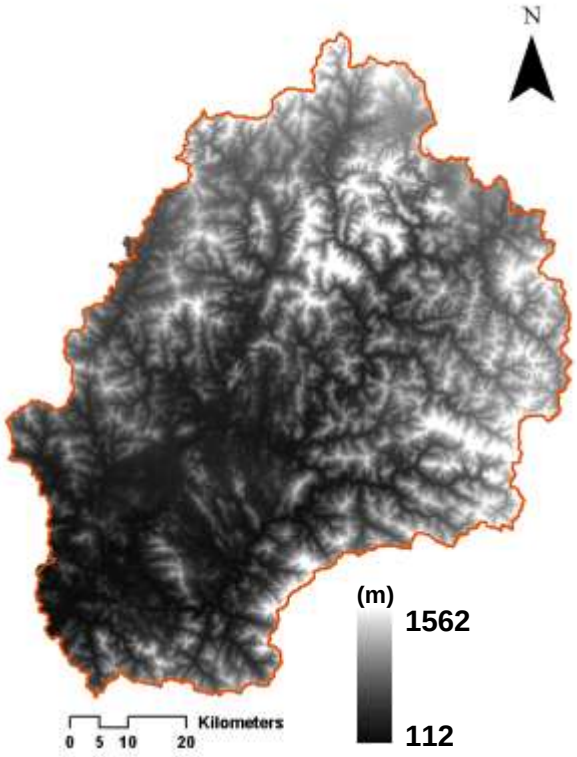


Data Set for SWAT model

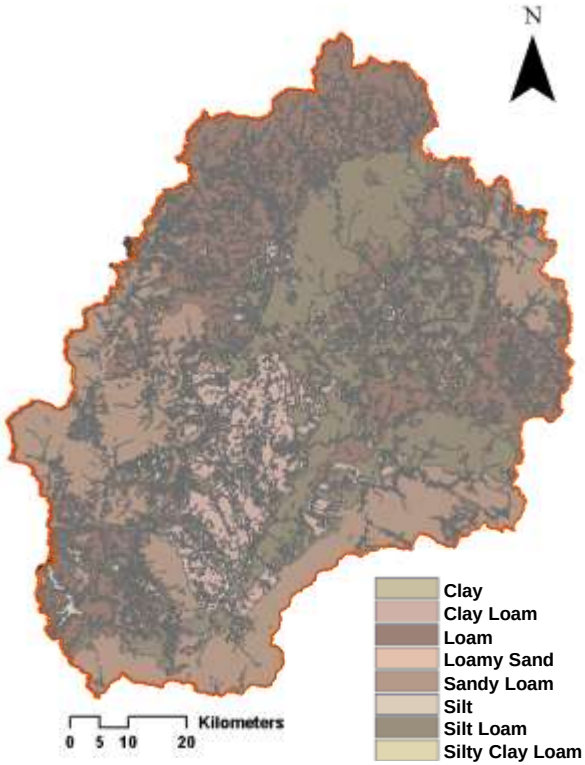
Data Type	Source	Scale / Periods	Data Description / Properties
Terrain	Korea National Geography Institute	30 m	Digital Elevation Model (DEM)
Soil	Korea Rural Development Administration	1/25,000	Soil classification and physical properties viz. texture, porosity, field capacity, wilting point, saturated conductivity, and soil depth
Land use	2004 Landsat TM Satellite Image	1/25,000	Landsat land use classification
Weather	Korea Institute of Construction Technology / WAter Management Information System	1971-2009	Daily precipitation, minimum and maximum temperature, mean wind speed and relative humidity data

GIS Input Data

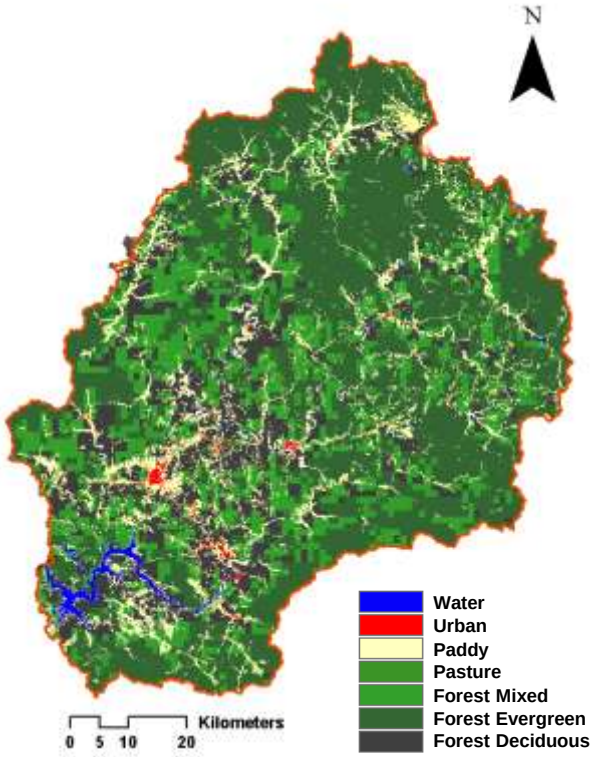
- SWAT Input Data



(a) DEM

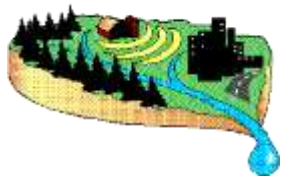


(b) Soil



(c) Landuse

Model theory



- **SWAT (Soil and Water Assessment Tool)**

  - ✓ **Water Balance Equation :**

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

SW_t = *Final soil water content (mm)*

SW_0 = *Initial soil water content on day i (mm)*

R_{day} = *Amount of precipitation on day i (mm)*

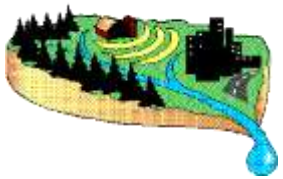
Q_{surf} = *Amount of surface runoff on day i (mm)*

E_a = *Amount of evapotranspiration on day i (mm)*

W_{seep} = *Amount of water entering the vadose zone from the soil profile on day i (mm)*

Q_{gw} = *Amount of return flow on day i (mm)*

Model theory



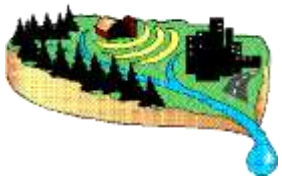
- **SWAT-CUP (SWAT Calibration Uncertainty Program)**
  - ✓ Developed by **Eawag*** Swiss Federal Institute, to analyze the prediction uncertainty of SWAT model calibration and validation results
  - ✓ **Equipped Algorithms :**

a. **SUFI2** (Abbaspour, et al., 2007) : **S**equential **U**ncertainty **FI**tting ver.**2,** the parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data.

b. **GLUE** (Beven and Binley, 1992) : **G**eneralized **L**ikelihood **U**ncertainty **E**stimation is based on the estimation of the weights or probabilities associated with different parameter sets, based on the use of a subjective likelihood measure to derive a posterior probability function, which is subsequently used to derive the predictive probability of the output variables.

*__E__idgenössische __A__nstalt für __W__asserversorgung, __A__bwasserreinigung und __G__ewässerschutz

Model theory



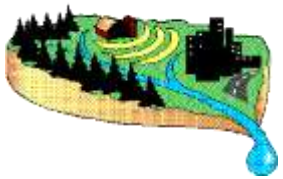
- **SWAT-CUP (SWAT Calibration Uncertainty Program)**
  - ✓ Developed by **Eawag*** Swiss Federal Institute, to analyze the prediction uncertainty of SWAT model calibration and validation results
  - ✓ **Equipped Algorithms :**

c. **ParaSol** (van Griensven and Meixner, 2006) : **Para**meter **Sol**ution method aggregates objective functions (OF) into a global optimization criterion (GOC) and then minimizes these OF's or a GOC using the SCE-UA (Shffled Complex Evolution, Duan, et al., 1992) algorithm.

d. **MCMC** : **M**arkov **C**hain **M**onte **C**arlo generates samples from a random walk which adapts to the posterior distribution (Kuczera and Parent, 1998). This simple techniques from this class is the Metropolis Hasting algorithm (Gelman et al. 1995), which is not applied in this study.

*Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz

Model theory



◆ SWAT-CUP (SWAT Calibration Uncertainty Program)

✓ **Remarkable Words :**

a. **95PPU** : **95** **P**ercent **P**rediction **U**ncertainty, This value is calculated at the 2.5% and 97.5% levels of an output variable, disallowing 5% of the very bad simulations.

b. **Objective Function** : Coefficient of determination (R^2), Nash-Sutcliffe (1970) coefficient… Etc.

c. **p-factor** : The percentage of observations covered by the 95PPU.

d. **r-factor** : Relative width of 95% probability band.

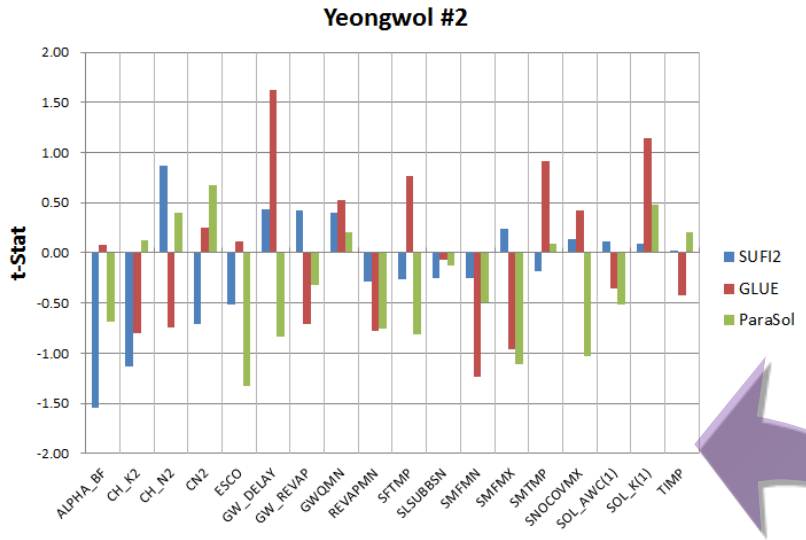
e. **t-Stat** : Provides a measure of sensitivity, larger absolute values are more sensitive.

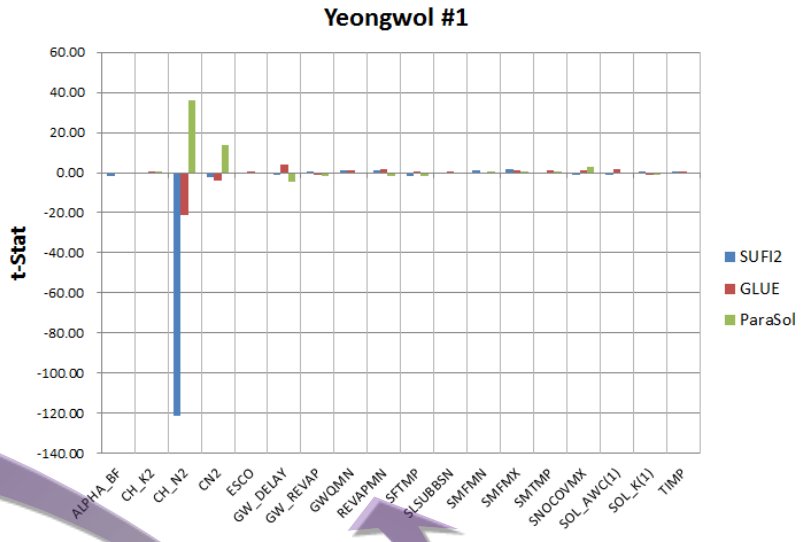
f. **P-Value** : Determined the significance of the sensitivity. A values close to zero has more significance.

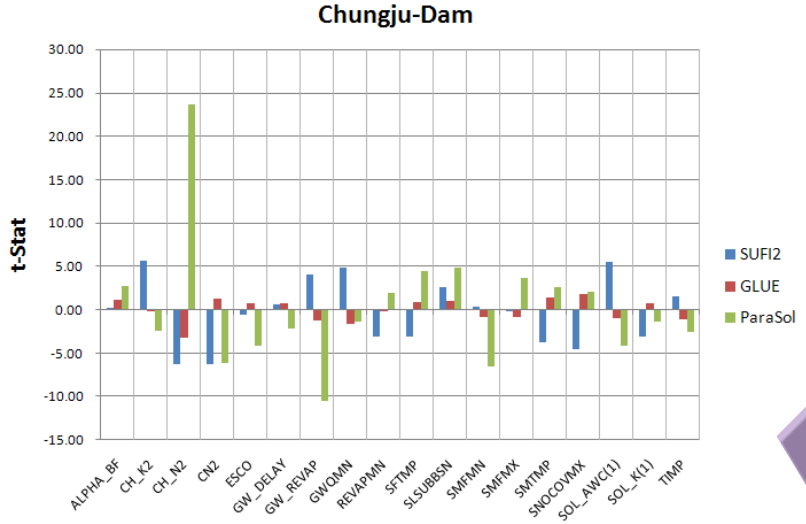
- A P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to measured data. (Karim C. Abbaspour, 2009, SWAT-CUP User maunal)

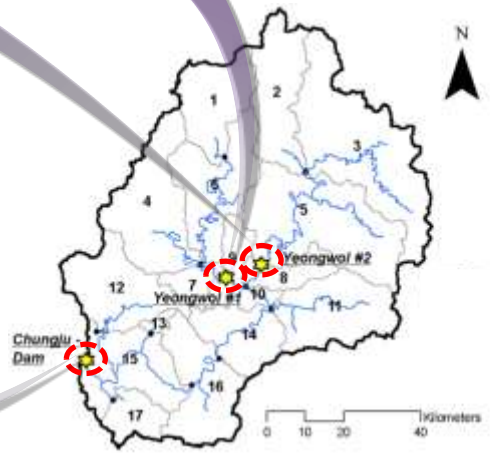
Sensitivity Analysis (SA)

t-Stat



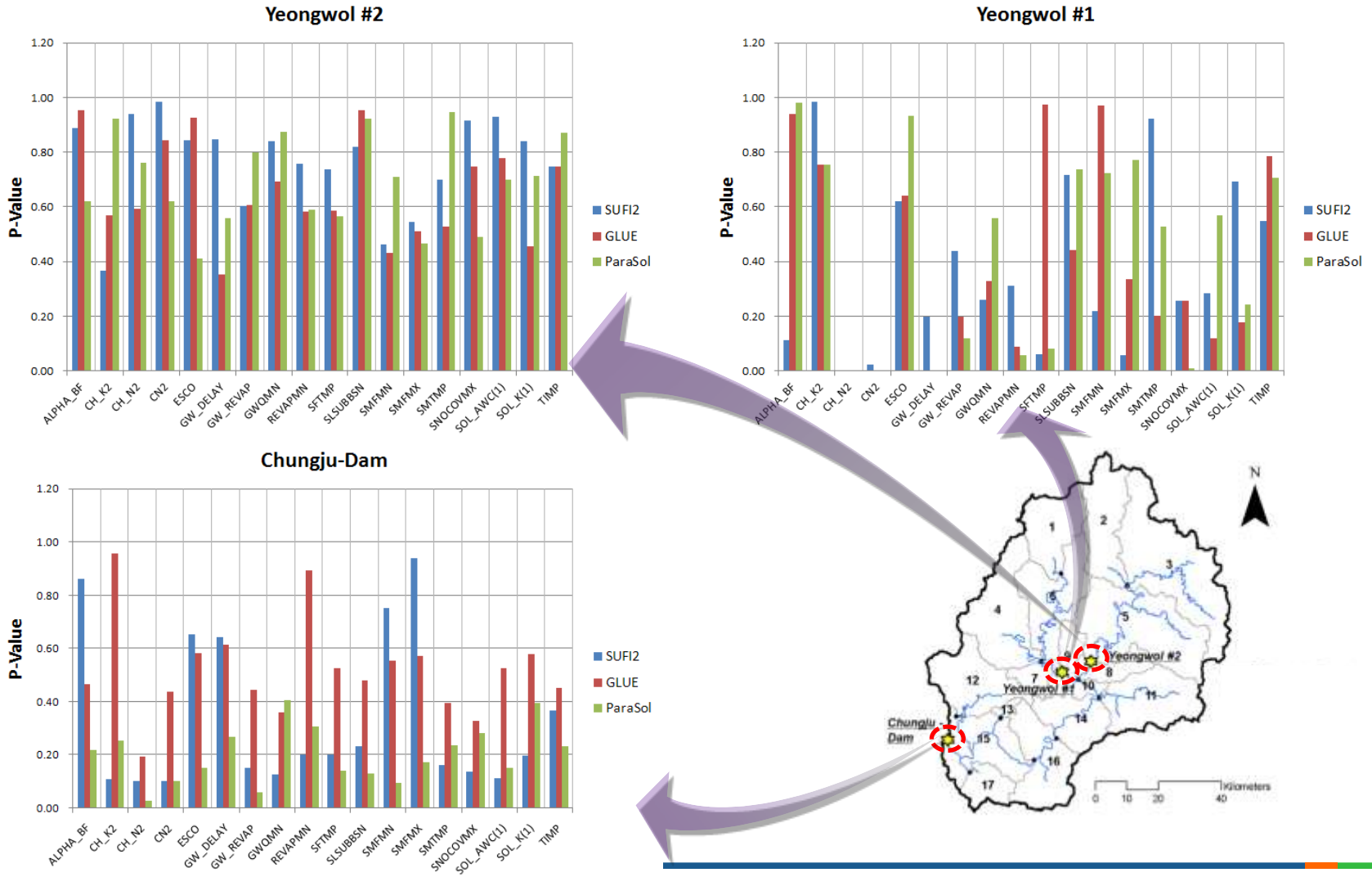




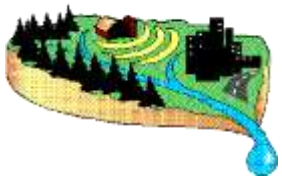


Sensitivity Analysis (SA)

- P-Value

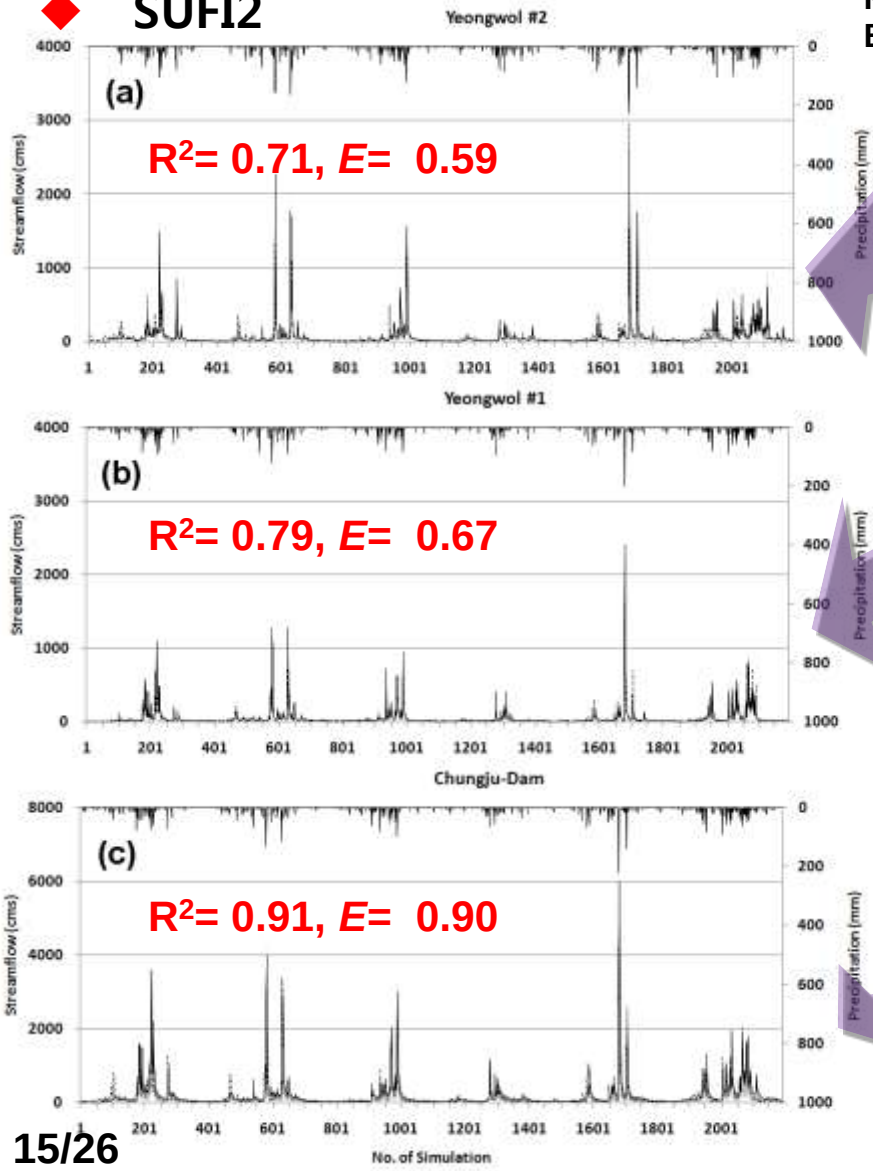


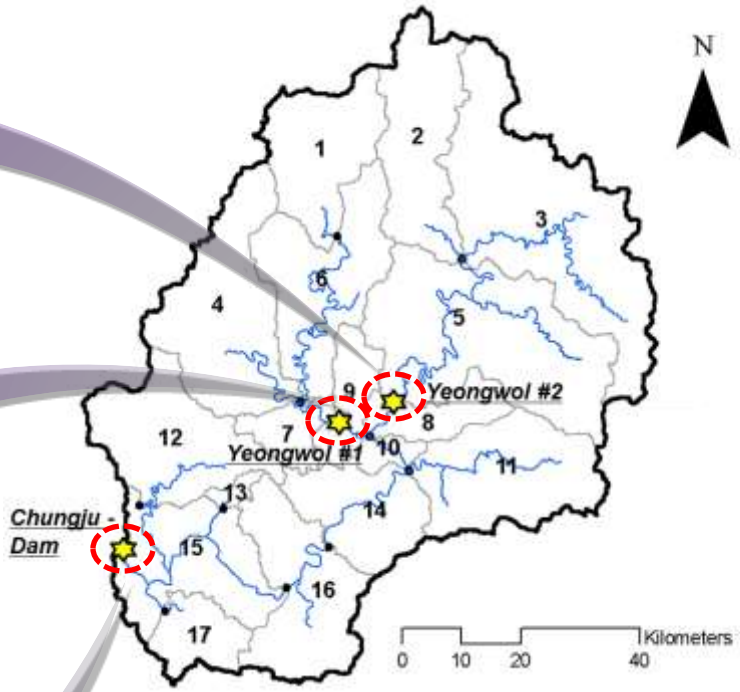
Calibration and Validation



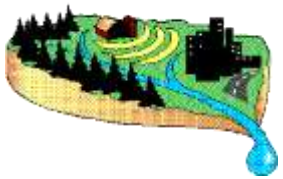
SUFI2

R^2 : Determination Coefficient
E : Model Efficiency



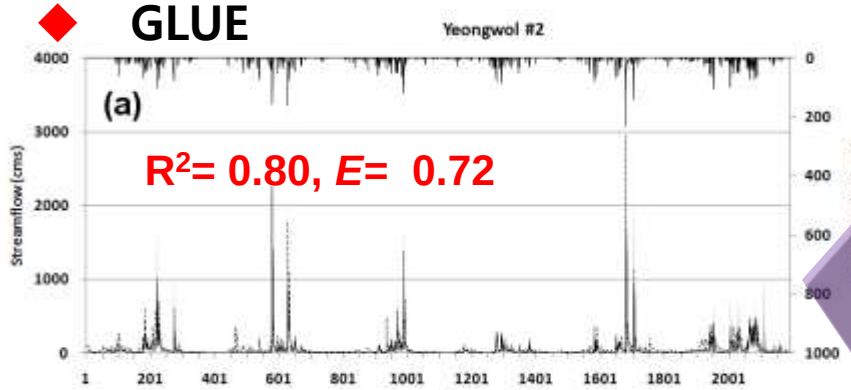


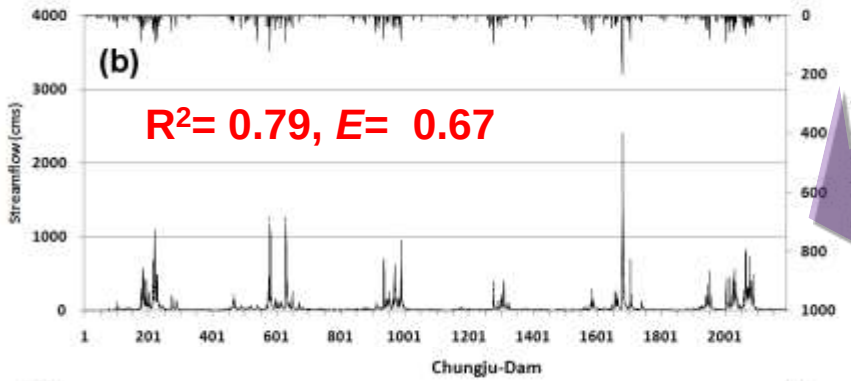
Calibration and Validation

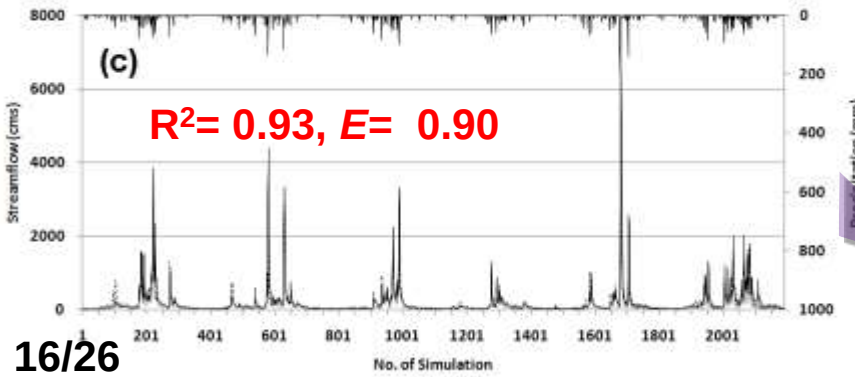


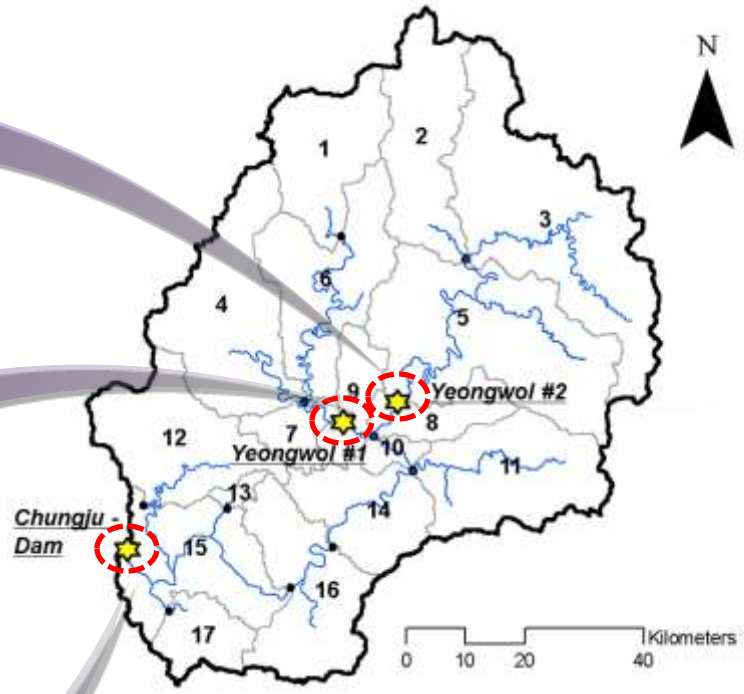
GLUE

R^2 : Determination Coefficient
E : Model Efficiency

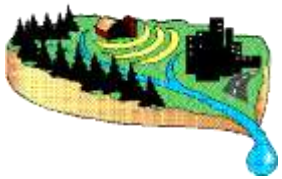






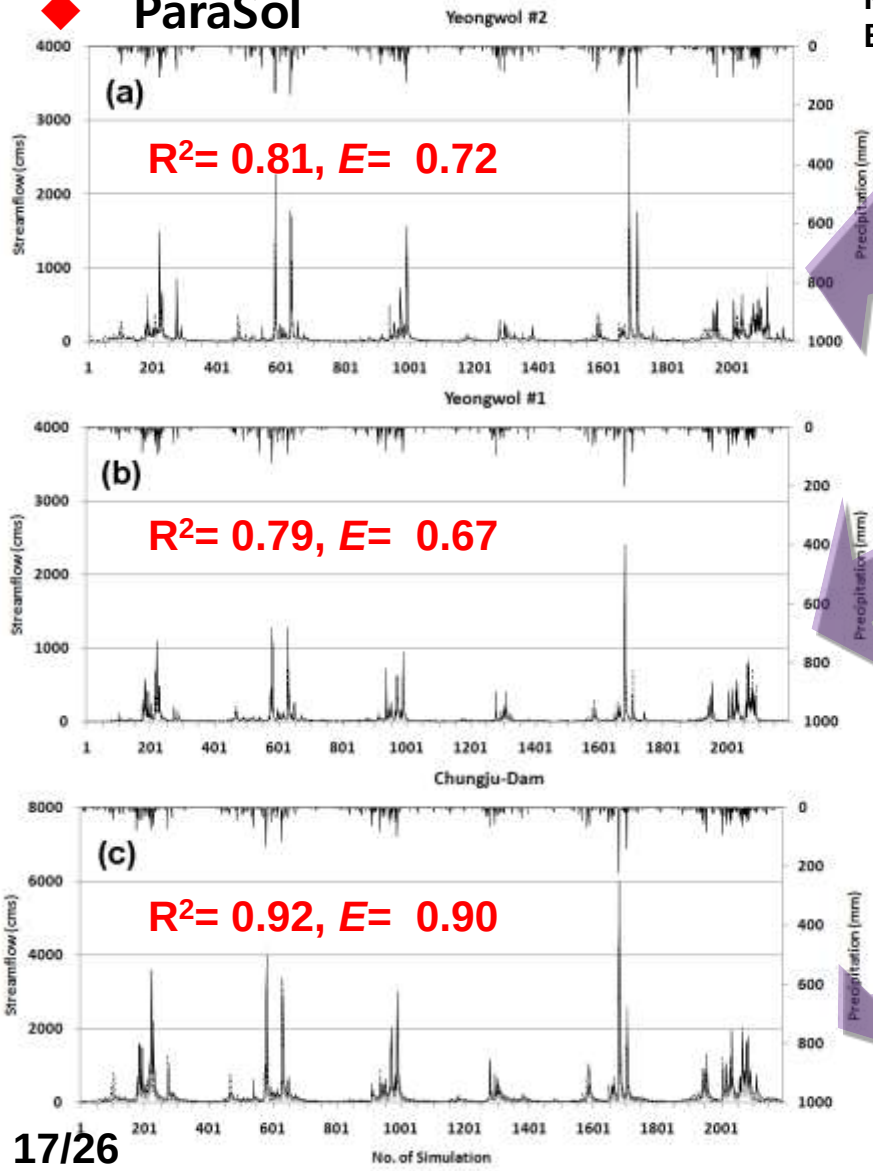


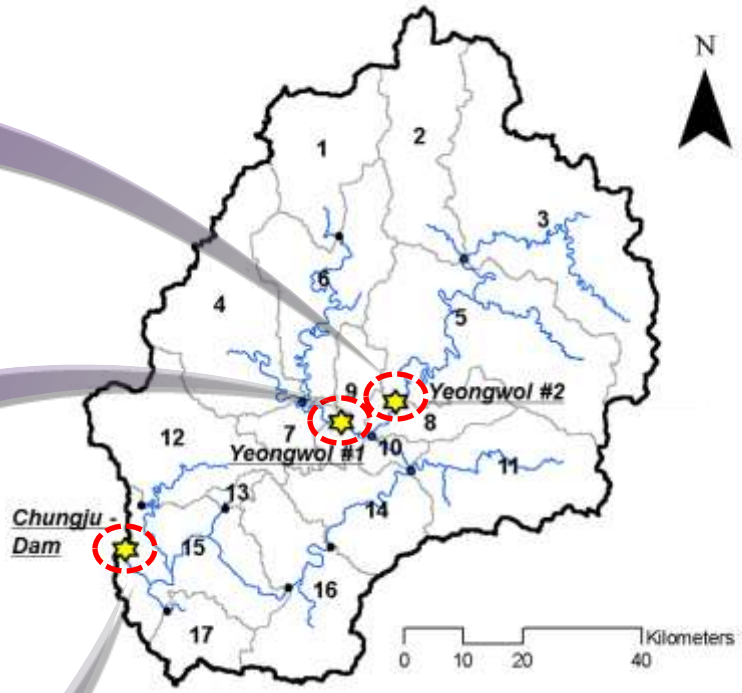
Calibration and Validation



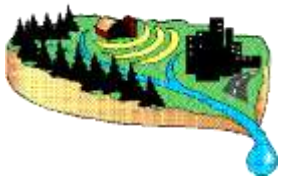
ParaSol

R^2 : Determination Coefficient
E : Model Efficiency



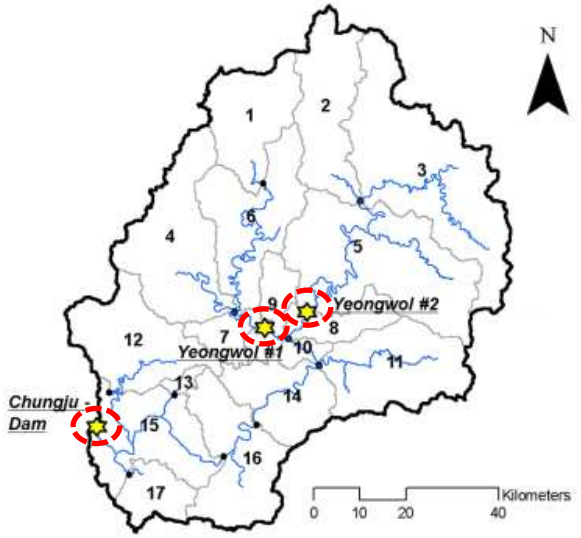


Calibration and Validation



◆ Objective Function and 95PPUs for streamflow

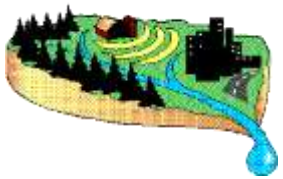
	R^2			E		
Subbasin	No. 5	No. 7	No. 15	No. 5	No. 7	No. 15
SUFI2	**0.71**	**0.79**	**0.91**	**0.59**	**0.67**	**0.90**
GLUE	**0.80**	**0.79**	**0.93**	**0.72**	**0.67**	**0.90**
ParaSol	**0.81**	**0.79**	**0.92**	**0.72**	**0.67**	**0.90**



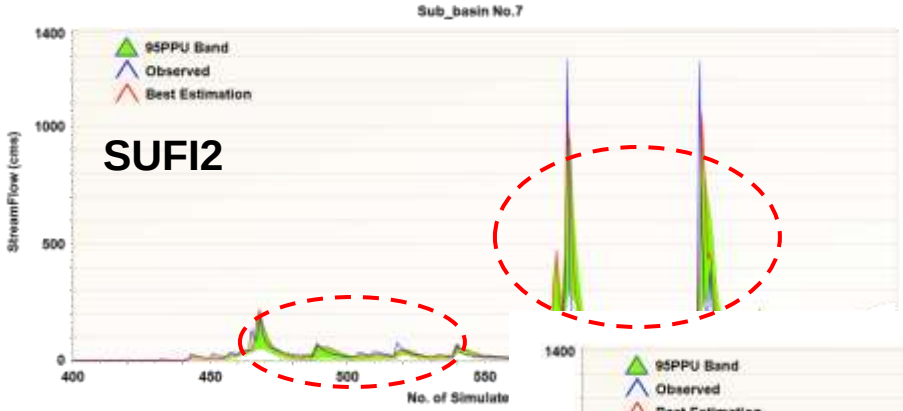
	p-factor			r-factor		
Subbasin	No. 5	No. 7	No. 15	No. 5	No. 7	No. 15
SUFI2	**0.33**	**0.66**	**0.79**	**0.30**	**0.38**	**0.52**
GLUE	**0.26**	**0.56**	**0.44**	**0.30**		
ParaSol	**0.02**	**0.14**	**0.07**	**0.03**		**0.05**

SUFI2 was the Best

Calibration and Validation

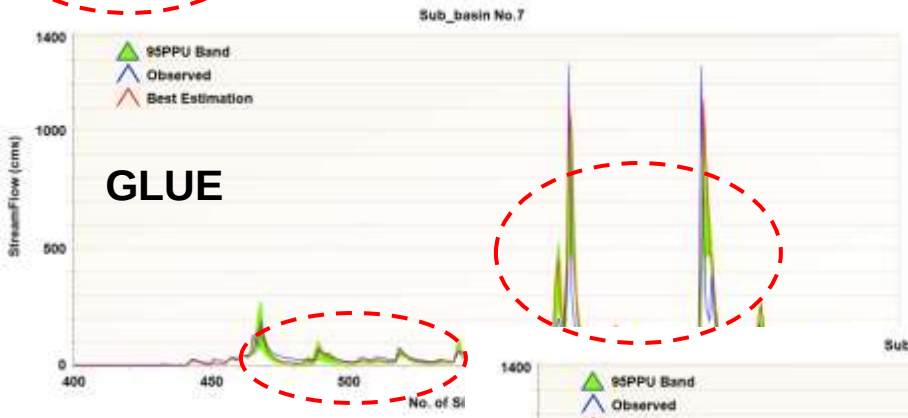


- **Comparing Each Result in Random Section**

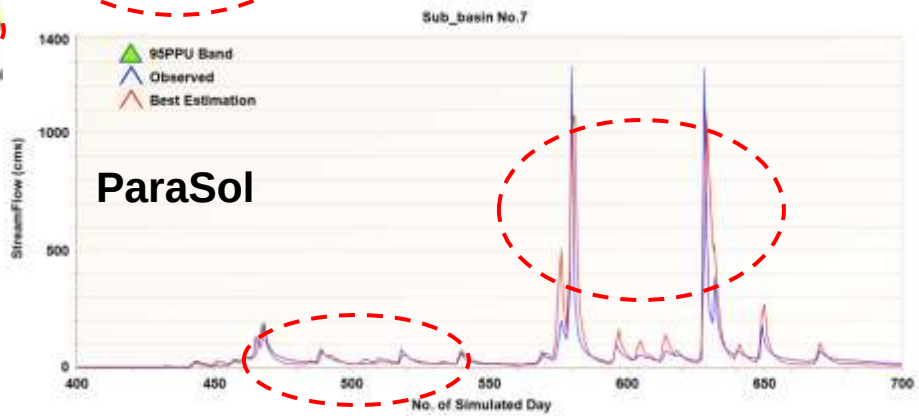


The 95PPU bands (model uncertainty): green color range were caused by the variable parameter set range.

Sensitive and well distributed ↑



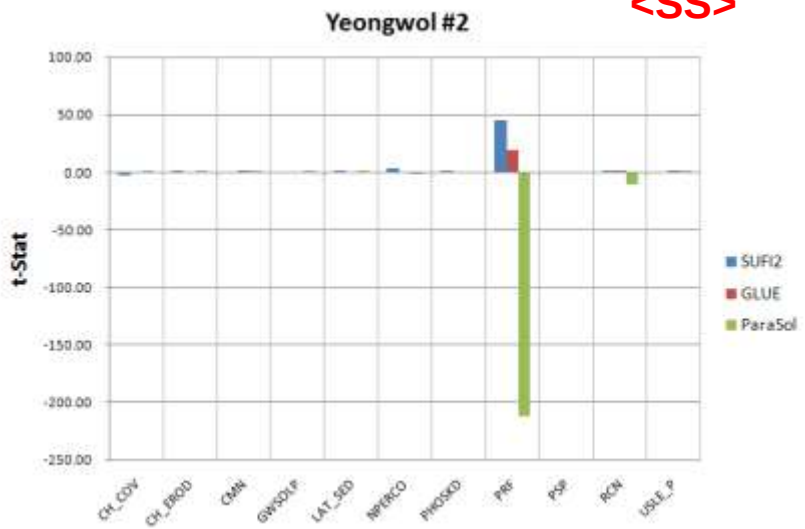
The SUFI2 was the most suitable way to find the SWAT Uncertainty under the condition that the parameter range was specified. → Responded to parameter set more sensitive than any others.



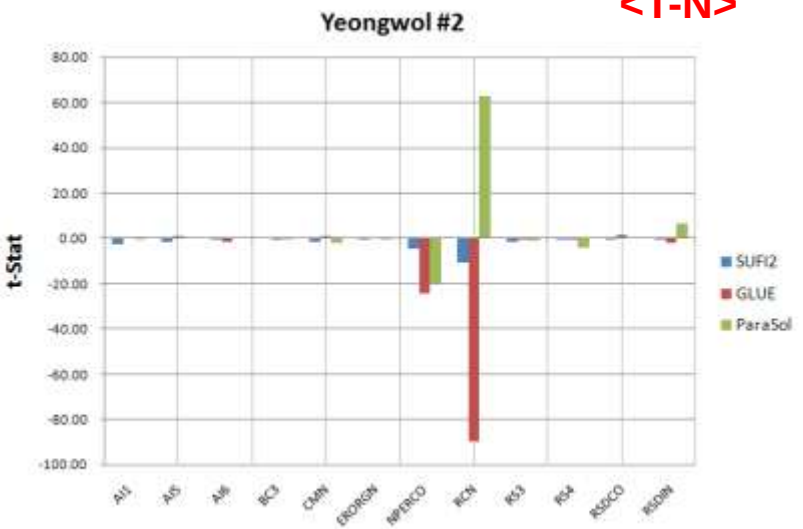
Sensitivity Analysis (SA)

- t-Stat

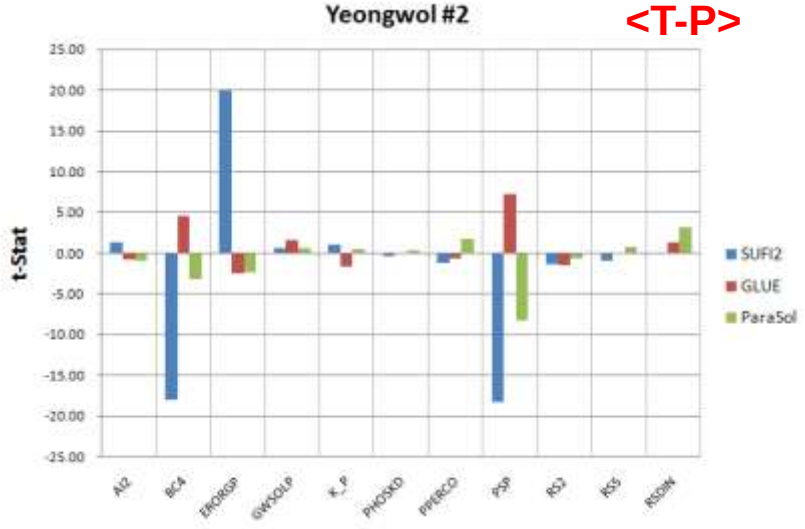
<SS>



<T-N>



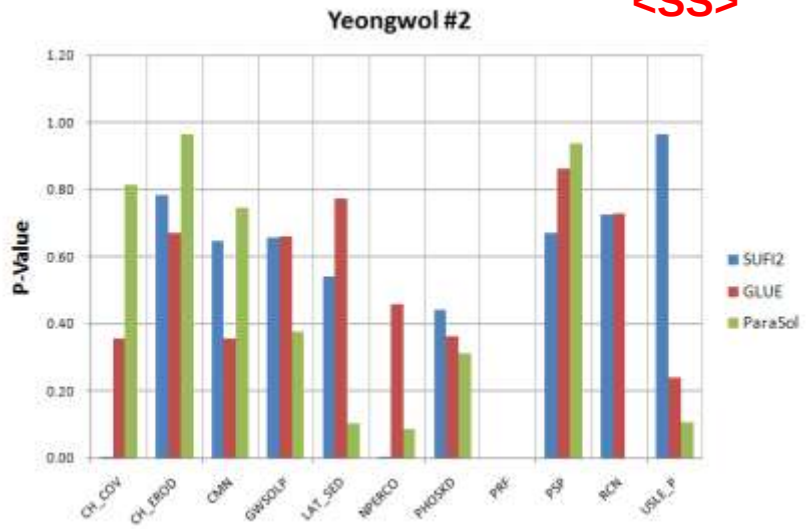
<T-P>



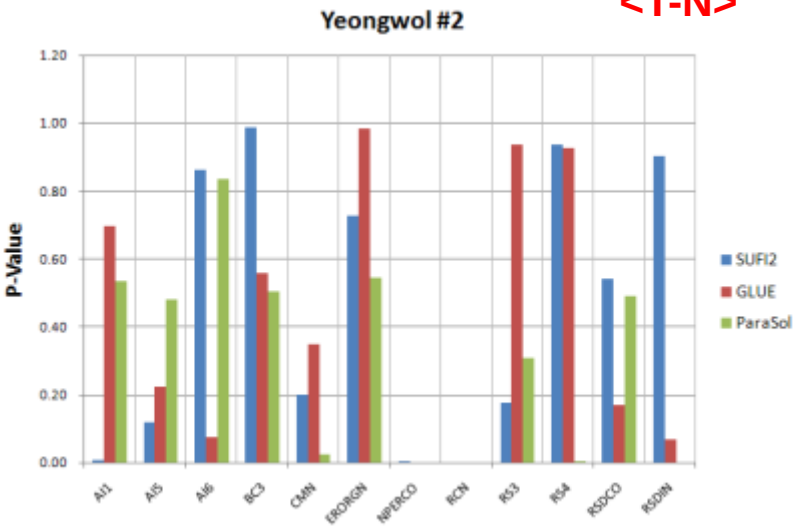
Sensitivity Analysis (SA)

- P-Value

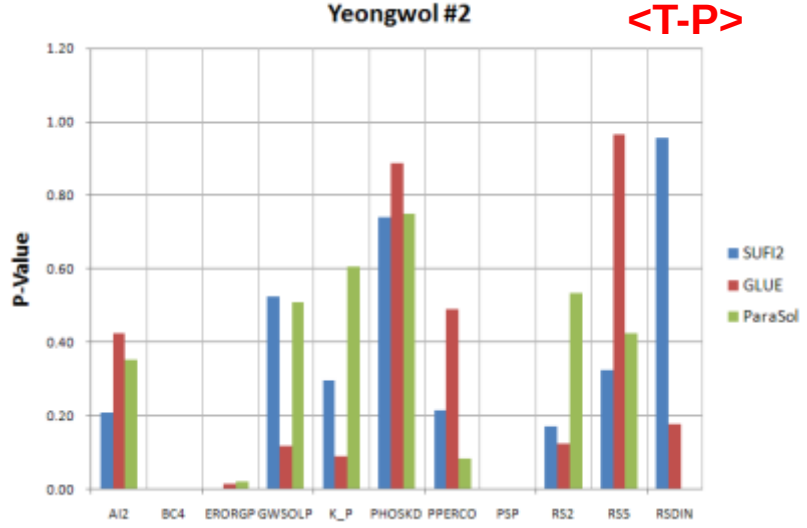
<SS>



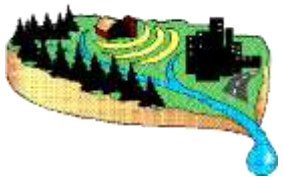
<T-N>



<T-P>



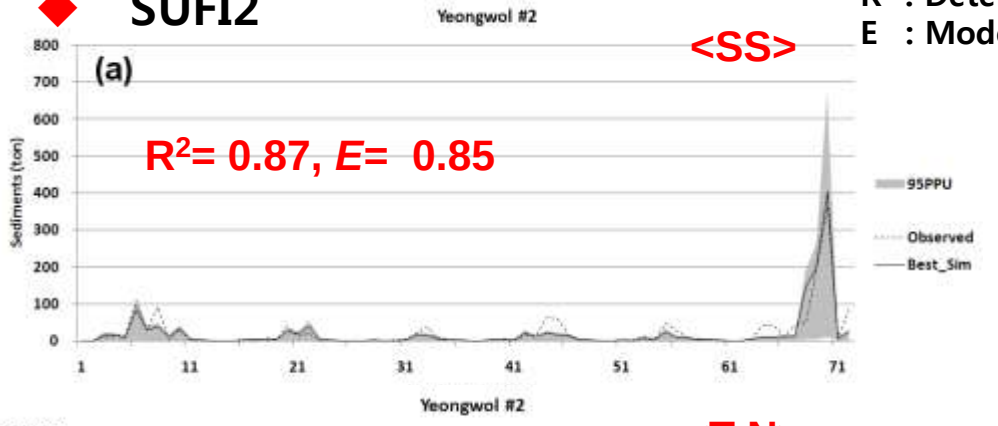
Calibration and Validation



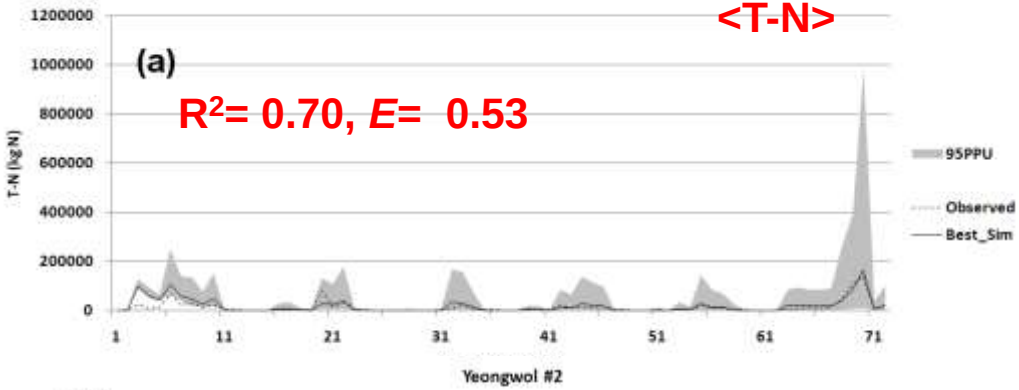
◆ **SUFI2**

R^2 : Determination Coefficient
E : Model Efficiency

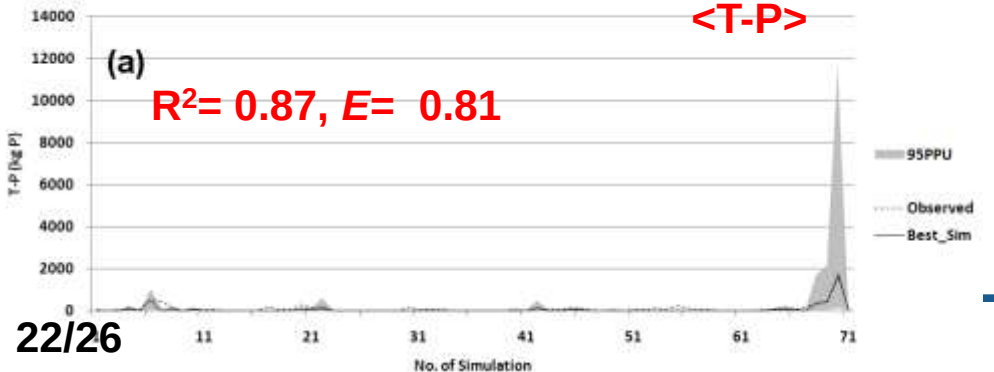
<SS>

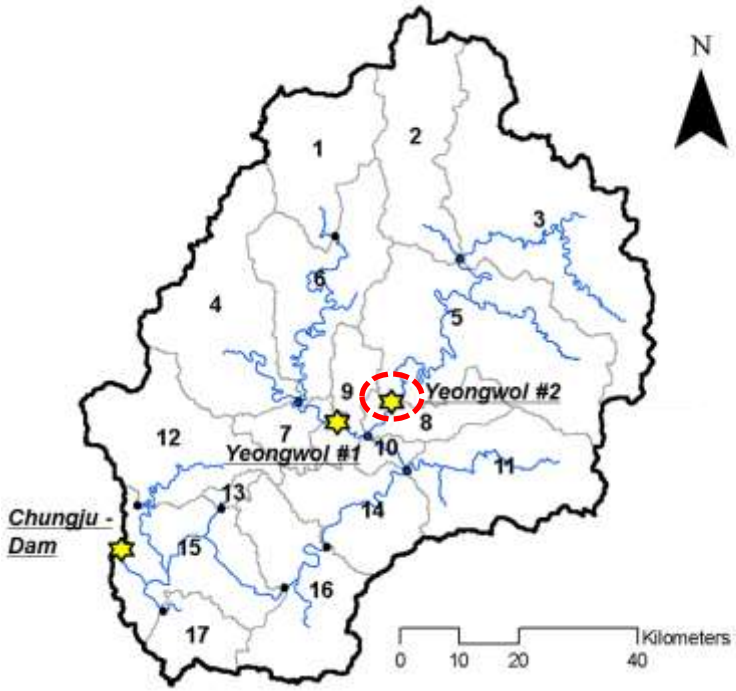


<T-N>

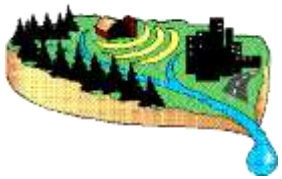


<T-P>





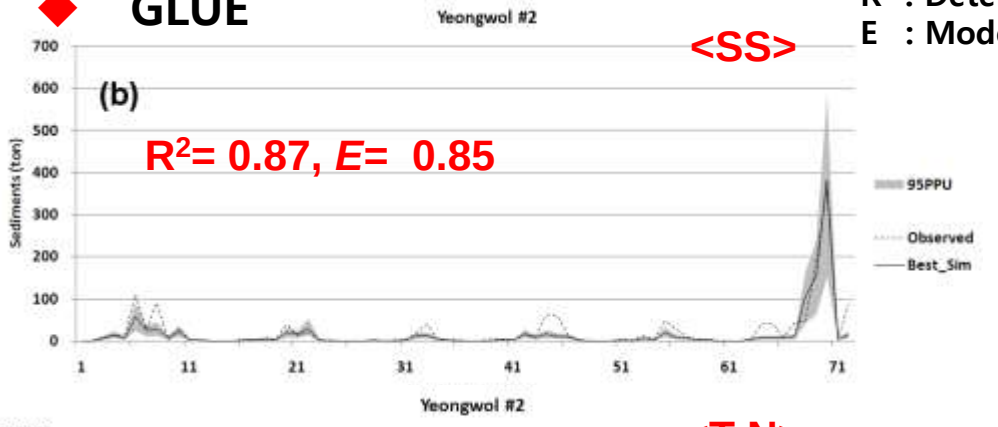
Calibration and Validation



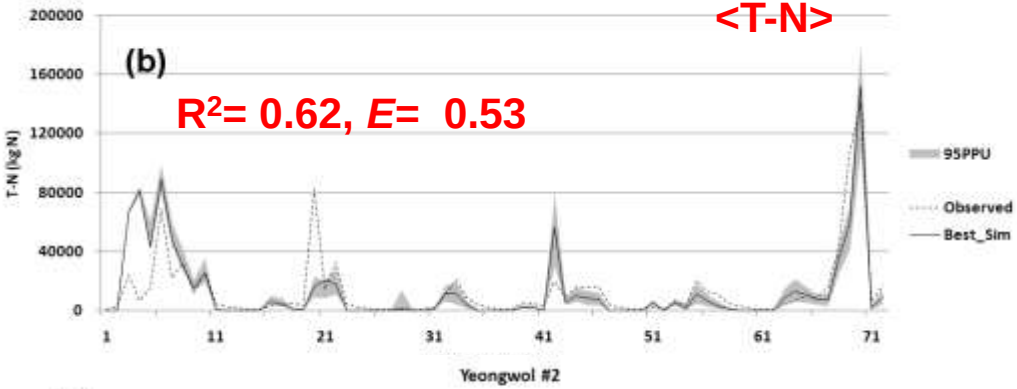
◆ **GLUE**

R^2 : Determination Coefficient
E : Model Efficiency

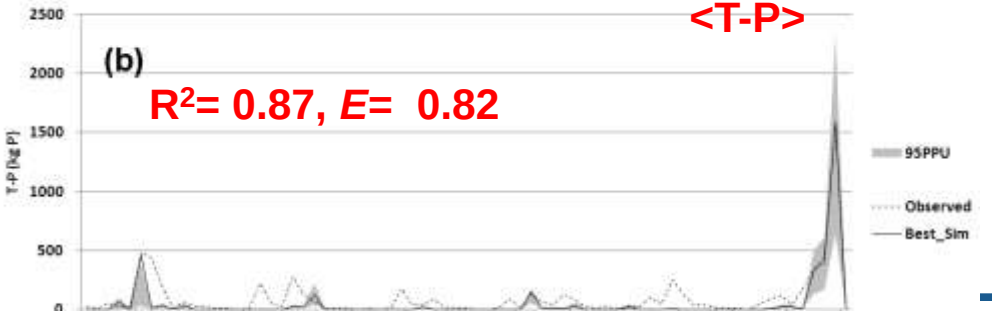
<SS>

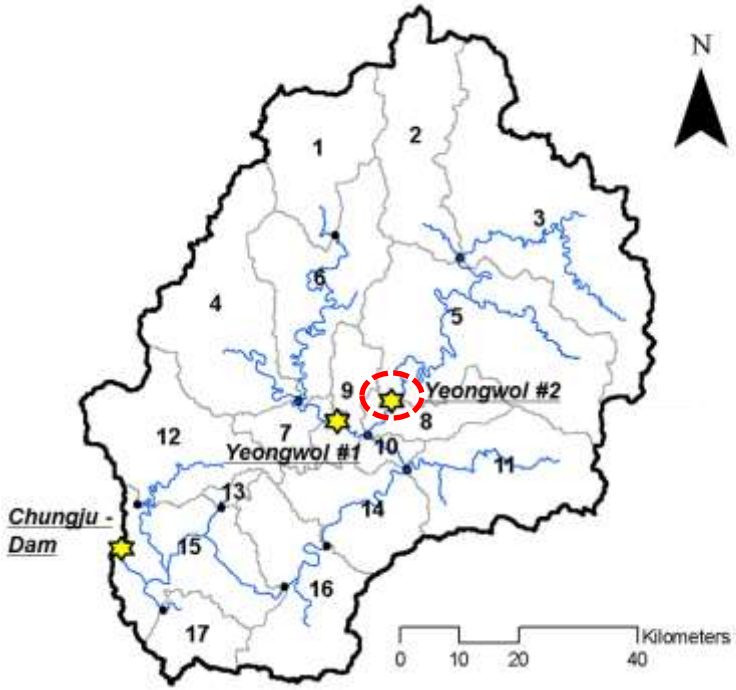


<T-N>

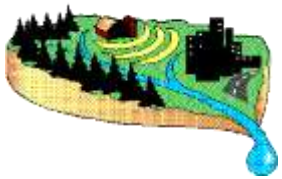


<T-P>





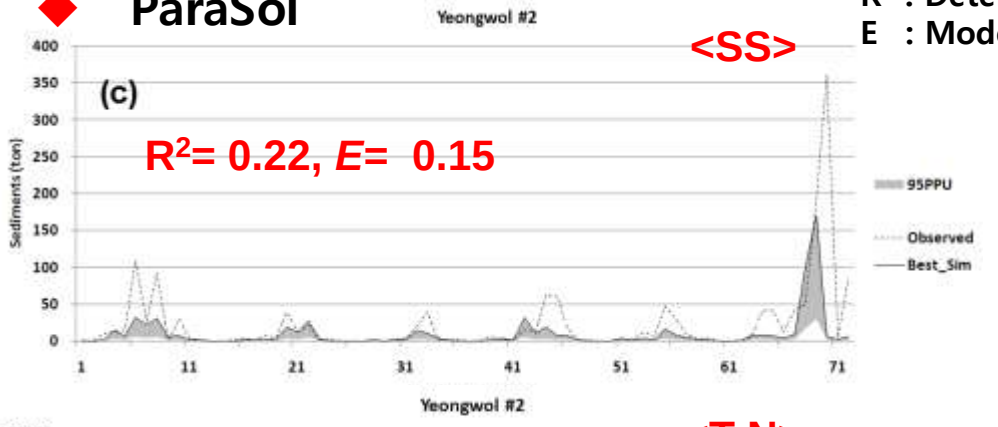
Calibration and Validation



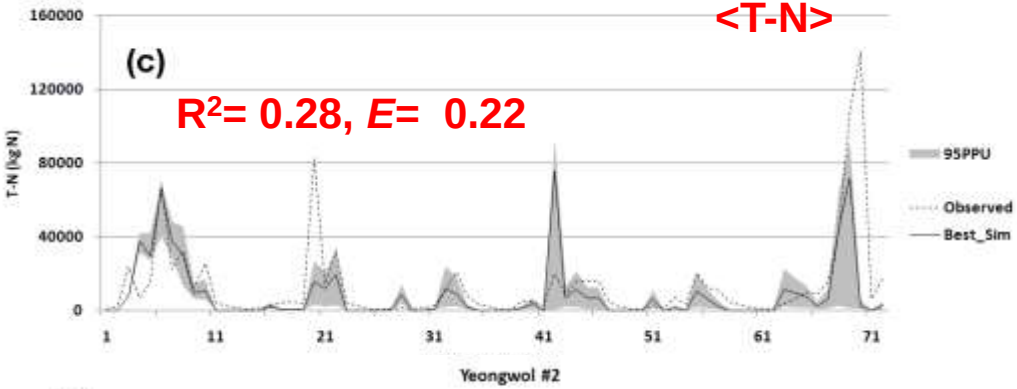
◆ **ParaSol**

R^2 : Determination Coefficient
E : Model Efficiency

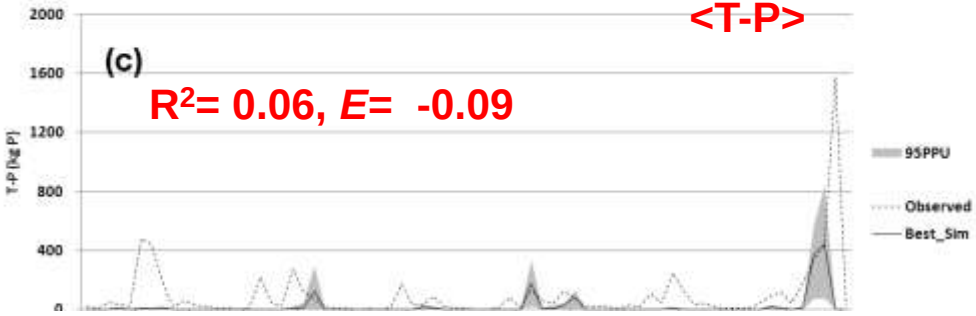
<SS>

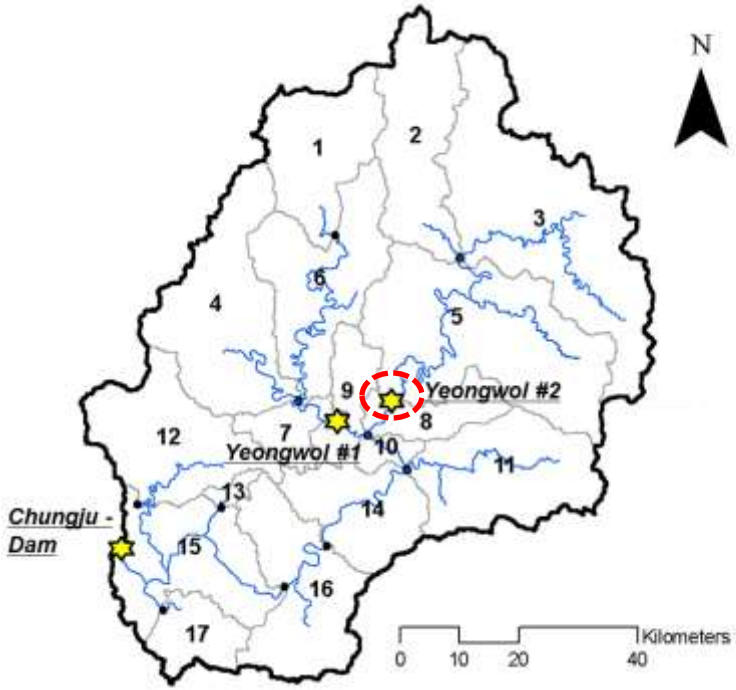


<T-N>

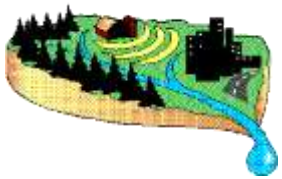


<T-P>



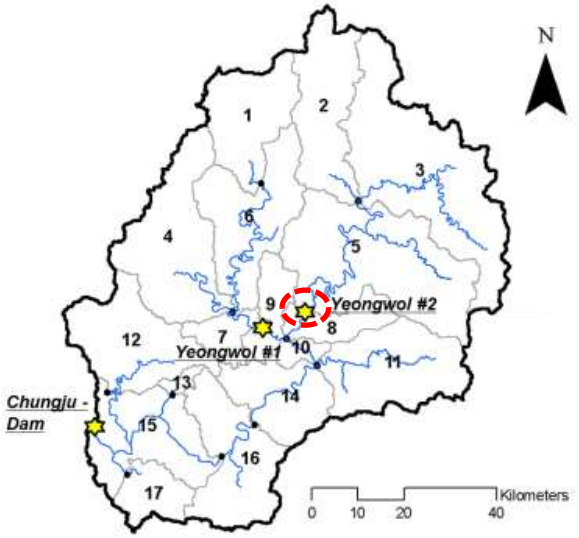


Calibration and Validation



Objective Function and 95PPUs for Water Quality

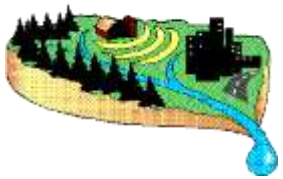
	R^2			E		
	SS	T-N	T-P	SS	T-N	T-P
SUFI2	**0.87**	**0.70**	**0.87**	**0.85**	**0.53**	**0.81**
GLUE	**0.87**	**0.62**	**0.87**	**0.85**	**0.53**	**0.82**
ParaSol	**0.22**	**0.28**	**0.06**	**0.15**	**0.22**	**-0.09**



	p-factor			r-factor		
	SS	T-N	T-P	SS	T-N	T-P
SUFI2	**0.67**	**0.54**	**0.23**	**0.53**	**2.73**	**1.30**
GLUE	**0.40**	**0.17**	**0.10**	**0.35**		
ParaSol	**0.19**	**0.22**	**0.07**	**0.15**		**0.15**

SUFI2 was the Best

Summary and Conclusion



- ✓ This study tried to evaluate the prediction uncertainty of SWAT model for streamflow and water quality.

  - As a result, there was no significant difference in the R^2, Nash-Sutcliffe coefficient (NSE) values for each procedure.

  - However, the p-factor and r-factor indicated that the numerical 95PPUs bands showed clear distinction in this analysis. In this study, ParaSol algorithm showed the lowest p-factor and r-factor, while SUFI-2 algorithm was the highest in the p-factor and r-factor.

  - The SUFI2 algorithm showed the most sensitive and evenly distributed 95PPUs bands for streamflow and water quality.

  - **With the SUFI2 algorithm, we could assess the most sensitive results and reduce model uncertainty effectively.**

  - **This study gave us an obvious information that the evaluation of model uncertainty caused by SWAT hydrologic modeling could be predictable and quantified by SWAT-CUP.**

This work was supported by Mid-career Researcher Program through NRF grant funded by the MEST (No. 2009-0080745).

" Thank You "

For further information, please contact:

JOH, Hyung-Kyung
Graduate student, Dept. of Civil & Environmental System Engineering, Konkuk University
jawbreak@konkuk.ac.kr

Soil & Water Assessment Tool | SWAT

Dept. of Civil and Environmental System Eng.,
Konkuk University, Seoul, South Korea