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Parameter Calibration of SWAT Hydrology and Water Quality Focusing on Long-term Drought Periods

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Introduction (Why this study?)

- For water resources management in river watershed area, it is essential to make reliable predictions on discharge pattern including scale and frequency during flood or drought periods.

- Hydrological model is employed to draw consistent predictions on the stream discharge of such watersheds. Results of hydrological models sensitively convey various factor including spatial assessment of hydrological cycle and parameter estimation scheme.

- Recent droughts over past two successive years, 2014 and 2015, were a concentrated long-term drought over north central region of South Korea. In addition to existing annual chronic agricultural drought, it was a severe drought that impeded domestic and industrial water supply.

- Thus, to conduct hydrological analysis on long-term drought, additional calibration on parameters should be arranged.

Introduction (Why this study?)

- In general, the SWAT parameter values are to determine to obtain high efficiency for the whole calibration periods (including flood and drought years).

- This study try to calibrate the SWAT parameters focusing on the stream discharge of drought periods. From the results, we will discuss the calibration performance (between the whole period and drought focused), and the meaning of calibrated parameter values.

- Long-term droughts are expected to:
  - increase interception amount of trees and crops
  - increase evaporation from ground surfaces (especially forest litter layer)
  - affect infiltration capacity and hydraulic conductivity by soil aggravation
  - influence subsurface flow and groundwater recharge amount by the lowered groundwater level

Research procedure

Model Input

Meteorological Data

- *Daily weather data (2002-2015)*
  - *3weather stations (SW, IC, CA)*
  - *Precipitation (mm/day), Temperature (℃), Wind speed (m/s), Solar radiation (MJ/㎡), Relative humidity(%)*

GIS Data

- *Watershed boundaty*
- *Digital Elevation Model(30m)*
- *Soil map (1:25,000)*
- *Land use map*
  - *7categories*

Monitoring Data

- *Daily streamflow data (2002-2015)*
  - *Watershed outlet (Gongdo)*
- *Daily water quality data (2002-2015)*
  - *Water quality Observation post (Anseong cheon2)*

Model Process

SWAT Model Setup

- *Model run (2002-2015), warm-up(1998-2001)*
- *Parameters sensivity analysis*
- *Streamflow, Sediment, T-N, T-P*

Hydrology

- *Normal Calibration (2002-2006, 5yr)*
- *Drought period Calibration (2014-2015, 2yr)*

Key Parameters

- *Each period of normal and drought*
  - *Surface runoff (CN2)*
  - *Canopy storage (CANMX)*
  - *Evapotranspiration (ESCO)*
  - *Soil water (SOL-K, SLSOIL, LAT-TIME)*
  - *Groundwater (GW-DELAY, GWQMN, ALPHA-BF)*

Water Quality

- *Normal and drought period Calibration (2002-2015, 14yr)*
- *Key parameters*

Model Results

SWAT Model application

- *Application of difference parameters*
  - *Normal vs. drought period calibrated versions*
- *Analysis of hydrologic and water quality response to climate variability*
- *Evaluation of model performance (R^2, NSE, RMSE)*

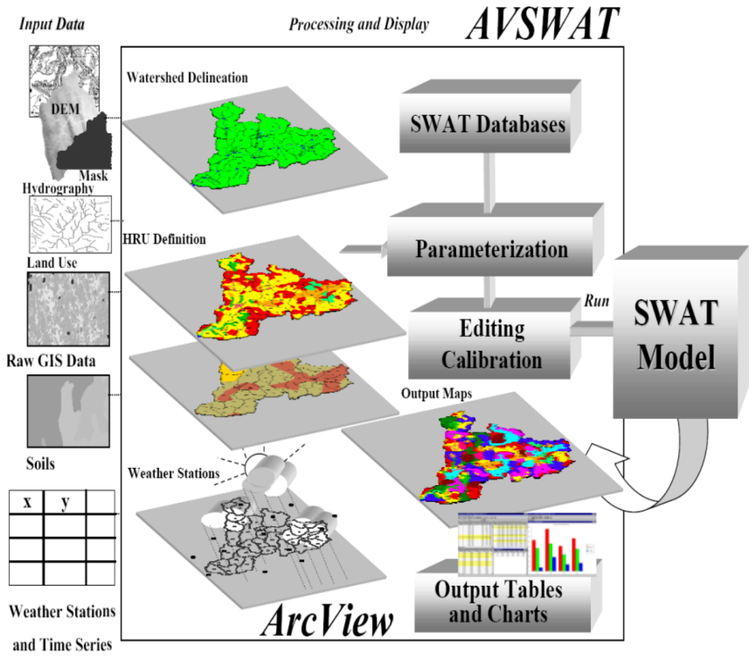
SWAT model (Soil and Water Assessment Tool)

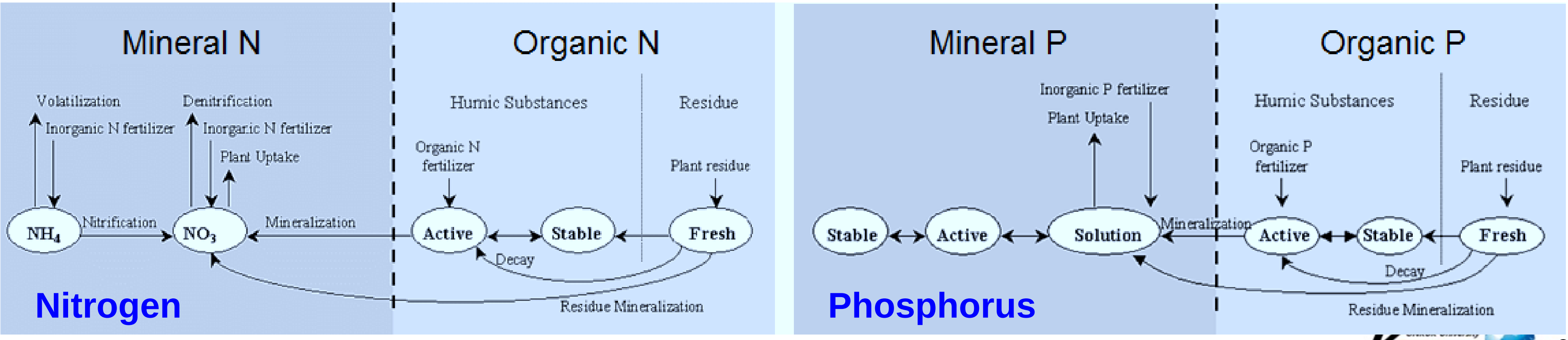
❖ ***SWAT (Soil and Water Assessment Tool)***

✓ SWAT model operations on daily time step and based on the concept of hydrologic response units (HRUs).

✓ HRUs are portion of a sub watershed that possess unique land use / management / soil attributes.

✓ SWAT is able to simulate surface and subsurface flow, sediment generation and deposit, and nutrient late and movement through the landscape and river .





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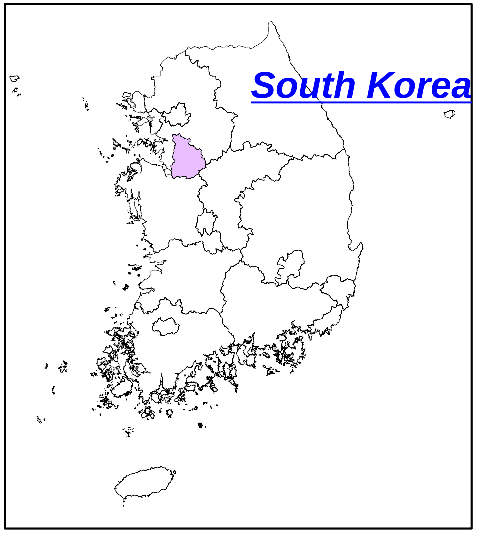
Study area



Location

Latitude 36°94′ to 36°95′
Longitude 127°23′ to 127°24′

Observation Station

Water quality station

Watershed & Stream

❖ *Gong-do Watershed(362.7 km²)*
- ✓ *Average precipitation 1219.4 mm*
- ✓ *Average temperature 13℃*

SWAT model (18 sub-basins)

BG

N

Suwon

SW

Icheon

YJ HH

Monitoring Station

DY OS

JD PT AS AS

SS

PS GD

TB YR

Watershed outlet

Cheonan

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Materials and Methods

SWAT Input DATA

Data Type	Source	Scale / Period	Data Description / Properties
Topography	Water Resources Management Infor mation System	30m by 30m	DEM (Digital Elevation Model)
Soil	Korea Rural Development Administration	1/25,000	Soil classifications and physical properties viz. texture, porosity, field capacity, wilting point, saturated conductivity, and soil depth
Land cover	Water Resources Management Information System	30m by 30m	2010 Landsat land use classification (7 classes)
Weather	Korea Meteorological Administration	2002~2015	Daily precipitation, minimum and maximum temperature, mean wi nd speed and relative humidity data
Streamflow	Water Resources Management Information System	2002~2015	Daily precipitation, minimum and maximum temperature, mean wind speed, solar radiation and relative humidity dat a
Water Quality	Water Information System	2002~2015	Water quality (SS, T-N and T-P) data

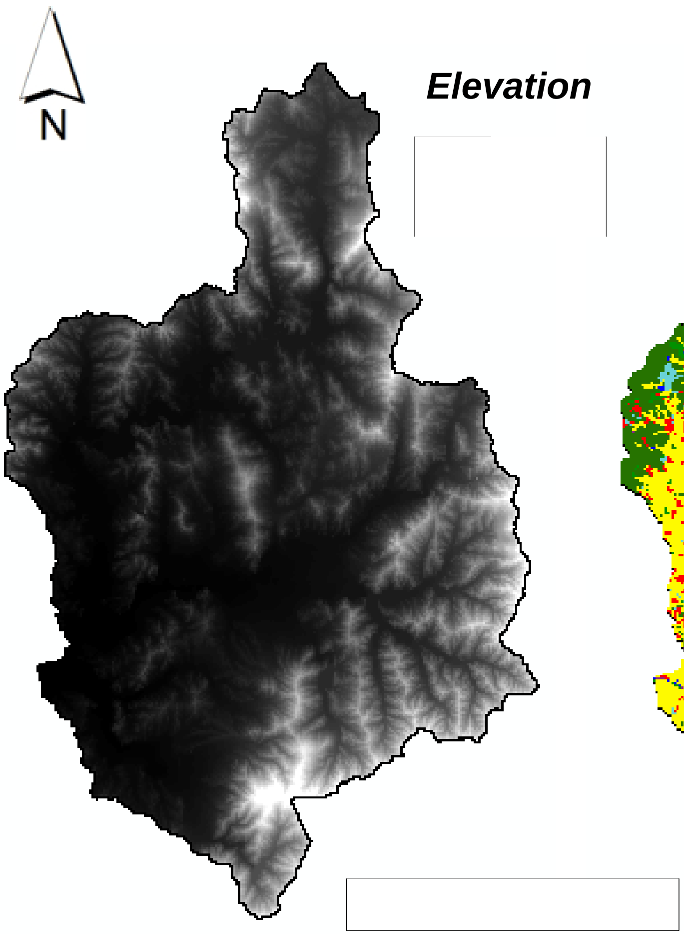
Data for SWAT model evaluation

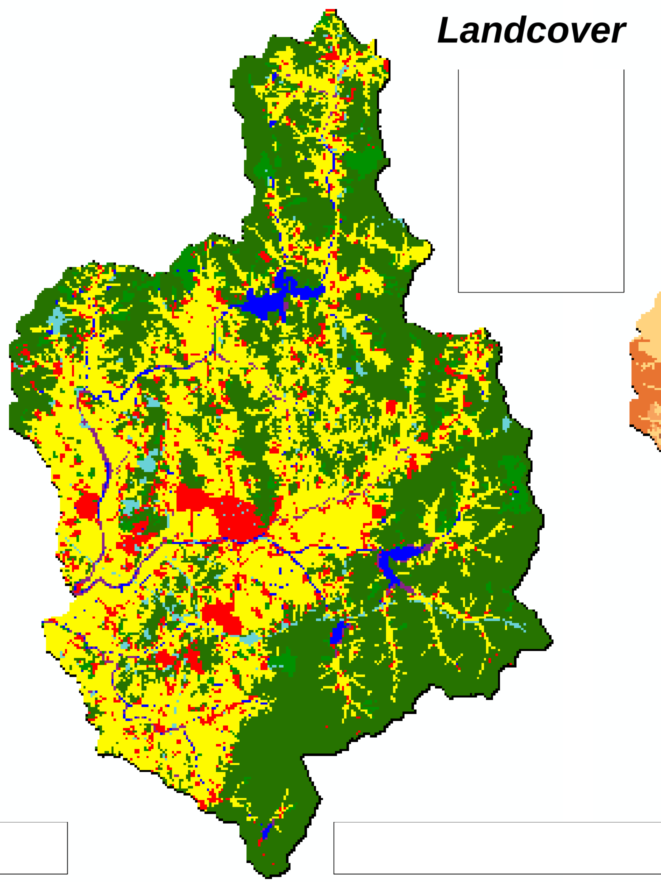
GIS data

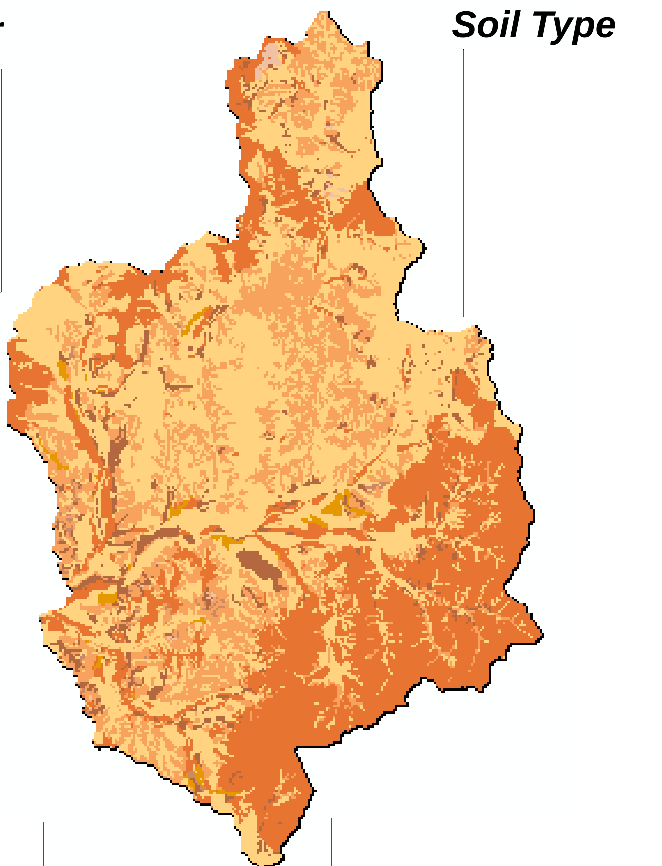
Elevation: 15 - 540m (average: 278m)

Land cover: forest(52%) and agriculture(19%)

Soil: slit loam(49%) and slit clay loam (17%)



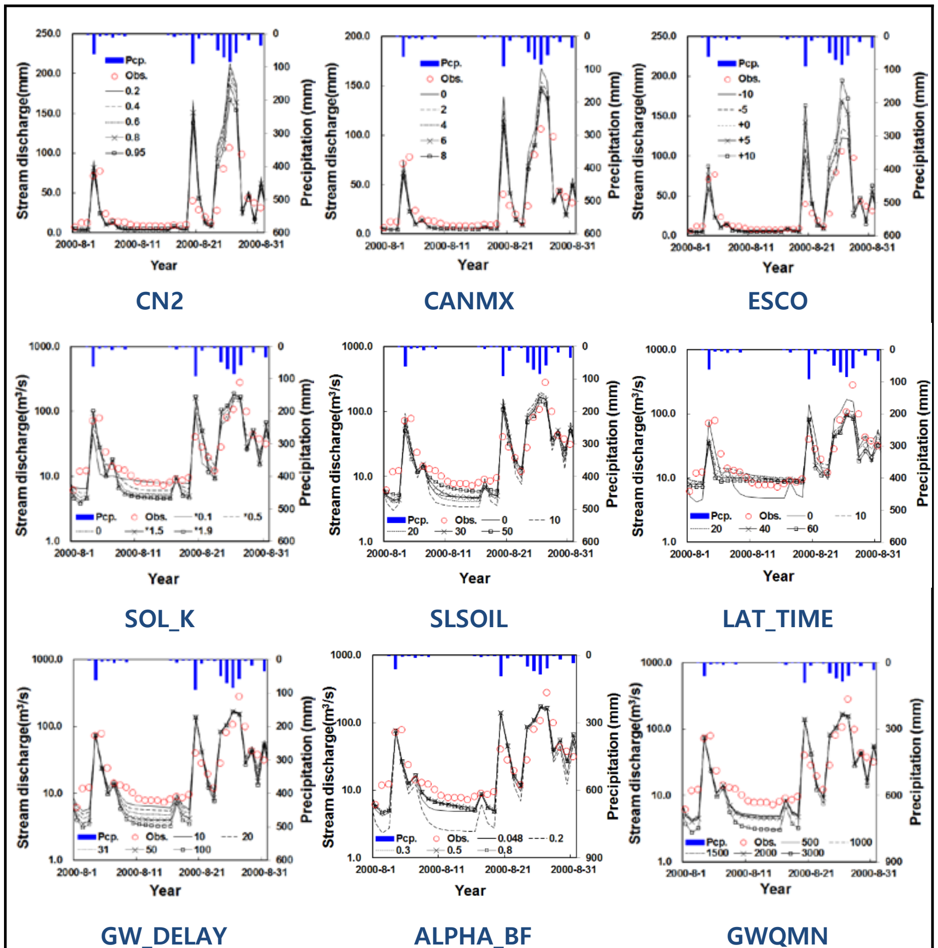




Sensitivity Analysis

❖ SWAT hydrological parameters sensitivity analysis

- ✓ ***A sensitivity analysis was conducted on the SWAT model parameters before the calibration.***
- ✓ ***3 of 9 parameters were selected and examined in terms of how they affect the quantity and the shape of the runoff curve.***



	Parameter	Definition
Surface flow	**CN2**	**SCS curve number for moisture condition**
	CANMX	Maximum canopy storage
	ESCO	Soil evaporation compensation coefficient
Inter flow	**SOL_K**	**Saturated hydraulic conductivity (mm/hr)**
	SLSOIL	**Slope length of lateral subsurface flow (m)**
	LAT_TIME	Lateral flow travel time (days)
Base flow	GW_DELAY	Delay time for aquifer recharge (days)
	GWQMN	Threshold water level in shallow aquifer for base flow (mm)
	ALPHA_BF	Base flow recession constant

*** Neisch et al.(2002)**

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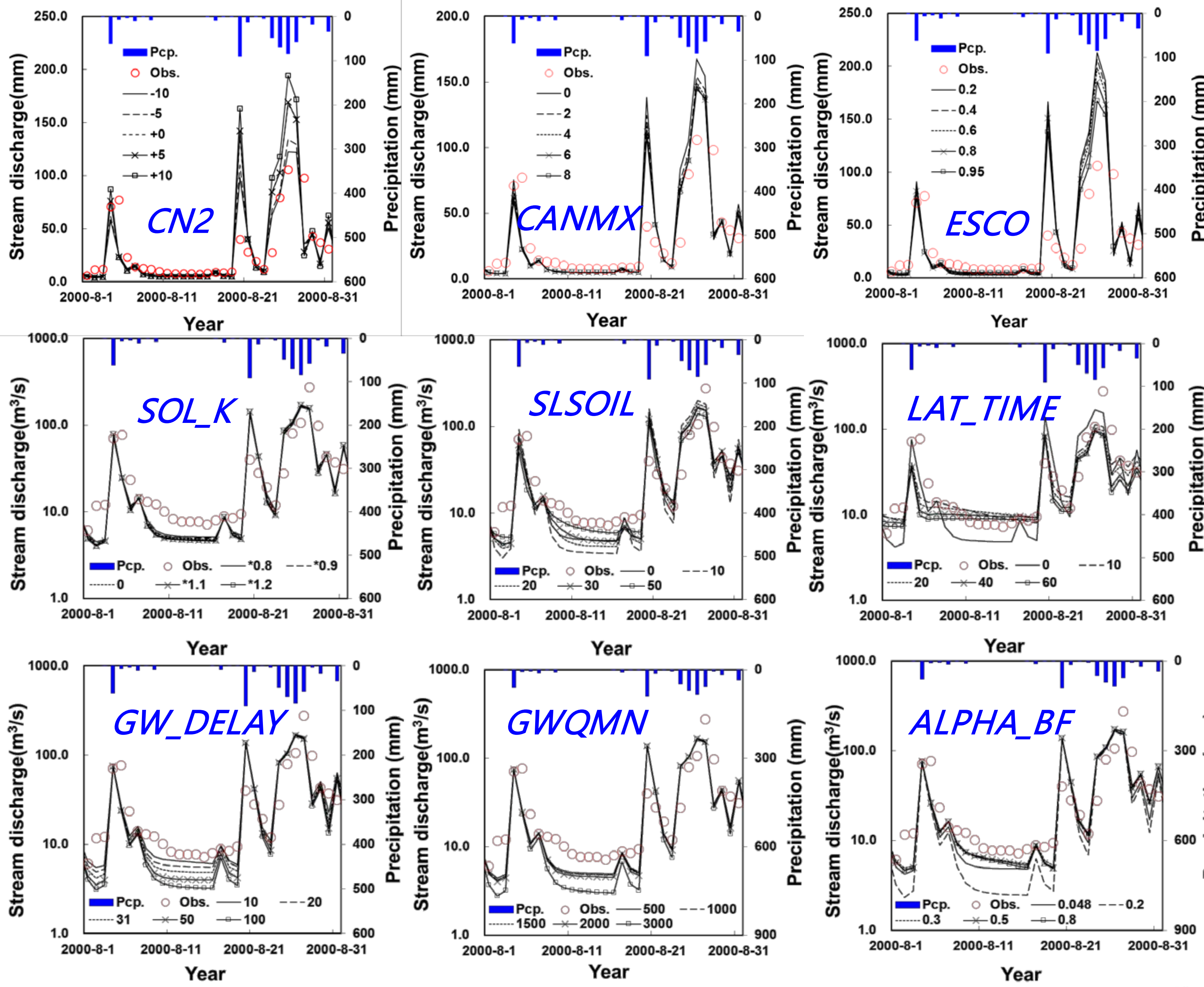
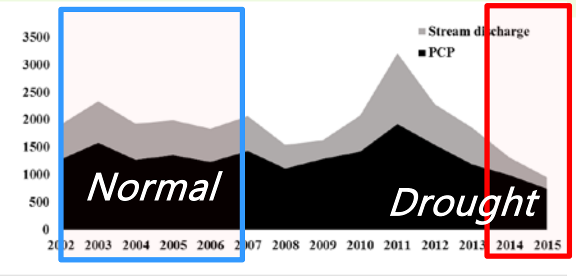

CN2
Pcp.
Obs.
-10
-5
+0
+5
+10
CANMX
0
2
4
6
8
ESCO
0.2
0.4
0.6
0.8
0.95
SOL_K
*0.8
*0.9
0
*1.1
*1.2
SLSOIL
0
10
20
30
50
LAT_TIME
0
10
20
40
60
GW_DELAY
10
20
31
50
100
GWQMN
500
1000
1500
2000
3000
ALPHA_BF
0.048
0.2
0.3
0.5
0.8
Stream discharge(mm)
Stream discharge(m³/s)
Precipitation (mm)
Year
2000-8-1
2000-8-11
2000-8-21
2000-8-31

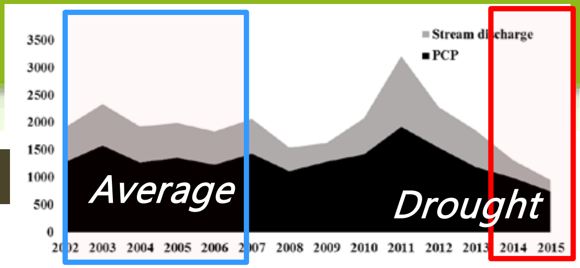
SWAT calibrated parameters

- ***SWAT calibration focusing on 2 target periods***
  - ✓ **Long-term patterns of annual precipitation and stream flow in the study site**
  - ✓ **Target period 1: 5 years (2002-2006)**
  - ✓ **Target period 2: 2 years (2014-2015) drought periods**



Parameter	Definition	Default	Calibration	
			Normal	Drought
CN2	**SCS curve number for moisture condition**	Given by HRU	66 (default)	**-5**
CANMX	Maximum canopy storage	0	5	**7**
ESCO	Soil evaporation compensation coefficient	0.95	0.2	**0.75**
SOL_K	**Saturated hydraulic conductivity (mm/hr)**	Given by HRU	1 (default)	***0.6**
SLSOIL	**Slope length of lateral subsurface flow (m)**	0	0 (default)	**5**
LAT_TIME	Lateral flow travel time (days)	0	8	**3**
GW_DELAY	Delay time for aquifer recharge (days)	31	100	**180**
GWQMN	Threshold water level in shallow aquifer for base flow (mm)	1000	2000	**2500**
ALPHA_BF	Base flow recession constant	0.048	0.3	**0.55**

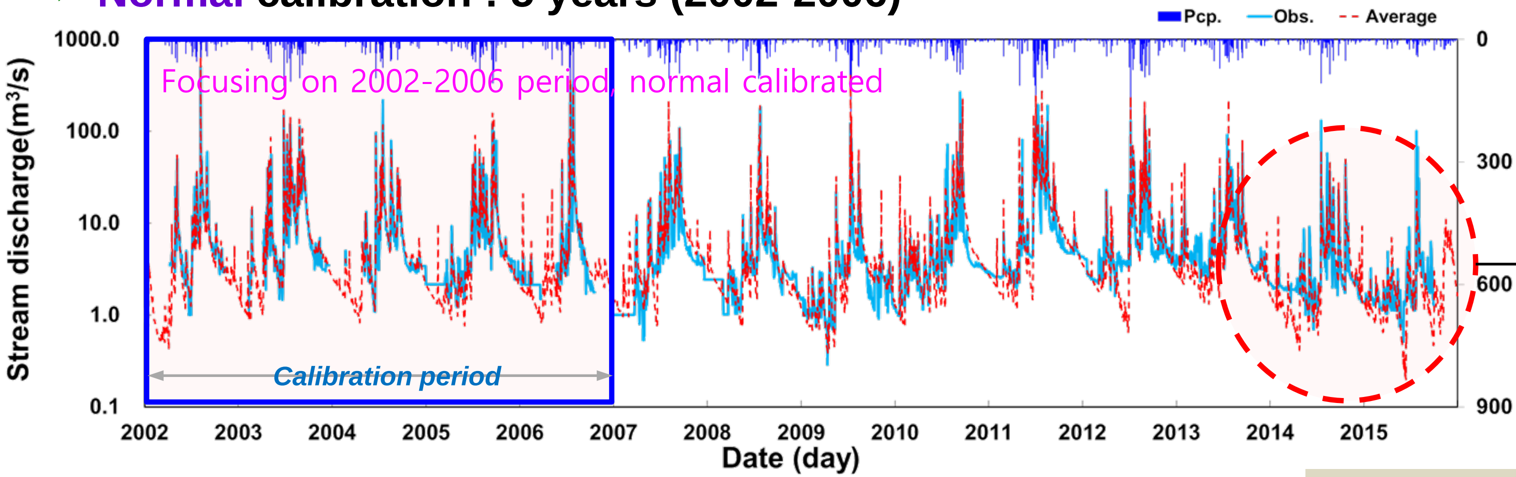
SWAT calibration (Hydrology)



❖ SWAT model calibration

Hydrology >> Water Quality (SS >> T-P >> T-N)

✓ Normal calibration : 5 years (2002-2006)

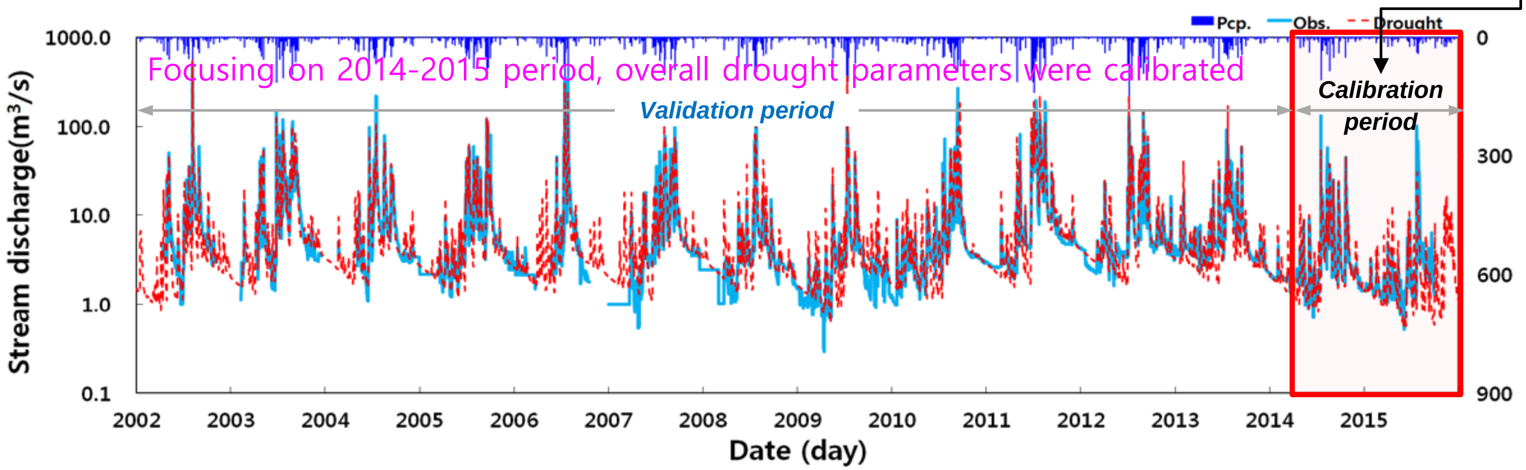


( ): 2014-2015 results

R^2: 0.60 (0.63)
RMSE: 3.68 (3.87)
NSE- Q: 0.78 (0.90)
NSE- 1/Q: 0.58 (-0.15)

Recession shape Low flow

✓ Drought period calibration : 2 years (2014-2015)



R^2: **0.69** (0.58)
RMSE: **3.25** (**1.3**)
NSE- Q: **0.86** (**0.92**)
NSE- 1/Q: **0.76** (**0.73**)

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Model calibration result (Hydrology)

❖ Normal vs. Big-drought results of model calibration

- ✓ *NSE Q : Evaluate the peak flow rate of the high-level part*
- ✓ *NSE 1/Q (inverse Q) : Low-flow simulation of the submerged part*

Year	Precipitation (mm)			Stream discharge(mm)			Runoff Ratio (%)			NSE			
										Q		1/Q	
	Total	Jun. ~ Sep.	Oct. ~ May	Obs.	Nor.	Drou.	Obs.	Nor.	Drou.	Nor.	Drou.	Nor.	Drou.
2002	1,285.0	840.7	444.3	555.0	622.0	663.5	48.4	54.3	57.9	0.91	0.96	0.56	0.51
2003	1,586.4	1,120.6	465.8	857.8	890.3	948.5	56.3	58.5	62.3	0.92	0.96	0.68	0.86
2004	1,275.9	928.3	347.6	635.2	654.3	723.3	54.4	56.0	61.9	0.92	0.94	0.95	0.90
2005	1,362.5	1,074.7	287.8	690.9	624.7	686.4	50.7	45.9	50.4	0.97	0.98	0.75	0.91
2006	1,235.8	902.3	333.5	647.8	644.9	695.5	64.2	64.0	69.0	0.78	0.82	0.63	0.88
2007	1,437.9	1,025.0	412.9	630.9	742.4	781.7	43.9	51.6	54.4	0.92	0.95	0.74	0.64
2008	1,118.8	859.6	260.2	428.5	461.6	511.6	38.3	41.3	45.7	0.89	0.92	0.79	0.79
2009	1,291.1	908.1	383.0	338.5	526.1	566.6	26.2	40.7	43.9	0.11	0.44	0.83	0.80
2010	1,426.0	1,036.4	389.6	653.8	699.2	721.7	45.8	49.0	50.6	0.32	0.49	0.69	0.75
2011	1,927.3	1,499.2	428.1	1285.5	1219.1	1230.0	66.7	63.3	63.8	0.64	0.81	0.60	0.75
2012	1,548.8	1,170.5	378.4	797.1	789.5	835.1	47.6	51.0	53.9	0.94	0.97	0.79	0.73
2013	1,193.4	783.4	410.0	663.8	564.7	633.5	55.6	47.3	53.1	0.85	0.90	0.43	0.71
2014	997.9	668.6	329.3	375.2	310.2	362.7	37.6	31.1	36.3	0.97	0.97	**0.12**	**0.88**
2015	514.4	331.7	418.8	201.2	130.1	169.4	39.2	25.3	32.9	0.84	0.86	**-0.42**	**0.58**
AVG.	1,300.1	939.1	377.8	621.5	634.2	680.7	48.2	48.5	52.6	0.78	0.86	0.58	0.76

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SWAT parameters (Water quality)

❖ ***Water quality calibration*** **Hydrology >> Water Quality (SS >> T-P >> T-N)**

- ***The runoff calibration should come first, since the water quality affects the surface runoff that contributes to the streamflow.***
- ***The calibration on the sediment should be preceded because T-N and T-P are influenced by the runoff and the sediment transfer.***

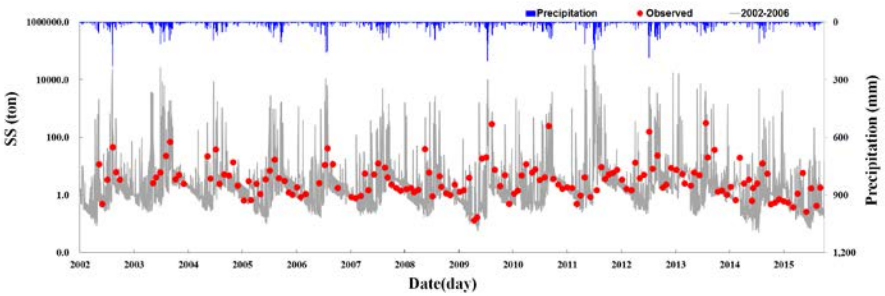
Component	Parameters	Definition	Default*	Calibration	
				Normal	Drought
Sediment	CH_COV2	Channel cover factor	0	-0.001	-0.001
	LAT_SED	Sediment concentration in lateral and groundwater flow (mg/L)	0	15	15
Nitrogen	LAT_ORGN	Organic N in the baseflow (mg/L)	0	150	150
	RAMMO_SUB	Atmospheric deposition of ammonium	0	0.95	0.95
	RCN_SUB	Atmospheric deposition of nitrate	0	2	2
	N_UPDIS	Nitrogen uptake distribution parameter	**20**	**20**	**80**
	CMN	Rate coefficient for mineralization of the humus active organic nutrients	**0.0003**	**0.0003**	**0.003**
	NPERCO	Nitrate percolation coefficient	0.2	0.25	0.25
Phosphorus	LAT_ORGP	Organic P in the base flow (mg/L)	0	4	4
	GWSOLP	Concentration of soluble phosphorus in groundwater contribution to stream from subbasin (mg P/L or ppm)	0	0.4	0.4

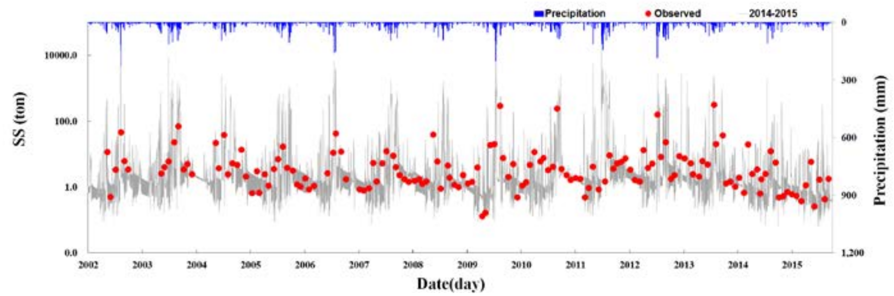
Model calibration (Water quality)

( ): 2014-2015 results

Normal	***Drought***
R^2: 0.62 (**0.76**)	R^2: 0.71(**0.84**)

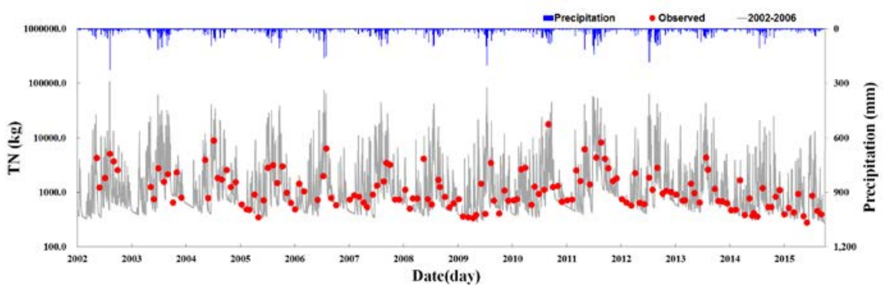
SS

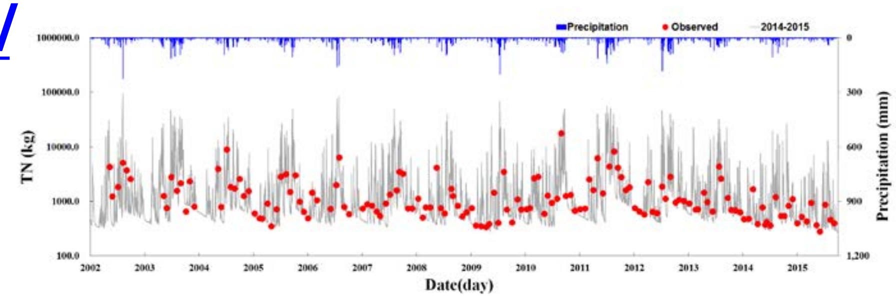




Normal	Drought
R^2: 0.58 (**0.69**)	R^2: 0.65 (**0.77**)

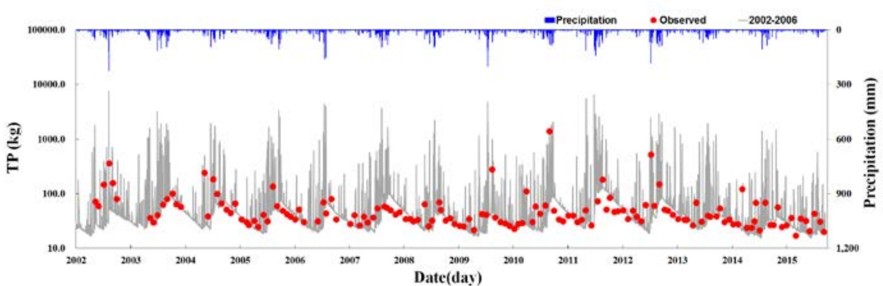
T-N

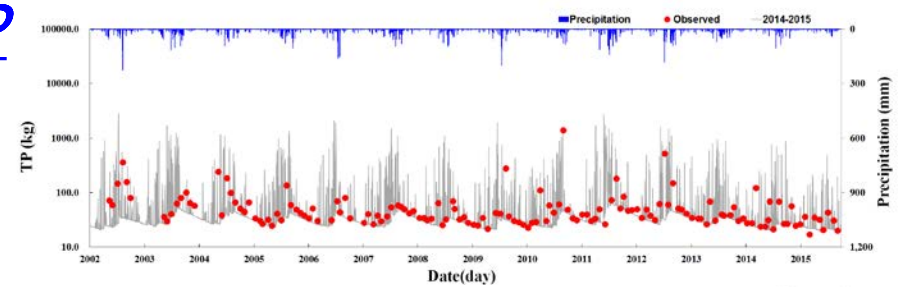




Normal	Drought
R^2: 0.50 (**0.54**)	R^2: 0.62 (**0.60**)

T-P



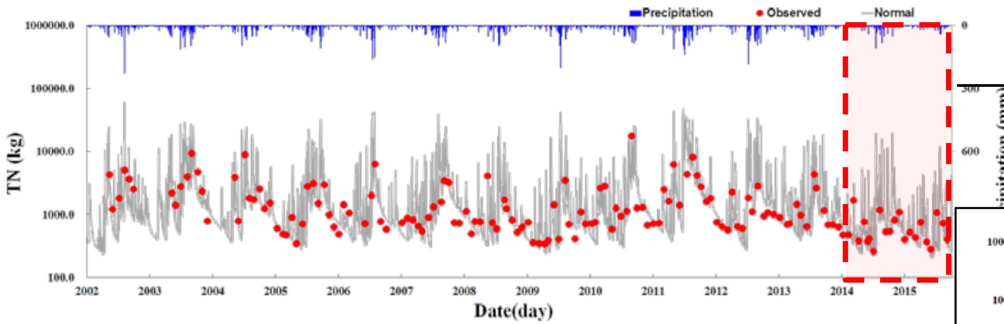


Model calibration (Water quality)

❖ ***SWAT model calibration***

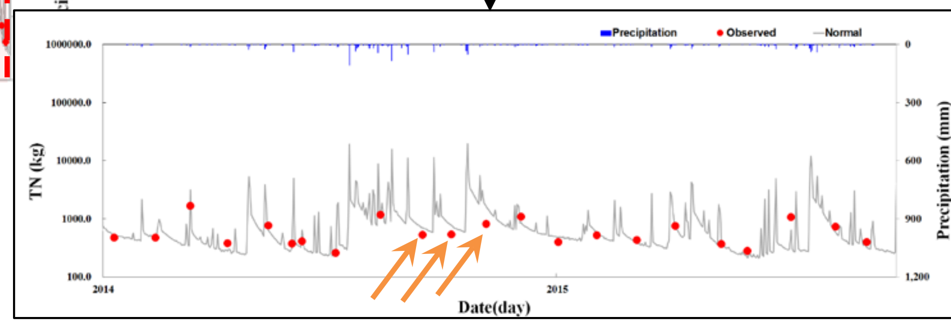
***T-N case** of Water quality*

✓ **Normal calibration : 5 years (2002-2006)**

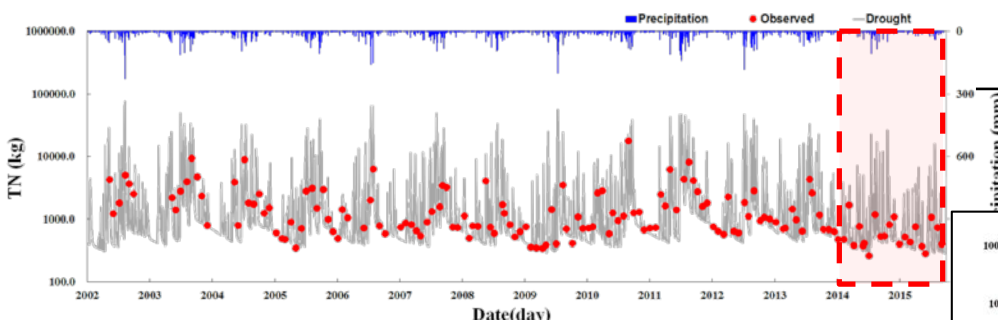


( ): 2014-2015 results

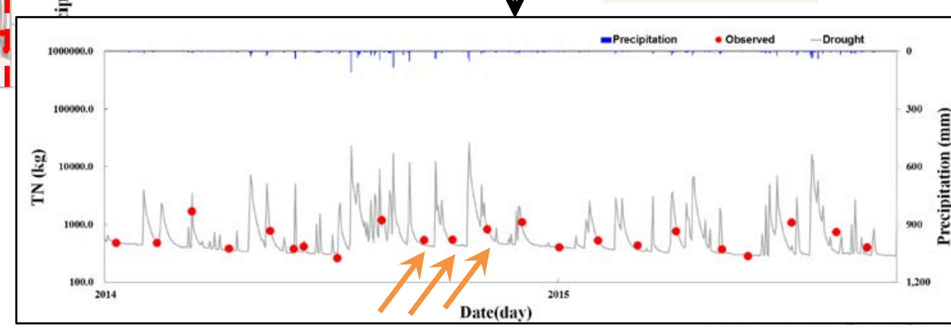
R^2: 0.58 (0.69)



✓ **Big-drought period calibration : 2 years (2014-2015)**



R^2: 0.58 (0.77)



Model calibration result (Water quality)

❖ **Normal vs. Big-drought results of model calibration**

Year	Sediment (ton/day)			T-N (kg/day)			T-P (kg/day)			R^2					
										Normal			Drought		
	Obs.	Nor.	Drou.	Obs.	Nor.	Drou.	Obs.	Nor.	Drou.	SS	T-N	T-P	SS	T-N	T-P
2002	6.6	2.0	2.6	1,528.0	1,052.3	992.0	71.3	42.9	40.9	0.90	0.53	0.78	0.90	0.53	0.73
2003	6.9	12.0	19.9	2,260.4	1,674.0	1,610.9	43.4	42.9	56.1	0.17	0.34	0.30	0.90	0.33	0.10
2004	7.5	5.6	5.2	1,842.3	2,111.1	1,780.6	64.6	55.8	67.4	0.85	0.40	0.55	0.23	0.15	0.50
2005	6.5	1.5	1.3	1,279.0	1,168.1	1,216.2	44.5	39.8	45.9	0.48	0.57	0.90	0.44	0.59	0.93
2006	5.9	21.2	49.8	1,097.7	1,587.2	1,409.9	30.6	35.0	37.9	0.93	0.34	0.28	0.45	0.85	0.47
2007	5.0	2.2	2.1	1,276.6	879.0	842.1	41.3	34.9	48.4	0.24	0.30	0.56	0.18	0.53	0.40
2008	3.2	2.7	4.4	1,110.1	914.5	888.1	52.0	38.6	33.6	0.90	0.86	0.00	0.96	0.48	0.55
2009	6.9	10.1	24.5	852.8	950.7	961.3	48.9	26.6	27.4	0.92	0.75	0.56	0.99	0.83	0.65
2010	8.3	15.8	25.8	2,602.6	1,694.2	1,653.8	154.4	60.3	69.7	1.00	0.91	0.89	1.00	0.92	0.92
2011	25.5	6.1	1.7	2,951.3	1,794.7	1,773.3	57.3	41.8	64.2	0.02	0.45	0.62	0.18	0.61	0.54
2012	7.7	13.9	18.4	1,172.2	1,373.0	1,216.4	92.7	52.6	44.4	0.82	0.43	0.02	0.98	0.76	0.96
2013	10.5	2.5	26.7	1,273.0	1,016.7	1,239.9	37.7	33.5	38.4	0.02	0.82	0.43	0.99	0.92	0.76
2014	2.7	2.1	2.2	681.0	876.1	805.2	51.0	34.1	36.9	0.74	0.76	0.71	0.72	0.82	0.78
2015	1.8	1.2	1.5	407.2	640.4	605.1	22.6	25.0	23.1	0.77	0.62	0.37	0.95	0.72	0.42
AVG.	**7.5**	**7.1**	**13.3**	**1,452.4**	**1,266.6**	**1,213.9**	**58.0**	**40.3**	**45.3**	**0.63**	**0.58**	**0.50**	**0.71**	**0.65**	**0.62**

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Summary and conclusions

- *In this study, we tried to calibrate the SWAT (Soil and Water Assessment Tool) parameters for drought periods and validate other periods.*

- *The SWAT Hydrology calibration results in Gong-do watershed*
  - *Drought periods (2014~2015) showed low NSE values for 1/Q when calibrating 5 years (2002-2006) data.*
  - *Drought periods were re-calibrated with 0.73 for 1/Q(low flow) just targeting 2-years (2014-2015) streamflow data and the NSEs of other periods (2002~2013) were maintained as usual.*
  - *For the calibration of drought condition, the parameters SCS_CN(SCS curve number for moisture condition), SOL_K(Saturated hydraulic conductivity), and SLSOIL (Slope length of lateral subsurface flow) were the most sensitive and important for the water balance accounting.*

- *The SWAT calibration focusing on drought periods improved NSEs of both Q and 1/Q.*
  - *We could handle the 9 parameters (the above 3 parameters were more important) more for drought condition*
  - *The drought data helped the value calibration direction for the 9 parameters and improved the whole calibration results.*

Summary and conclusions

- ***The SWAT Water quality calibration results in Gong-do watershed***
  - ***In the case of T-N, we tried to adjust the N-UPDIS, in consideration of the soil drying effect due to drought and to reflect the uptake phenomenon in the plant rewetting process.***
  - ***The efficiency was influenced by the runoff rate and there was no significant difference in the correlation (R^2) analysis between the normal calibration model and drought focus model.***
  - ***However, when the drought model was calibrated, it was possible to obtain more accurate results by further considering the parameters related to the soil (N-UPDIS, CMN).***

- ***Based on the results, we propose a new method to model extreme hydrological phenomenon, such as drought, that is more accurate and efficient than the overall modeling methods.***

Thank you

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