SWAT 2013
Toulouse France

SESSION G2: ENVIRONMENTAL APPLICATIONS
Amphitheater Shannon, Room U4.6
11:00 – 12:20 p.m.




Assessment of Climate Change Impact on Future Turbidity Current Regimes in Soyang Lake with CE-QUAL-W2 Considering SWAT Inflows

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Ha, Rim

J. Y. Park, S. R. Ahn, S. H. Kim, S. J. Kim*

Dept. of Civil & Environmental System Eng. Konkuk University
South Korea

KU KONKUK UNIVERSITY

Earth Information Engineering Lab.

CONTENTS

1. Introduction

Change of water quality issues in Korea

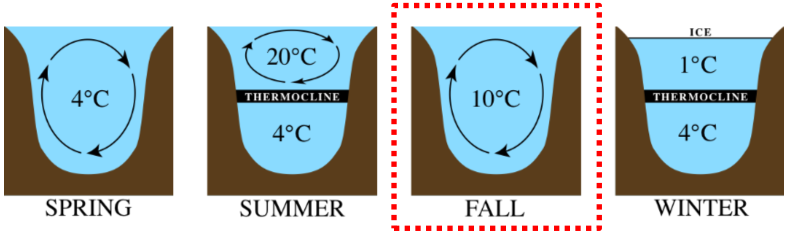
- Before 1970s
  - No pollution problems
  - No concern about environmental conservation
- In 1980s
  - High BOD from sewage
  - Fish farms installed in many reservoirs
- In 1990s
  - Sewage treatment systems established
  - Active operations of fish farms within reservoirs
  - Eutrophication problems emerged
  - Algal toxins were reported
- **Current issues in 2000s**
  - Turbidity and siltation – major ecological hazard
  - TMDL of BOD and TP for water quality management
    - Phosphorus removal from sewage

1. Introduction

❑ Turbidity problem in reservoirs

- Turbid water lasts 3 months after summer monsoon in the Han River.
- Reservoirs are filled with turbid water after monsoon.
- Large dams prolong the duration of turbid water in downstream.

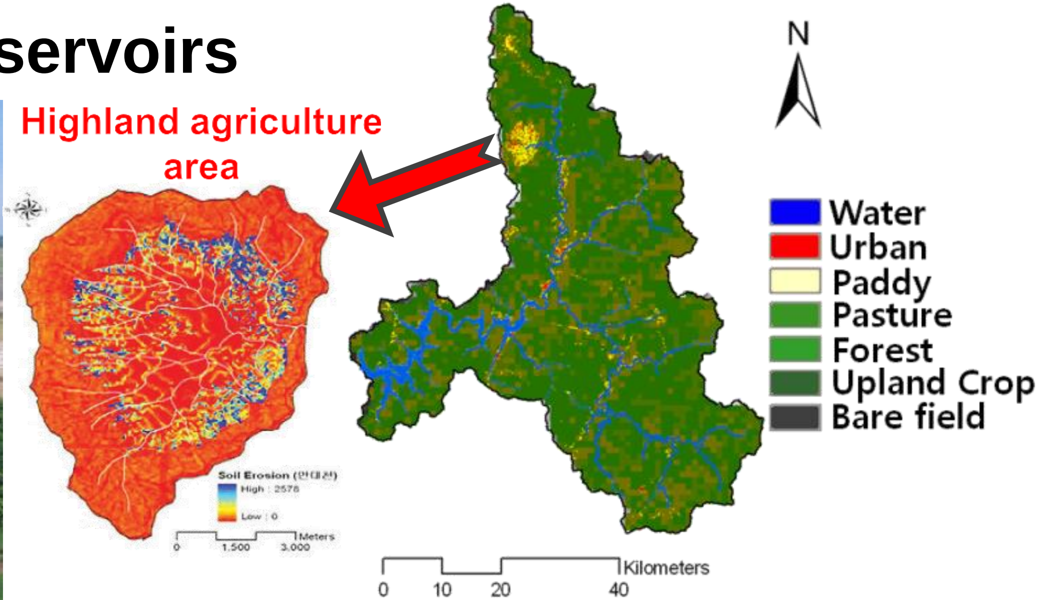
- Destroys aquatic ecosystems.
- SAV is reduced.
- Fisheries are reduced.
- Fall: Sediments emerged.



***In 2006**, turbid water in Soyang river <u>aggravated by the typhoon Ewiniar</u>, sustained for over 280 days unlike conventional years,*
then which interrupted water supply of Chuncheon and Seoul areas.

1. Introduction

❑ Turbidity problem in reservoirs



❑ Cause of Turbidity problem

- ❖ Highland agriculture area
  - ✓ 63% of the total highland agricultural area in South Korea
- ❖ luding imprudent development of mountainous area
- ❖ Landslides, Road expansion, washed and road construction for forestry…

1. Introduction

- Persistent turbidity in reservoirs and their downstream after flood events is an important environmental issues in Korea.

- One of the most important water management issues of **Soyang Lake** (located in North Han River in Korea) is a long term discharge of turbid water to downstream during flood season.

- Water in Soyang river is an essential source for citizens of Chuncheon and Seoul areas.

- In these situations, it is very urgent to look for the fundamental causes of long term effects by climate change of turbidity in lake, and to also get measures about for such problems.

- *The main goal of this study is to evaluate the future climate change impact on turbidity current regimes for Soyang Lake watershed in South Korea using SWAT watershed model and CE-QUAL-W2 lake water quality model.*

1. Flowchart of Study

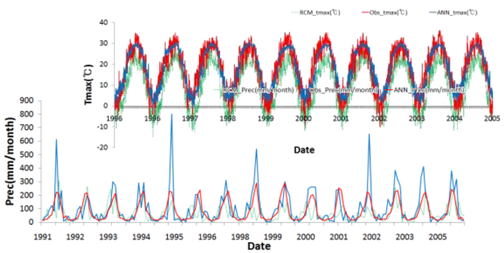
Meteorological Data
Daily Precipitation, Temperature, Wind speed, Relative humidity, Solar radiation

GIS Data
Watershed boundary, Digital elevation model, Land use, Soil

Observed Data
Streamflow, Stream and lake water quality, Point source

Simulation: 1990-2010

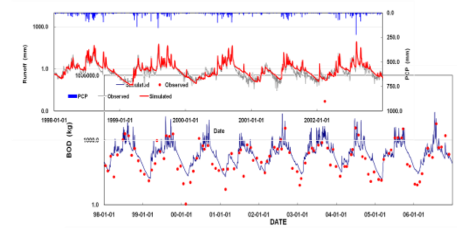
Watershed Model (SWAT)



Climate Change Scenario
Baseline(1990-2010)
2011-2040
2041-2070
2071-2100

Calibration and Validation
Streamflow | Sediment | Water Quality

Calibrated Model



Simulation Results

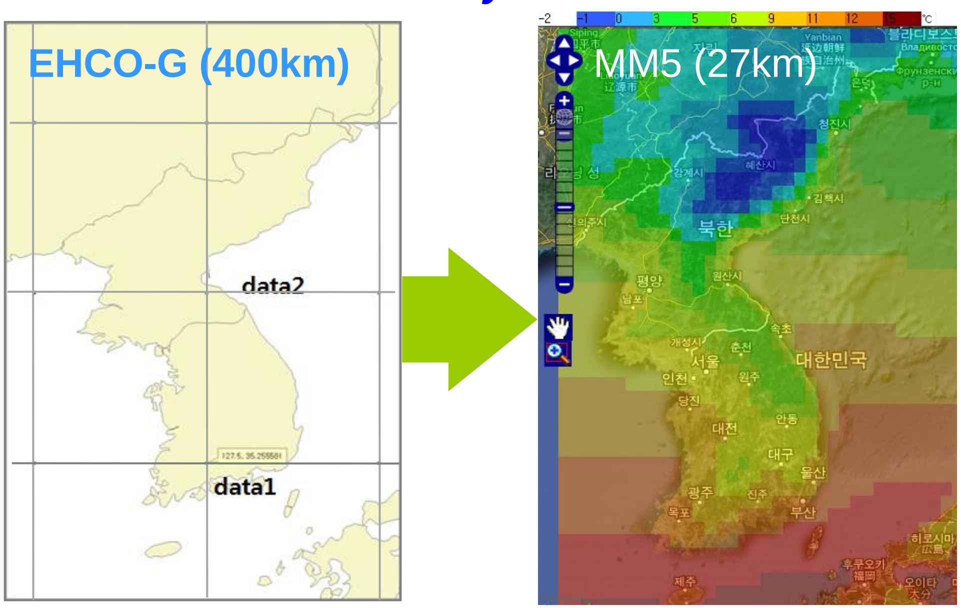
Streamflow	Sediment	Water Quality
-Dam inflow	-SS	- NH4 - NO3 - PO4 - BOD - Chl-a

Water Quality Model (CE-QUAL-W2)

2. Climate Change scenario Downscaling

IPCC AR4 RCM climate change scenario

- ***MM5 RCM (Regional Climate Model)***
  - ***Temperature (maximum, minimum)***
  - ***Precipitation***
  - ***Relative humidity***



Model	Country	Grid size
CONS: EHCO-G	Germany / Korea	96 × 48

ECHO-G (GCM)

- 1860 – 2100
- A1B, B1, A2
- 400 km (~3.75°)
- Monthly

↓ *Dynamic Downscaling*

MM5 (RCM)

- 1871 – 2100
- A1B
- 27 km (~0.243°)
- Monthly, Daily

↓

Downscaling (Artificial Neural Networks method)

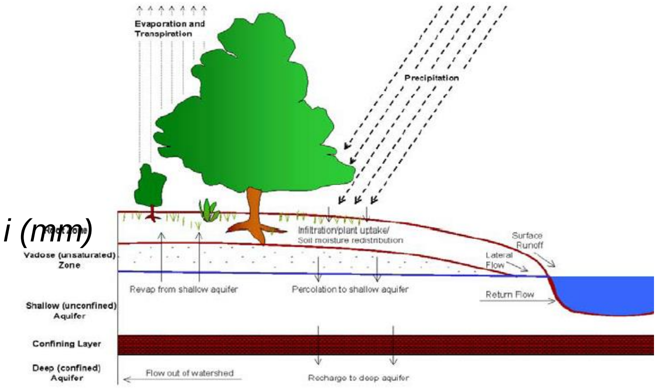
↓ *Typhoon Simulation, Quantile Mapping*

SWAT model

❑ 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)*



❑ Sediments : MUSLE (Modified Universal Soil Loss Equation)

$$Sed = 11.8(Q_{surf} \times q_{peak} \times area_{hru})^{0.56} K \times C \times P \times LS \times CFRG$$

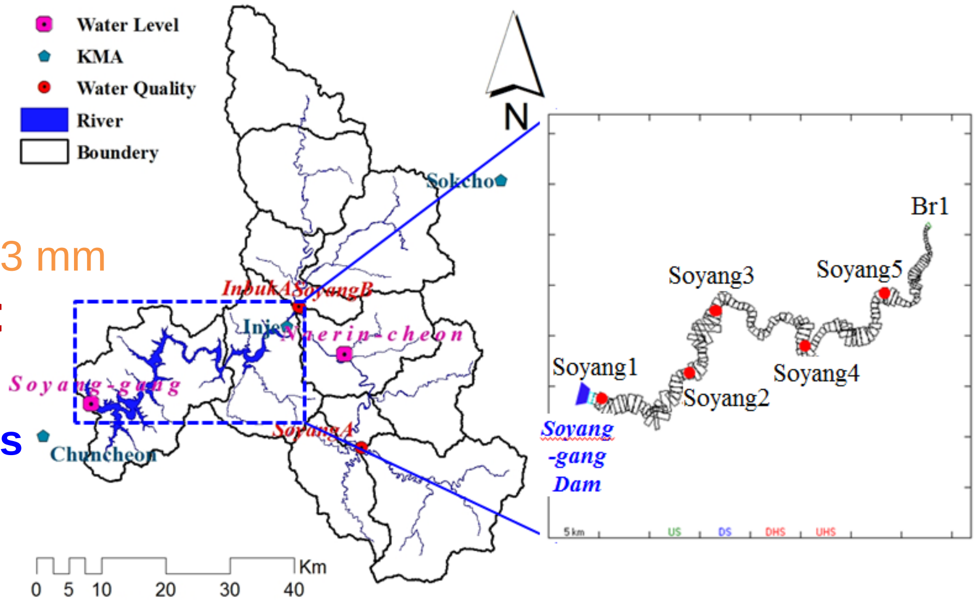
- *Sed = Sediment yield on a given day (ton)*
- *Q_{surf} = Surface runoff volume (mm/ha)*
- *q_{peak} = Peak runoff rate (m3/s)*
- *$area_{hru}$ = Area of the HRU (ha)*
- *K = USLE soil erodibility factor*
- *C = USLE cover and management factor*
- *P = USLE support practice factor*
- *LS = USLE topographic factor*
- *CFRG = coarse fragment*

Multi-purpose Dam Watershed Description

❑ Soyang Lake Watershed

- ❖ Study area: 2,694.4 km^2
- ✓ Forest area ratio: 88.6 %
- ✓ South Korea: 99,373 km^2
- ❖ The annual average precipitation: 1,153 mm
- ❖ The annual mean temperature: 10.3 ℃

➢ **The 123 m (404 ft) tall dam withholds a reservoir of 2,900,000,000 m^3**



❑ Model Input data

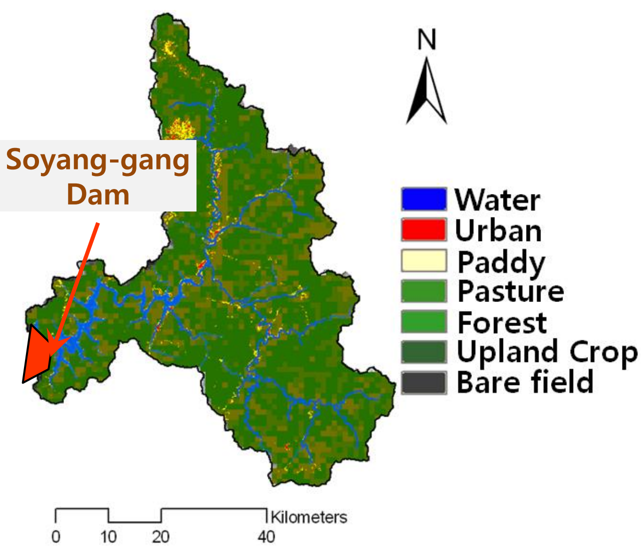
Observed data		Station	Period
Hydrological	Dam inflow	Soyang-gang Dam	1998~2010
	Stream flow	Naerin-cheon	1998~2010
Water quality	TMDL 8day	Inbuk A	2004~2010
		Soyang B	2004~2010

❑ Map data (Land use, soil and elevation data)

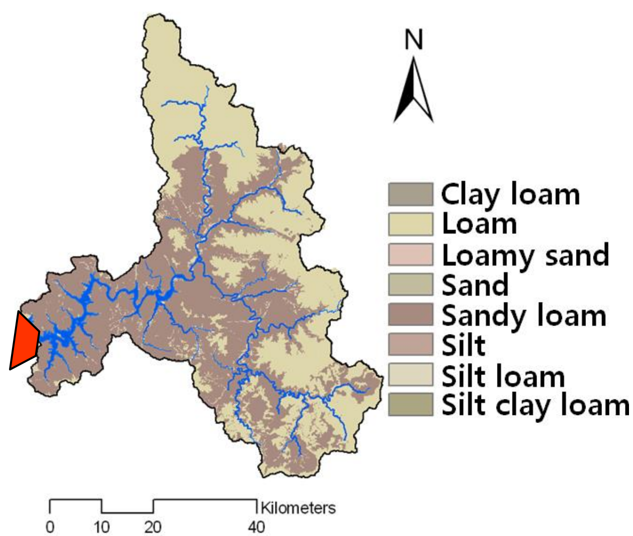
Spatial resolution : 100 m

- ❖ Landuse : Land cover was classified with 7 categories. Forest (88.6%), Upland Crop (4.4%), Paddy (2.1%)
- ❖ Soil Texture : Most soil cover is Sandy Loam (32.3%), Loam (31.8%), and Silty Loam (21.5%) respectively.
- ❖ Average Elevation : 650 EL.m

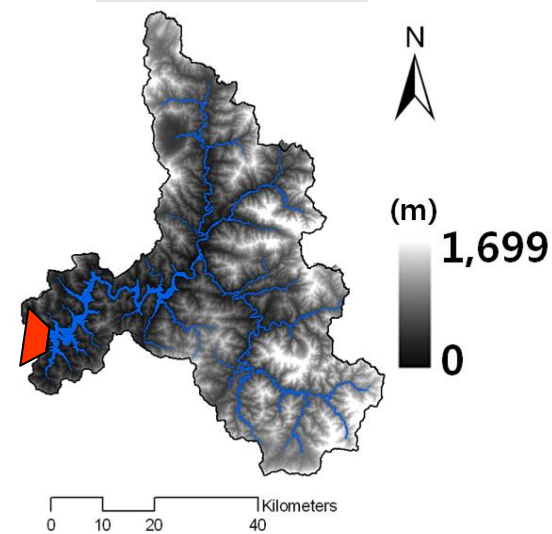
Land use



Soil type

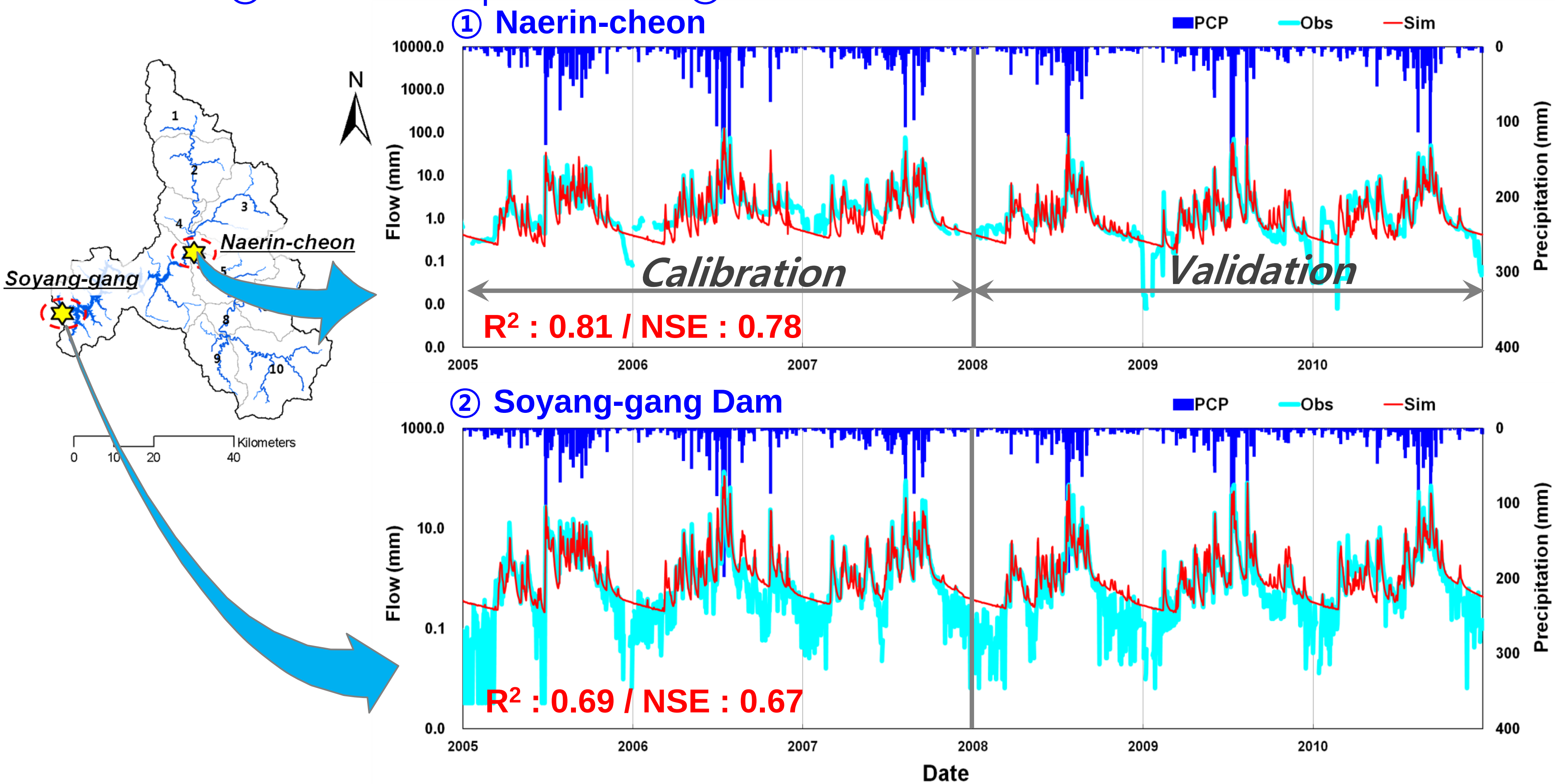


DEM



Streamflow results

- ***Calibration : 3 years (2005-2007) / Validation : 3 years (2008-2010)***
  - ① **NC** located upstream and ② **SD** in the watershed outlet

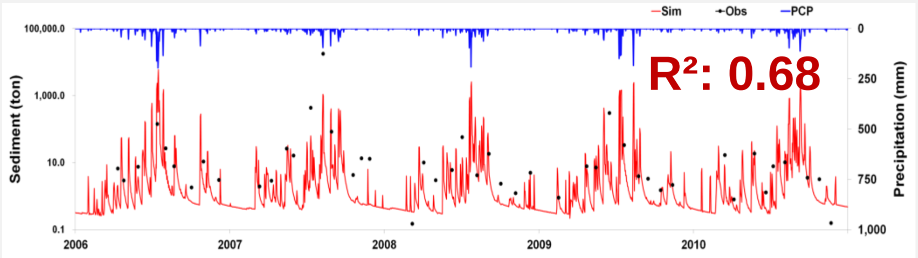


3. SWAT Modeling

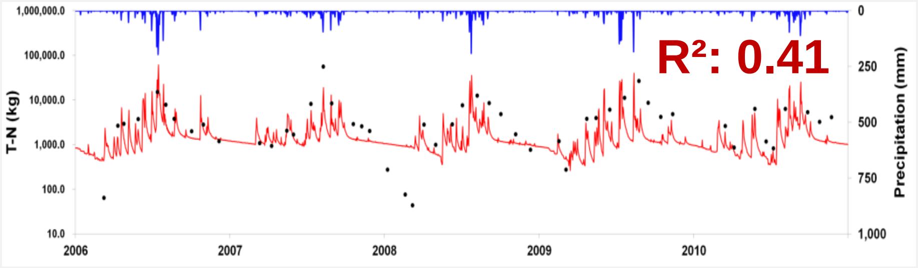
- **Stream water quality results**

Inbuk A

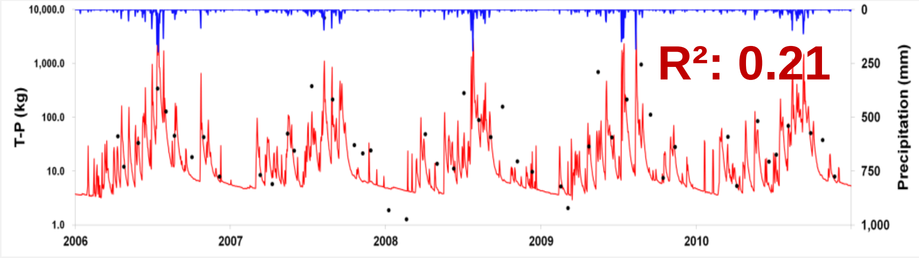
Sediment



Total Nitrogen

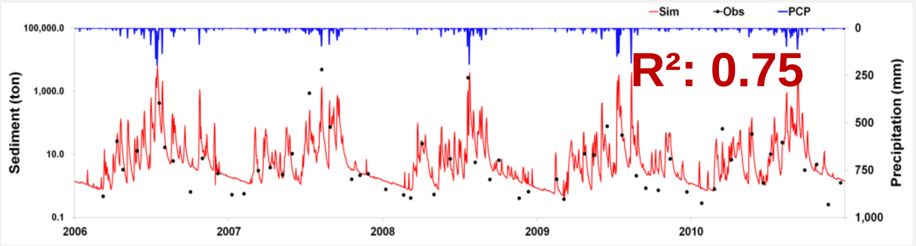


Total Phosphorus

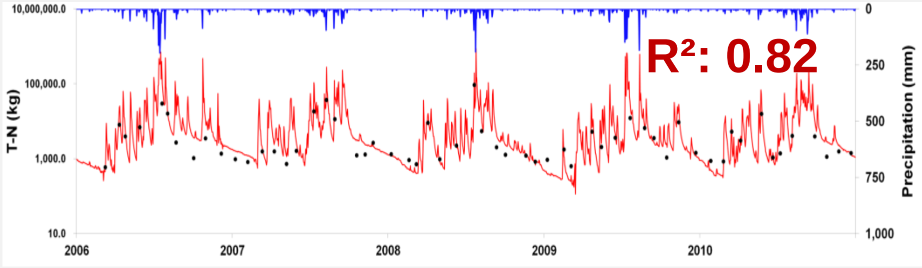


Soyang B

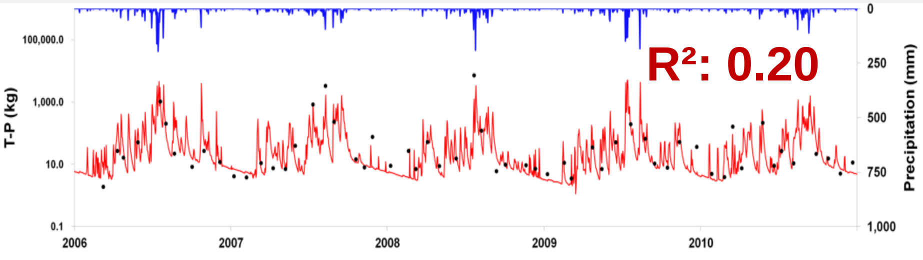
Sediment



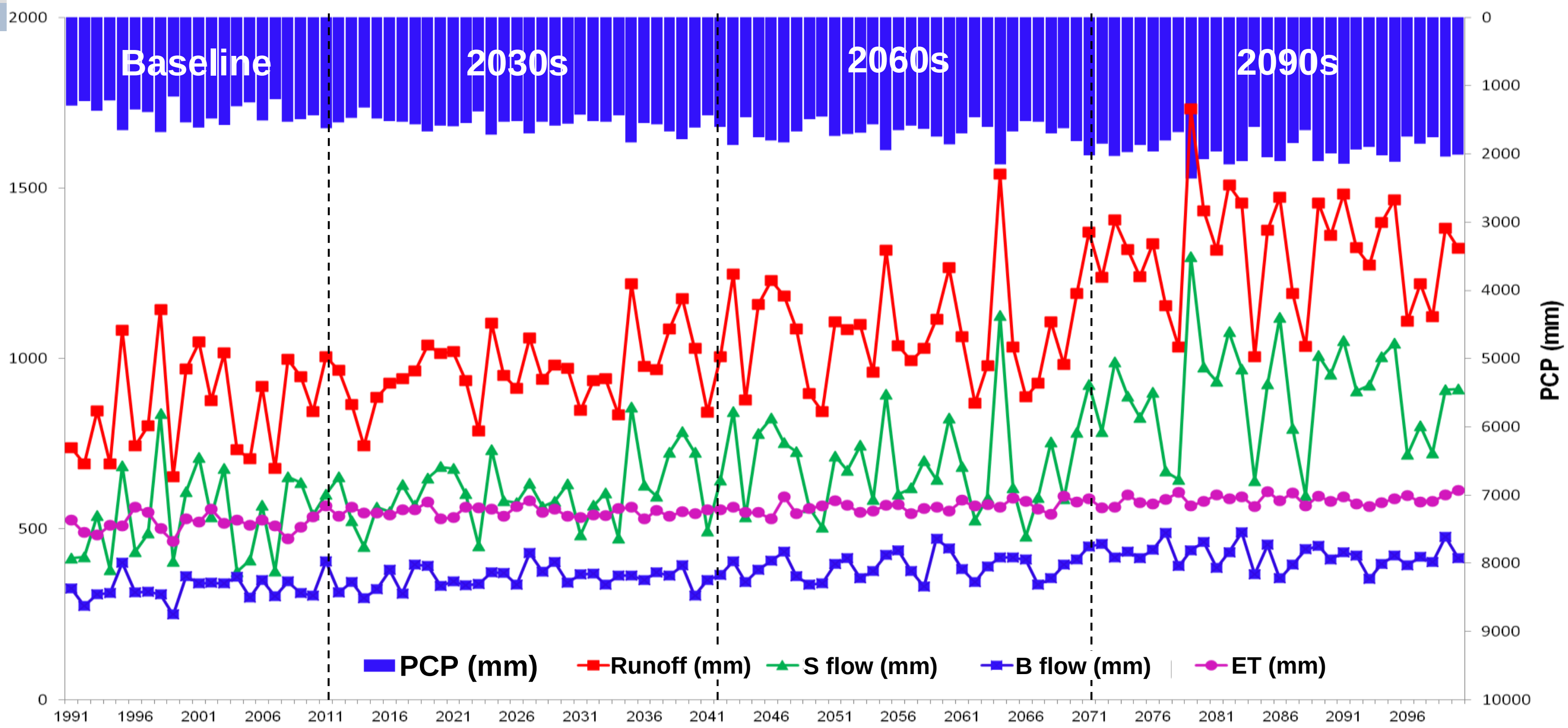
Total Nitrogen



Total Phosphorus



3. SWAT Modeling – Future hydrologic cycle

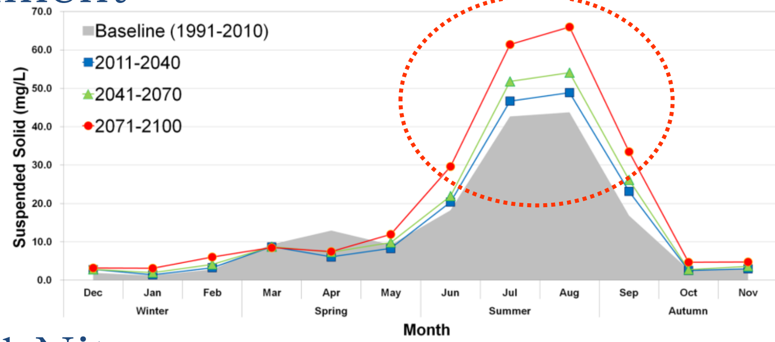


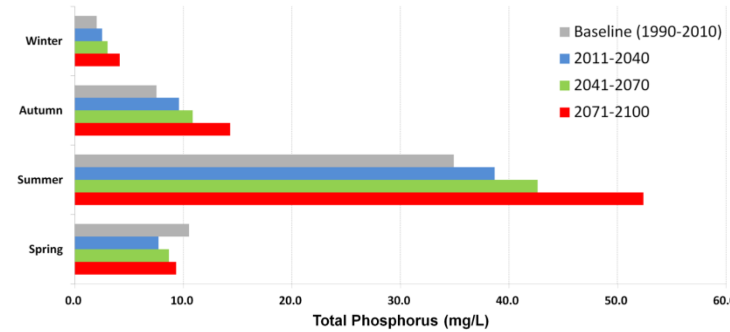
Scenarios	Precipitation (mm)	Evapotranspiration (mm)	Surface flow (mm)	Base flow (mm)	Runoff (mm)
Baseline	1412.8	515.3	534.8	323.6	856.1
2030s (2011-2040)	1563.5 (+10.7%)	551.2 (+7.0%)	612.0 (+14.4%)	357.9 (+10.6%)	967.3 (+13.0%)
2060s (2041-2070)	1677.4 (+18.7%)	564.3 (+9.5%)	680.9 (+27.3%)	387.2 (+19.7%)	1065.3 (+24.4%)
2090s (2071-2100)	1959.4 (+38.7%)	586.0 (+13.7%)	897.5 (+67.8%)	423.5 (+30.9%)	1317.9 (+54.0%)

3. SWAT Modeling – Future stream water quality

Sediment

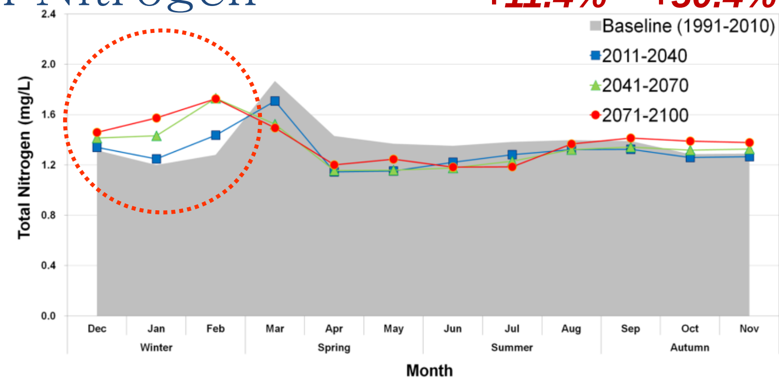
+22.9% ~ +126.5%

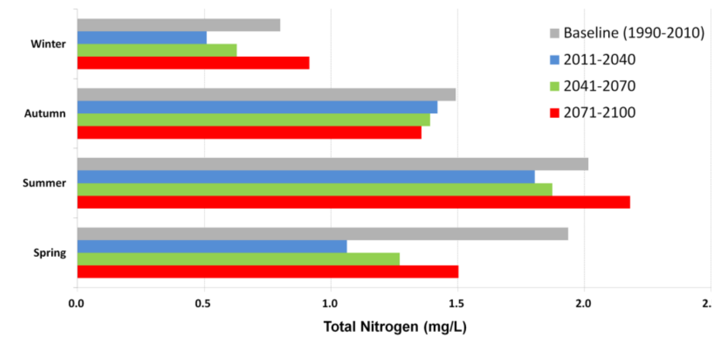




Total Nitrogen

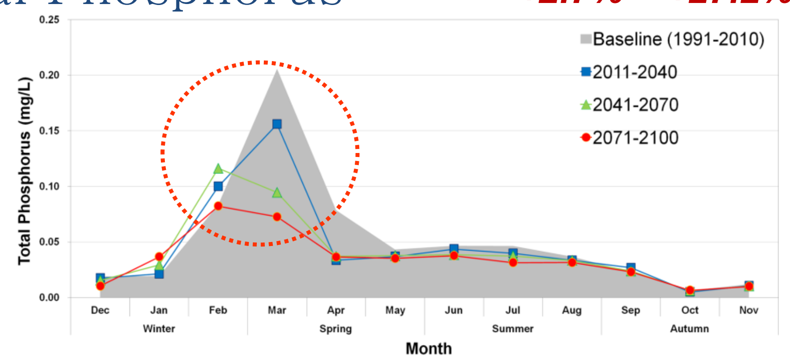
+11.4% ~ +50.4%

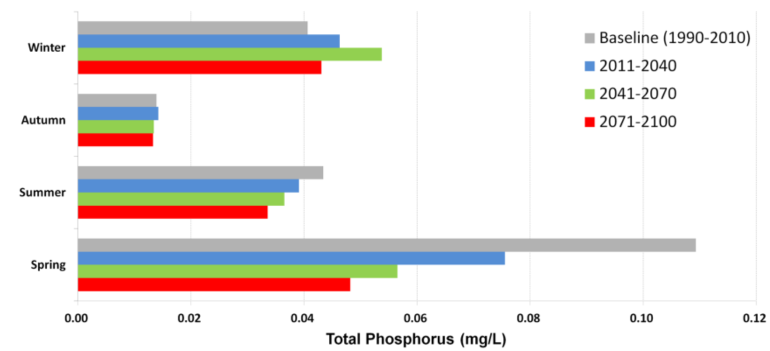




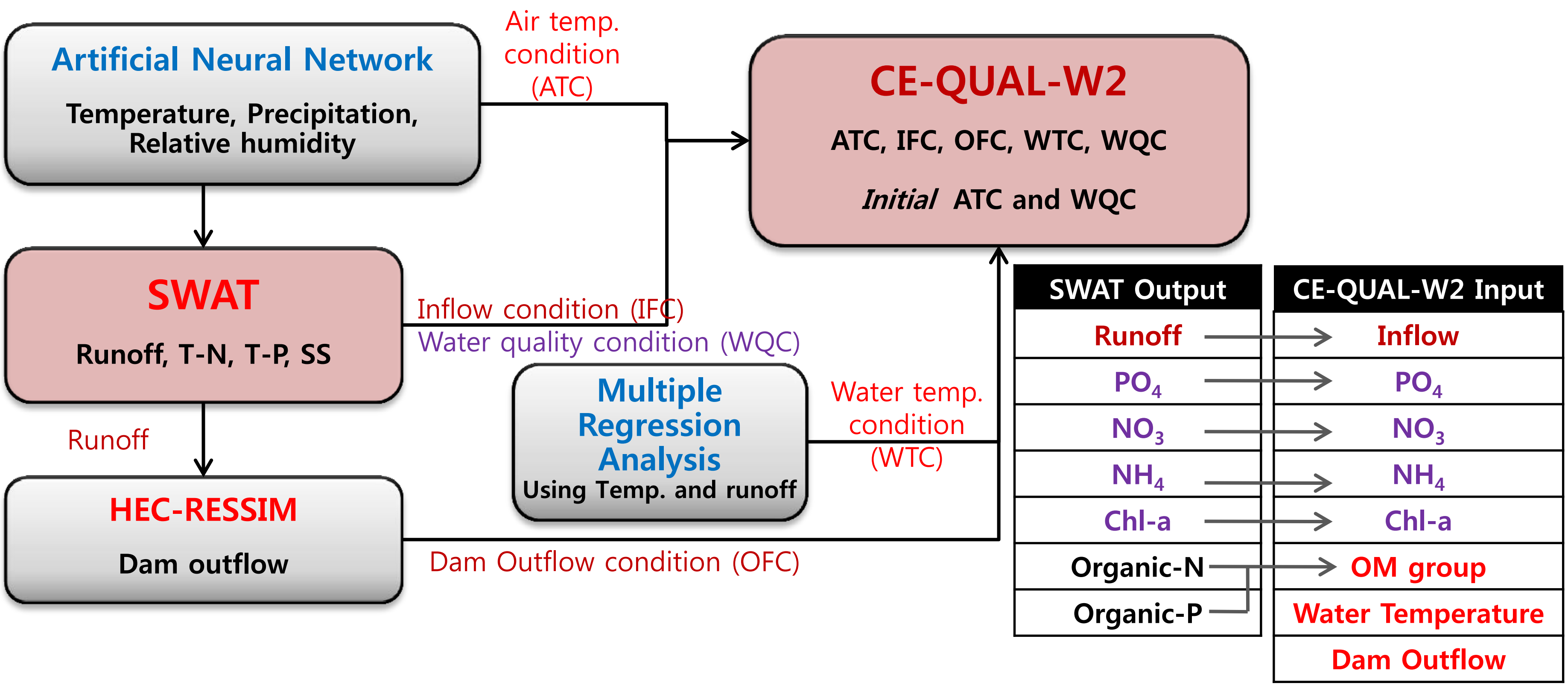
Total Phosphorus

+2.7% ~ +17.1%

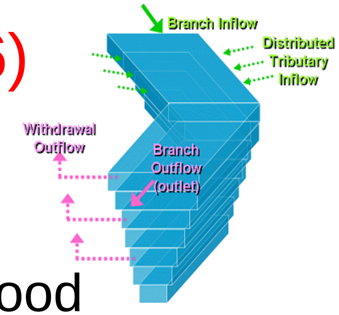




❑ Model coupling Technique



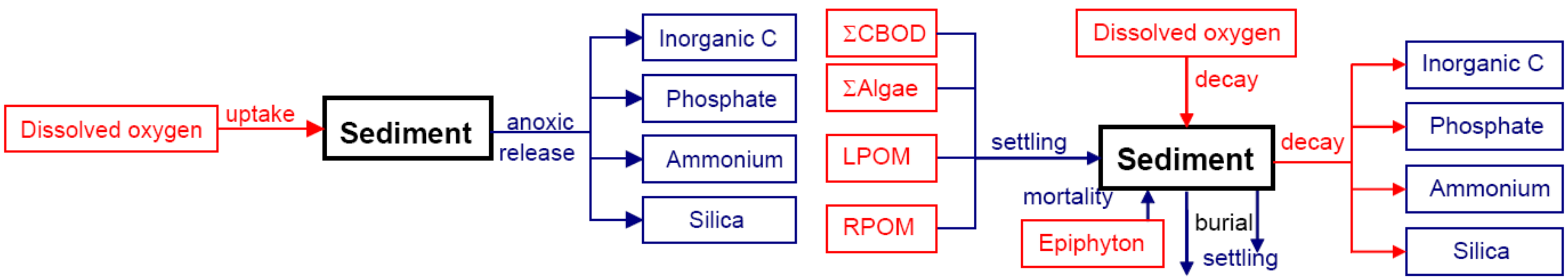
4. CE-QUAL-W2 Modeling



❑ CE-QUAL-W2 (U.S Army Corps of Engineers, 1986)

- It has been applied successfully to hundreds of rivers, lakes, and reservoirs around the world.
- At a reach scale, a long, narrow, pooled river is typically a good candidate for a two-dimensional, laterally averaged model.
- Useful for metalimnion modeling.

❑ Sediment

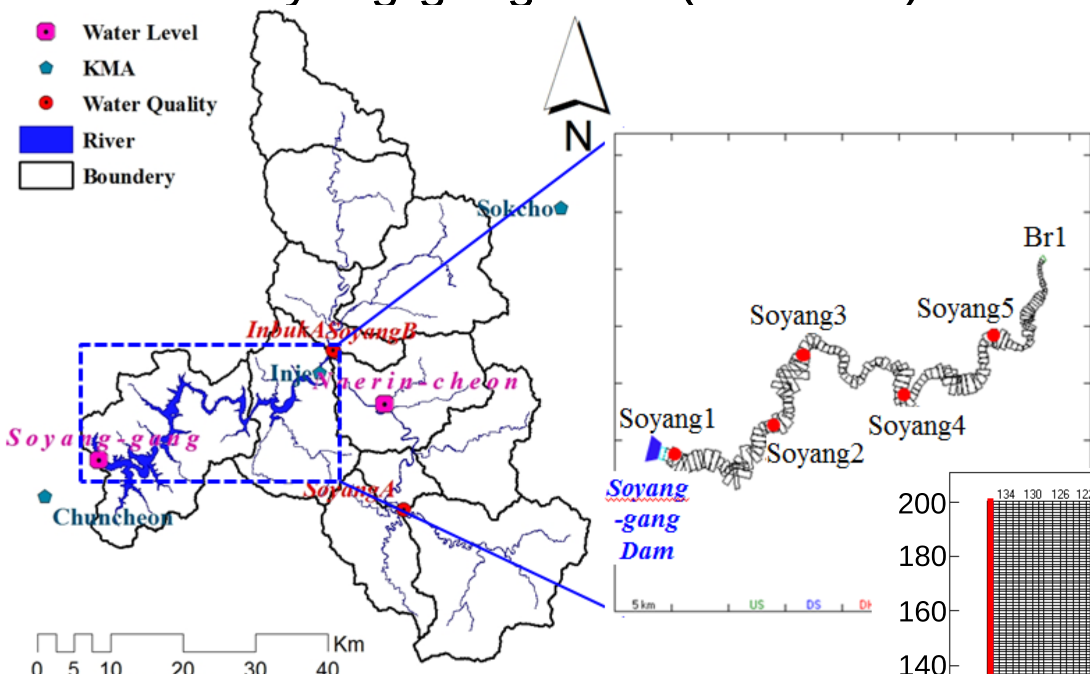


$$S_{sed} = \overbrace{\underbrace{\frac{\omega_{POMR} A_{bottom}}{Vol_{cell}} \Phi_{POMR}}_{\text{POMR sedimentation}}}^{\text{LPOM}} + \overbrace{\underbrace{\frac{\omega_{POML} A_{bottom}}{Vol_{cell}} \Phi_{POML}}_{\text{POML sedimentation}}}^{\text{RPOM}} + \overbrace{\underbrace{\sum \frac{\omega_a A_{bottom}}{Vol_{cell}} \Phi_a}_{\text{algae sedimentation}}}^{\text{Algae}} - \underbrace{\gamma_{om} K_s \Phi_s}_{\text{sediment decay}} + \overbrace{\underbrace{K_{epom} K_{eb} \Phi_e}_{\text{epiphyton burial}}}^{\text{Epiphyton}} -$$

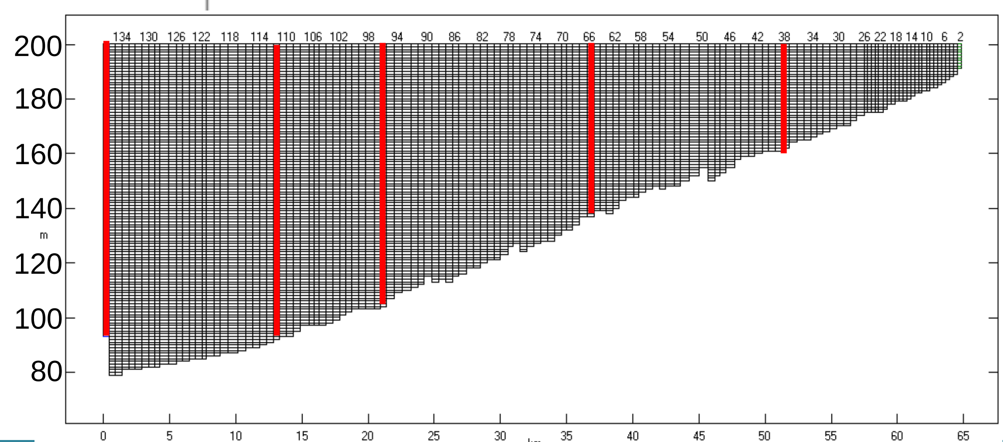
$$\underbrace{\frac{\omega_{SED} A_{bottom}}{Vol_{cell}} \Phi_s}_{\text{sediment sedimentation}} + \overbrace{\underbrace{\frac{\omega_{CBOD} A_{bottom}}{Vol_{cell}} \Phi_{CBOD}}_{\text{CBOD sedimentation}}}^{\text{CBOD}} - \underbrace{K_{burial} \Phi_s}_{\text{sediment burial}}$$

❑ Model body Setup

- Segment boundaries were specified to form **138** active segments in the main river reach from upstream start point of Soyang River to Soyang-gang Dam (branch 1)



Water body	Branch	Segment	Layer (maximum)
1	1	138	134



4. CE-QUAL-W2 Modeling

Boundary condition Validation

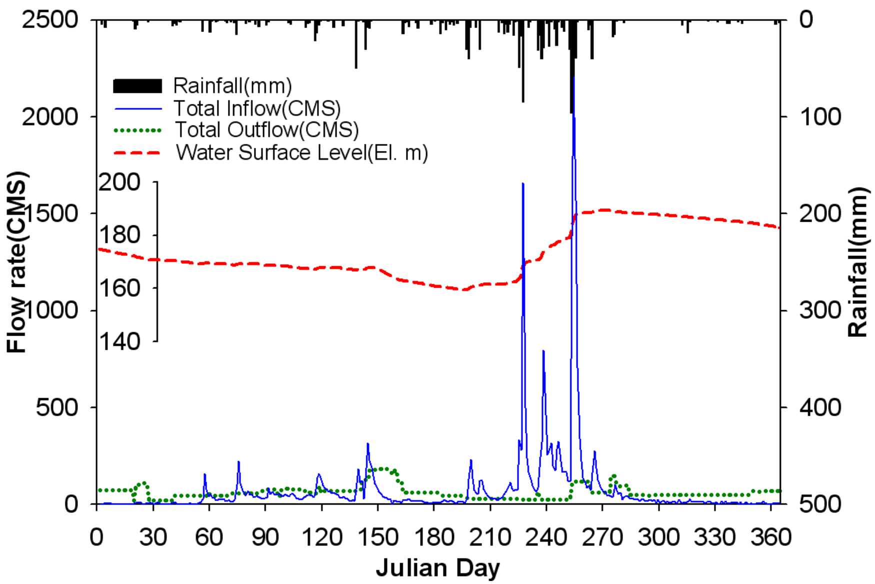
Water level : Observed vs. Simulated

→

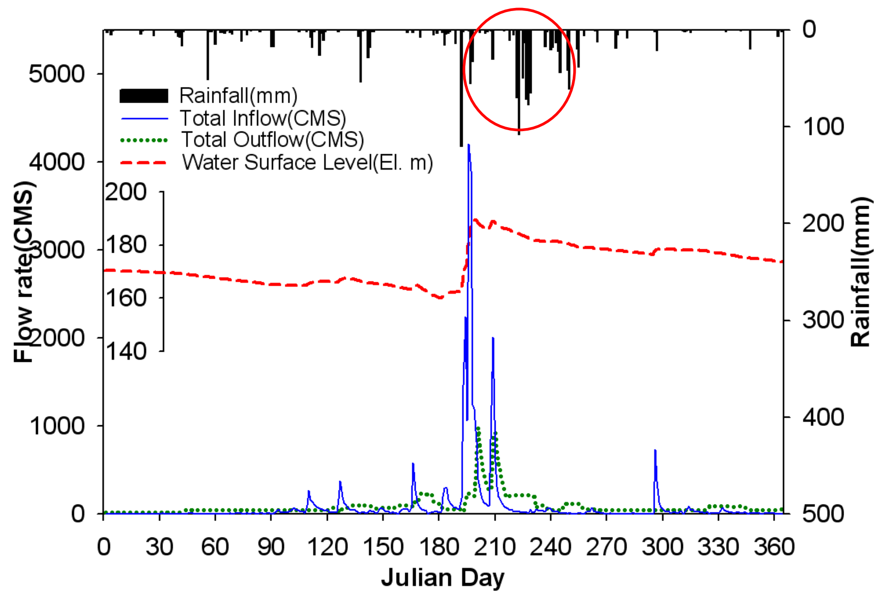
Water temperature, Sediment, Water quality Calibration / Validation

❑ Model Input Data (Boundary conditions)

- **CE-QUAL-W2 Inflow ← SWAT outflow**
- **CE-QUAL-W2 Outflow : Consider of release for hydropower and spillway**



Calibration : 2010



Validation : 2006

4. CE-QUAL-W2 Modeling

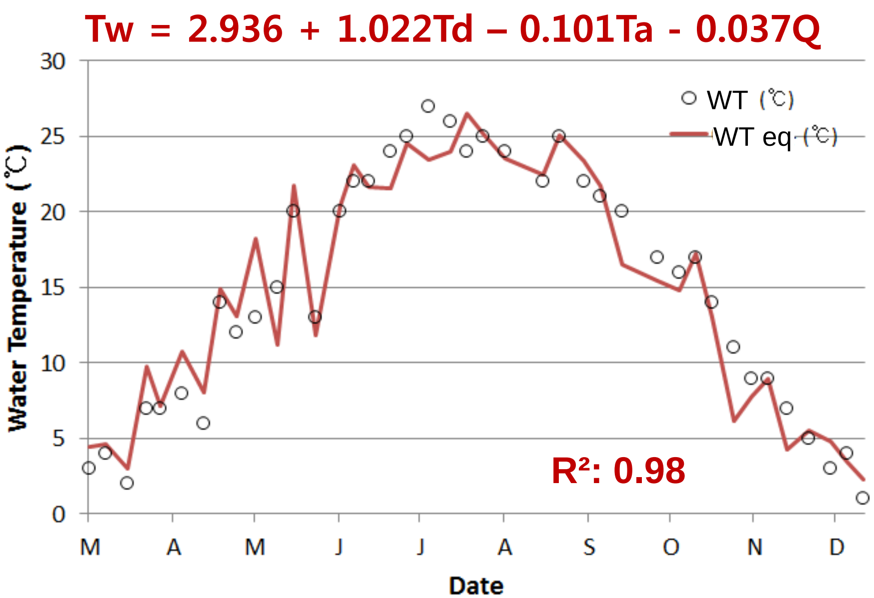
❑ Model Input Data (Initial conditions)

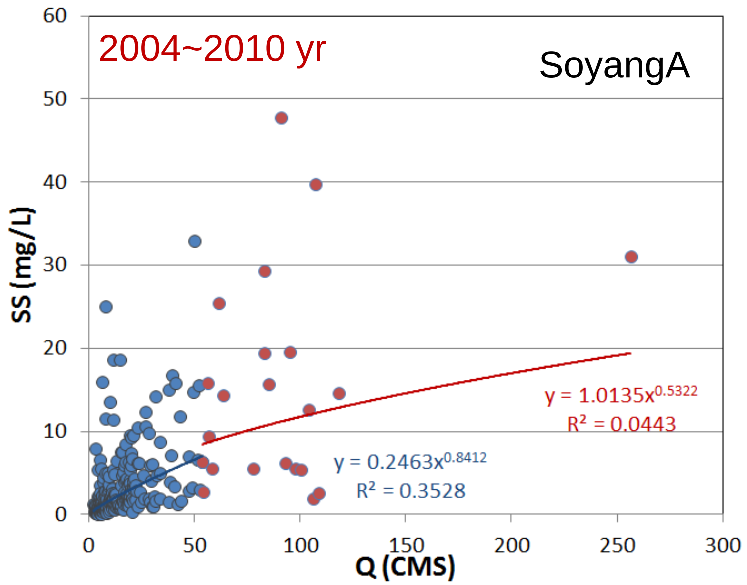
❖ Inflow water temperature

- Use of the Multiple Regression Equation ($Q \sim T_{water} \sim T_{dewpint} \sim T_{air}$)
- SoyangA station data : Intervals of about 8 days

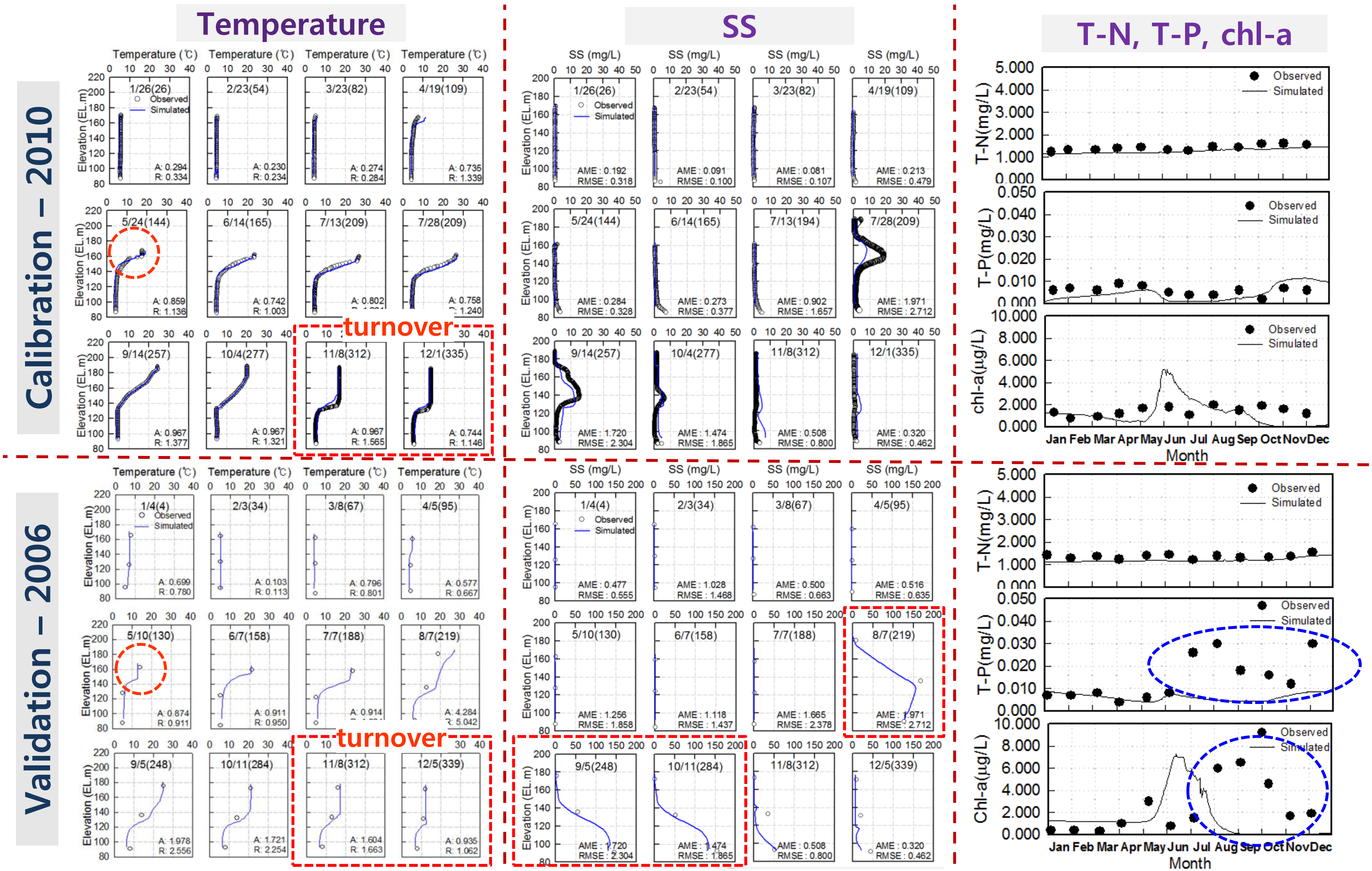
❖ Inflow water turbidity(SS)

- Use the Multiple Regression Equation (Q~SS)
- SoyangA station data: Interval of about 8 days





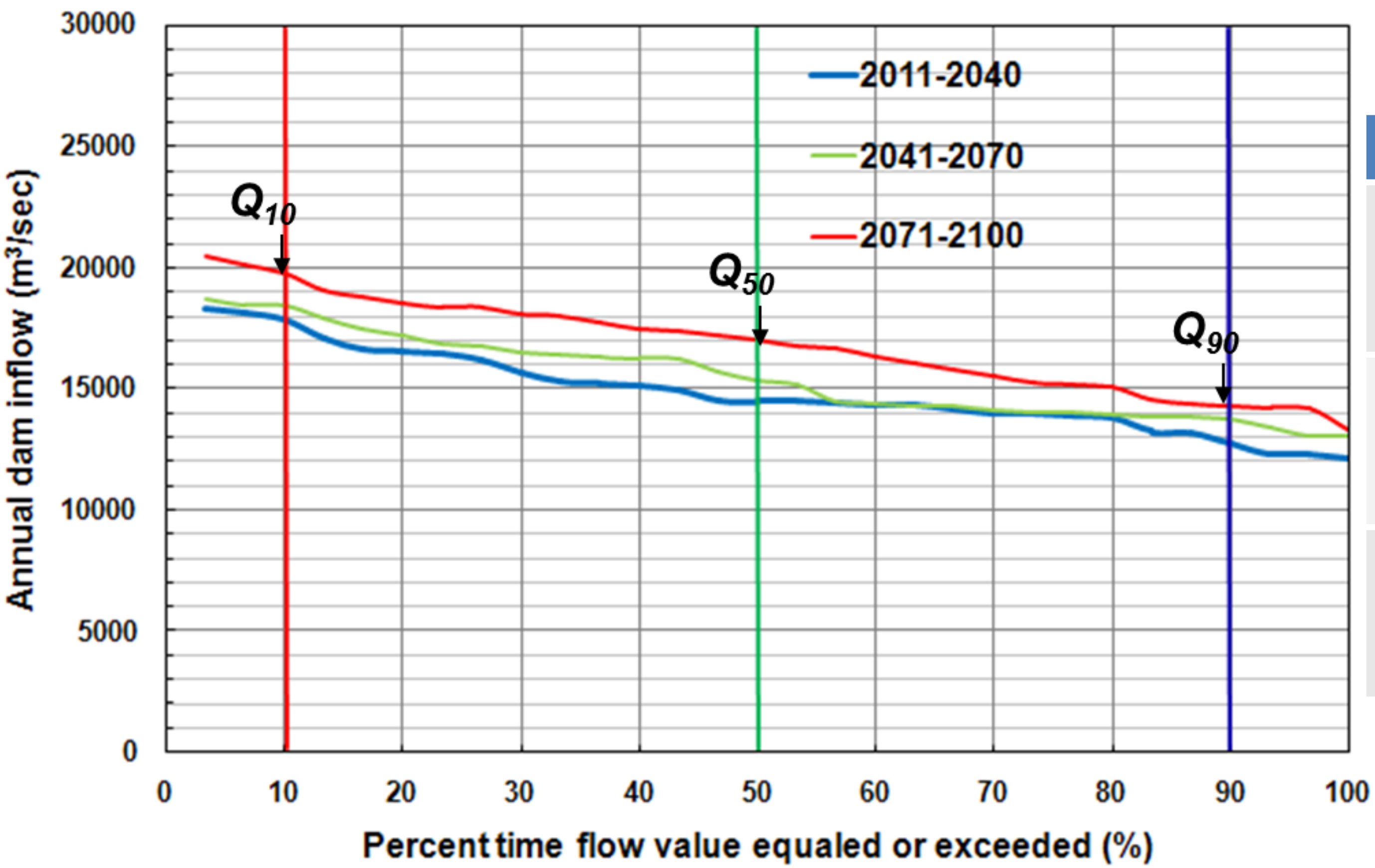
4. CE-QUAL-W2 Modeling



5. Future Turbidity Current Regimes

❑ Select future flow condition

- ❖ 10%(Flood year), 50%(Normal year), 90%(Drought year)



	Year	Period
10 %	2024 2060 2082	F.F M.F L.F
50 %	2018 2056 2090	F.F M.F L.F
90 %	2013 2066 2096	F.F M.F L.F

* F.F : 2011~2040
* M.F : 2041~2070
* L.F : 2071~2100

5. Future Turbidity Current Regimes

❑ Future Detention Time of SS

- In the future, the average detention time of SS increased by all period.

	Year		Yearly Dam Inflow (CMS)	Detention Time		
				Min.(day)	Max.(day)	Avg.(day)
10% (Flood year)	2024	F.F	93.2	0.13	510.0	94.5
	2060	M.F	106.9	0.48	329.1	94.9
	2082	L.F	127.7	0.67	424.4	95.4
50% (Normal year)	2018	F.F	81.5	0.29	241.6	68.4
	2056	M.F	87.6	0.20	139.5	36.1
	2090	L.F	115.3	0.74	534.6	124.6
90% (Drought year)	2013	F.F	73.3	0.10	165.9	38.5
	2066	M.F	75.2	0.30	147.3	37.1
	2096	L.F	93.7	0.20	243.4	64.6

5. Future Turbidity Current Regimes

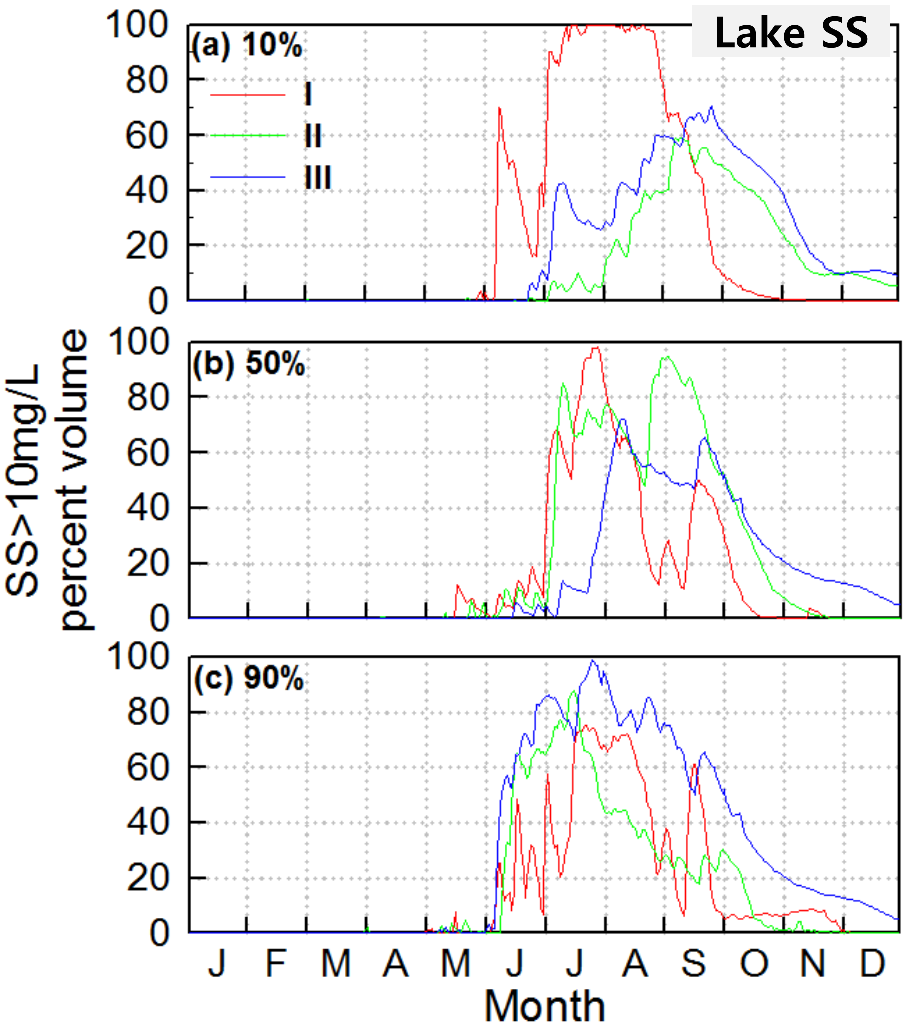
❑ Statistical summary of the future SS of segment inflow, share of lake inside, and dam outflow

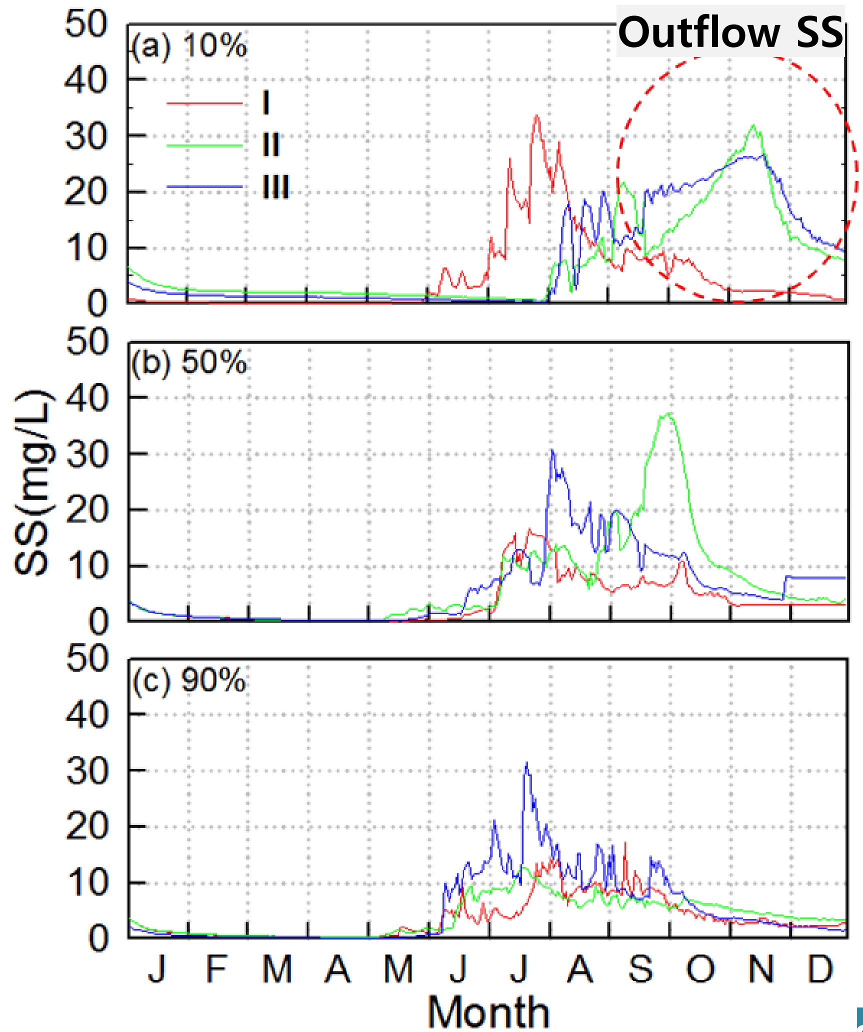
- ❖ Under the future impact on reservoir inflow by SWAT, the future reservoir turbid current will be stayed longer more than present in metalimnion due to thermal stratification.

Class	Year		Inflow SS > 25mg/L		Lake Share SS > 10 mg/L			Outflow SS > 25mg/L	
			Days	Max. (mg/L)	Days	Max. (%)	Avg. (%)	Days	Max. (mg/L)
10%	2027	F.F	98	166.7	152	100.0	22.9	10	33.8
	2058	M.F	120	196.4	184	58.9	12.1	20	32.0
	2095	L.F	134	164.7	191	70.4	18.3	19	26.7
50%	2020	F.F	108	155.5	163	98.2	14.6	0	19.6
	2047	M.F	127	182.2	155	94.7	20.6	21	37.2
	2077	L.F	126	160.5	199	72.4	15.5	8	30.7
90%	2021	F.F	101	137.8	173	75.0	14.4	0	17.3
	2048	M.F	120	132.5	155	87.8	15.5	0	12.7
	2073	L.F	117	155.6	209	99.1	28.4	4	31.6

5. Future Turbidity Current Regimes

❑ The future SS of segment inflow, share of lake inside, and dam outflow





6. Summary & Concluding remarks

- In this study, watershed model (SWAT) and reservoir water quality model (CE-QUAL-W2) were applied to assess the future climate change impact on turbidity current regimes in Soyang lake.

- CE-QUAL-W2 using SWAT inflows simulated the features of lake stratification regime, including the formation of a turbid intermediate layer in the reservoir.

- ***By the future prediction of lake turbidity current regimes considering SWAT watershed impact, the proper management of both watershed and lake would be possible for Soyang reservoir.***

- **This study results may include optimizing certain positive effects of reservoir operation as well as minimizing negative effects to downstream communities.**

“ Thank You ”

For further information, please contact:

Ha, Rim

Ph.D. Candidate, Dept. of Civil & Environmental System Engineering, Konkuk University
rim486@konkuk.ac.kr

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Q & A