SWAT | Soil & Water Assessment Tool

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SESSION G4:
CLIMATE CHANGE APPLICATIONS
Amphitheater Baillaud, Room U4.4

2013 International SWAT Conference

Evaluation of Turbidity Water and Eutrophication in Chungju Lake by Future Climate Change Using CE-QUAL-W2 and SWAT

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Contents

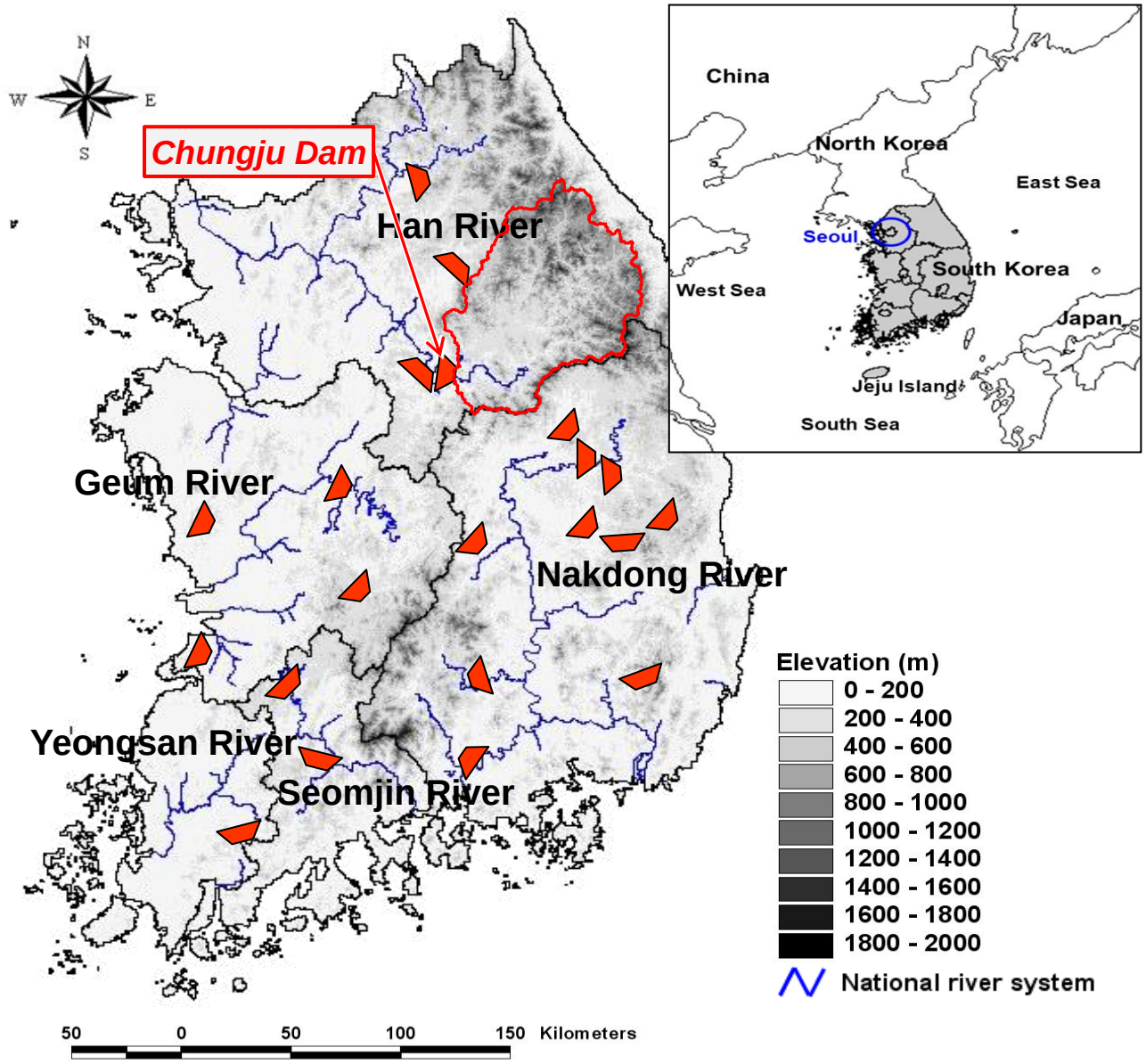
Introduction (Why this study?)

- ***Recently, long time turbidity water and algae proliferation in Korea water supply multi-purpose reservoir occurs with high frequency due to the rise in temperature and turbid flood by climate change.***
  - ✓ ***It causes dangerous impacts on aqua-ecosystem itself and municipal water supply to downstream cities.***
  - ✓ ***We need to estimate the impact how much from watershed and within lake for the turbidity and algae blooms, and also the future possible impact for proper mitigation planning from now on.***

- ***Most lake studies are limited to just within waterbody not considering upstream watershed impact.***

- ***The main objective of this study is to evaluate the future climate change impact on turbidity water and eutrophication of Chungju Lake in South Korea by applying reservoir water quality model (CE-QUAL-W2) with watershed model (SWAT).***

20 Multi-purpose Dams of South Korea



- ***5 river basins** in our country (Han, Geum, Yeongsan, Seomjin and Nakdong)*
- ***A total of 20 multipurpose dams** in South Korea are being managed by Korea Water Resources Corporation (K-water).*
- ***They have been successfully managed by K-water to fulfill water demands, flood control and hydropower generation.***

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Research Procedure

Climate Change Scenarios Data

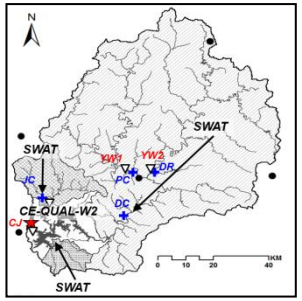
Climate scenarios (RCM)

IPCC AR4 A1B scenario

- *Temperature*
- *Precipitation*
- *Relative humidity*

Runoff and water quality scenarios (SWAT)

- *Inflow*
- *Stream water quality*



Multiple regression analysis

- *Water temperature*

Boundary Condition (Weather)

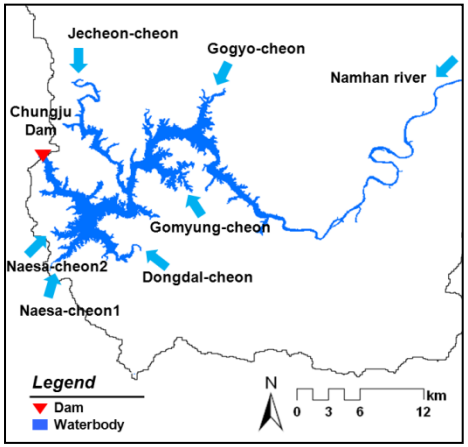
Boundary Condition (Runoff and water quality)

Boundary Condition (Water temperature)

Future Lake Water Quality modeling

CE-QUAL-W2 boundary conditions

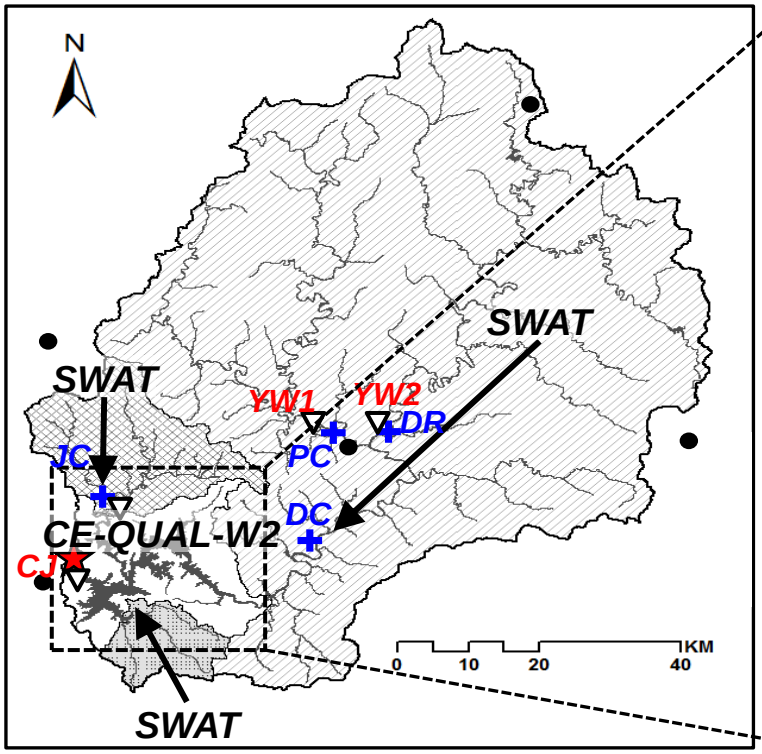
- *Inflow*
- *Inflow temperature*
- *Water quality*

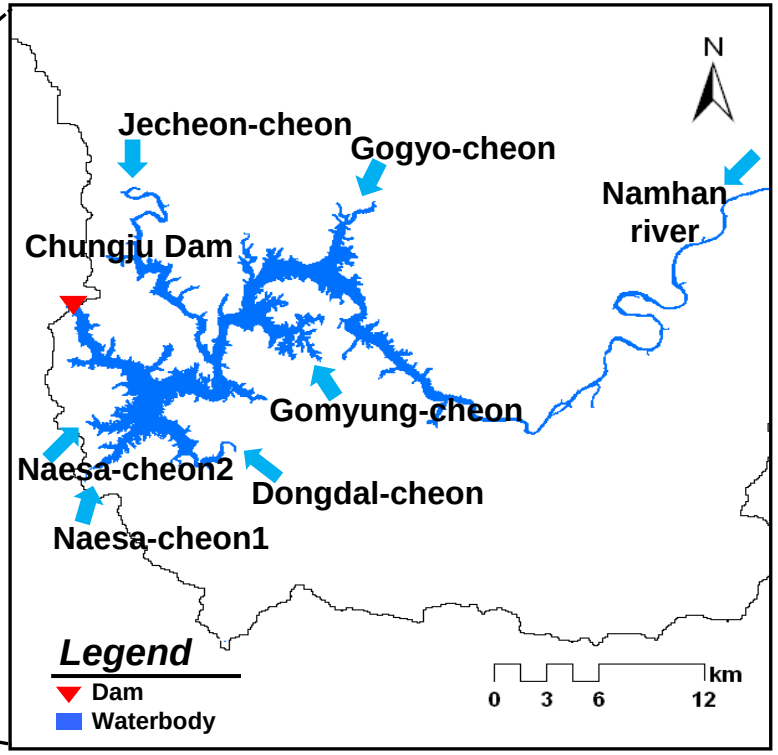


Study Area

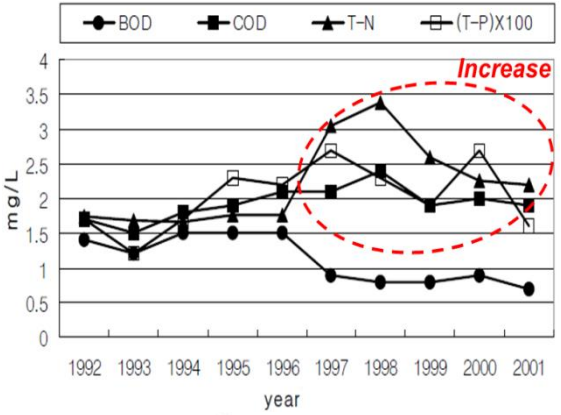
Legend

- Namhan river (main stream)
- Jecheon-cheon (tributary)
- Dongdal-cheon (tributary)
- Stream
- Watershed
- Reservoir water quality station
- Stream water quality station
- Streamflow station
- Weather station





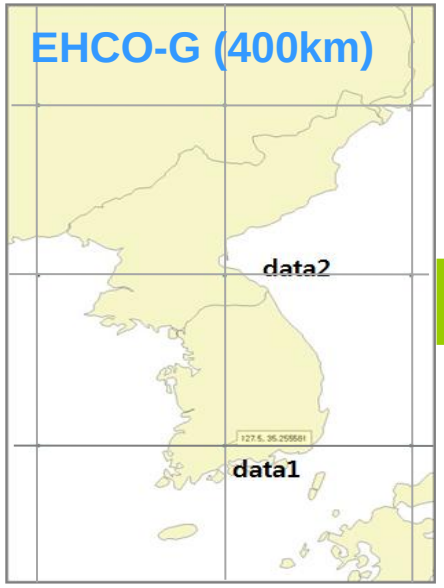
- **Chungju Dam Watershed (6,662 km²)**
  - ✓ Average precipitation 1359.5 mm
  - ✓ Average temperature 9.4℃

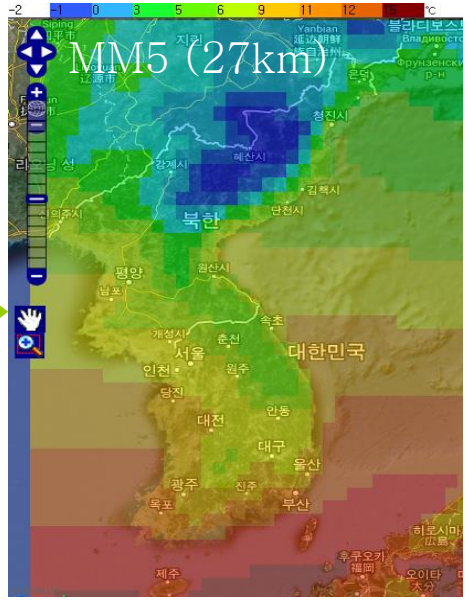


Climate Scenarios (IPCC AR4 RCM)

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

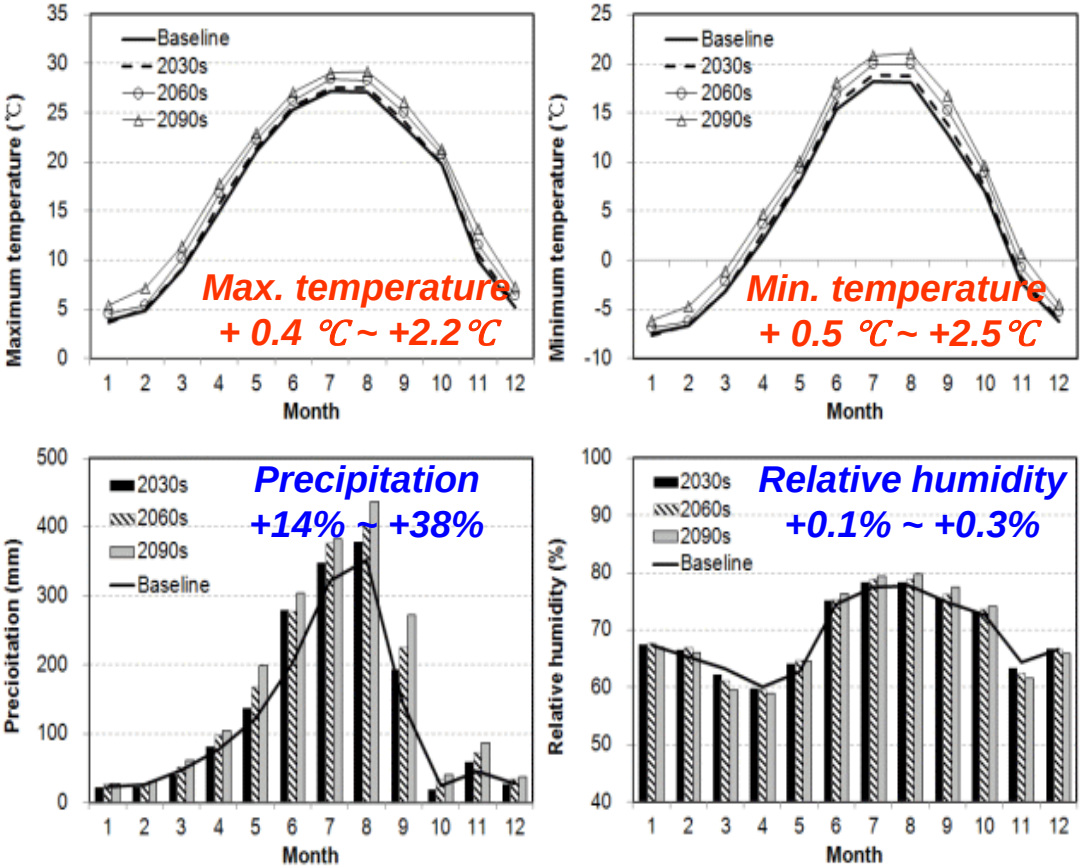
SWAT model

Climate Scenarios (IPCC AR4 RCM)

IPCC AR4 RCM climate change scenario

- ***Three time periods: 2030s (2011~2040), 2060s (2041~2070), 2090s (2071~2100)***
  - ***Future precipitation showed the biggest change in summer period.***
  - ***Future relative humidity has slightly increased.***

Period	Baseline (1991 ~2010)	2030s (2011~2040)	2060s (2041~2070)	2090s (2071~2100)
Max. temperature (℃)	15.6	15.9 (0.4℃)	16.8 (1.2℃)	17.8 (2.2℃)
Min. temperature (℃)	4.3	4.8 (0.5℃)	5.7 (1.4℃)	6.8 (2.5℃)
Precipitation (mm)	1449.7	1651.1 (13.9%)	1800.3 (24.2%)	1998.3 (37.8%)
Relative humidity (%)	69.3	69.6 (0.1%)	69.7 (0.2%)	69.8 (0.3%)



Data for SWAT Model Evaluation

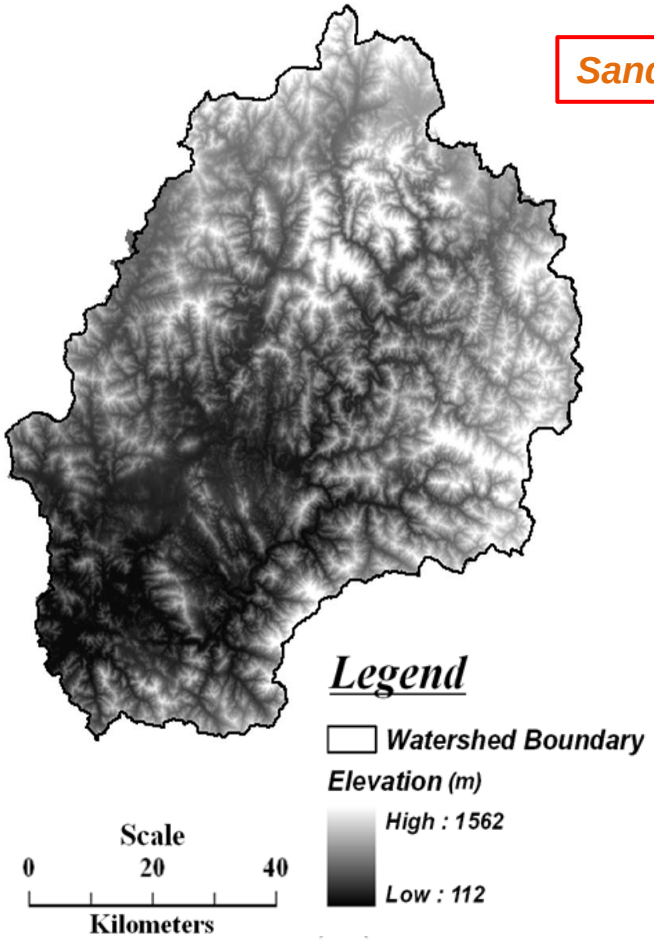
SWAT input data

Data Type	Source	Scale / Period	Data Description / Properties
Topography	Korea National Geography Institute	1/5,000	Digital Elevation Model (DEM), 30m X 30m
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 use	Landsat TM satellite Image NOAA/AVHRR satellite Image	30m	Landsat land use classification (9 classes)
Weather	Korea Meteorological Administration	1998~2010	Daily precipitation, minimum and maximum temperature, mean win d speed and relative humidity data
Streamflow	Water Management Information System	1998~2010	Daily streamflow data at watershed outlet
Dam inflow	K-water	1998~2010	Daily dam inflow data
Water quality	Water Information System	1998~2010	SS, TN, TP, DO, BOD, Chl-a
Climate change	Korea Meteorological Administration	1971-2100	Daily precipitation, minimum and maximum temperature and relative humidity data from RCM

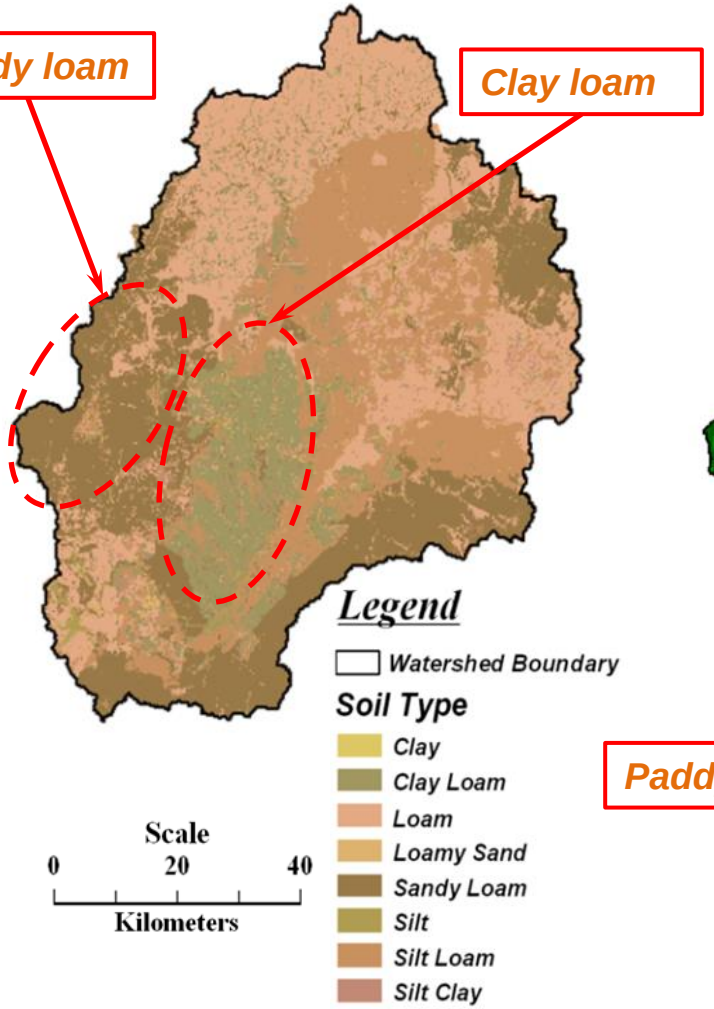
Data for SWAT Model Evaluation

GIS data

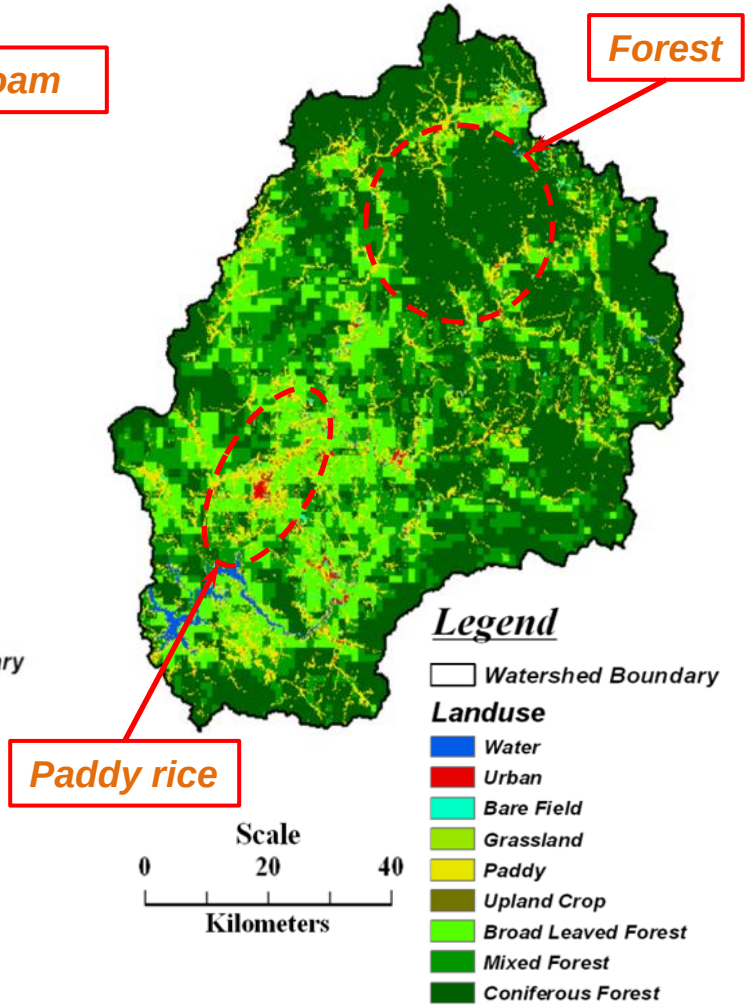
Elevation : 112 - 1562m (average: 607m)



Soil : clay loam (45%) and sandy loam (40%)

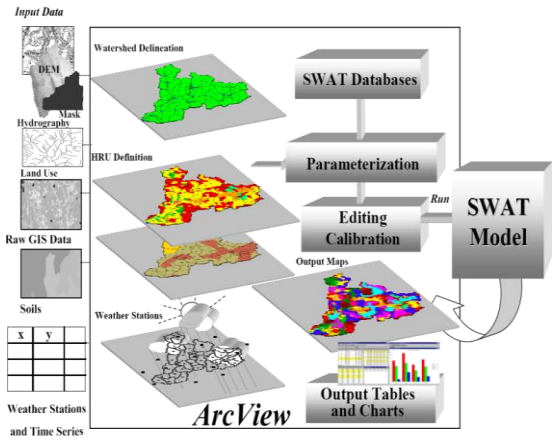


Land cover (2000) : forest (81%) and paddy rice (10%)

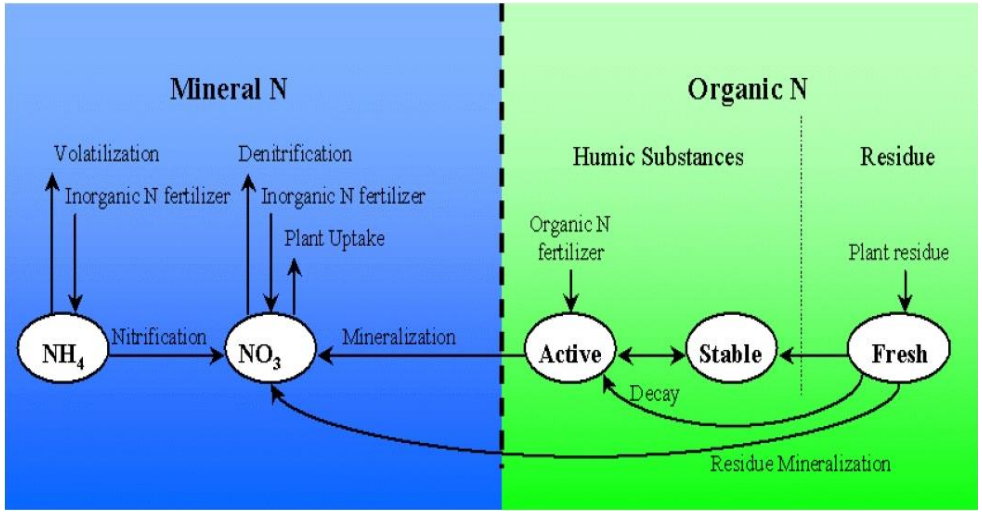


SWAT Model

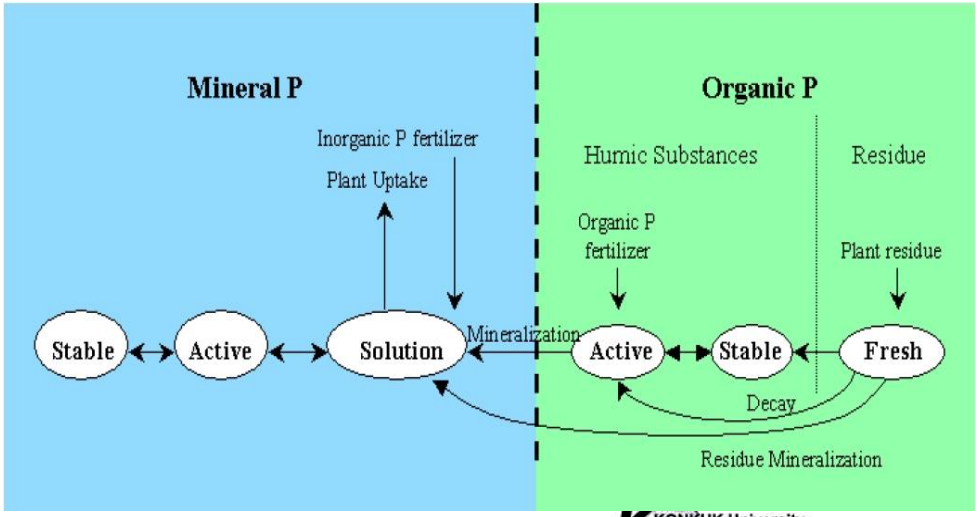
- ***SWAT (Soil and Water Assessment Tool) model***
  - ***Developed by USDA Agriculture Research Service (ARS)***
  - ***Physically based continuous, long-term, distributed-parameter model***
  - ***To predict the effects of land management practices on the hydrology, sediment, and contaminant transport in agricultural watersheds under varying soils, land use, and management conditions***



Nitrogen



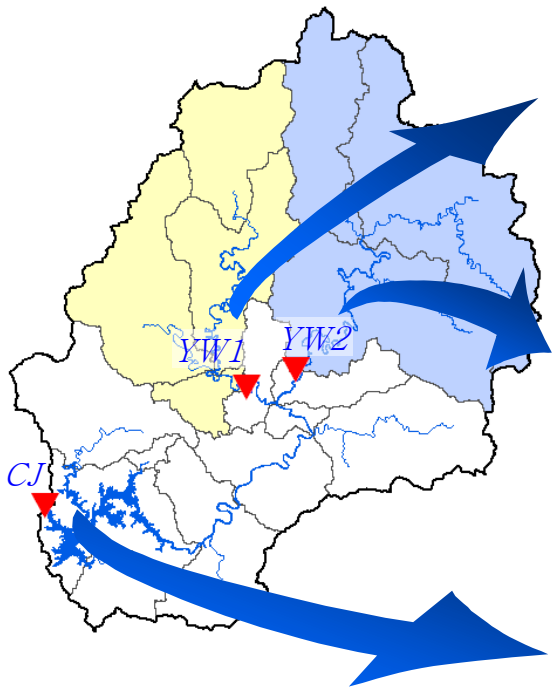
Phosphorus

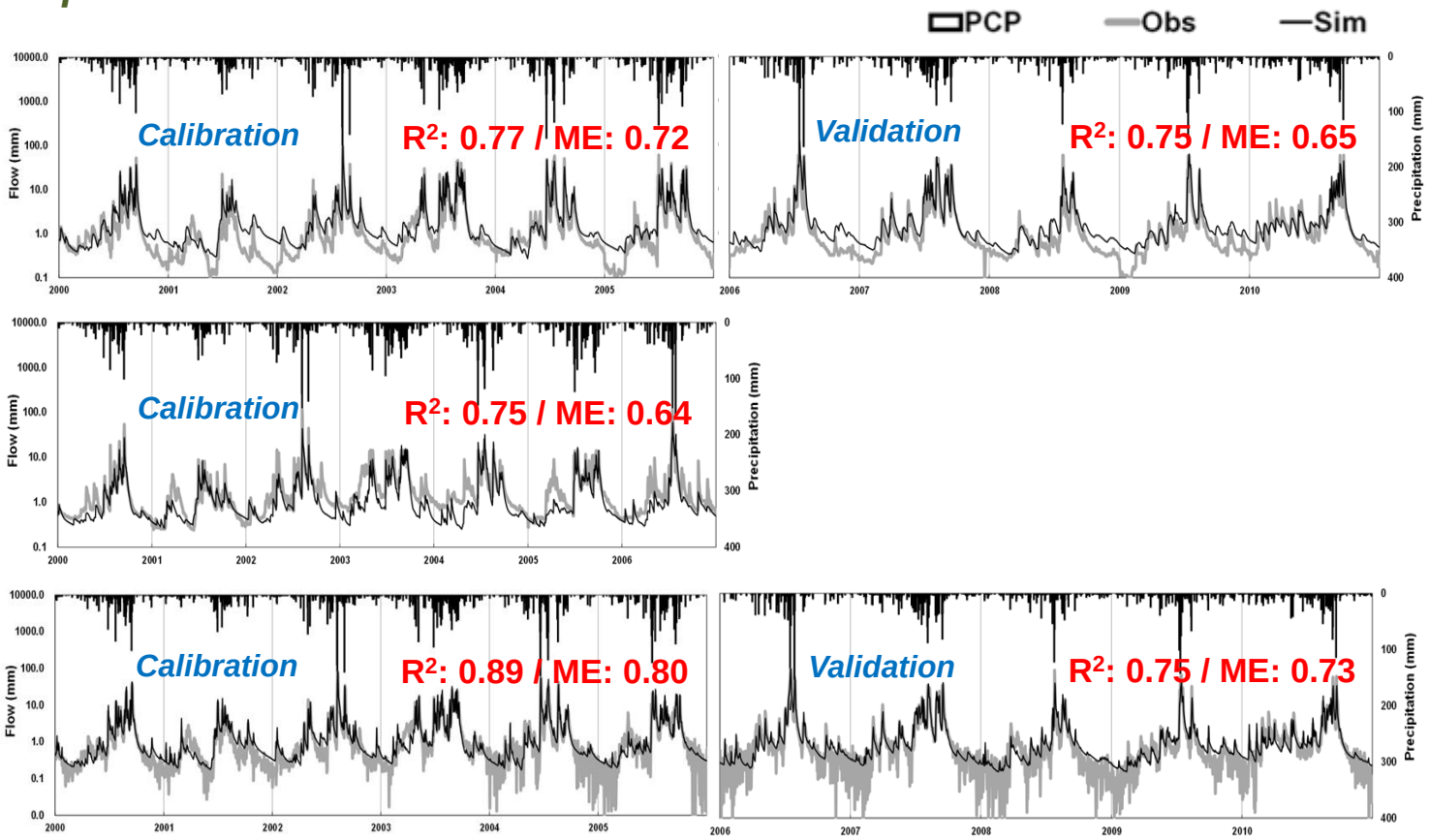


SWAT Model Calibration and Validation

Watershed streamflow results

- **Calibration : 6 years (2000-2005) / Validation : 5 years (2005-2010)**
  - **YW1, YW2 located upstream and CJ in the watershed outlet**

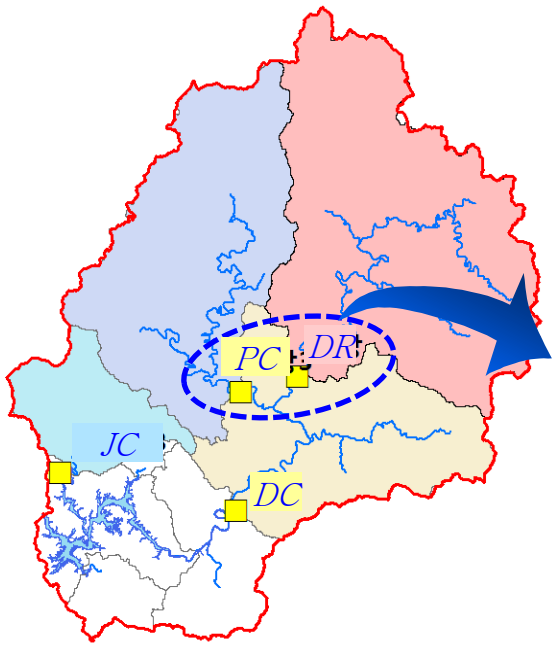


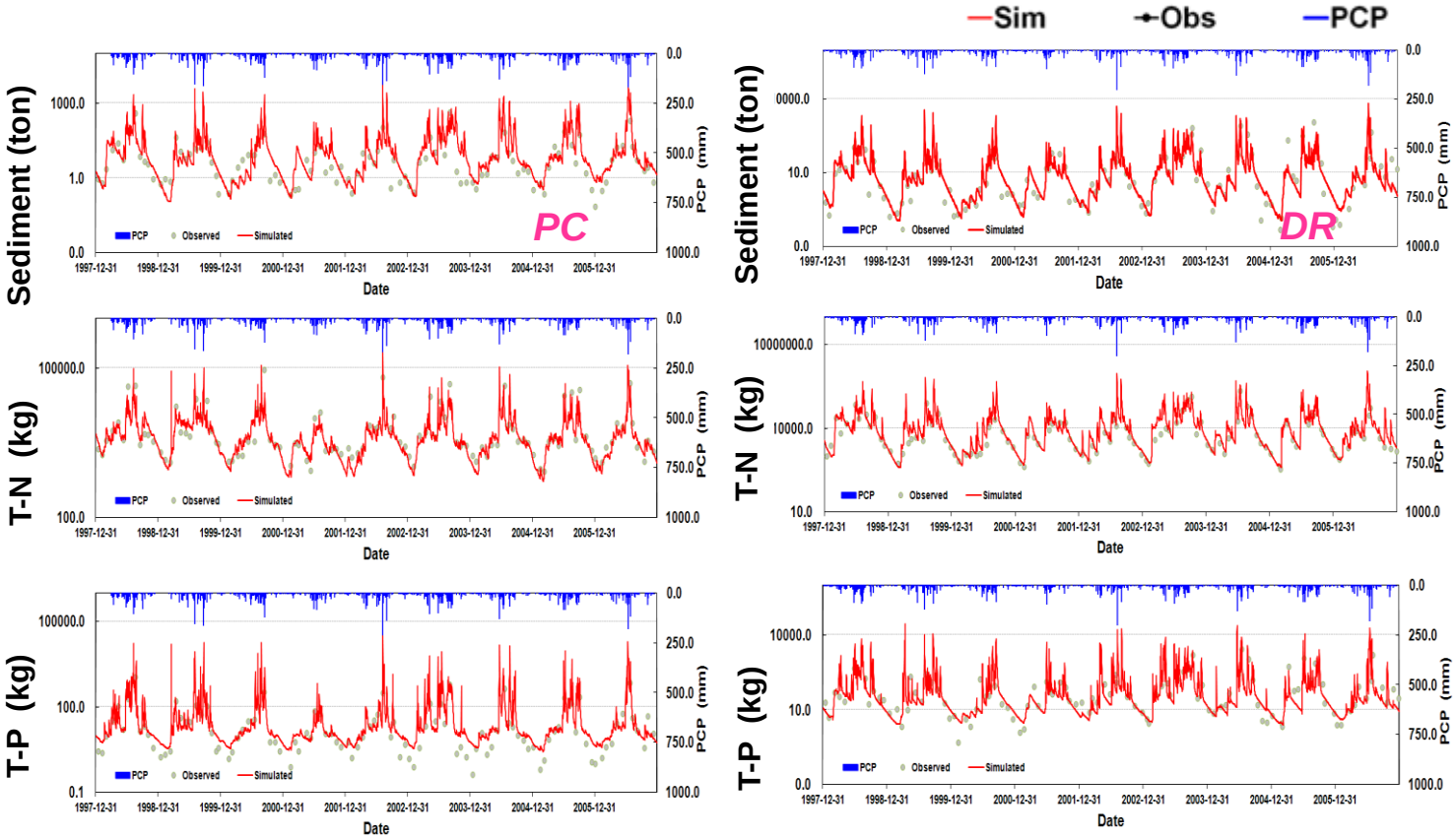


SWAT Model Calibration and Validation

Stream water quality results

- **Calibration : 6 years (2000-2005) / Validation : 5 years (2005-2010)**
  - **Sediment, T-N, T-P in four sites (PC, DR, DC, and JC)**





SWAT Model Calibration and Validation

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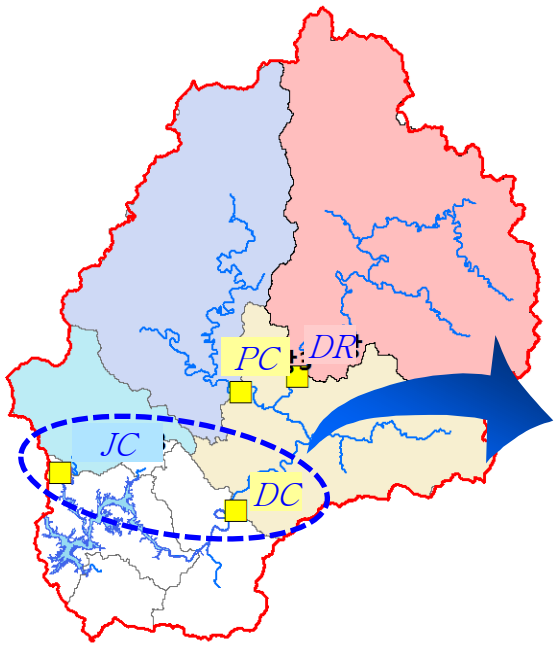
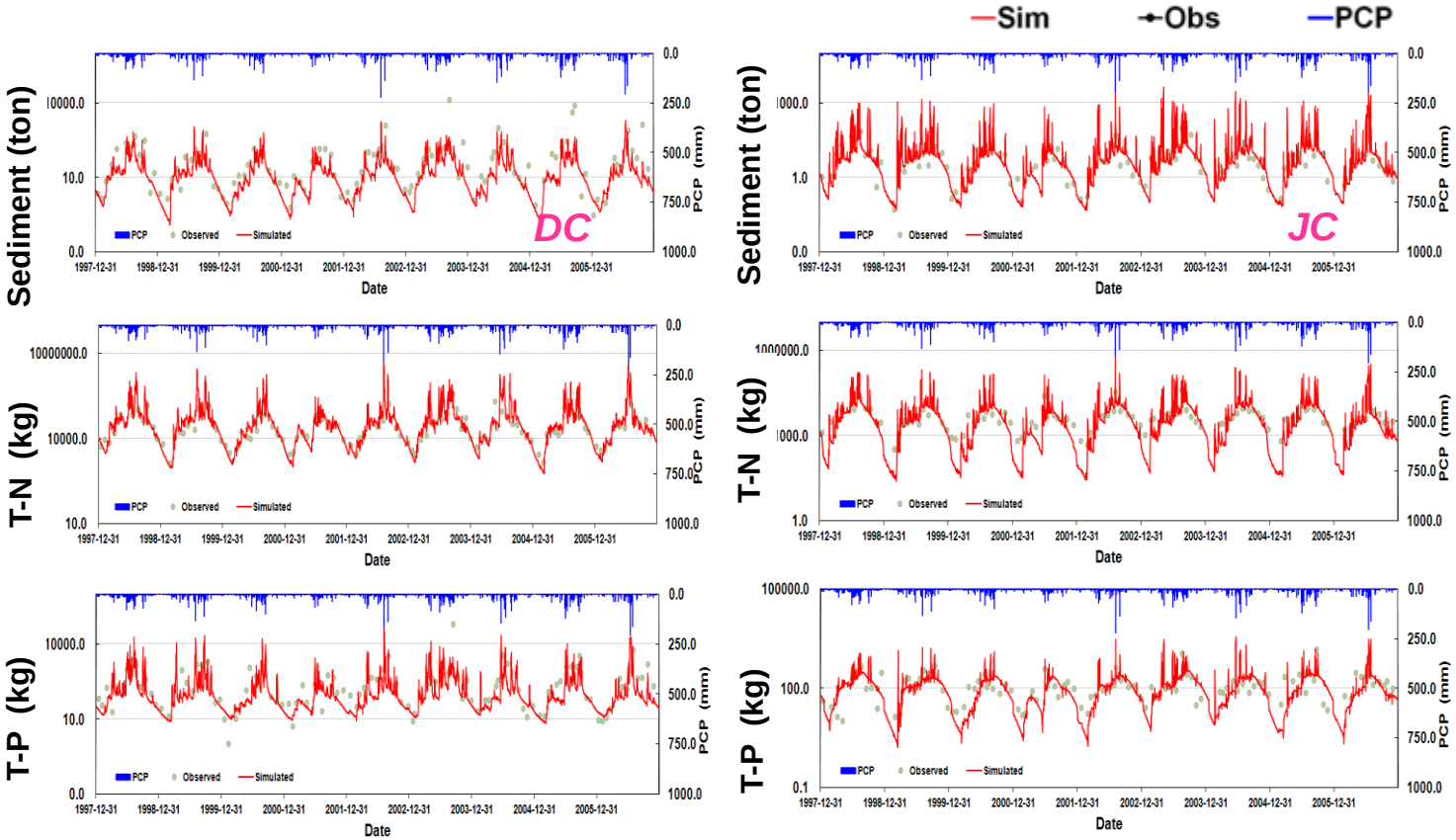
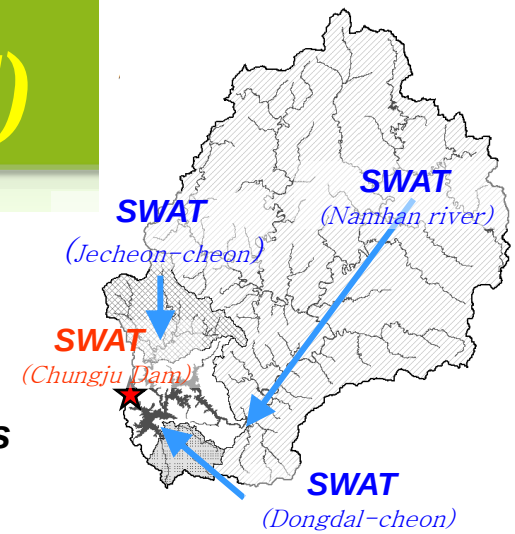


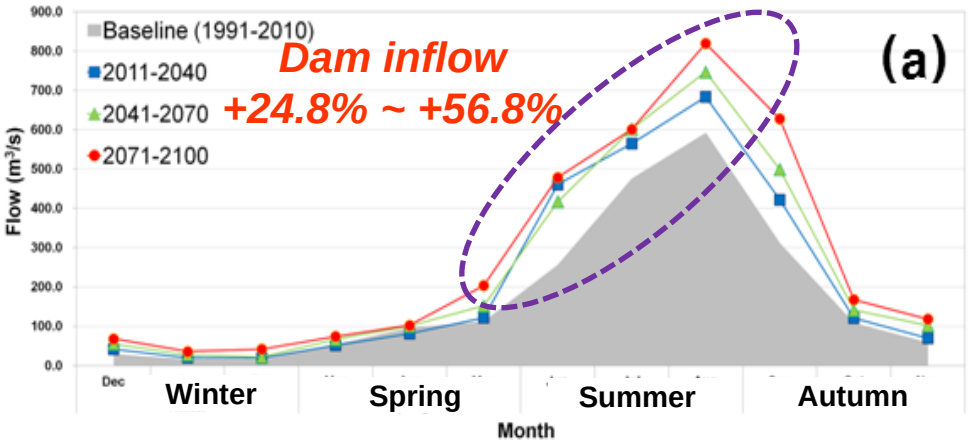


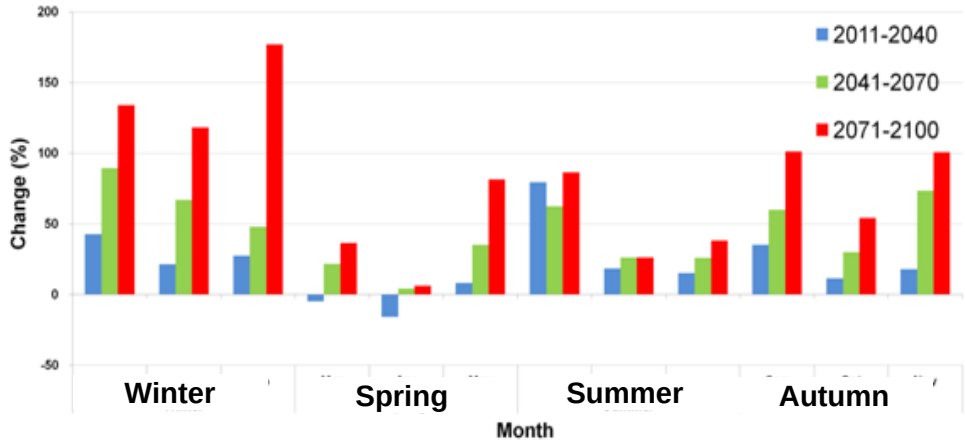
Future Watershed Runoff (SWAT)

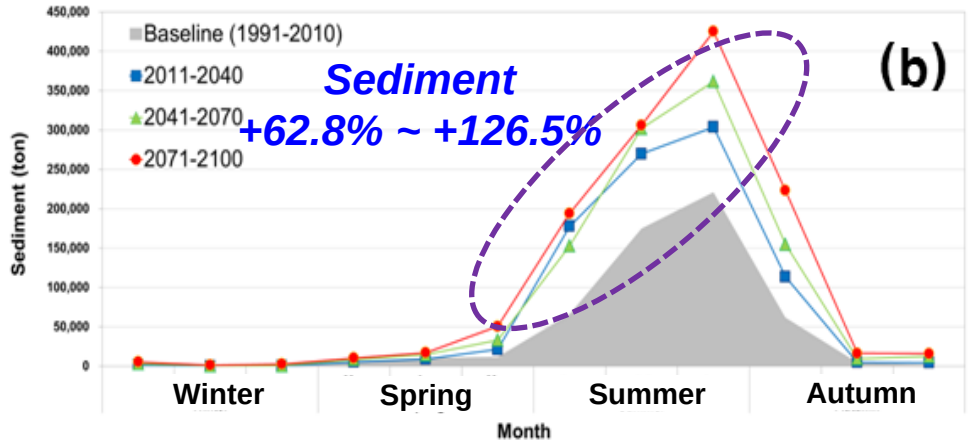


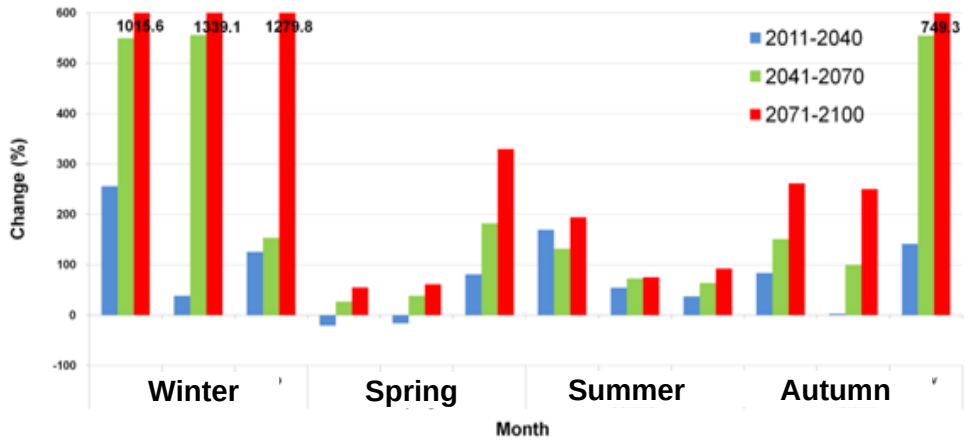
Future lake inflow and sediment from watershed

- **Dam inflow** : + 24.8 % in 2030s, + 37.7 % in 2060s, and + 56.8 % in 2090s
- **Sediment load** : + 62.8 % in 2030s, + 88.2 % in 2060s, and + 126.5 % in 2090s

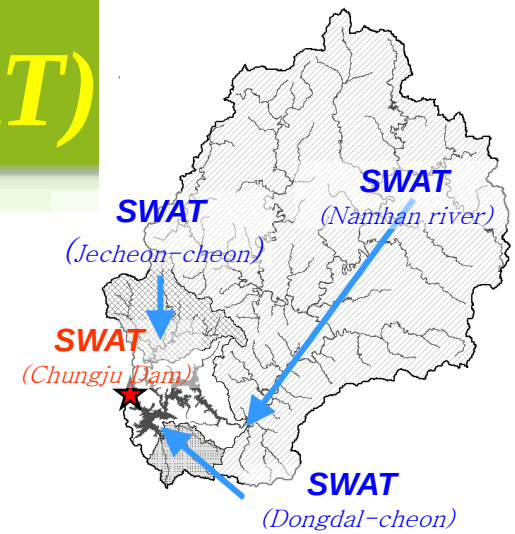






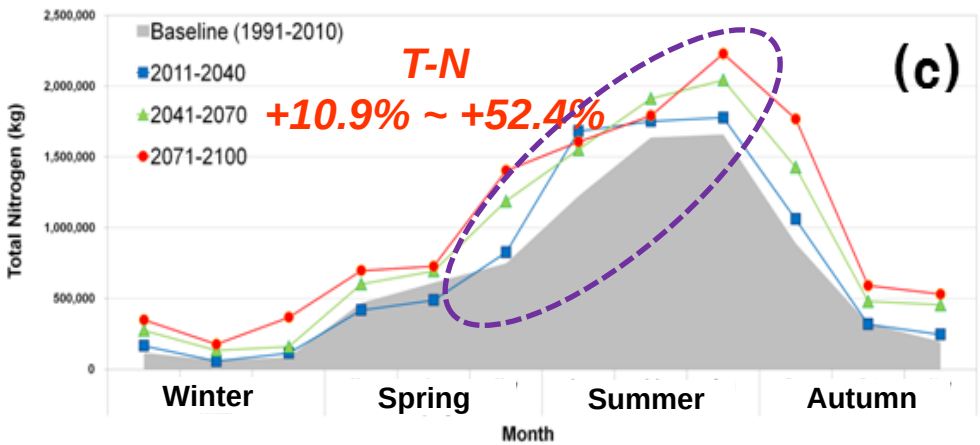


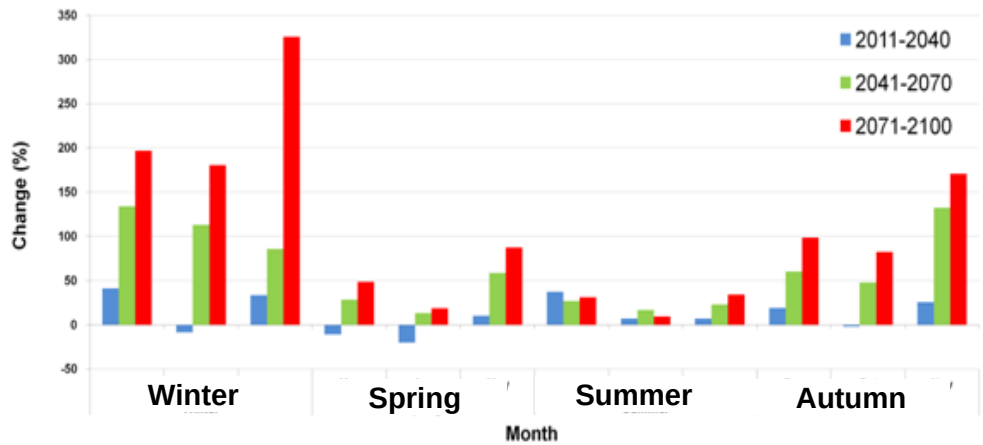
Future Stream Water Quality(SWAT)

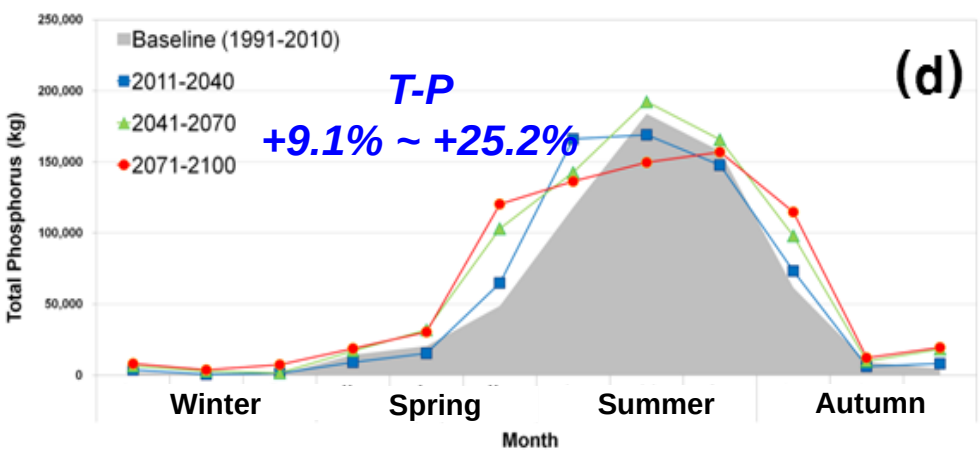


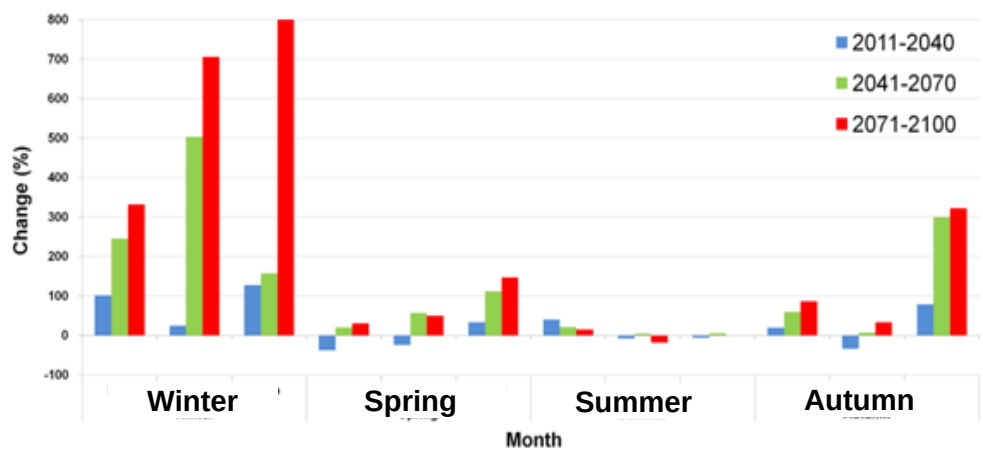
Future T-N and T-P to lake from watershed

- **T-N : + 10.9% in 2030s, + 36.0 % in 2060s, and + 52.4 % in 2090s**
- **T-P : + 9.1 % in 2030s, + 27.2 % in 2060s, and + 25.2 % in 2090s**





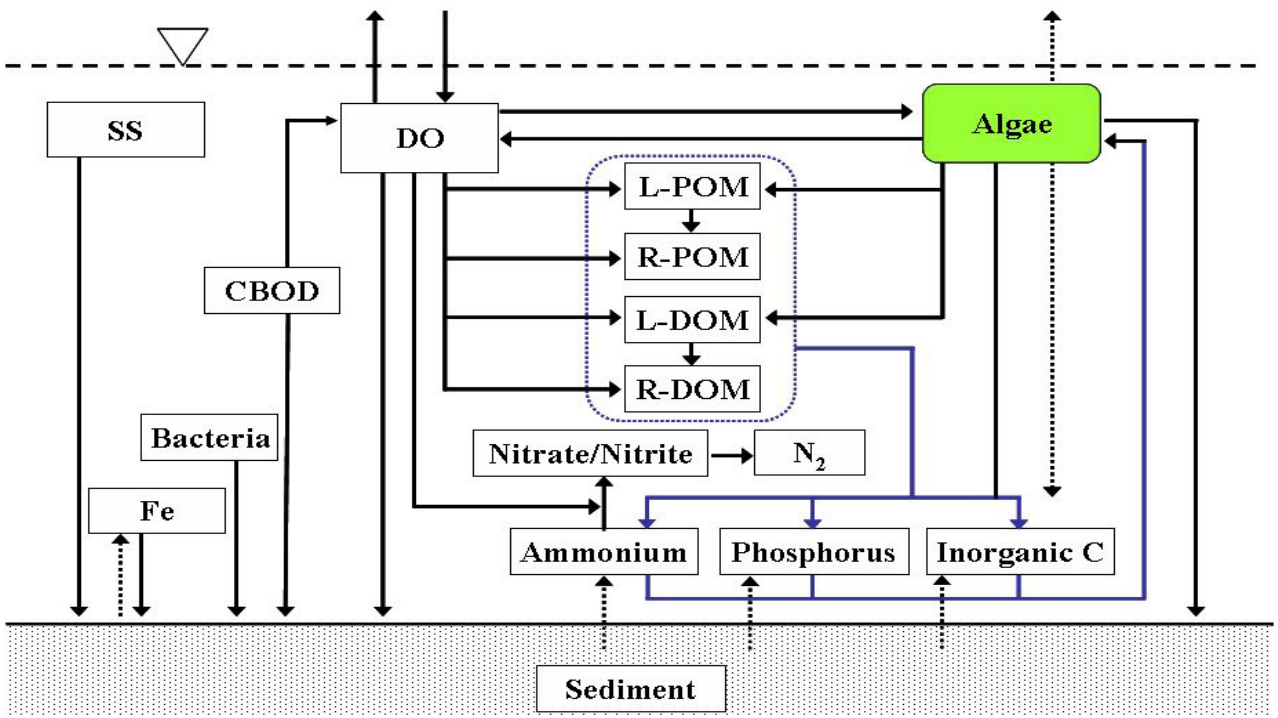


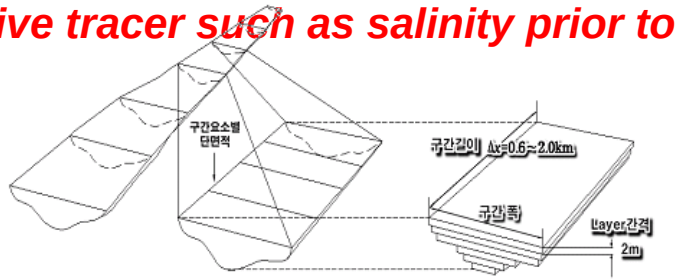


CE-QUAL-W2 model

CE-QUAL-W2 model

- *A two-dimensional (longitudinal–vertical) hydrodynamic and water quality model*
- *Developed by U.S. Army Corps of Engineers' Waterways Experiment Station*
- *In CE-QUAL-W2 model applications, the hydrodynamic runs provide real-time simulations of velocities, temperature, and a conservative tracer such as salinity prior to the water quality calculations.*





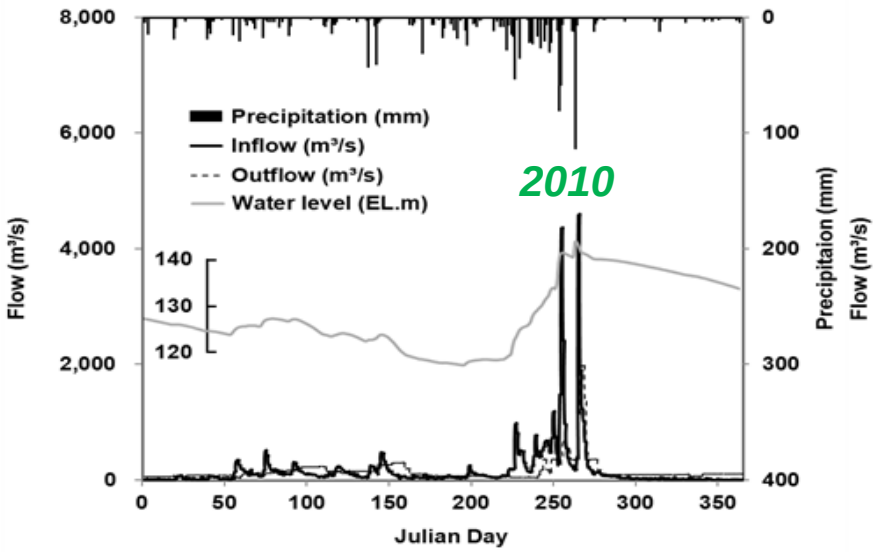
Water Quality

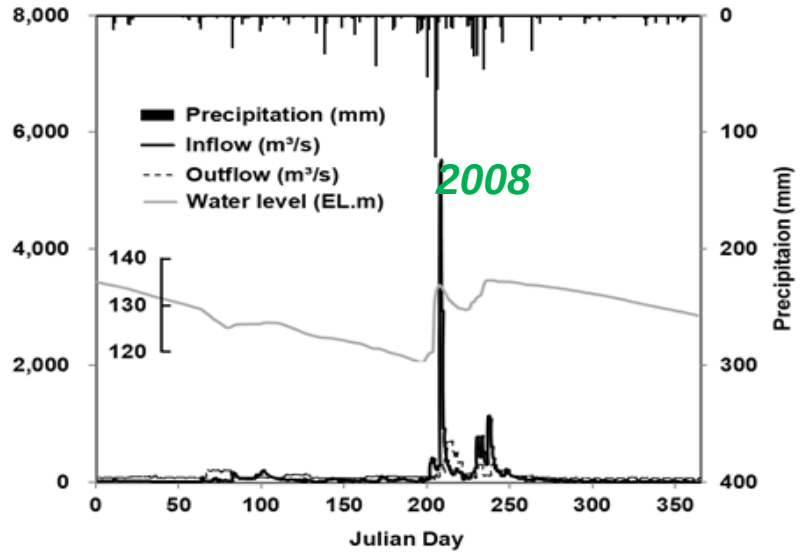
- Conservative tracer
- SS, Coliform bacteria, TSD
- Labile-, Refractory-DOM
- Algae
- Labile-, Refractory-POM
- Phosphorous
- NH3, NOX- nitrogen
- DO, pH, CBOD
- CO2, HCO3, CO3
- Fe etc. (22 items)

Data for CE-QUAL-W2 Model Evaluation

CE-QUAL-W2 input data

- **Calibration (2010) / Validation (2008)**
- **Meteorological data**
  - *Air temperature (℃), dew point temperature (℃), wind speed (m/s), wind direction (phi), and cloud cover (%)*
- **Initial conditions**
  - *Observed water temperature and turbidity data by depth on each starting date (January 1) in lake*
- **boundary conditions**
  - *Inflow, outflow, inflow temperature and water quality data (SS, NO3, NH4, PO4-P,DO, Chl-a)*

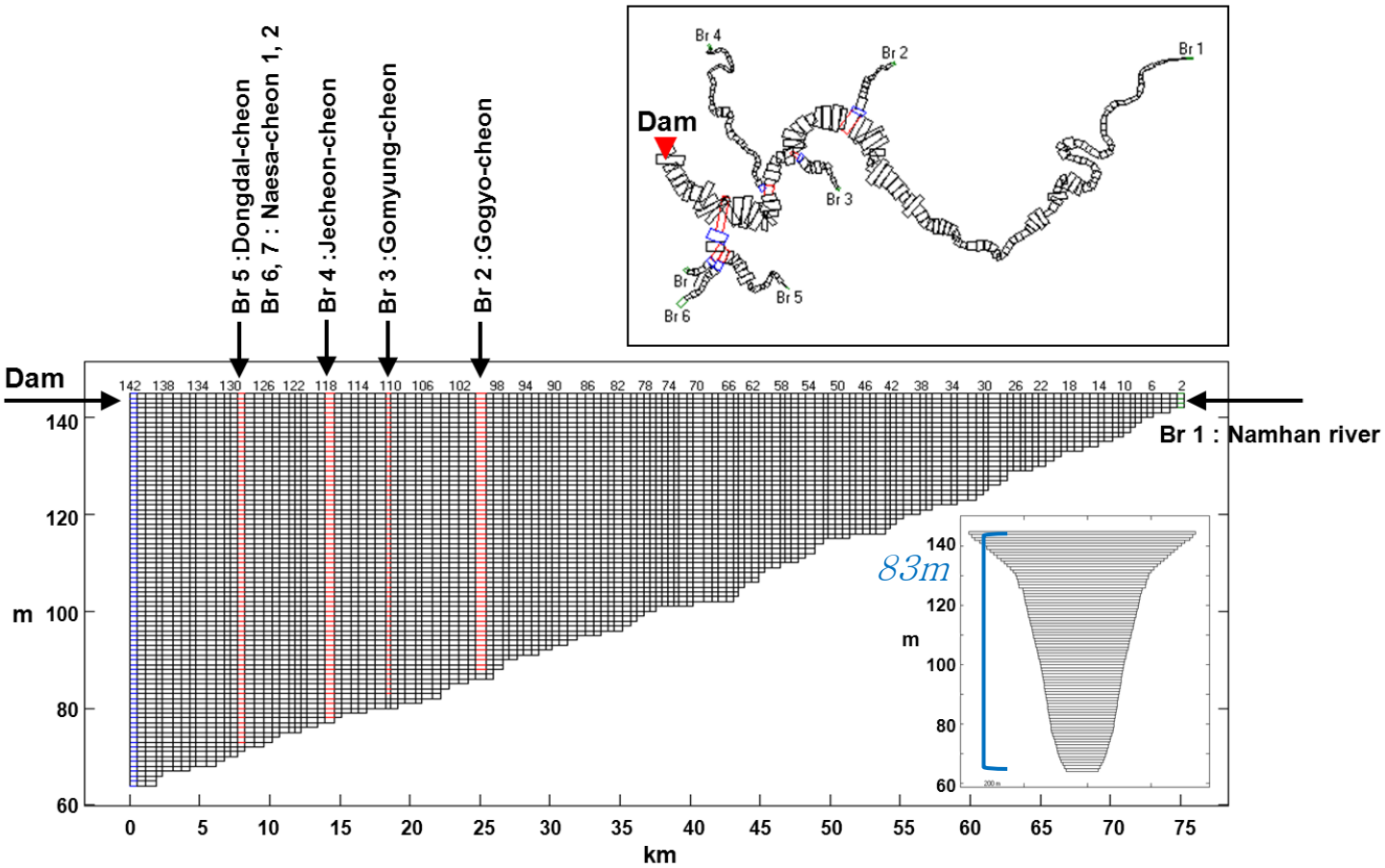




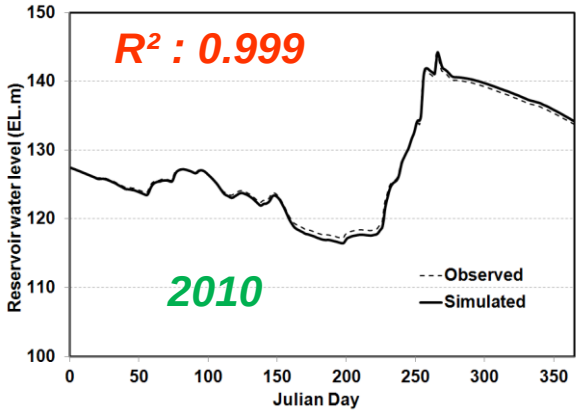
CE-QUAL-W2 Model Calibration and Validation

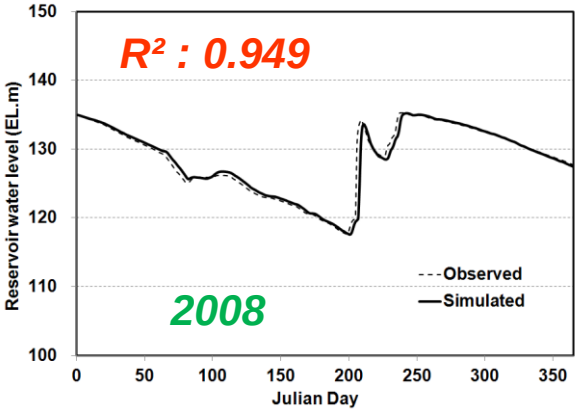
Topographical profile and water balance

- Chungju Lake segmentation was configured as 7 branches, 261 segments and 83 layers according to their shape and tributary distribution.



Water level Observed vs. Simulated

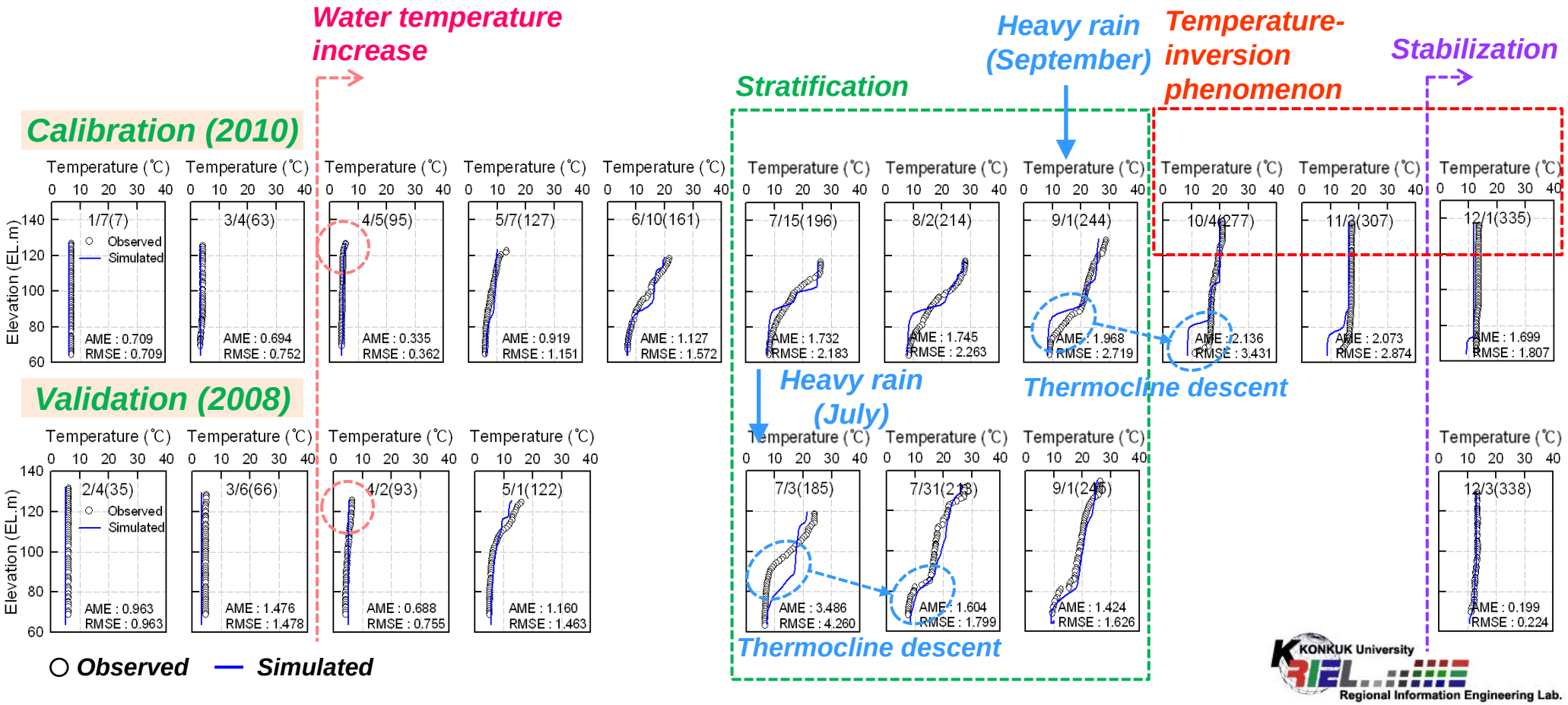




CE-QUAL-W2 Model Calibration and Validation

Lake water temperature results

- The water temperature **began to increase in depth from April** and the **stratification occurred at about 10 m by early July heavy rain.**



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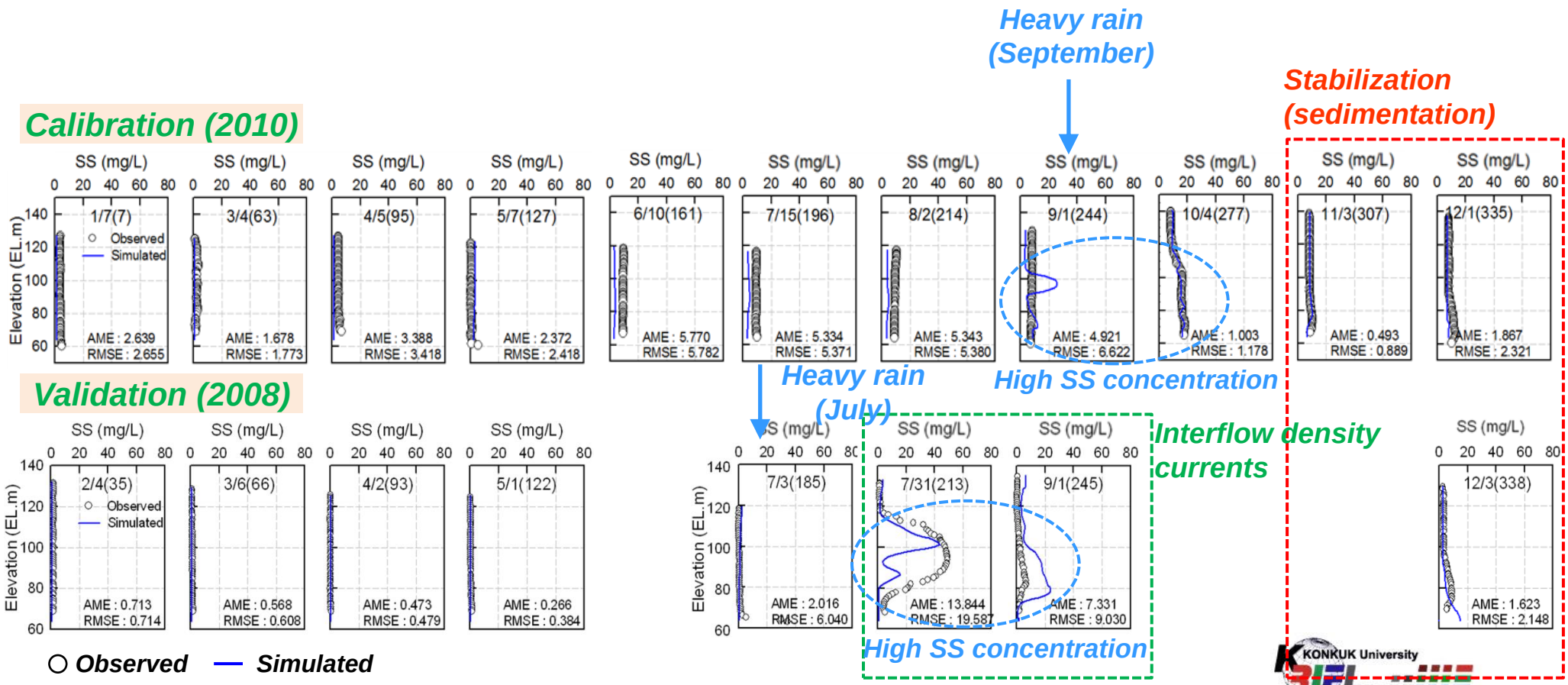
CE-QUAL-W2 Model Calibration and Validation

Suspended solid (SS) results of model calibration and validation

- ***The high SS concentration of the interflow density currents** entering from the watershed was well simulated especially for **July 2008** heavy rainfall event.*



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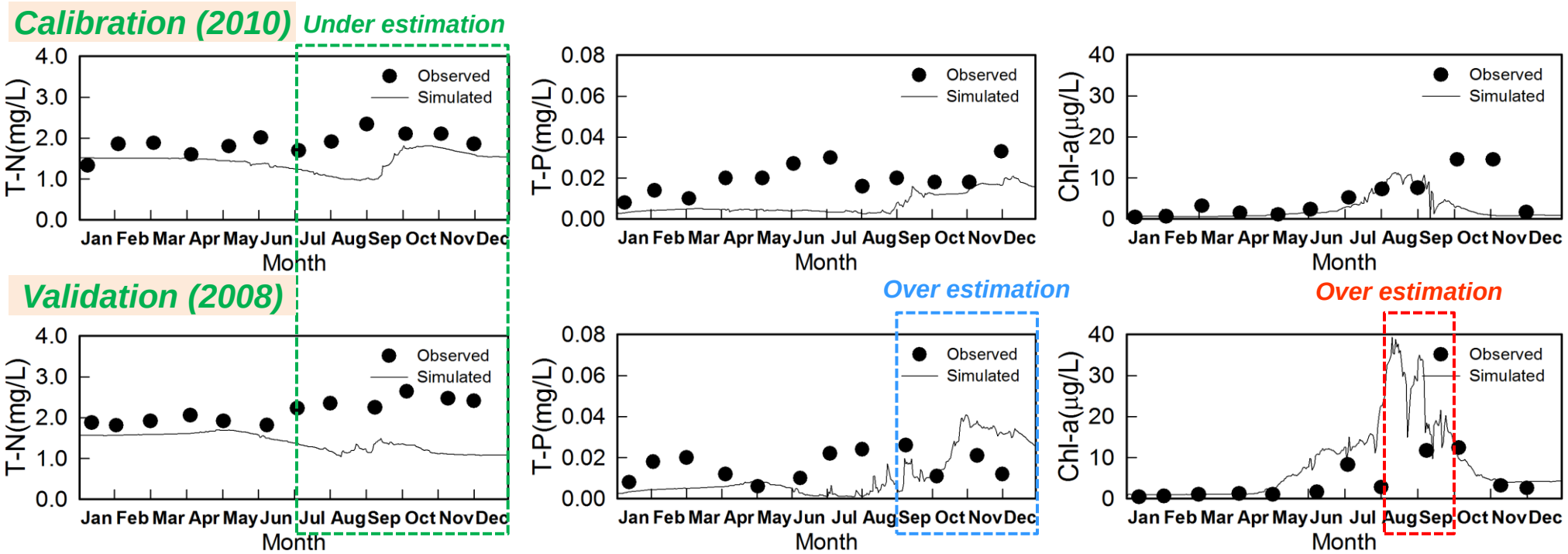
CE-QUAL-W2 Model Calibration and Validation

T-N, T-P and algae (Chl-a) results of model calibration and validation

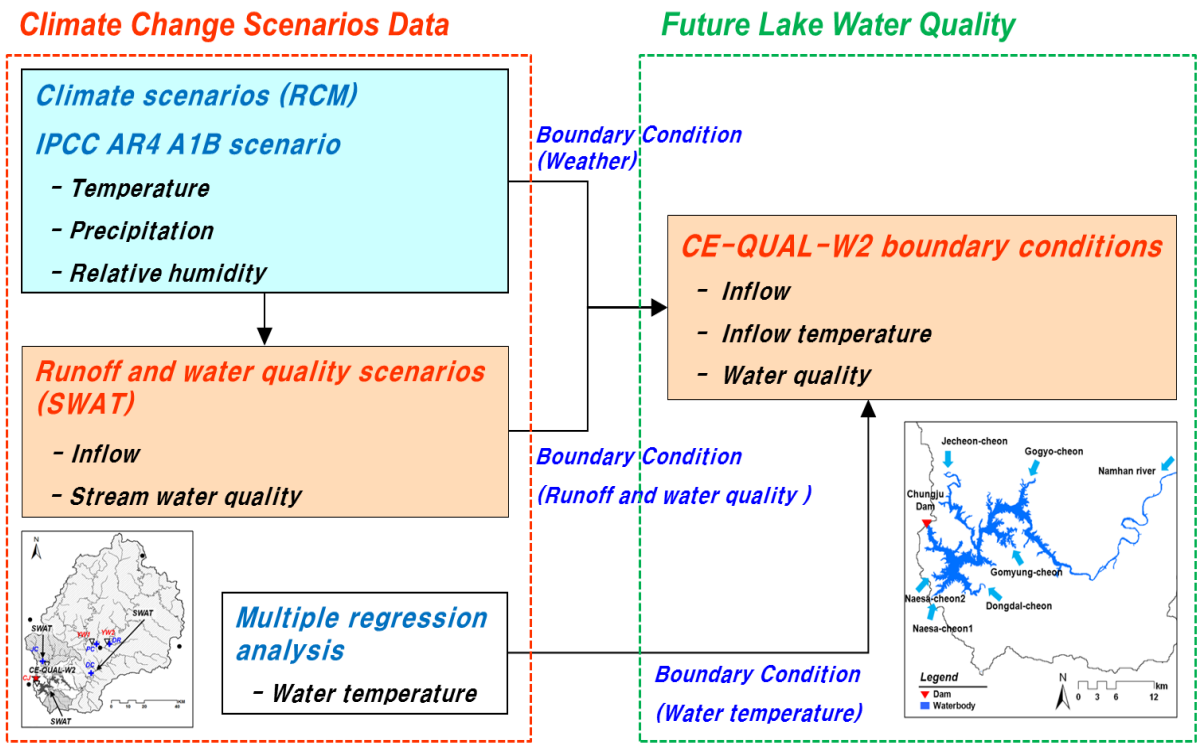
- *The simulated concentration range of T-N and T-P was acceptable.*
- *The errors might occur form the poor reflection for sedimentation velocity of nitrogen component and adsorption-sediment of phosphorus by the model limitations.*
- *The concentration of Chl-a was simulated well with the algal growth patterns in summer of 2010 and 2008.*
- *The errors of under-estimation may come from the use of width-averaged velocity and concentration in the model, not considering the actual to one side inclination by wind effect.*



Relations between SWAT Output and CE-QUAL-W2 Input

- The outputs of daily dam inflow and stream water quality data from SWAT model became inputs for boundary conditions for CE-QUAL-W2 model to evaluate the future water environment variation in lake.

SWAT Output	CE-QUAL-W2 Input
Streamflow	Inflow
SS	SS
PO4	PO4
NO3	NO3
NH4	NH4
Chl-a	Chl-a
Organic-N	Water temperature
Organic-P	OM group



Climate Change Impact on Lake Water Temperature

Evaluation of future lake water temperature

- *The future change in shallow-water temperature showed upward tendency by temperature rise.*
- *But deep-water temperature showed downward tendency.*
- *In the future, the period span of stratification increased by shallow-water temperature increase and the time of stratification advanced except wet year.*

Year		Shallow-water temperature (depth 5m) (℃)			Deep-water temperature (from the bottom 5m) (℃)			Stratification	
		Min.	Max.	Avg.	Min.	Max.	Avg.	Period (day)	Time
Wet year	2027 (Ⅰ)	2.9	27.4	16.4	3.4	12.6	8.5	190	April 6
	2058 (Ⅱ)	2.8	27.2	15.5 (1.5%)	3.3	13.8	8.2 (-3.0%)	187 (-1.6%)	April 17
	2095 (Ⅲ)	4.0	27.7	16.4 (7.4%)	4.0	20.4	9.8 (15.0%)	141 (-25.8%)	April 27
Average year	2020 (Ⅰ)	2.1	26.2	15.4	2.9	10.5	7.1	219	April 9
	2047 (Ⅱ)	2.7	26.6	16.0 (3.8%)	3.3	11.0	8.0 (13.9%)	209 (-4.6%)	April 9
	2077 (Ⅲ)	3.0	27.1	16.1 (4.8%)	3.3	7.7	5.8 (-18.2%)	235 (+7.3%)	April 13
Dry year	2021 (Ⅰ)	2.2	26.7	15.3	3.0	10.3	7.7	196	May 7
	2048 (Ⅱ)	2.6	27.4	15.4 (0.8%)	3.3	14.1	7.0 (-9.1%)	206 (+5.1%)	April 17
	2073 (Ⅲ)	3.0	27.4	16.0 (5.1%)	3.5	10.0	7.2 (-5.5%)	212 (+8.2%)	April 27

Climate Change Impact on Lake Turbidity Water

Evaluation of future lake water turbidity

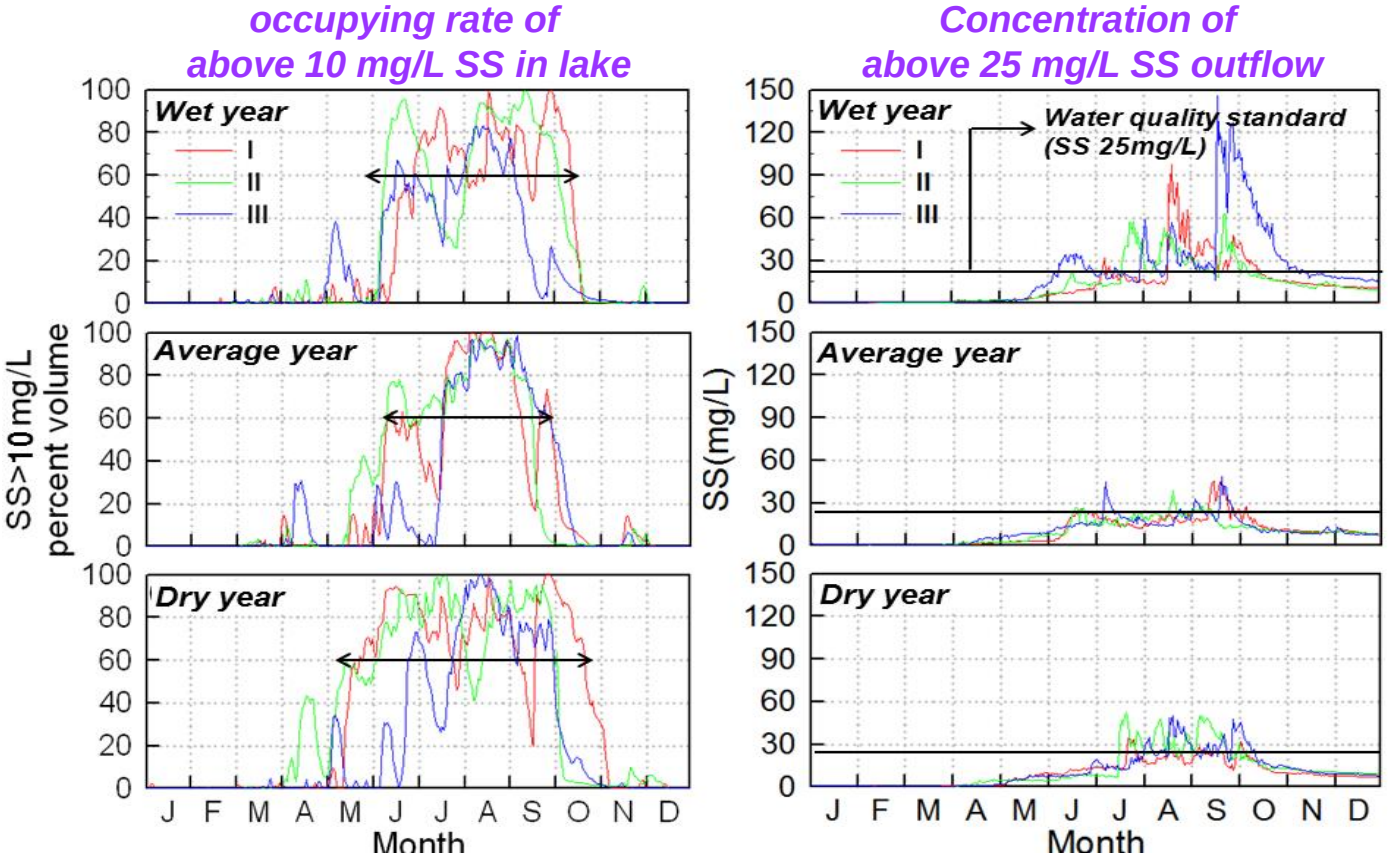
- *The future suspended solids concentration above 25 mg/L incoming to the lake from watershed showed the value from wet year (47.2 mg/L) to dry year (42.2 mg/L)*
- *The future predicted residence time above 10 mg/L suspended solids in the lake showed the value from wet year (166 days) to dry year (153 days)*
- *The occupying period of suspended solids above 10 mg/L showed about 7 % increase in the future.*

Year		Inflow SS>25mg/L				In lake SS>10 mg/L			Outflow SS>25mg/L	
		Number of days	Min. (mg/L)	Max. (mg/L)	Avg. (mg/L)	Residence time (day)	Occupying ratio (%) Max.	Occupying ratio (%) Avg.	Number of days	Ave. (mg/L)
Wet year	2027 (Ⅰ)	146	0.6	419.3	47.6	143	100.0	24.8	90	16.2
	2058 (Ⅱ)	119	1.5	477.7	43.4	170	100.0	22.9	91	18.6
	2095 (Ⅲ)	140	0.8	412.1	50.7	186	100.0	35.0	149	22.3
Average year	2020 (Ⅰ)	122	1.3	362.8	44.1	147	99.7	26.0	116	18.2
	2047 (Ⅱ)	147	0.3	370.3	50.5	152	97.6	24.5	83	14.4
	2077 (Ⅲ)	169	0.9	348.1	67.2	218	99.8	33.6	96	17.4
Dry year	2021 (Ⅰ)	137	1.5	353.4	42.0	168	83.0	18.4	70	14.2
	2048 (Ⅱ)	104	1.0	358.2	37.1	137	98.6	20.3	89	17.0
	2073 (Ⅲ)	145	1.4	373.0	47.5	156	100.0	22.3	93	15.7

Climate Change Impact on Lake WaterTurbidity

Evaluation of future lake water turbidity

- ***The occupying period above 10 mg/L suspended solids in lake* is expected to increase, and in the order of average, wet and dry year.**
- ***The future reservoir releases of monthly concentration above 25 mg/L suspended solids* are expected to increase, especially in wet year.**

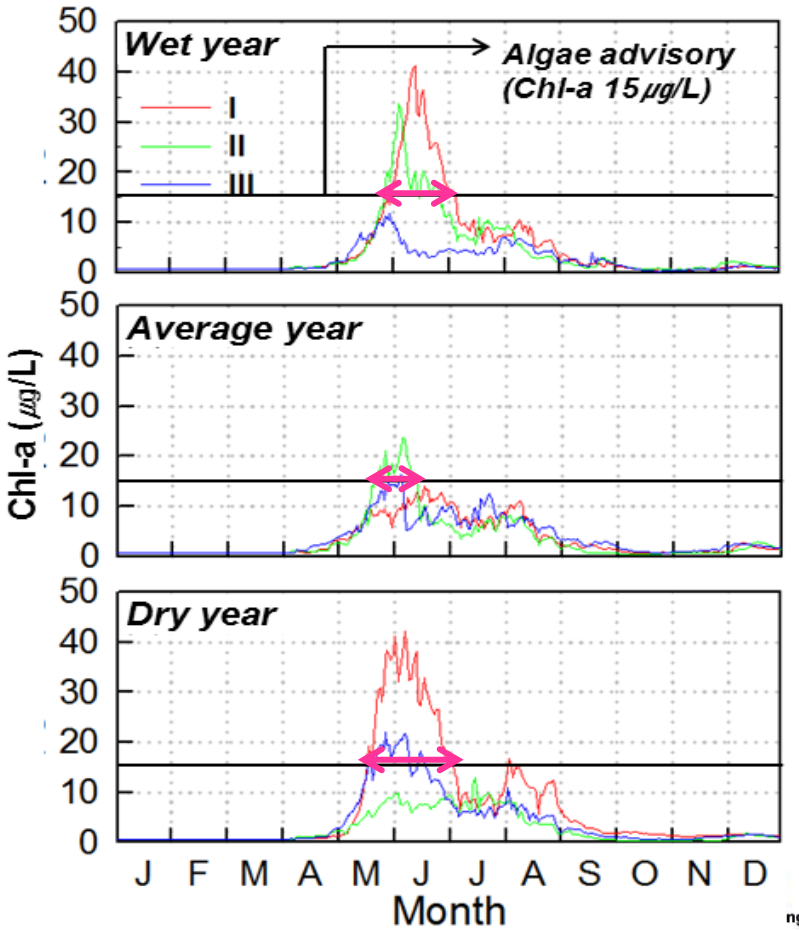


Climate Change Impact on Future Lake Eutrophication

Evaluation of future lake algal bloom

- *The future Chl-a growth increased in wet and dry years than average year.*
- *The peak concentration of Chl-a in dry year appeared one month advanced than wet year under the reduced lake inflow and storage condition.*

Year		Chl-a (μg/L)		
		Min.	Max.	Avg.
Wet year	2027 (Ⅰ)	0.4	41.3	4.9
	2058 (Ⅱ)	0.5	33.6	4.0
	2095 (Ⅲ)	0.2	11.7	2.3
Average year	2020 (Ⅰ)	0.6	14.1	3.3
	2047 (Ⅱ)	0.3	23.7	3.3
	2077 (Ⅲ)	0.6	16.2	3.6
Dry year	2021 (Ⅰ)	0.6	42.2	6.5
	2048 (Ⅱ)	0.2	12.9	2.7
	2073 (Ⅲ)	0.5	22.1	3.9



Summary & Concluding remarks

- ***In this study, the reservoir water quality model (CE-QUAL-W2) and watershed model (SWAT) were applied to evaluate the future climate change impact on water turbidity and eutrophication in Chungju lake.***
  - ✓ ***For future climate change data, the MM5 RCM data of IPCC A1B scenario was adopted and downscaled by Artificial Neural Networks method. The future dam inflow and stream water quality (sediment, T-N, and T-P) by SWAT showed an increase tendency.***
  - ✓ ***The future watershed results by SWAT simulation were used to CE-QUAL-W2 lake water quality modeling.***
  - ✓ ***The future shallow-water temperature and period of stratification of lake increased directly affected by future temperature rise. The future concentration of suspended solids and algae seriously increased in both wet and dry years.***
- ***We hope the results of this study are incorporated into the MOE (Ministry of Environment) watershed TDML (Total Maximum Daily Load) management and K-water (Korea Water Resources Corporation) lake water quality management .***

Thank you

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