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Assessment of Future Climate Change Impacts on Stream-and-Lake Water Quality using SWAT and WASP model

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Soil & Water Assessment Tool SWAT

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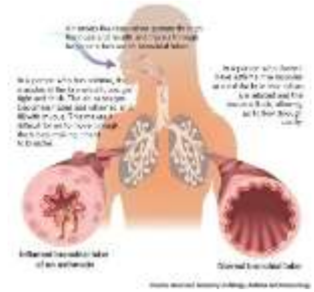
Four seasons of South Korea

- Spring (March to May)
- Summer (June to August)
- Autumn (September to November)
- Winter (November to February)

Human Health



Infrastructure

Agriculture/Economics

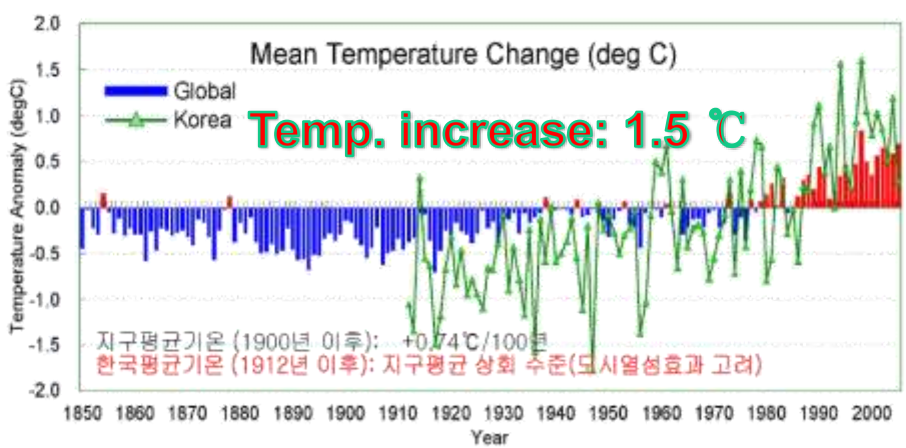
Water Resources

A comprehensive climate change impacts assessment for South Korea

Coasts

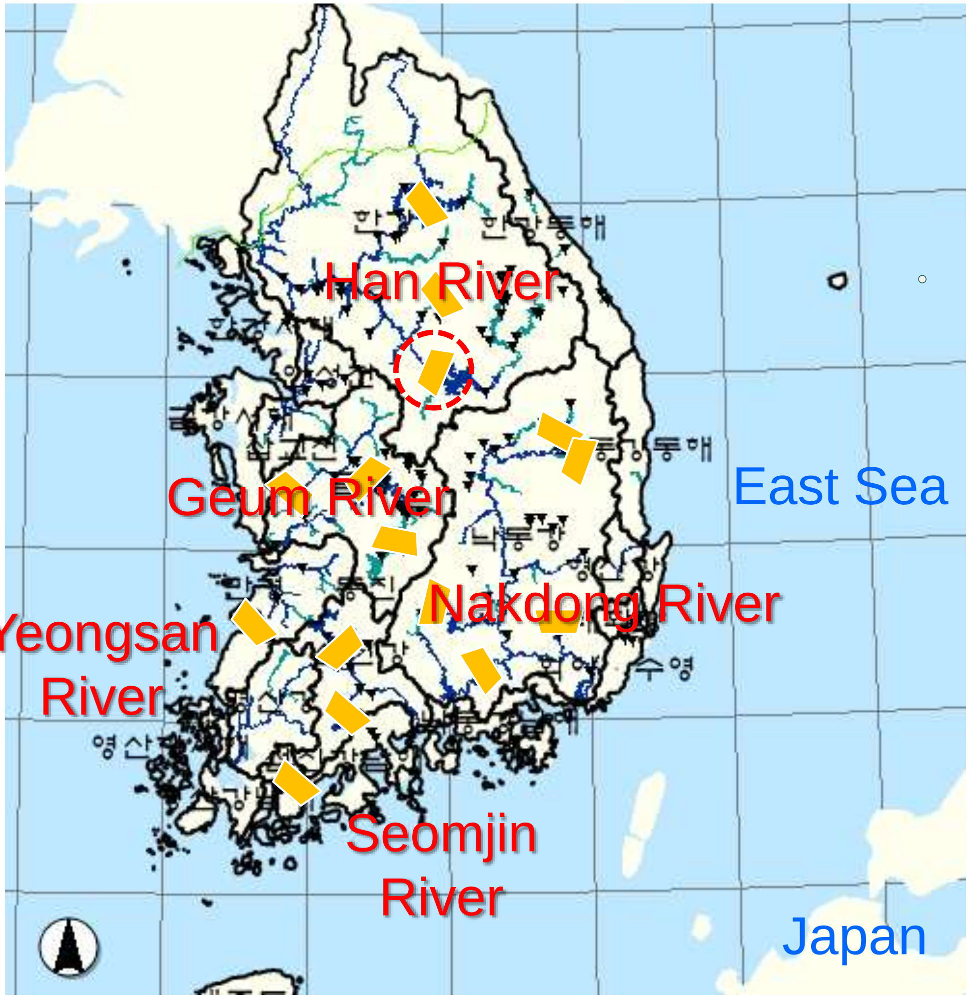
Energy

Forest Resources



Ecosystem

Five river basins and 15 multi-purpose dams in South Korea



Mutli-purpose dam

- Annual Prec.: 1283 mm
  - 1993: 754 mm ~
  - 2003:1792 mm
- Area: 99,000 km^2
  - Forest: 65 %
  - Paddy: 10 %
- Water Resources: 127.6 bi m^3/yr
- Runoff ratio: 57 %
- Multi-purpose dams: 15
- Agricultural dams: 17,649

Background and purpose of this study

- Lakes contain 90% of liquid freshwater on the earth's surface and are critical elements of the water cycle, since they sustain the aquatic biodiversity and provide the livelihoods, as well as the social, economic and aesthetic benefits, necessary for the quality of life in lake basin communities.

- Climate change affects the hydrological cycle, thus modifying the transformation and transport characteristics of sediment and nutrients.

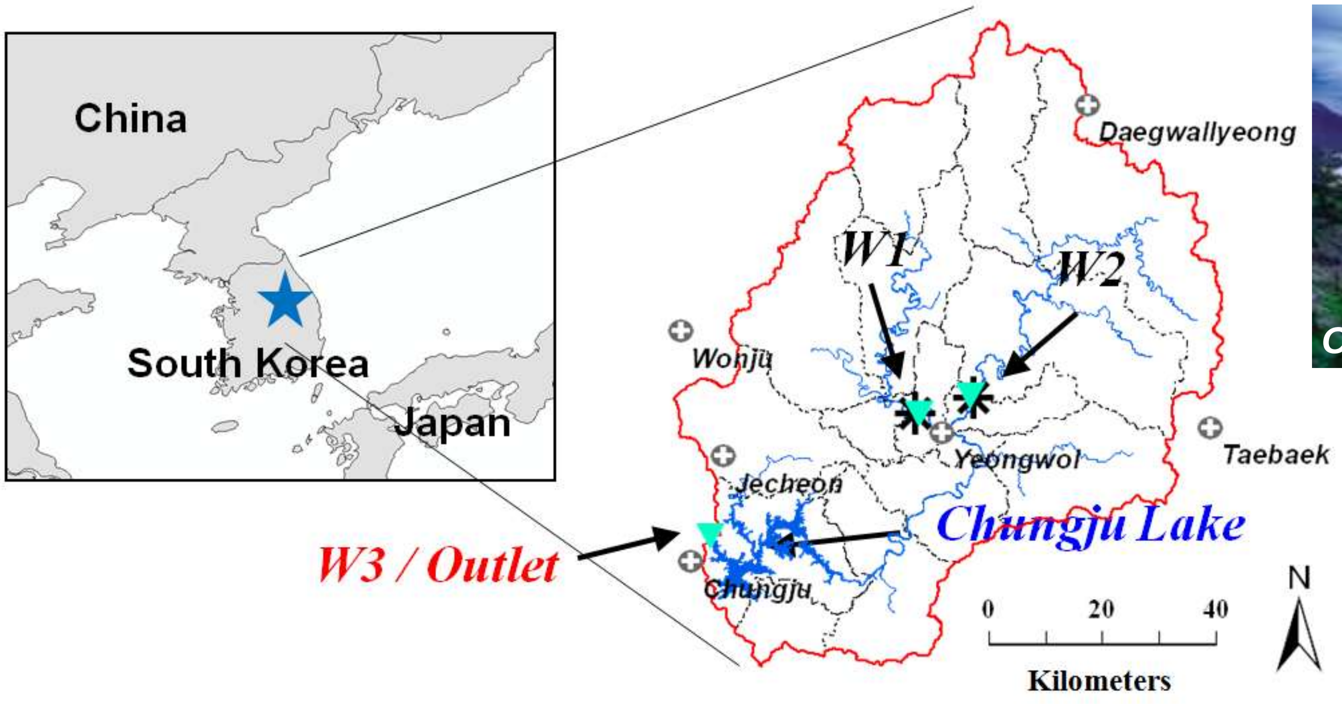
- The T-N and T-P concentrations will be changed in the future which probably led to eutrophication of the lakes.

- Lakes respond directly to climate changes, quantifying their sensitivity to possible climate change and variability in the responses will provide information crucial for the assessment of water resources, water quality and aquatic ecosystems in future.

- This study is to evaluate the future potential climate change impacts on stream and lake water quality for a 6,642 km^2 dam watershed of South Korea.

Study area

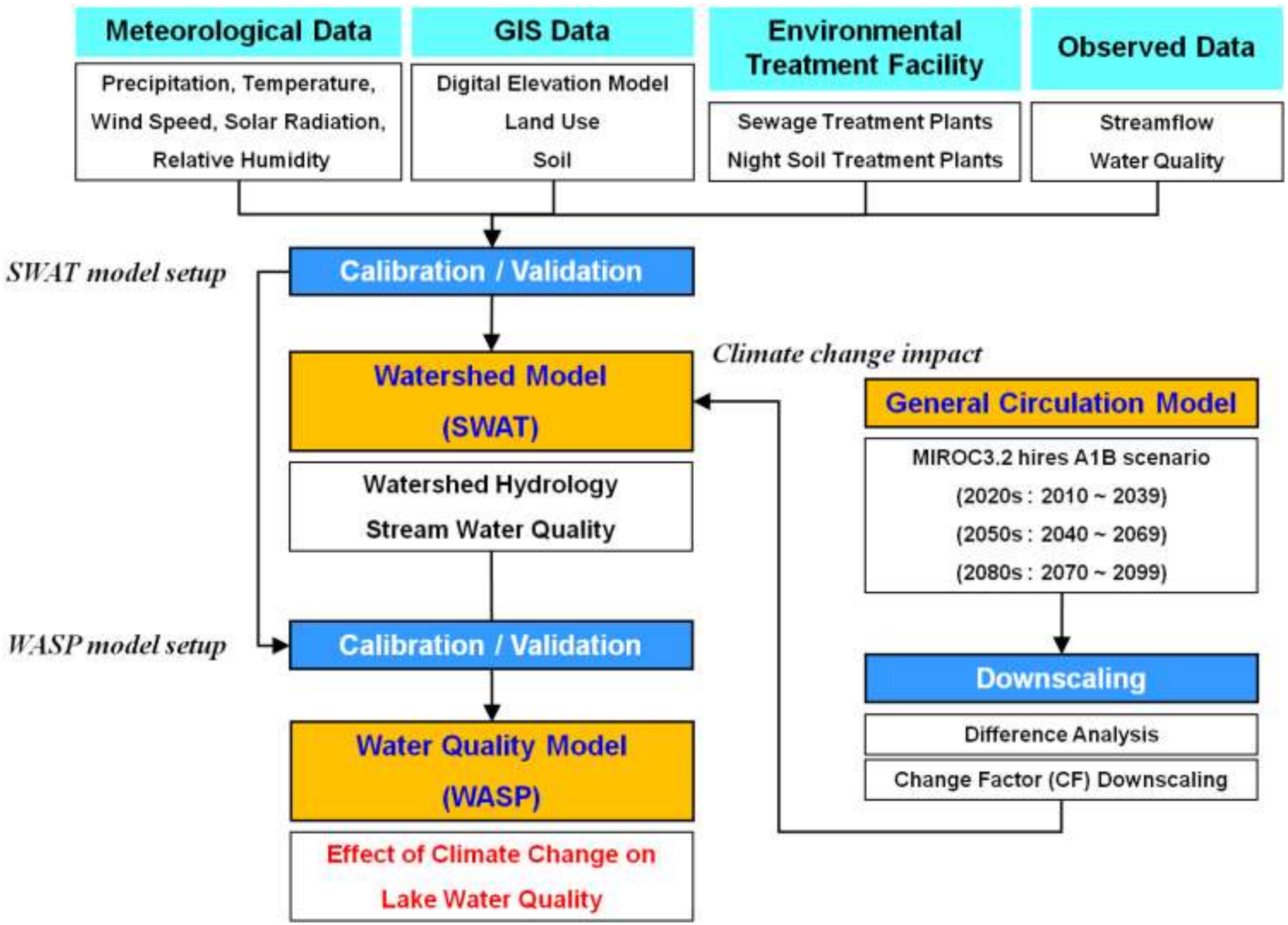
◆ **Chungju dam watershed**



- ✓ Watershed area : 6,581 km^2
- ✓ Annual average precipitation : 1,359.5 mm
- ✓ Annual average temperature : 9.4 ℃
- ✓ Forest area : 84.6 % (5573.1 km^2)

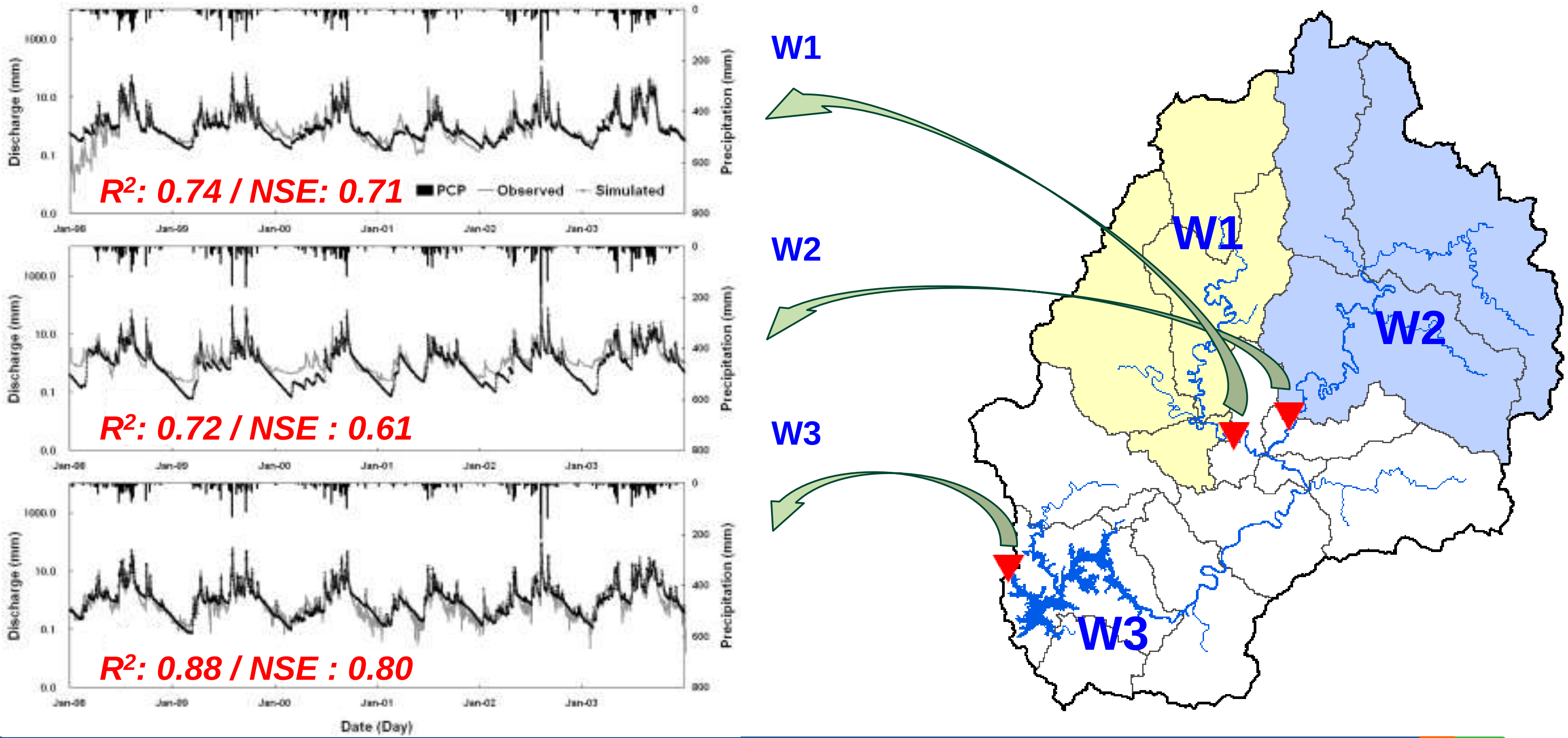
- Energy (412MW of capacity)
- Water for Seoul (metropolitan city of South Korea), adjacent urban areas, and irrigation of 22,000 hectares
- Flood protection for rural area
- 334 million ton per year water for stream maintenance

Modeling approach

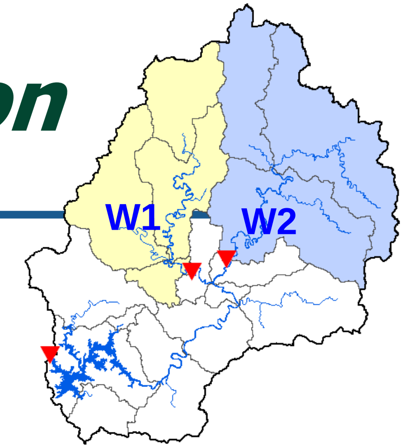


SWAT Calibration and validation

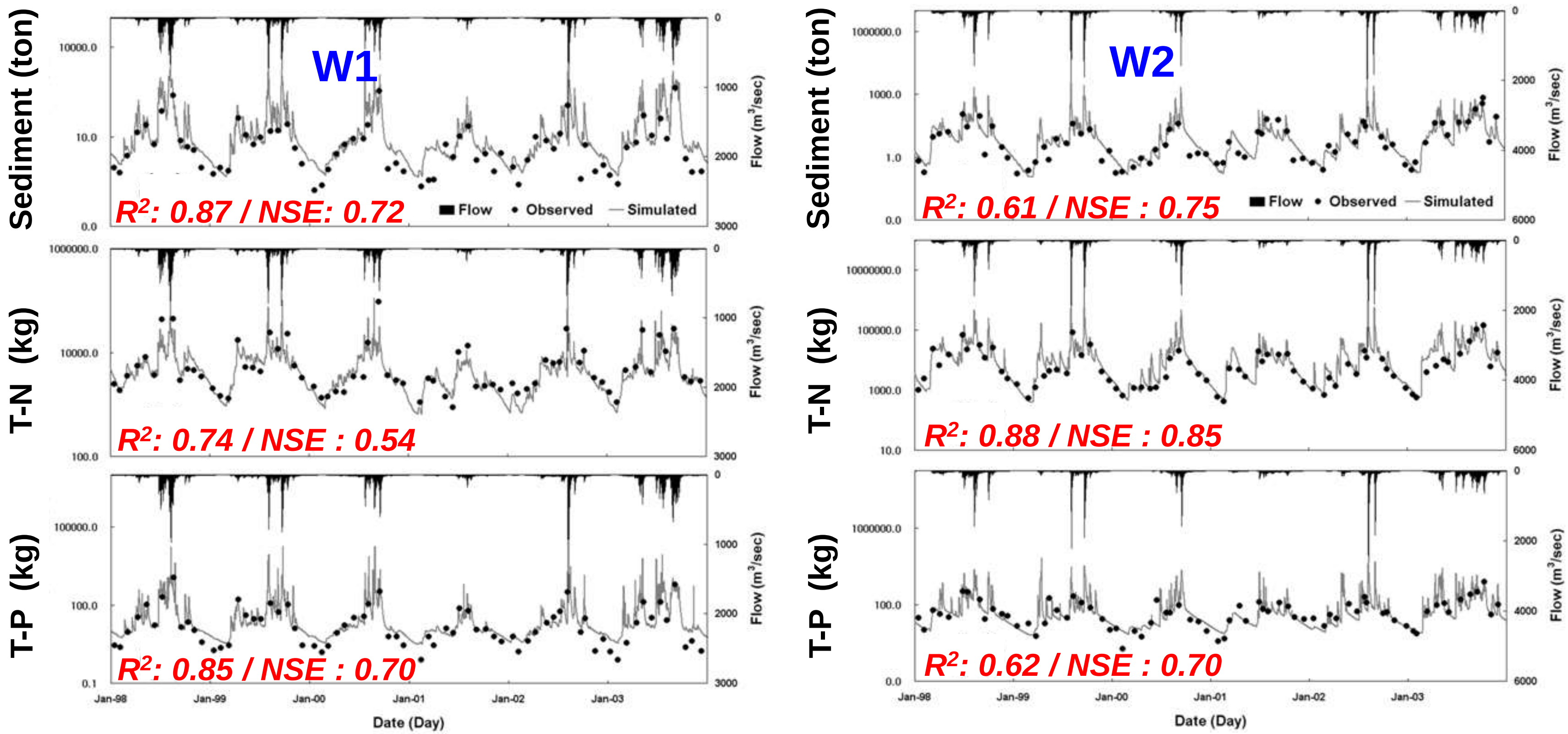
- **Streamflow**
  - ✓ Calibration period : 1998-2000 / Validation period : 2001-2003
  - ✓ Using daily discharge records at three calibration points



SWAT Calibration and validation



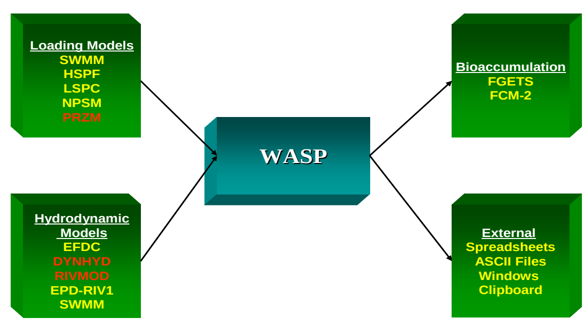
- **Stream water quality**
  - ✓ Calibration period : 1998-2000 / Validation period : 2001-2003
  - ✓ Using once per month water quality (SS, TN and TP) records at two calibration points



***WASP* water quality model**

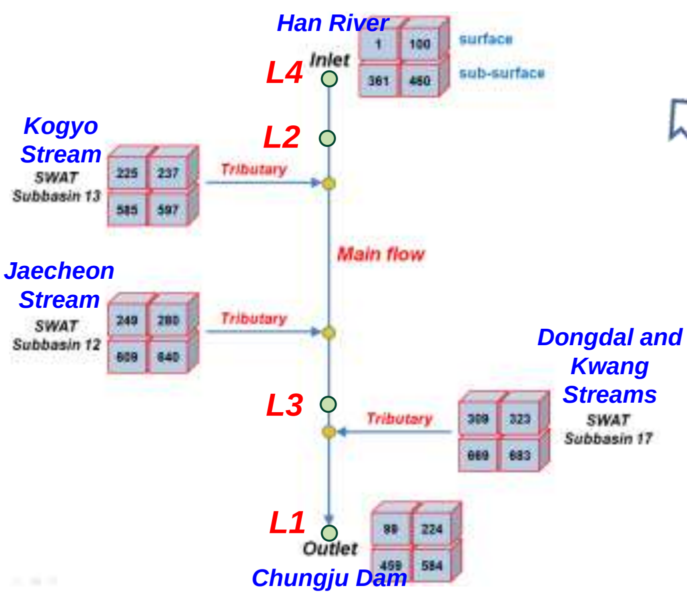
Water quality Analysis Simulation Program (WASP)

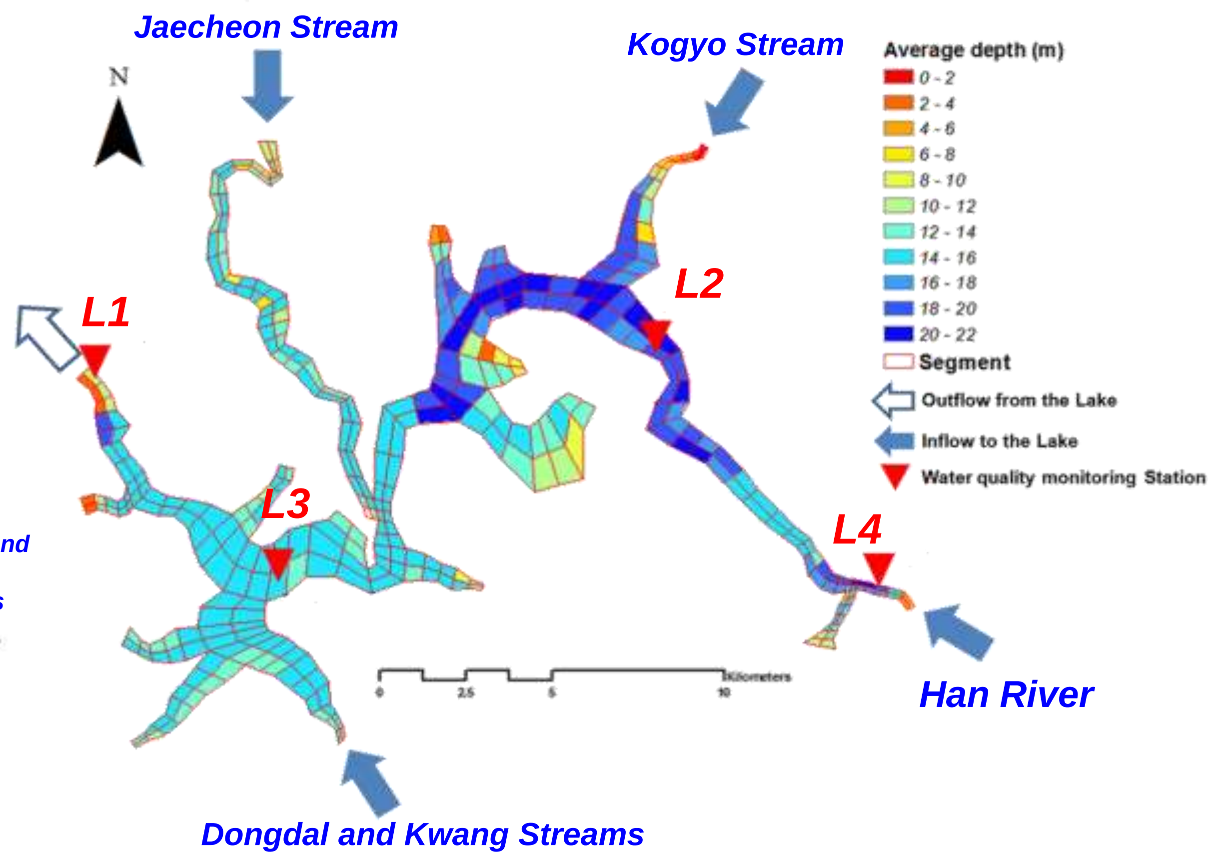
- ✓ WASP is a dynamic compartment water quality modeling program for aquatic systems, including both the water column and the underlying benthos.
- ✓ Two independent computational programs: 1) hydrodynamics-DYNHYD5; 2) water quality program.
- ✓ Allows the simulation of 1, 2, and 3 -D systems, and a variety of pollutant types.
- ✓ The time varying processes of advection, dispersion, point and diffuse mass loading and boundary exchange are represented.
- ✓ Four surface water flow options - net flows, cross flows, 1 -D kinematic wave, and hydrodynamic linkage.



WASP lake segments

- **Segmentation**
  - ✓ Volume: 2.75 billion m^3
  - ✓ Layer: surface with an area of 97 km^2 and subsurface
  - ✓ Average length and width: 497 m / 376 m
  - ✓ Total of 720 segments
  - ✓ Four monitoring stations
    : *L1, L2, L3* and *L4*





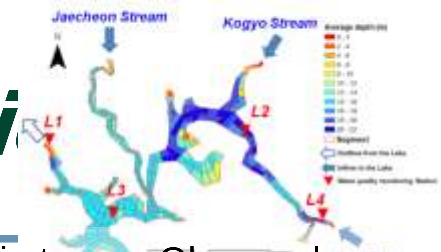
WASP Calibration and validation

Lake water quality

- ✓ Calibration period : 1998-2000 / Validation period : 2001-2003
- ✓ Using once per month water quality (DO, T-N, T-P and chlorophyll-a) records at four calibration points within the lake
- ✓ Boundary condition:

Boundary	Flow	Water quality
Han River (*L4*)	Calibrated SWAT model	▪ Calibrated SWAT model ▪ Measured DO and Chl-a of ME
Kogyo Stream (*L2*)	Calibrated SWAT model	▪ Calibrated SWAT model ▪ Measured DO and Chl-a of ME
Jaecheon Stream (*L3*)	Calibrated SWAT model	▪ Calibrated SWAT model ▪ Measured DO and Chl-a of ME
Dongdal and Kwang Streams (*L1*)	Calibrated SWAT model	▪ Calibrated SWAT model ▪ Measured DO and Chl-a of ME

WASP Calibration and validati



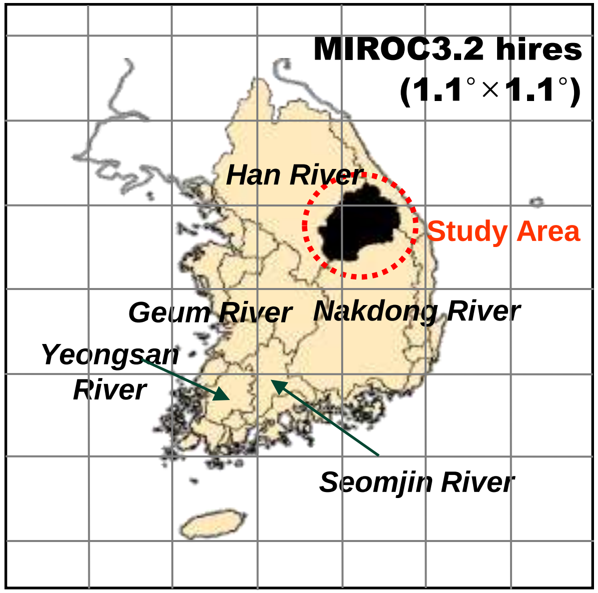
First rows: Observed
Second rows: Simulated

Lake water quality

Water quality parameter		N	Avg	Med	Std	75%	25%
DO (mg/L)	*L1*	74	9.1 10.5	8.9 10.3	2.0 1.7	10.4 12.2	8.0 9.0
	L2	72	10.0 10.4	10.1 10.0	2.3 1.9	11.6 12.0	8.3 8.8
	L3	72	9.9 10.5	9.9 10.2	2.6 1.7	11.7 12.2	8.0 9.0
	L4	72	10.5 10.5	10.3 10.2	2.4 1.7	12.3 12.2	8.8 9.0
TN (mg/L)	*L1*	74	2.3 1.6	2.2 1.5	0.5 0.7	2.5 1.9	2.0 1.2
	L2	72	2.7 0.9	2.7 0.8	0.4 0.3	3.1 1.0	2.4 0.6
	L3	72	2.6 0.7	2.6 0.7	0.4 0.3	2.9 0.8	2.3 0.5
	L4	72	2.8 0.9	2.8 0.9	0.4 0.4	3.1 1.1	2.5 0.7
TP (mg/L)	*L1*	74	0.018 0.025	0.016 0.020	0.011 0.019	0.023 0.028	0.012 0.014
	L2	72	0.018 0.018	0.018 0.010	0.010 0.027	0.023 0.019	0.011 0.007
	L3	72	0.019 0.020	0.019 0.014	0.011 0.022	0.024 0.022	0.012 0.008
	L4	72	0.023 0.017	0.022 0.010	0.014 0.022	0.029 0.016	0.013 0.008
Chlorophyll *a* (ug/L)	*L1*	71	5.5 4.5	3.0 4.0	6.5 6.7	6.3 6.1	1.3 1.4
	L2	72	3.9 4.9	3.1 3.8	3.3 4.0	5.4 5.8	1.5 2.5
	L3	72	4.4 10.3	2.8 7.8	4.0 11.2	5.7 12.7	1.8 4.2
	L4	72	6.4 6.5	4.7 4.7	5.6 6.5	8.2 7.5	2.5 3.6

General Circulation Models (GCMs)

◆ Future Climate Data from GCMs (MIROC3.2 hires)



Model	MIROC3.2 hires
Center	NIES (National Institute for Environmental Studies)
Country	Japan
Scenario	A1B, B1
Grid size	1.125° × 1.125°

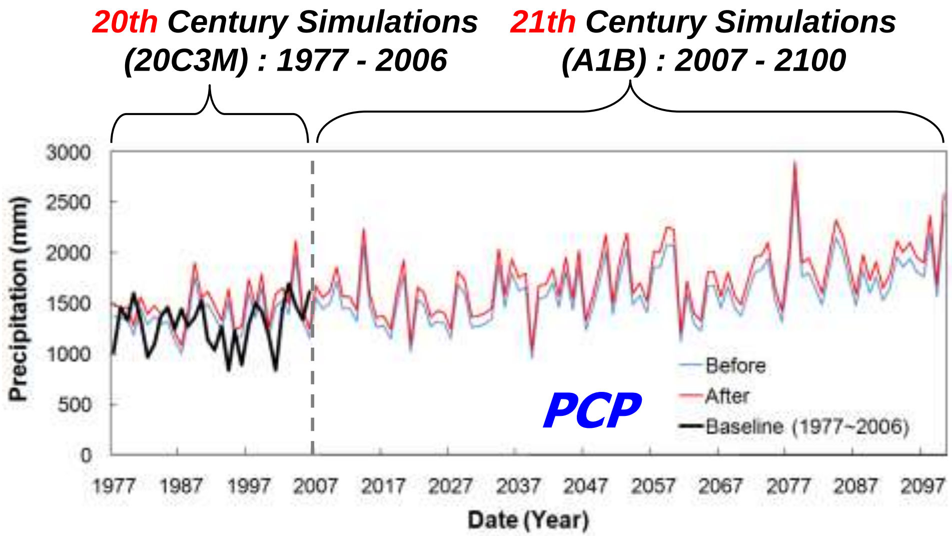
- ✓ The GCM (MIROC3.2 hires) data by two SRES climate change scenarios of the IPCC AR4 (fourth assessment report) were adopted.
- ✓ The MIROC3.2 hires model, developed at the NIES of the Japan, had the highest spatial resolution of approximately 1.1° among the selected model in IPCC AR4.

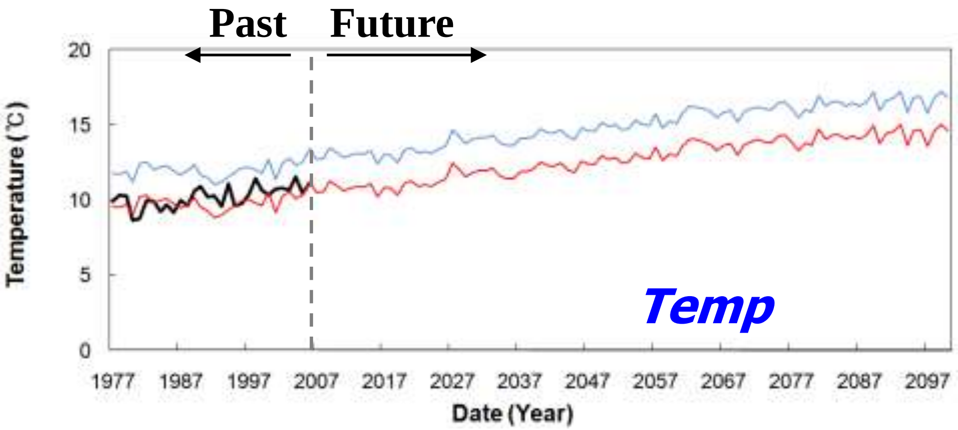
Downscaling technique of GCM data

- **Bias correction method**
  - ✓ The GCM data was corrected to ensure that 30 years observed data (1977-2006, baseline period).
  - ✓ GCM model output of the same period have similar statistical properties among the various statistical transformations.

For precipitation $$P'_{GCM,\,fut} = P_{meas} \times (\overline{P}_{GCM,\,fut} \div \overline{P}_{GCM,\,his})$$

For temperature $$T'_{GCM,\,fut} = T_{meas} + (\overline{T}_{GCM,\,fut} - \overline{T}_{GCM,\,his})$$

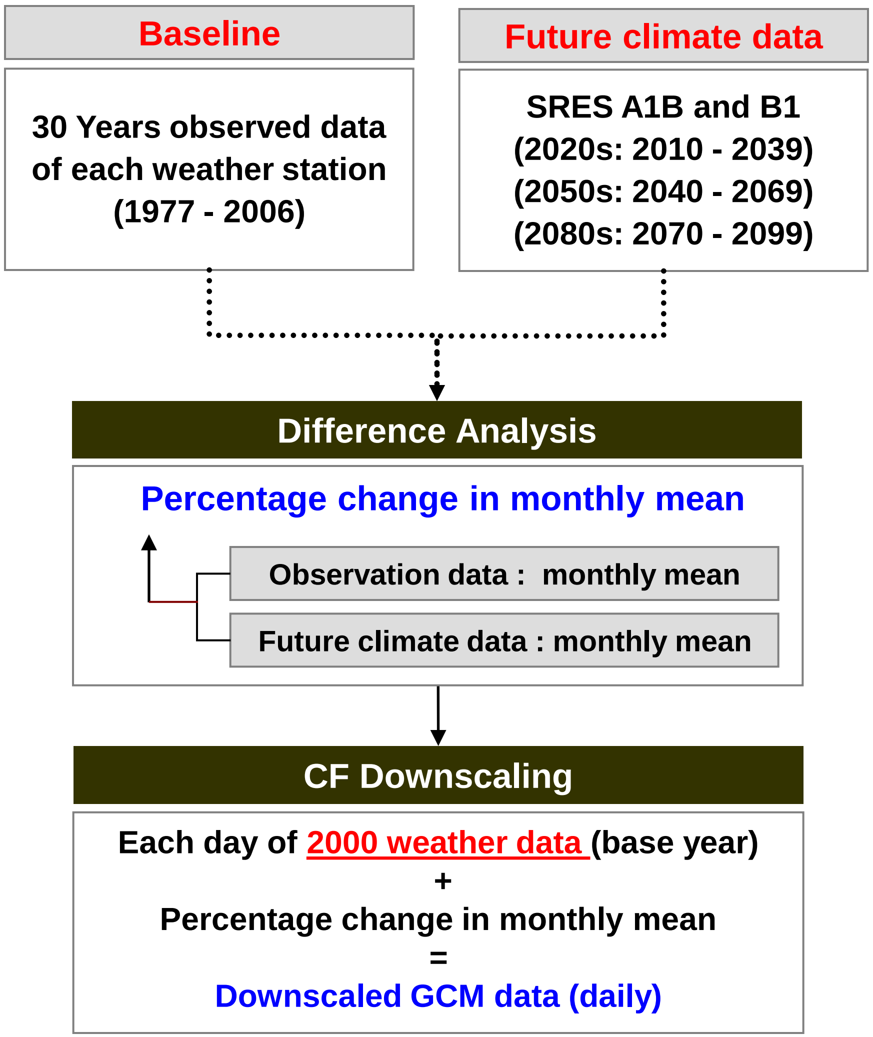




Downscaling technique of GCM data

◆ Change Factor (CF) method

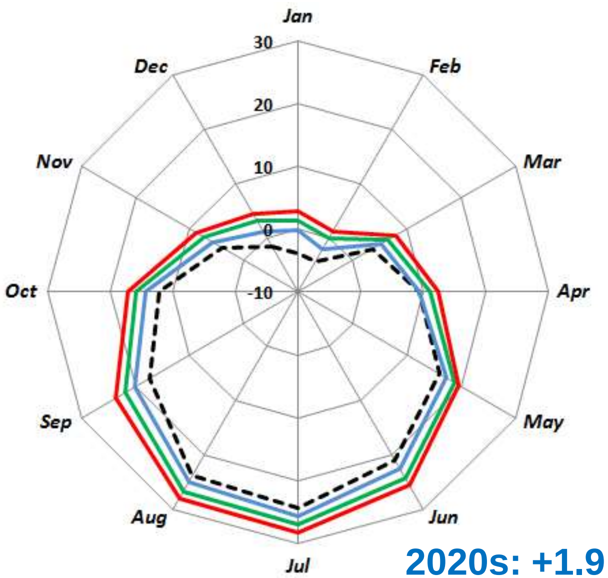
- ✓ GCM model was downscaled using Change factor (CF) method.
- ✓ Monthly mean changes in equivalent variables from the 30 years data (1977-2006, baseline period) and MIROC3.2 hires simulation for three time periods: 2020s, 2050s and 2080s were calculated for the GCM grid cell.
- ✓ The percentage changes in monthly mean were applied to each day of **2000** weather data (base year for future assessment) of each weather station.



Climate change scenario

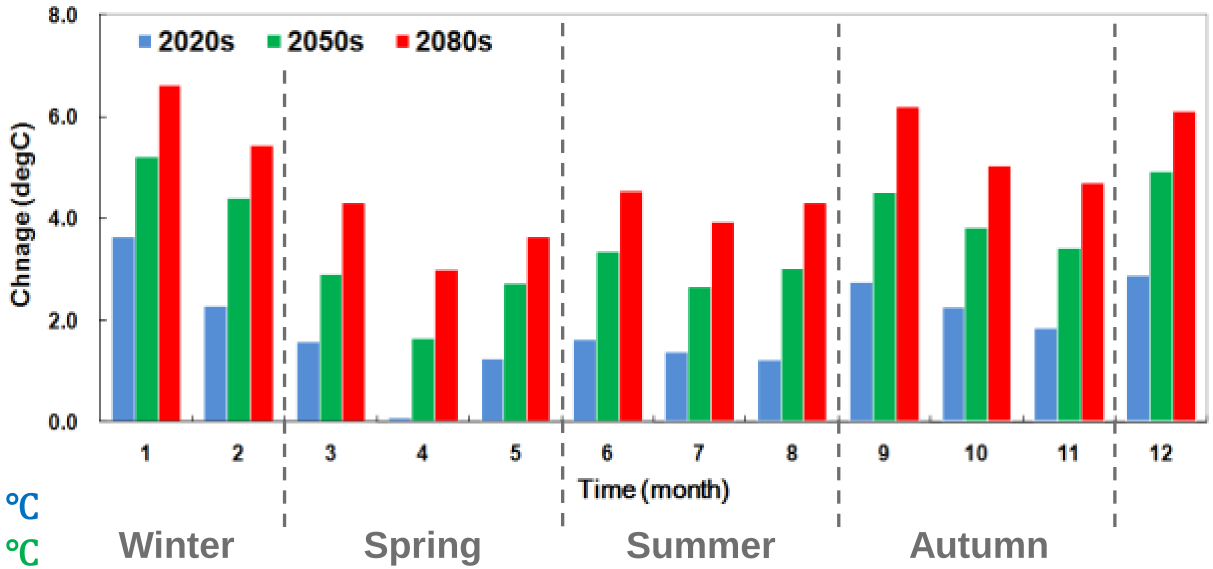
◆ Future climate data by applying CF downscaling method

✓ Temperature change



2020s: +1.9 ℃
2050s: +3.5 ℃
2080s: +4.8 ℃

Temperature change (℃)

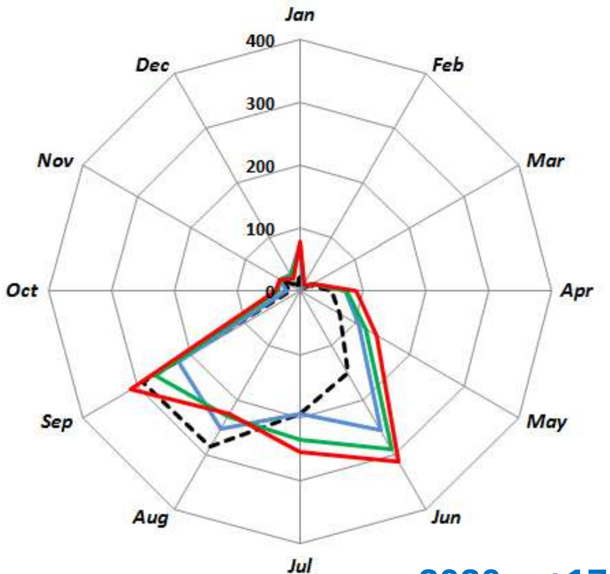


✓ The future temperature will give warming for the whole season from results of CF downscaling. Especially, the seasonal temperature change is that the intensity of big increase is found in Winter.

Climate change scenario

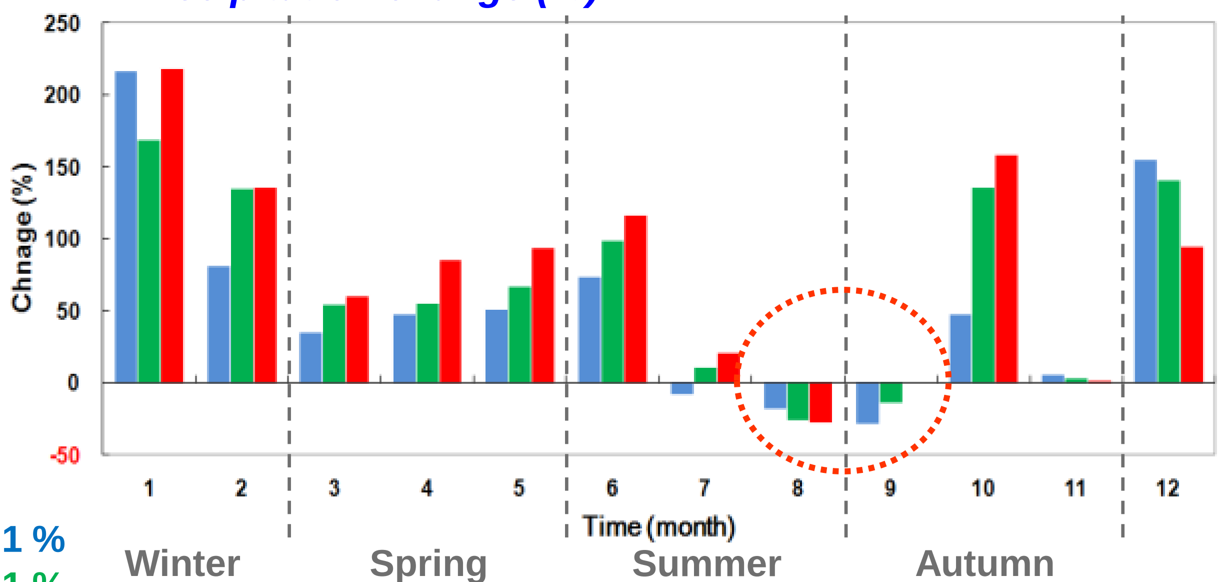
◆ Future climate data by applying CF downscaling method

✓ Precipitation change



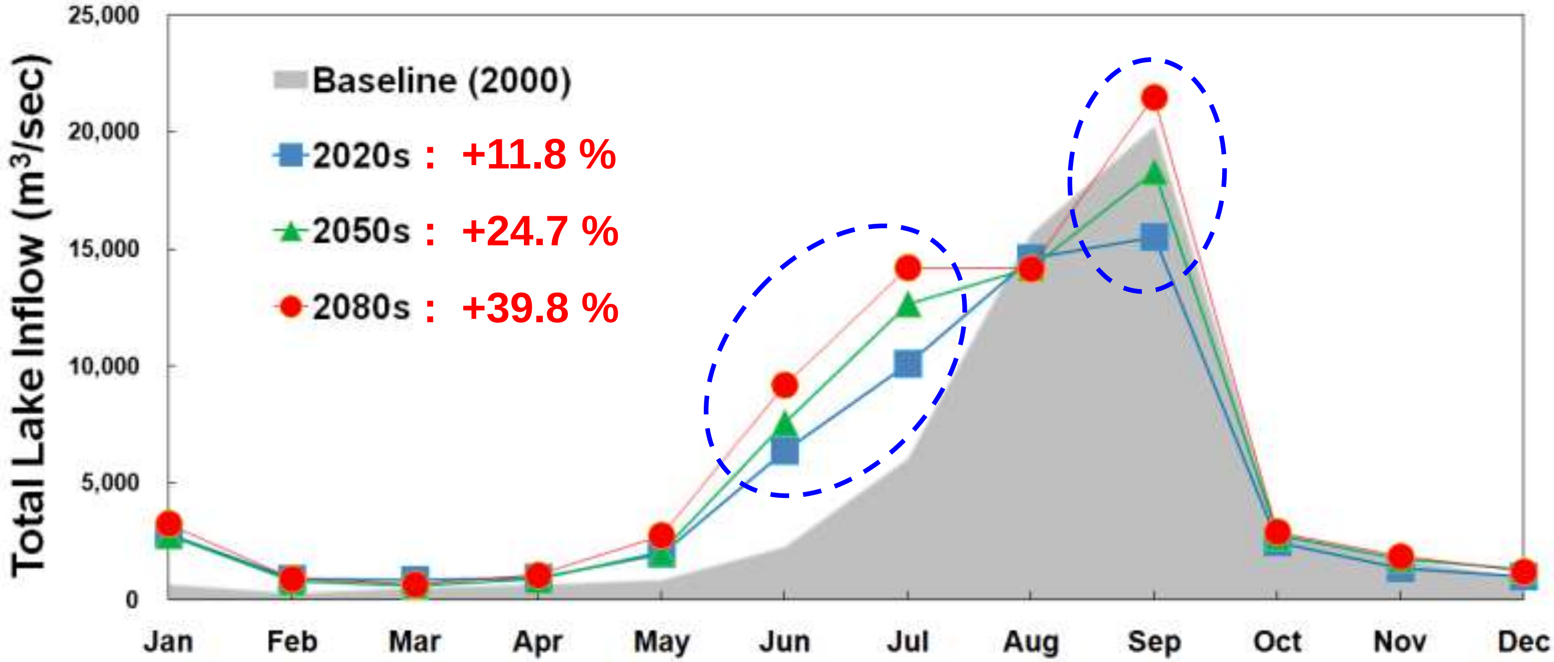
2020s: +17.1 %
2050s: +23.1 %
2080s: +34.4 %

Precipitation change (%)



✓ The future precipitation showed general tendency of decrease for August and September. Other months showed the increase tendency on the whole.

The future change in dam inflow



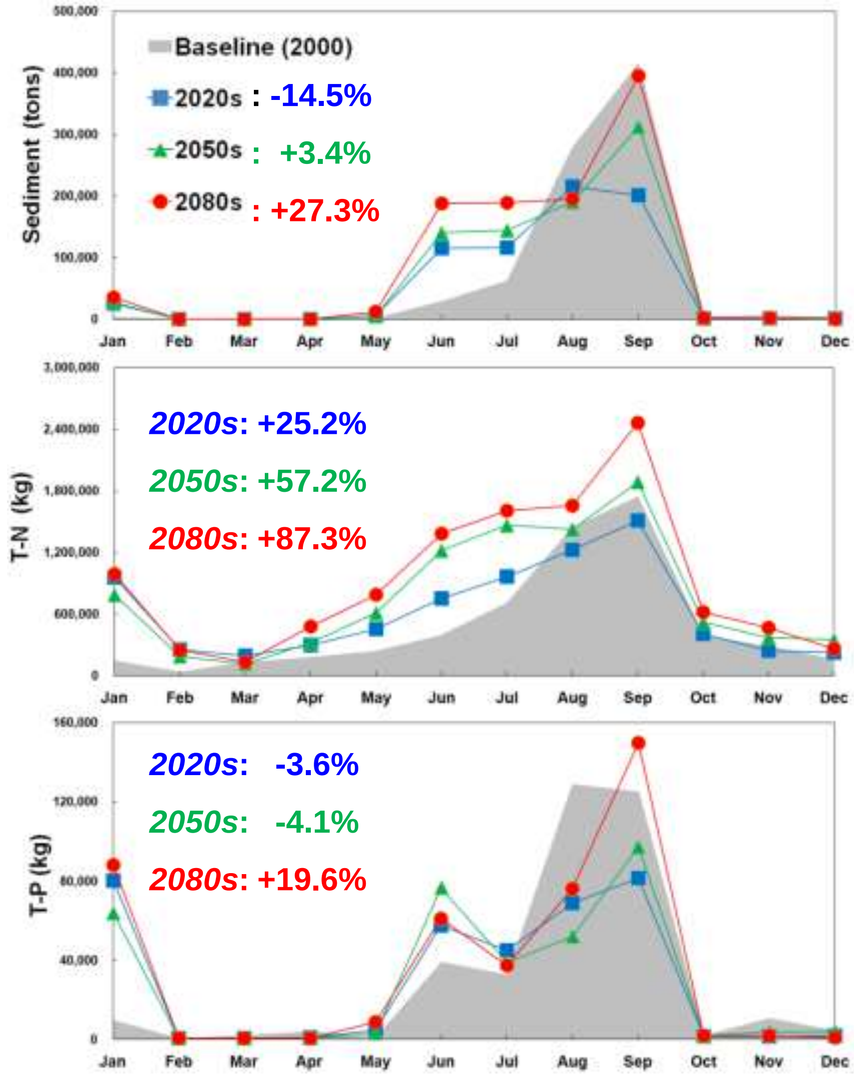
- ✓ For the monthly dam inflow changes in June and July of A1B scenario showed big increases but, in August and September showed decreases.
- ✓ The reason is big precipitation fluctuation of MIROC3.2 hires A1B scenario.
- ✓ Annual dam inflow increased gradually going by the future.

The future changes in hydrological components

Variable		Baseline 2000	MIROC3.2 hires A1B scenario		
			2020s	2050s	2080s
Hydrology (mm/yr)	Rainfall	1155	1,304 (12.9)	1,422 (23.1)	1,552 (34.4)
	Evapotranspiration	409	454 (11.5)	479 (17.7)	501 (23.1)
	Surface runoff	404	470 (12.1)	538 (28.3)	619 (47.7)
	Subsurface runoff	36	41 (14.3)	46 (30.2)	50 (39.4)
	Groundwater discharge	226	263 (13.1)	279 (19.9)	298 (28.1)
	Streamflow	678	773 (11.8)	862 (24.7)	966 (39.8)

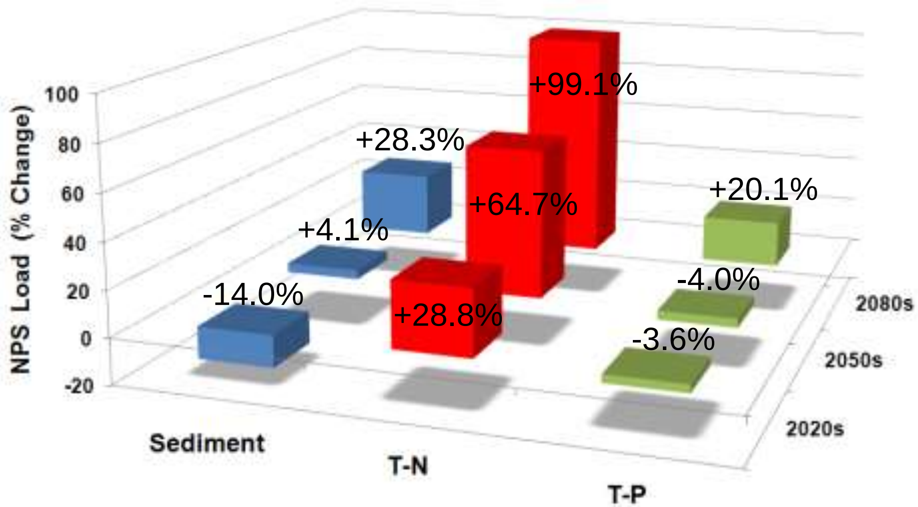
The future changes in stream water quality

- Key Assumption : Do not change watershed environment such as land use, vegetation, USLE C and P factors.
- The A1B scenario showed increase tendency in annual sediment load up to 27.3 %.
- The sediment load changed depending on surface runoff change.
- The annual Total Nitrogen (T-N) showed general tendency of increase for A1B and B1 scenarios.
- The annual Total Phosphorus (T-P) showed similar tendency of change with sediment.

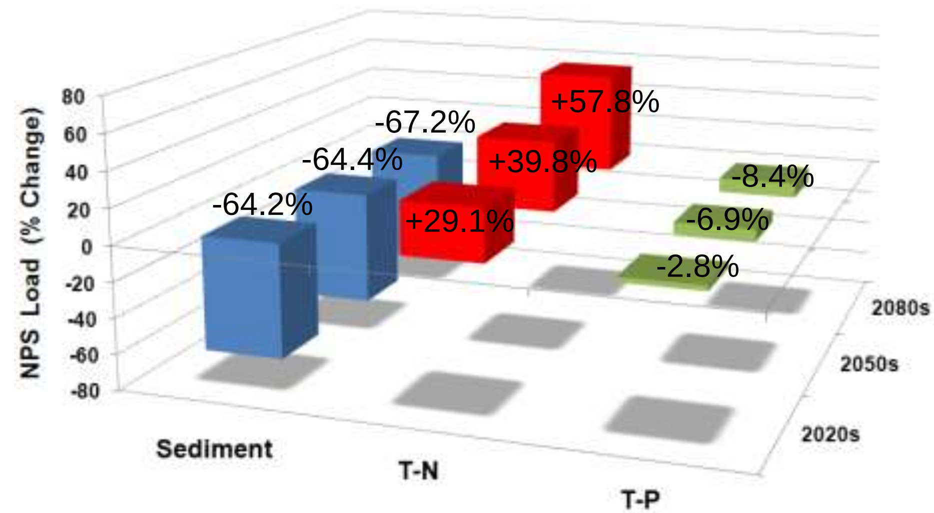


The future changes in stream water quality

Wet days



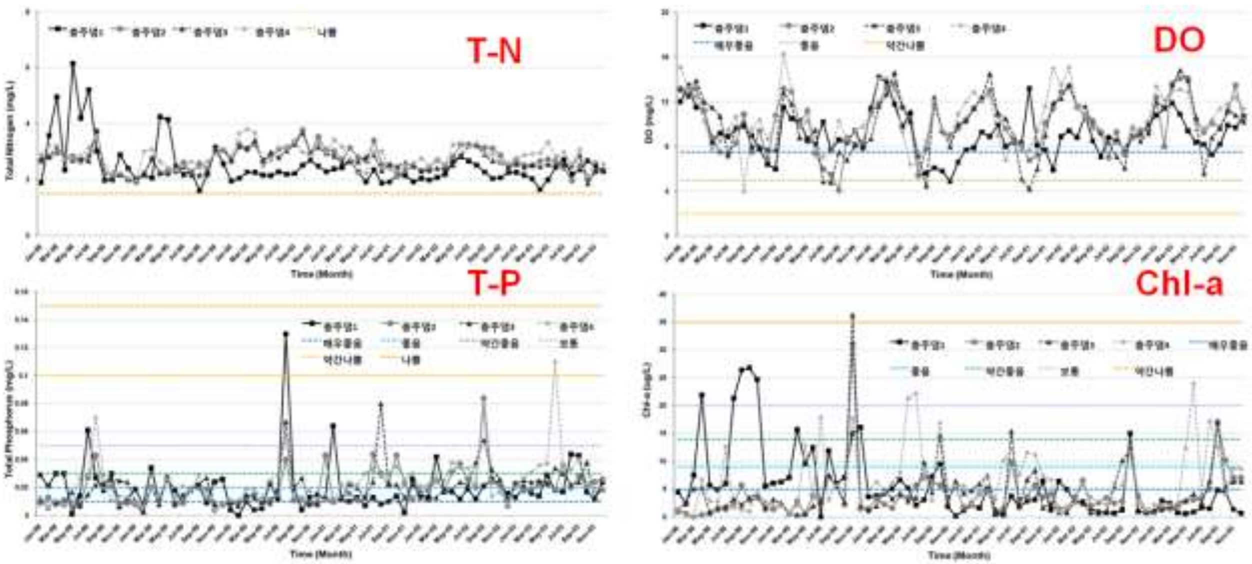
Dry days



- ✓ The wet days is defined by direct runoff because sediment is carried by direct runoff.
- ✓ The future sediment load showed general tendency of increase during wet days. On the other hand, the sediment load big decreased during dry days in A1B scenario.
- ✓ The T-N loads were projected to change between + 28.8 % and + 99.1 %, + 29.1 % and + 57.8 % in wet and dry days, respectively. The T-P loads were general tenden cy of decrease during wet and dry days.

The future changes in lake water quality

- **Lake water quality status ('98~'03)**

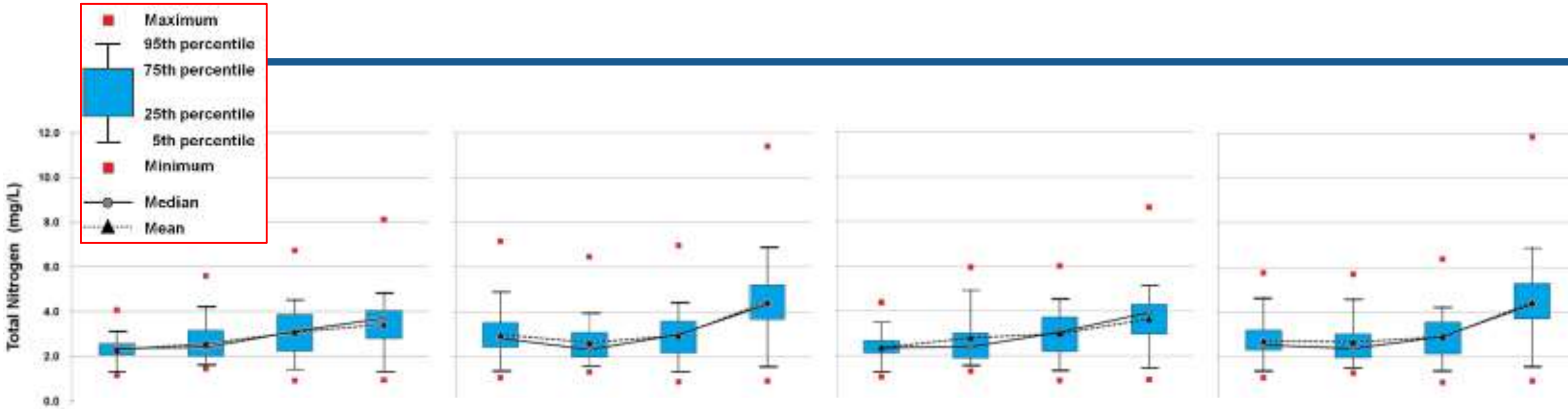


Environmental Lake Water Quality Standards (ME, 2007)

good ↑ / ↓ bad

등급		수소이온농도 (pH)	화학적산소요구량 (COD) (mg/L)	부유물질량 (SS) (mg/L)	용존산소량 (DO) (mg/L)	총인 (T-P) (mg/L)	총질소 (T-N) (mg/L)	클로로필-a (Chl-a) (mg/m³)	대장균군 (군수/100mL) 총대장균군	분원성 대장균군
매우좋음	Ia	6.5~8.5	2 이하	1 이하	7.5 이상	0.01 이하	0.2 이하	5 이하	50 이하	10 이하
좋음	Ib	6.5~8.5	3 이하	5 이하	5.0 이상	0.02 이하	0.3 이하	9 이하	500 이하	100 이하
약간좋음	II	6.5~8.5	4 이하	5 이하	5.0 이상	0.03 이하	0.4 이하	14 이하	1,000 이하	200 이하
보통	III	6.5~8.5	5 이하	15 이하	5.0 이상	0.05 이하	0.6 이하	20 이하	5,000 이하	1,000 이하
약간나쁨	IV	6.0~8.5	8 이하	15 이하	2.0 이상	0.10 이하	1.0 이하	35 이하	-	-
나쁨	V	6.0~8.5	10 이하	쓰레기 등이 떠있지 아니할 것	2.0 이상	0.15 이하	1.5 이하	70 이하	-	-
매우나쁨	VI	-	10 초과	-	2.0 미만	0.15 초과	1.5 초과	70 초과	-	-

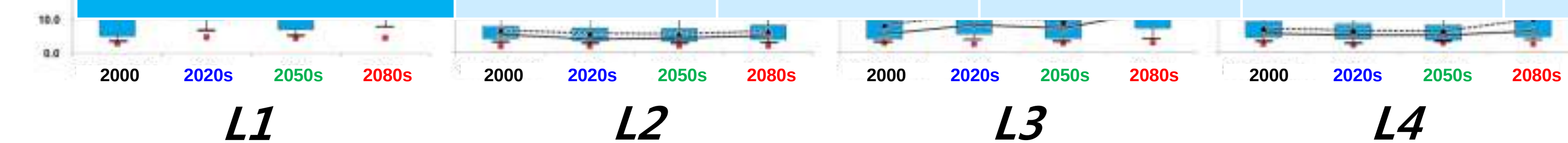
The future changes in lake water quality



2020s:
-13.9% ~ +15.6%
2050s:
-1.8% ~ +25.4%
2080s:
+32.8% ~ +38.3%

Trophic State Classifications by EPA-NES

Parameter	Oligotrophic	Mesotrophic	Eutrophic	2000 (Measured)	2080s (Predicted)
Chlorophyll-a (μg/L)	< 7	7 ~ 12	> 12	8.6	14.0
T-N (mg/L)	0.25	0.25 ~ 1.0	1.0 ~ 10.0	2.6	4.0
T-P (μg/L)	< 10	10 ~ 20	> 20	16.4	29.7



-5.2% ~ +52.3%

Concluding remarks

- This study was tried to evaluate the future potential climate change impacts on stream and lake water quality using watershed (SWAT) and lake water quality (WASP) models with MIROC3.2 hires A1B scenario.
  - ✓ The most significant impacts of the future, projected climate change at Chungju Lake are changes in hydrologic conditions and water quality.
- Hydrology output from the downscaled climate modeling suggests a significant increase in the amount of precipitation in the study watershed.
  - ✓ This could have consequences for water supply as well as irrigation and maintain streamflow.
  - ✓ The future monthly dam inflow change gave us the clue for the future adjustment of dam operation rule for both efficient water use and flood control.
- Internal loading of nutrients from the sediments will be very significant and will drive a fundamental change in the biological productivity status of the lake.
  - ✓ These nutrients, particularly phosphorus, will be available to drive algal growth.
  - ✓ Climate changes would cause more eutrophic lake conditions, further promoting algal growth and changing the aquatic ecosystems.
- Reducing the load of external nutrients entering the lake in the coming decades may be the only possible mitigation measure to reduce the impact of climate change on lake clarity and eutrophic status.

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Thank You

http://msyouth.blogspot.com/2008/04/global-warming-videos.html