Soil & Water Assessment Tool

Assessment of Future Climate Change Impacts on Snowmelt and the Stream Water Quality in a Mountainous Watershed using SWAT

K O N K U K U N I V E R S I T Y

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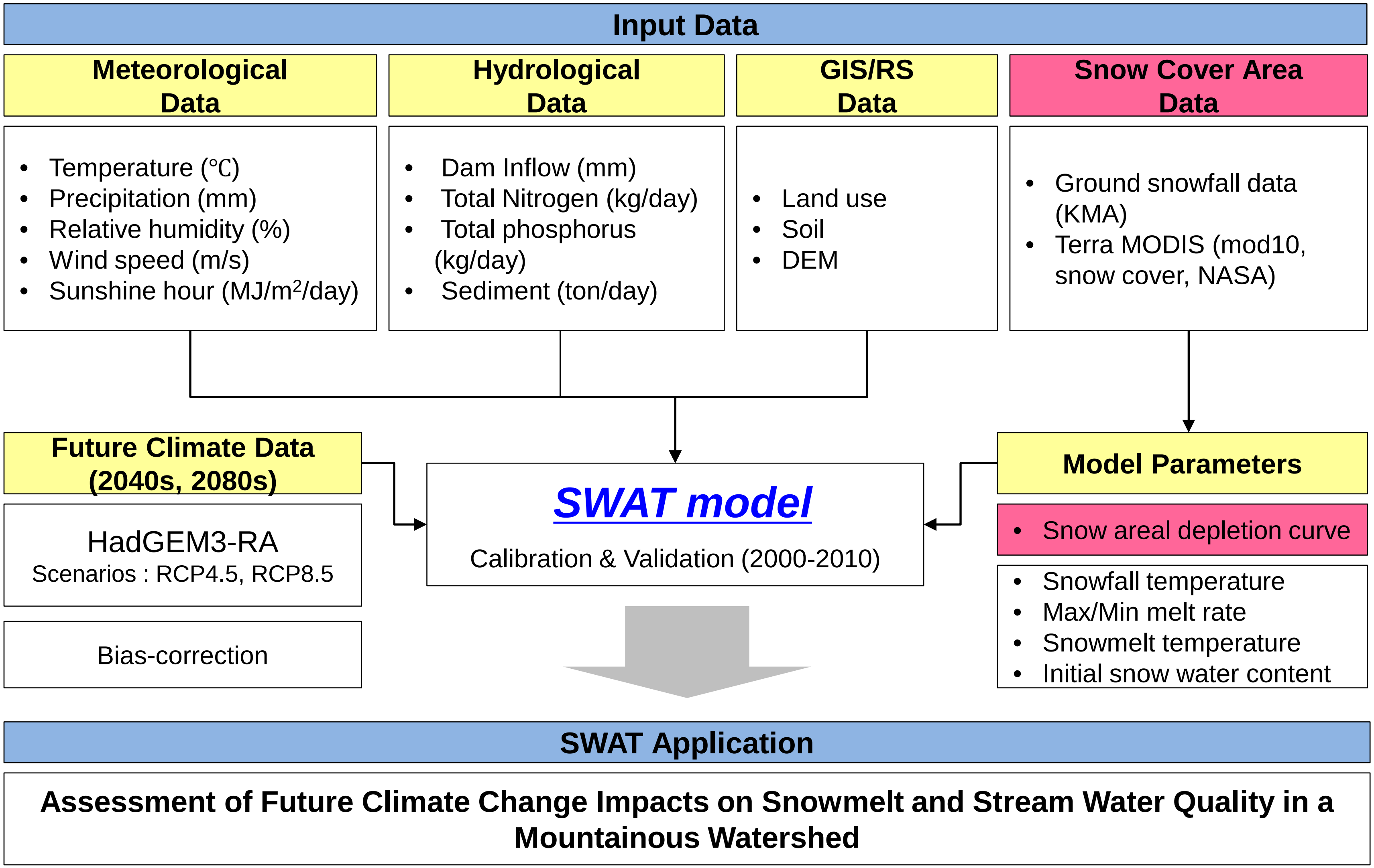
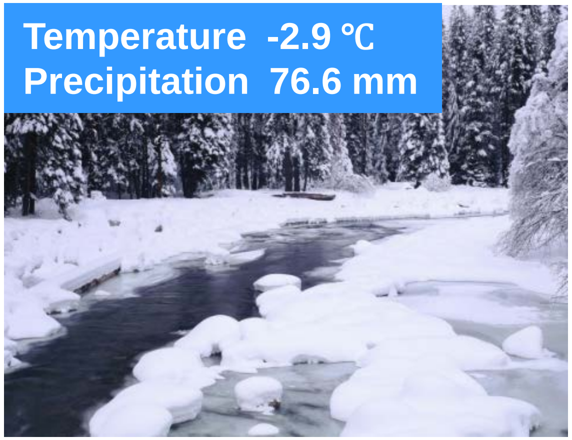
Study procedure



Korea seasons



Temperature -2.9 ℃
Precipitation 76.6 mm

Winter (December - February)

Temperature 9.5 ℃
Precipitation 210.0 mm

Spring (March - May)

Four Seasons

Summer (June - August)

Temperature 21.7 ℃
Precipitation 752.6 mm

Autumn (October - November)

Temperature 11.2 ℃
Precipitation 253.7 mm

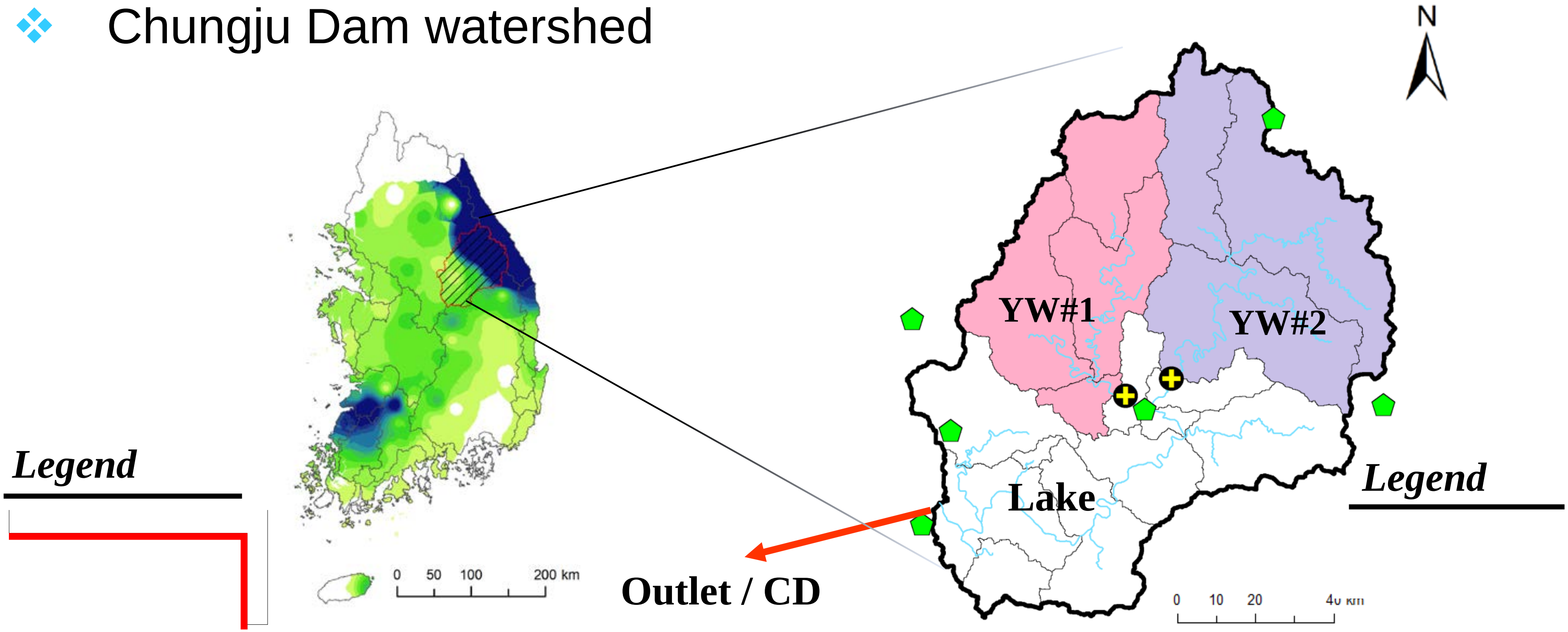
Korea Seasons

Winter (December – February)

- Winter lasts from December to mid-March. It can be bitterly cold and dry during this time due to the influx of cold Siberian air. Heavy snow in the northern and eastern parts of Korea. Winters can be extremely cold with the minimum temperature dropping below −20 °C in the inland region of the country: in Seoul, the average January temperature range is −7 °C to 1 °C (19 °F to 33 °F). January is the coldest month. Snow piled up and the snow is starting to melt in January especially in the mountain. It is a perfect time to have fun in the snow. One of the most polular winter activities is skiing.

Study Watershed

❖ Chungju Dam watershed



- Watershed area : 6,642.0 km^2 **(heavy snowfall area : about 40%)**
- <u>Annual average snow depth : **80.9 cm**</u>
- Annual average precipitation : 1,359.5 mm
- Annual average temperature : 9.4 ℃
- Forest area : 88.5 % (5573.1 km^2)
- Latitude range : 36.8 °N ~ 37.8 °N
- Longitude range : 127.9 °E ~ 129.0 °E

SWAT Model Description

- The hydrology cycle as simulated by SWAT is based on the 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)

SWAT Soil & Water Assessment Tool

SWAT Model Description

- **Mass balance equation**
  - In SWAT, snowmelt hydrology is realized on an HRU (Hydrologic Response Unit) basis.
  - The mass balance for the snowpack is computed as:

$$SNO = SNO + R_{day} - E_{sub} - SNO_{mlt}$$

SNO = *The water content of the snow pack on a given day (mm* H_2O*)*

Rday = *The amount of precipitation on a given day (mm* H_2O*)*

Esub = *The amount of sublimation on a given day (mm* H_2O*)*

SNOmlt = *The amount of snowmelt on a given day (mm* H_2O*)*

SWAT Soil & Water Assessment Tool

SWAT Model Description

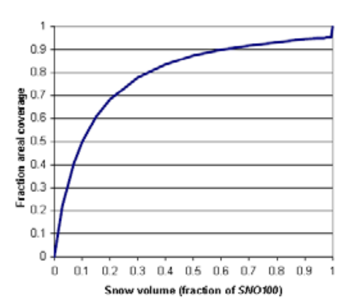
- **Snow depletion curve**
  - The areal depletion curve is based on a natural logarithm

$$sno_{cov} = \frac{SNO_i}{SNOCOVMX} \left[\frac{SNO_i}{SNOCOVMX} + \exp\left(cov_1 - cov_2 \frac{SNO_i}{SNOCOVMX}\right) \right]^{-1}$$

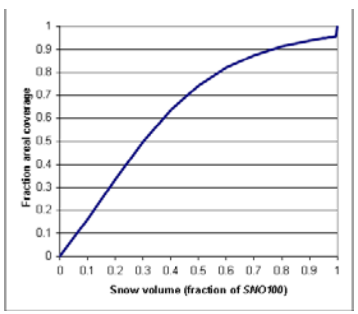
sno_{cov} : the fraction of the HRU area covered by snow on the current day

SNOCOVMX : the minimum snow water content that corresponds to 100% snow cover (mm H_2O)

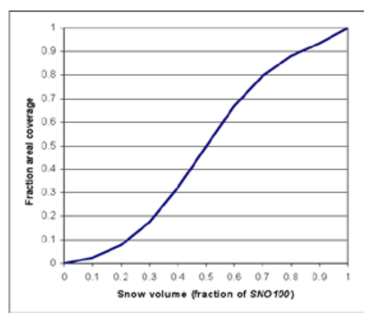
cov_1 and cov_2 : the coefficients that define the shape of the curve



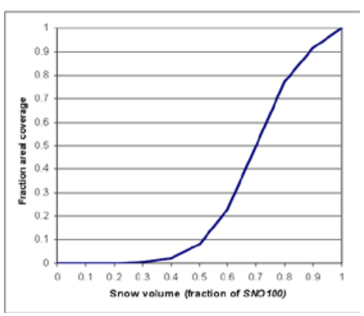
10% SNO_{100} = 50% coverage



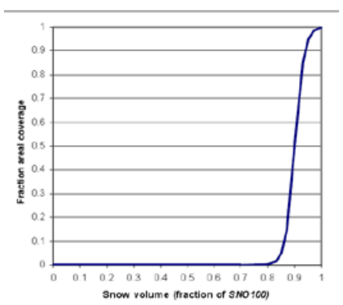
30% SNO_{100} = 50% coverage



50% SNO_{100} = 50% coverage



70% SNO_{100} = 50% coverage



90% SNO_{100} = 50% coverage

SWAT Soil & Water Assessment Tool

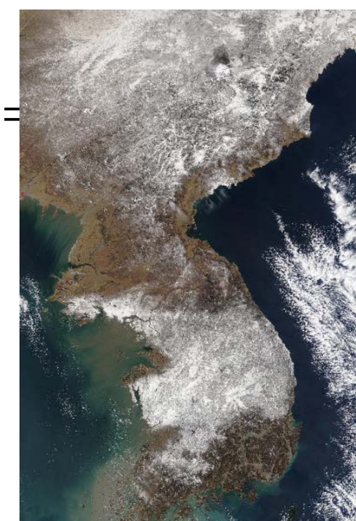
Terra MODIS Snow Cover Area

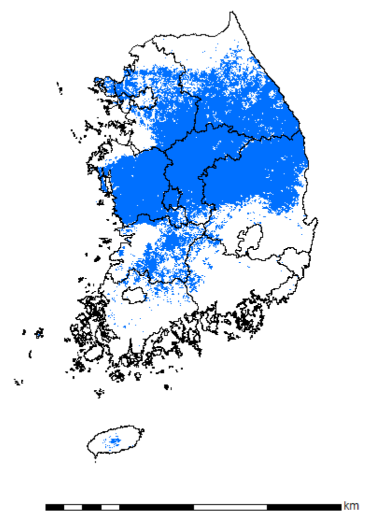
- MODIS (Moderate Resolution Imaging Spectroradiometer)
  - MODIS data is to permit the regional to global study of the land, atmosphere, and ocean on a daily or near-daily basis (Salomonson et al., 1992)
- NDSI (Normalized Difference Snow Index)
  - The automated MODIS snow-mapping algorithm uses at satellite reflectance in MODIS band 4 (0.545-0.565 ㎛) and band 6 (1.628-1.652 ㎛) to calculate the normalized difference snow index

$$NDSI = \frac{\ldots ODIS6}{\ldots ODIS6}$$

2004. 3. 7
MODIS image

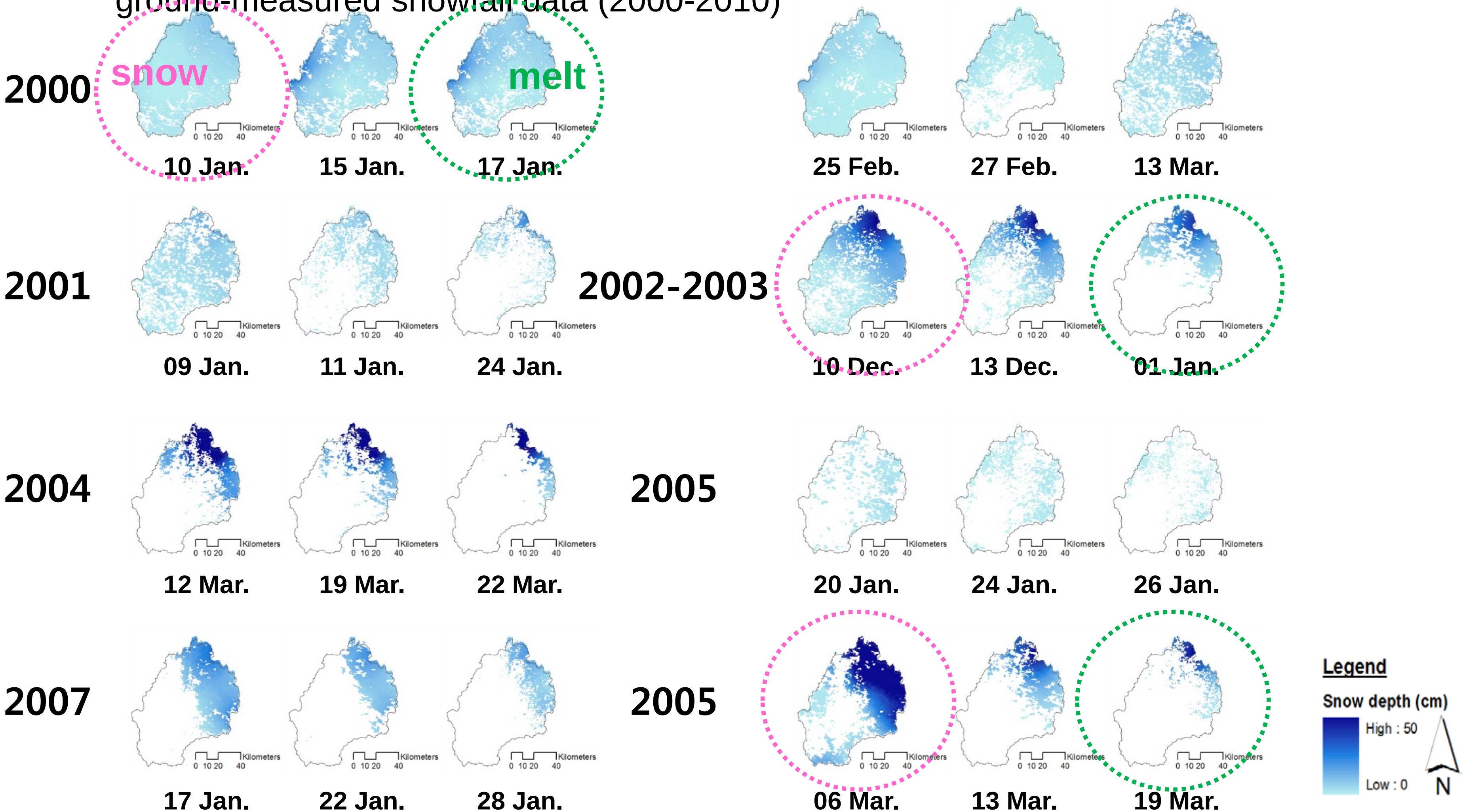
MODIS
Moderate Resolution Imaging Spectroradiometer



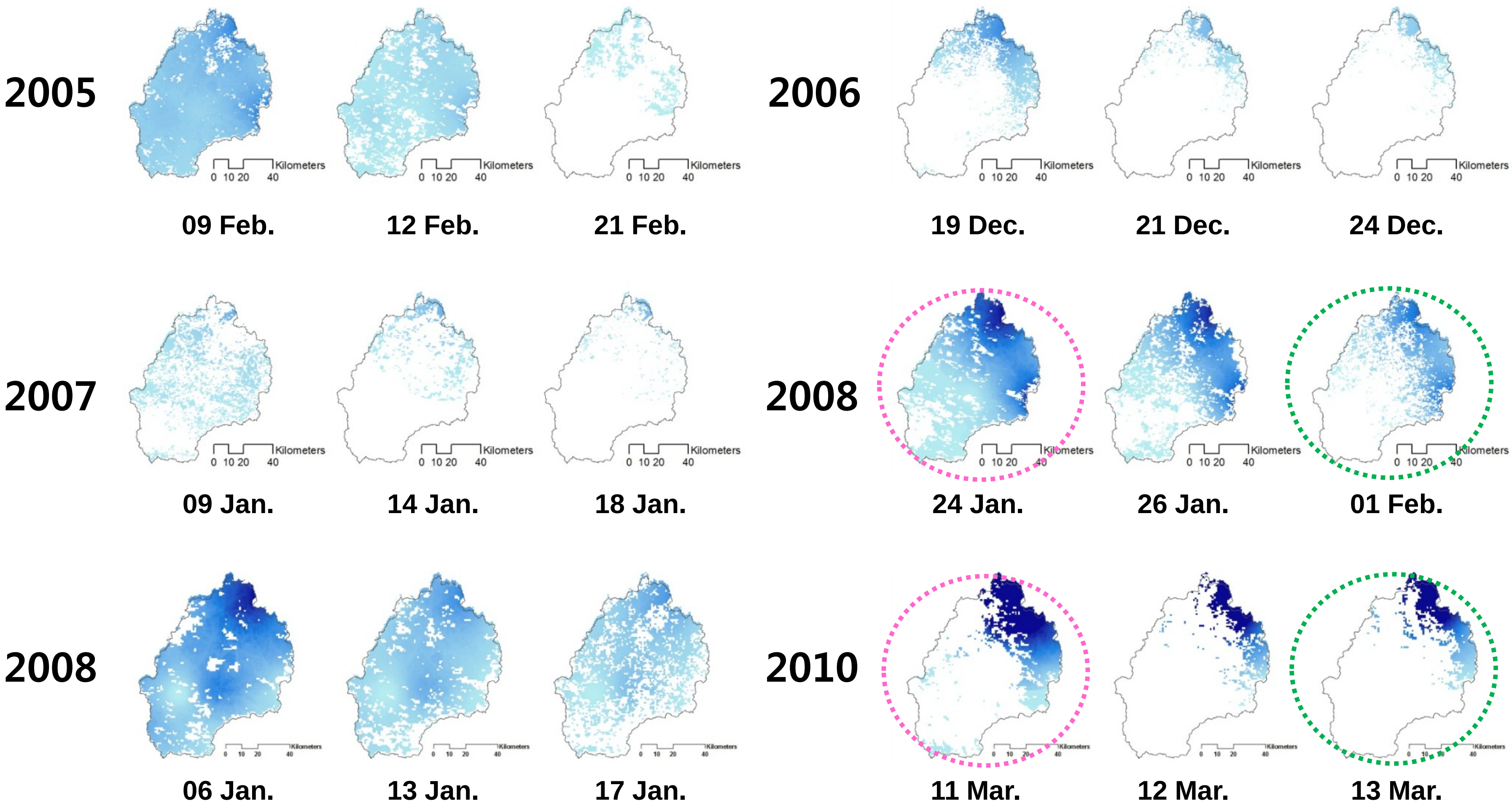


Terra MODIS Snow Cover Area

- The generated snow depth distribution using the MODIS snow cover extent and the ground-measured snowfall data (2000-2010)

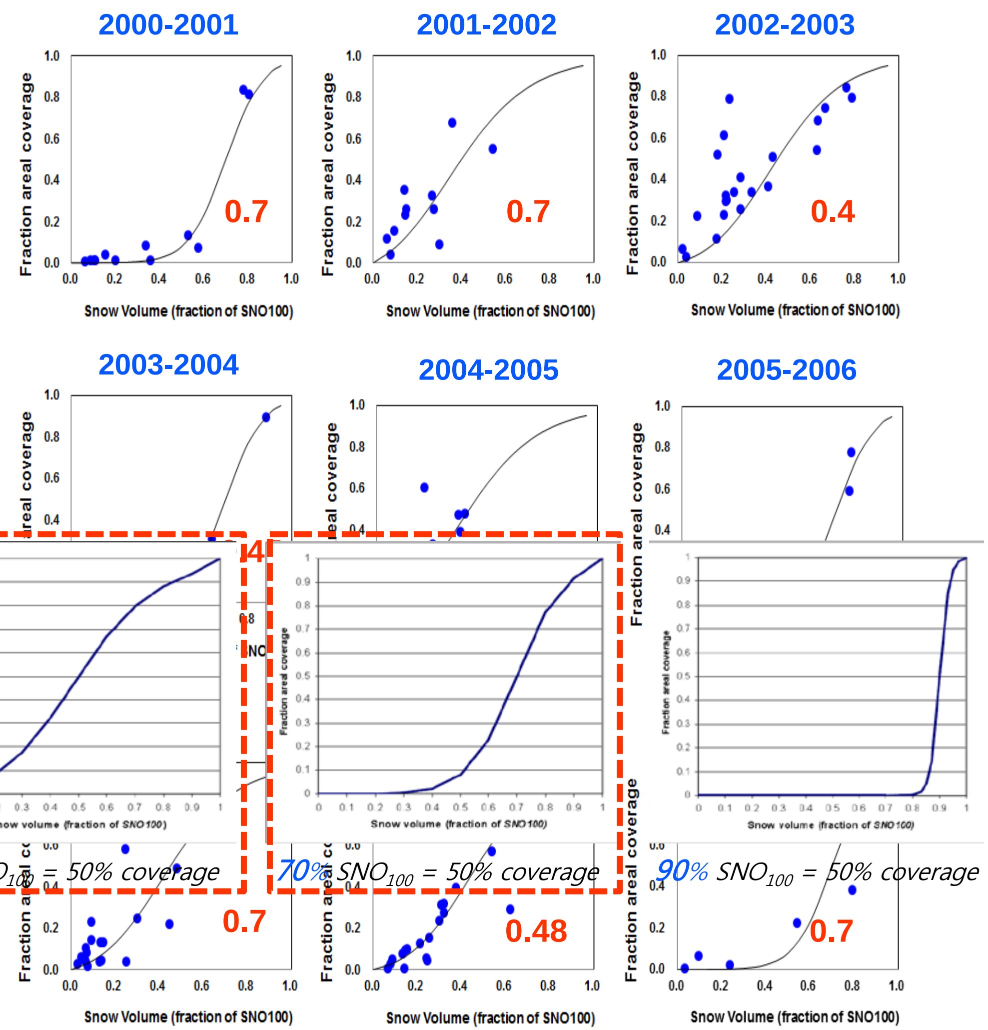


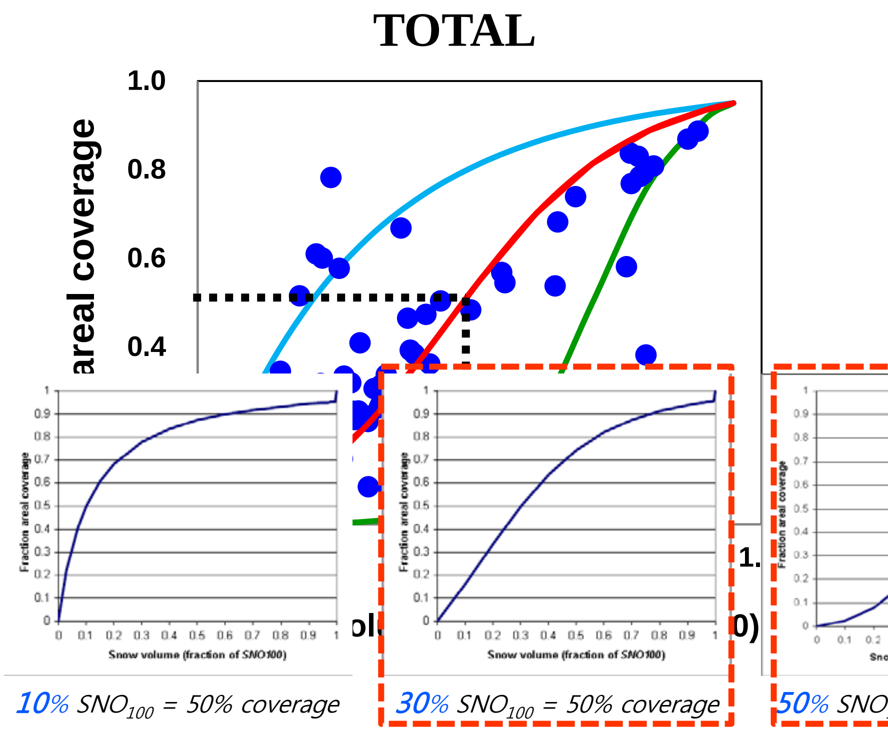
Terra MODIS Snow Cover Area



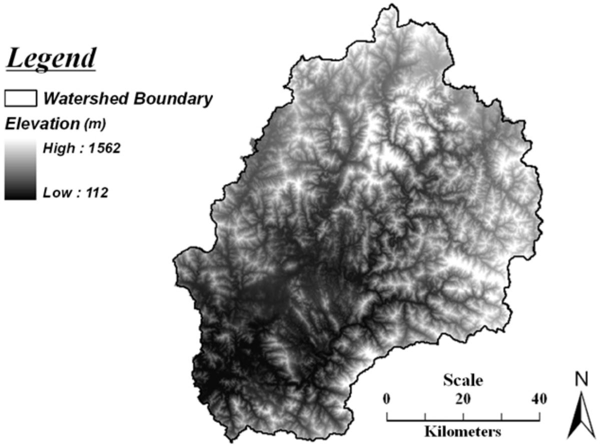
Snow Depletion Curve

- The snow depletion curves from the fraction of snow cover area and snow volume of each data set.

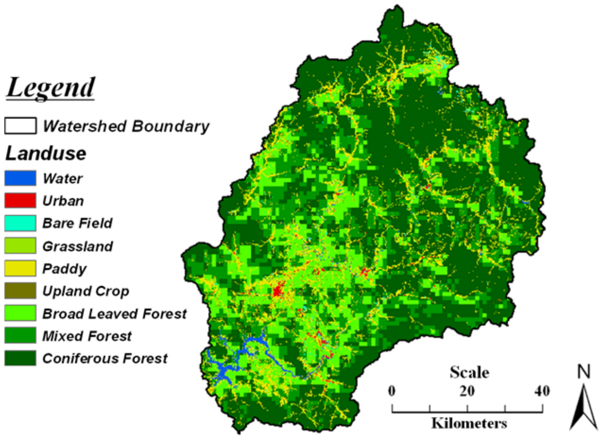




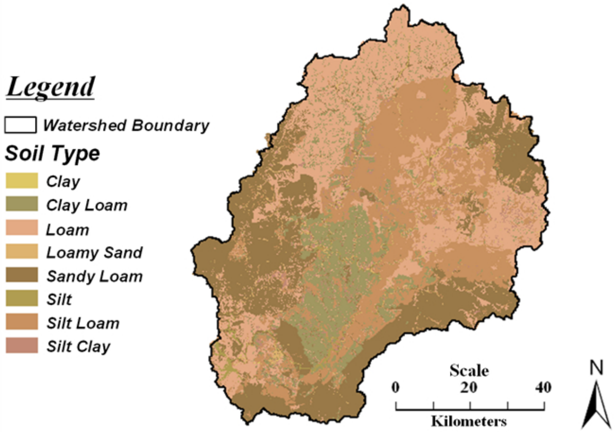
Preparation of SWAT input data



Elevation : 115 – 1,559m (average : 609.1 m)



Land cover (2000)



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

Data Set	Source	Scale	Data Description / Properties
Terrain	Korea National Geography Institute	1:5,000	**Digital Elevation Model (DEM) – 30 m**
Soil	Korea Rural Development Administration	1:25,000	**Soil classifications and physical properties such as bulk density, texture, and saturated conductivity.**
Land use	Landsat TM Satellite Image	30 m	**Land use classifications such as paddy, grass, and forest.**
Weather	Korea Meteorological Administration	Daily	**precipitation, minimum and maximum temperature, mean wind speed and relative humidity data from 1998 to 2010**
Streamflow	Han River Flood Control Office	Daily	**streamflow data from 1998 to 2010**
Water Quality	Ministry of Environment	Monthly	**Water quality (SS, T-N and T-P) data from 1998 to 2010**

Snow Parameters

The calibrated model parameters

- The 7 snowmelt parameters of **SFTMP, SMTMP, SMFMX, SMFMN, TIMP, SNOCOVMX and SNO50COV**

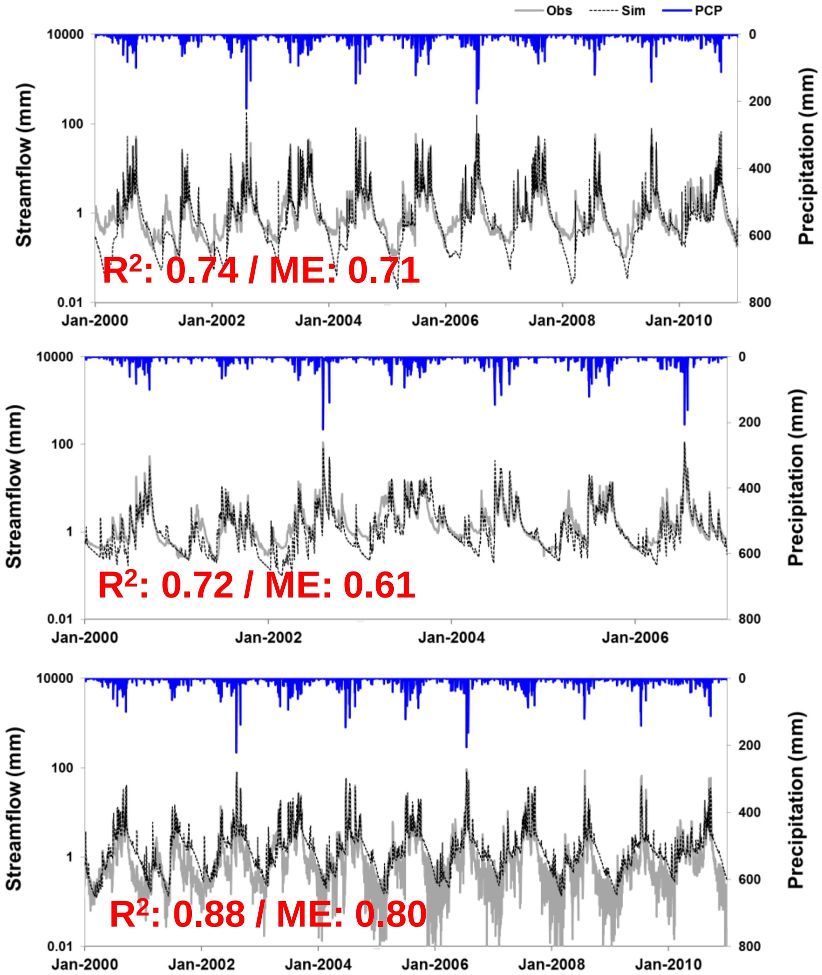
Parameter	*2000 2001*	*2001 2002*	*2002 2003*	*2003 2004*	*2004 2005*	*2005 2006*	*2006 2007*	*2007 2008*	*2008 2009*	*2009 2010*	*Avg.*
SFTMP	2.5	5	-2	5	-5	-5	-5	-5	7	1	-0.15
SMTMP	4.5	7	7	7	5	8	8	5	8	5	6.45
SNOCOVMX	1	1	1	1	1	1	1	1	1	1	1
SNO50COV	0.7	0.4	0.45	0.7	0.42	0.7	0.45	0.48	0.47	0.7	0.47
TIMP	1	1	1	1	1	1	1	1	1	1	1
SMFMX	1	8	5	1	1	1	4.5	4.5	1	4.5	3.39
SMFMN	4.5	4	5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5

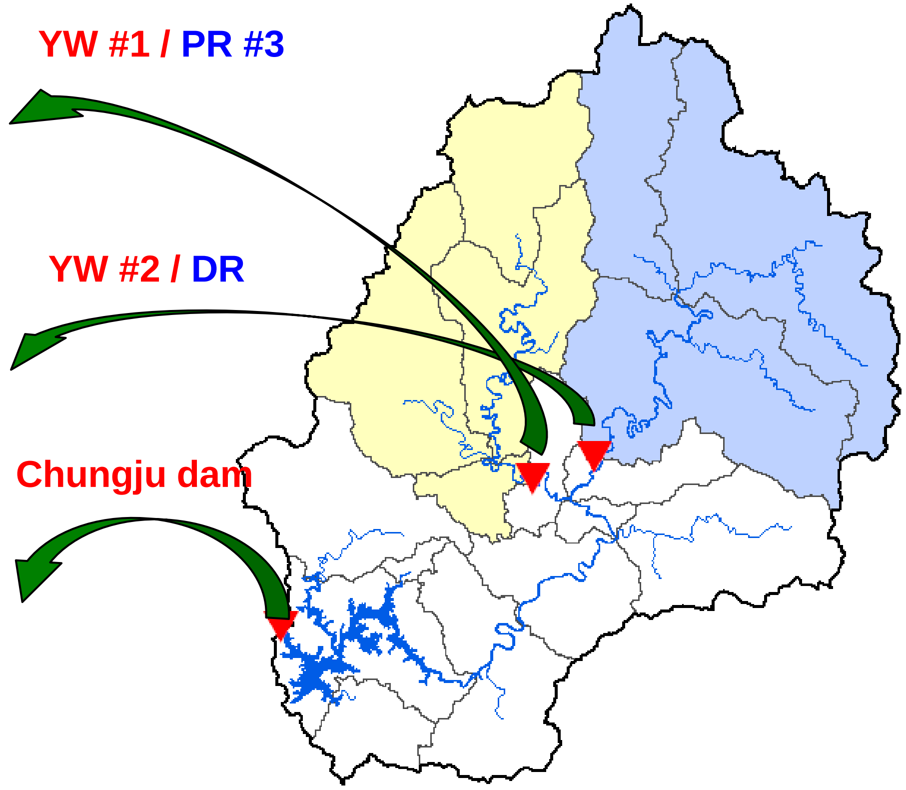
- SFTMP : Snowfall temperature (℃)
- SMTMP : Snow melt base temperature (℃)
- SNOCOVMX : Threshold depth of snow, above which there is 100% cover [mm]
- SNO50COV : Fraction of SNOCOVMX that provides 50% cover
- TIMP : Snow pack temperature lag factor
- SMFMX : Maximum snow melt factor (mm H_2O/°C-day)
- SMFMN : Minimum snow melt factor (mm H_2O/°C-day)

Calibration and Validation

K O N K U K U N I V E R S I T Y

- Streamflow
  - Calibration period : 2000-2010

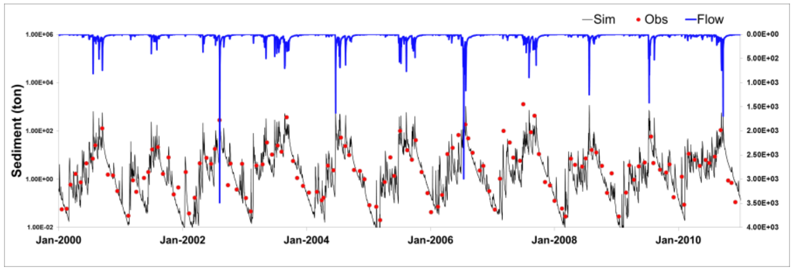




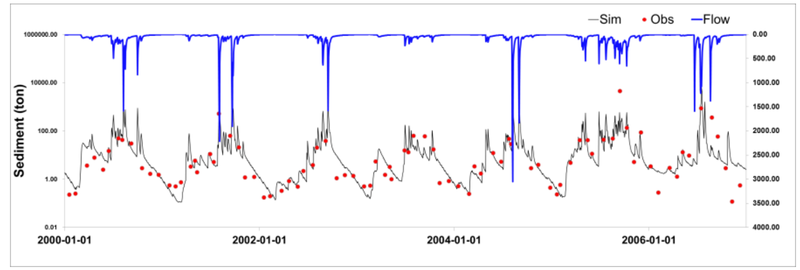
Calibration and Validation

- Stream Water Quality (SS, T-N and T-P)

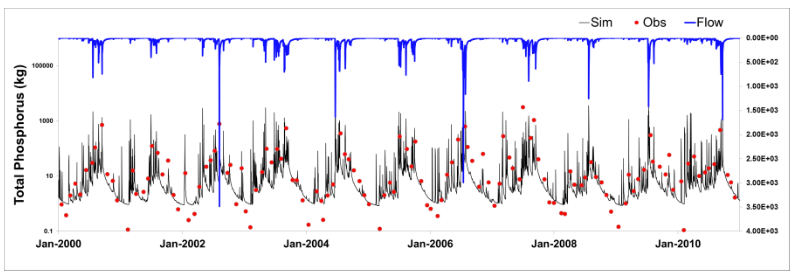
(PR #3) **(DR)**



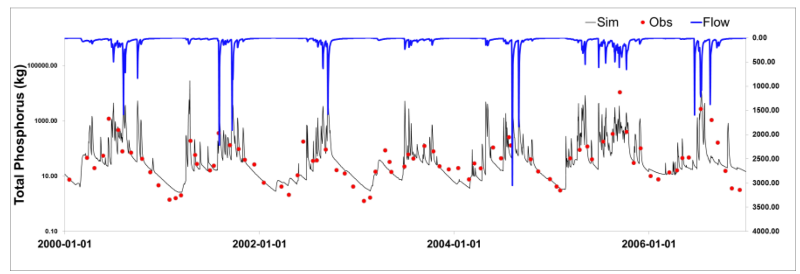
R^2: 0.87 / ME: 0.72



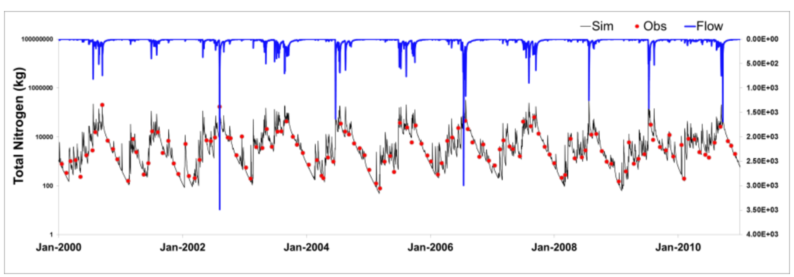
R^2: 0.61 / ME: 0.75



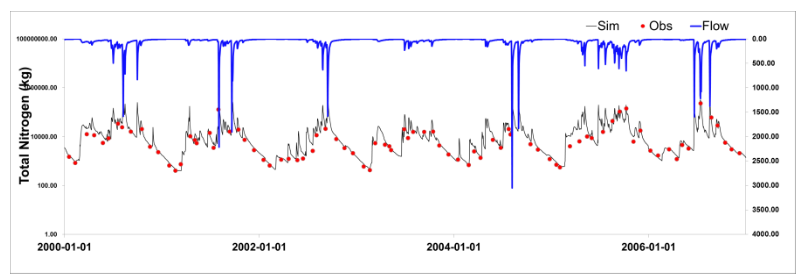
R^2: 0.74 / ME: 0.54



R^2: 0.88 / ME: 0.85



R^2: 0.85 / ME: 0.70

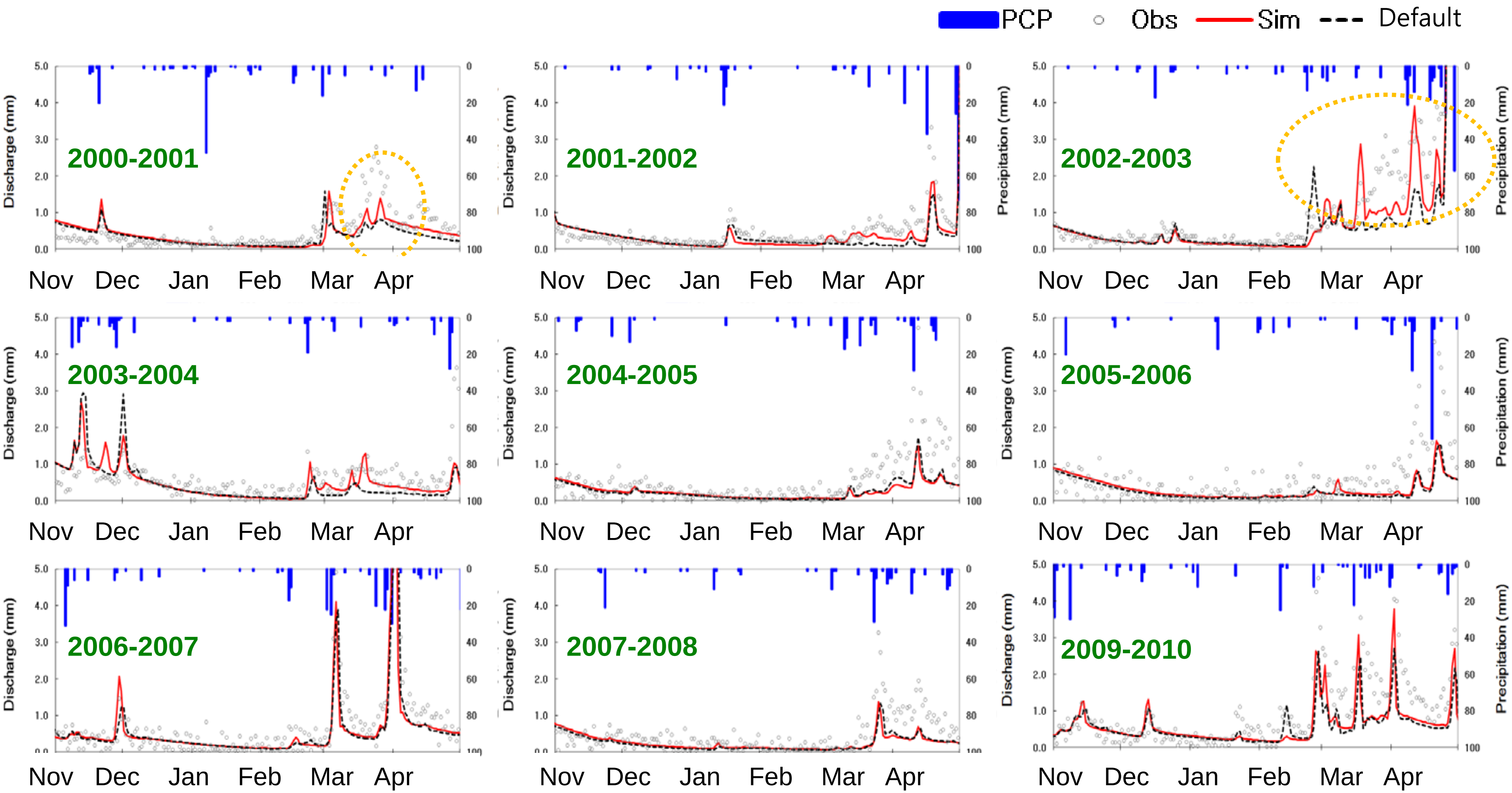


R^2: 0.62 / ME: 0.70

Calibration (November-April)

K O N K U K U N I V E R S I T Y

- **Snowmelt period : November to April**



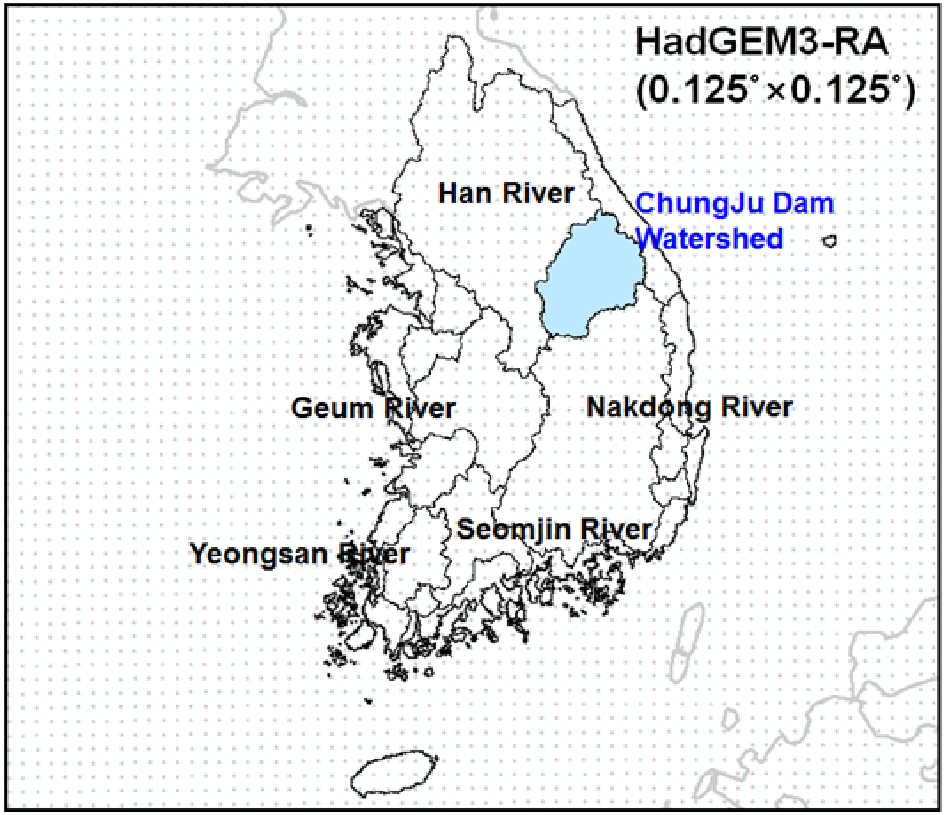
Calibration and Validation

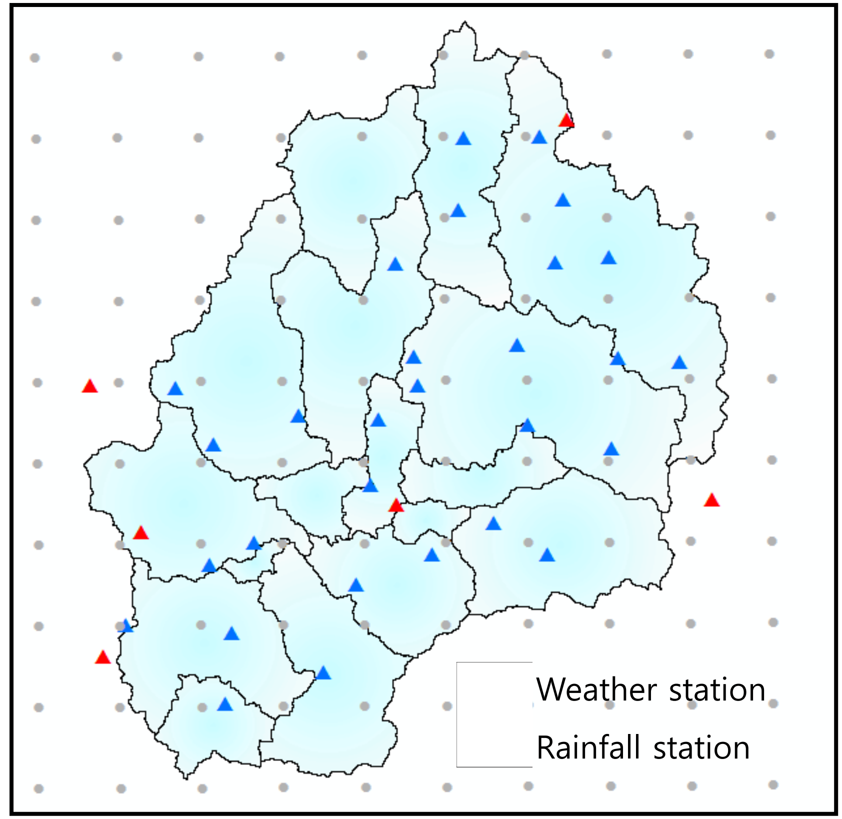
Year	Period	Snow depth (cm)	PCP (mm)	Q (mm) Obs.	Q (mm) Sim.	QR (%) Obs.	QR (%) Sim.	RMSE (mm/day)	NSE	QRA/ QRS
2000-2001	Annual	128.6	831.2	309.4	344.9	37.2	41.5	0.82	0.57	18.2
	Snowmelt		177.2	90.7	62.6	51.2	35.3	0.49	0.37	
2001-2002	Annual	56.5	1238.0	836.7	863.0	67.6	69.7	2.95	0.83	6.6
	Snowmelt		242.0	83.5	56.8	34.5	23.5	0.41	0.96	
2002-2003	Annual	129.7	1590.5	1032.2	1167.6	64.9	73.4	2.56	0.64	13.0
	Snowmelt		270.0	191.6	151.8	71.0	56.2	0.66	0.92	
2003-2004	Annual	59.6	1375.9	931.0	995.6	67.7	72.4	3.38	0.72	8.9
	Snowmelt		187.9	103.5	88.8	55.1	47.3	0.48	0.95	
2004-2005	Annual	86.9	1260.0	741.4	750.5	58.8	59.6	2.33	0.50	6.3
	Snowmelt		175.0	101.3	46.9	57.9	26.8	0.68	0.83	
2005-2006	Annual	52.2	1870.0	953.0	1015.9	51.0	54.3	5.50	0.64	5.6
	Snowmelt		218.0	105.0	57.2	48.2	26.3	0.69	0.90	
2006-2007	Annual	49.7	1538.0	1019.5	963.5	66.3	62.6	3.29	0.65	10.8
	Snowmelt		265.0	131.3	103.6	49.6	39.1	0.54	0.95	
2007-2008	Annual	80.5	1083.0	472.9	458.3	43.7	42.3	4.02	0.38	10.1
	Snowmelt		162.0	83.0	46.4	51.3	28.6	0.44	0.80	
2008-2009	Annual	33.1	1263.0	596.7	539.4	47.2	42.7	3.32	0.70	5.4
	Snowmelt		202.0	55.3	29.4	27.4	14.5	0.29	0.95	
2009-2010	Annual	92.5	1250.3	819.7	684.5	65.6	54.7	3.16	0.64	16.6
	Snowmelt		260.3	181.4	113.6	69.7	43.7	0.80	0.76	
Mean	Annual	76.9	1330.0	76.9	771.2	57.3	57.0	3.10	0.60	10.1
	Snowmelt		215.9	112.7	75.7	51.6	34.1	0.50	0.80	

Q : Streamflow, QR : Runoff ratio, QRA : Runoff ratio for annual period (Nov-Oct) , QRS : Runoff ratio for snowmelt period (Nov-Apr) , and RMSE : Root mean square error.

General Circulation Model (GCM)

- IPCC AR5 model

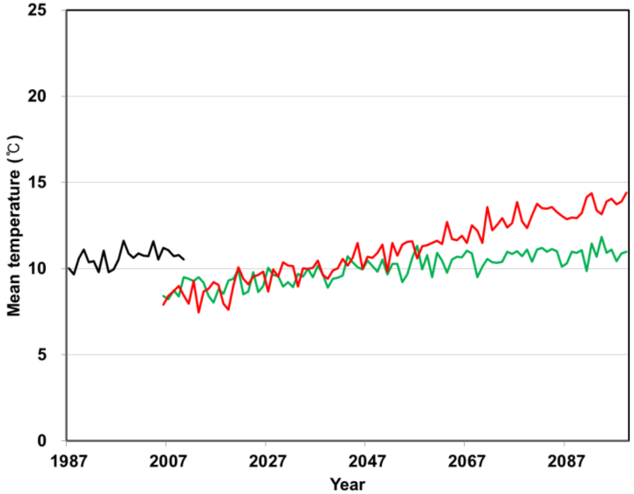


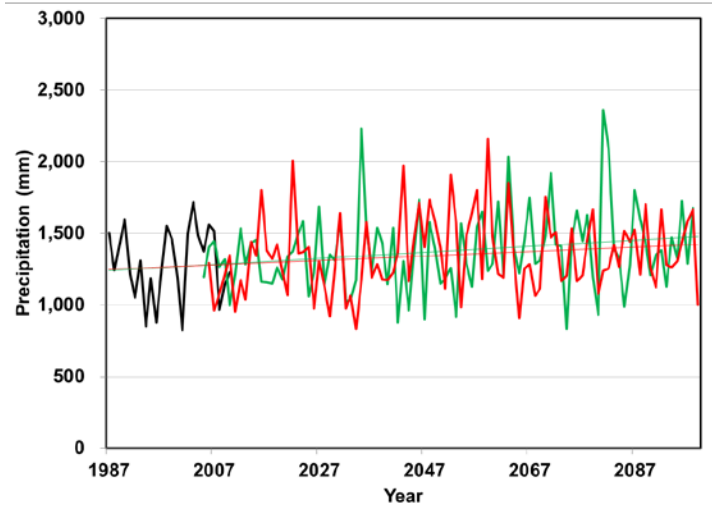


Model	Center	Country	Scenario	Grid size
HadGEM3-RA	**UKMO** (UK Met. Office)	**UK**	**RCP 4.5 (540 ppm)** **RCP 8.5 (940 ppm)**	**12.5km × 12.5km** **(0.125° × 0.125°)**

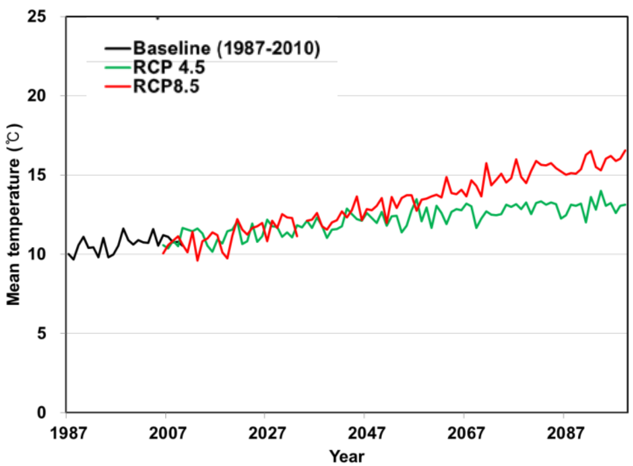
Bias correction

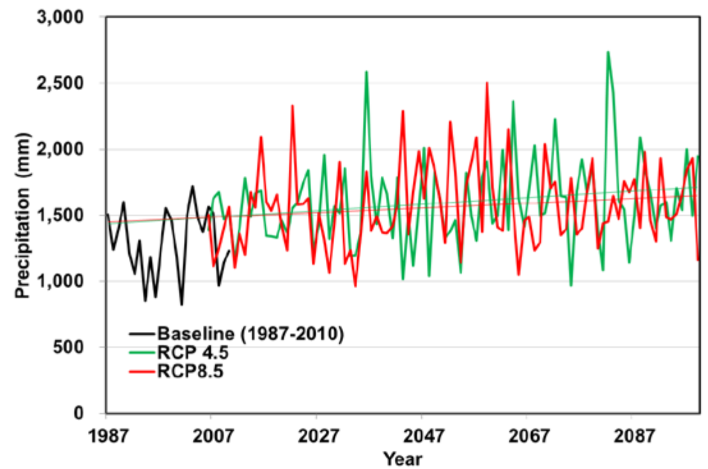
Before correction





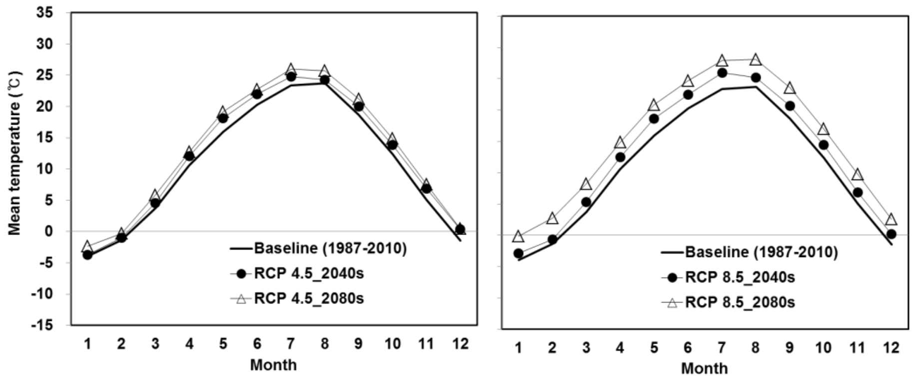
After correction



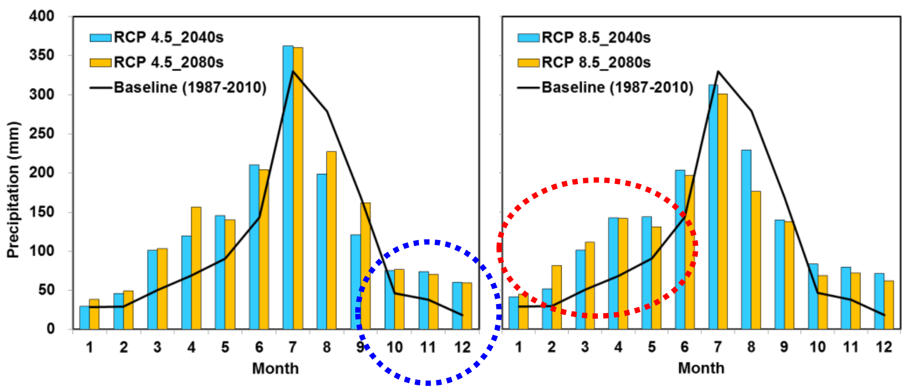


Climate Scenarios

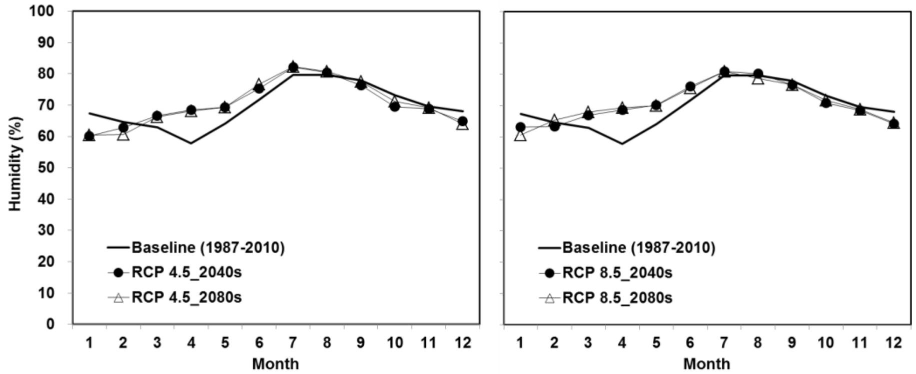
Temperature (℃)



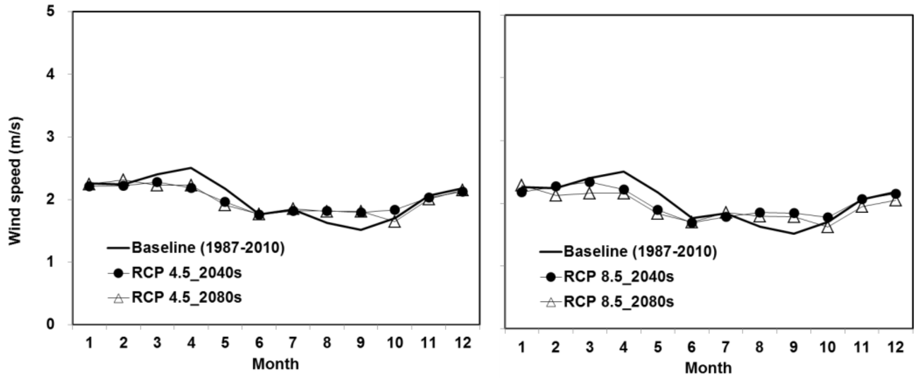
Precipitation (mm)



Humidity (%)



Wind speed (m/s)



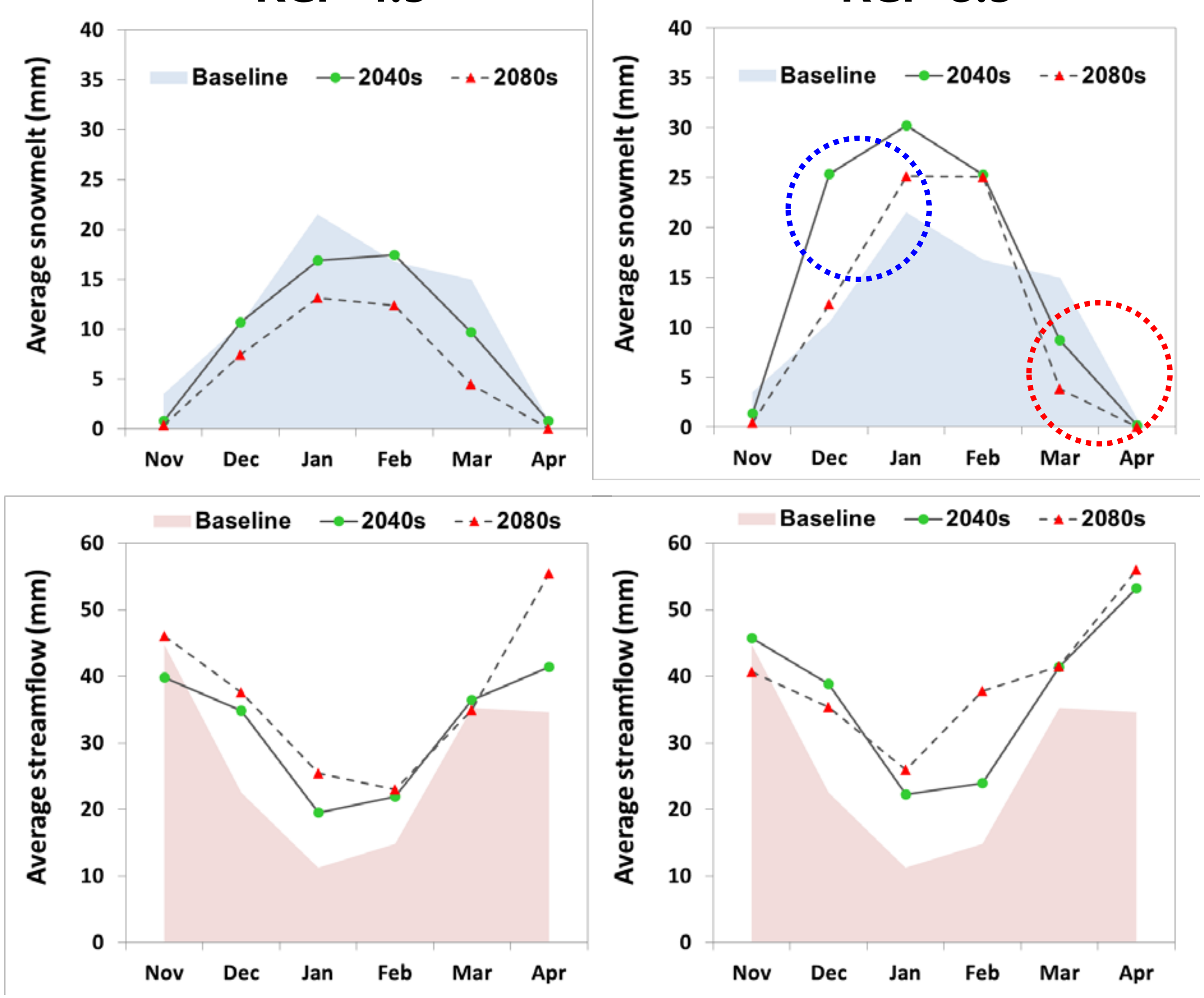
Climate Scenarios

Period	Scenario		TMN (℃)	TMN difference (℃)	TMP (℃)	TMP difference (℃)	TMX (℃)	TMX difference (℃)	PCP (mm)	PCP variation (%)
Annual (Nov – Oct)	Baseline (1987~2010)		5.33	-	10.58	-	15.83	-	1292.9	-
	RCP 4.5	2040s	6.74	1.40	11.84	1.26	16.94	1.11	1544.6	16.3
		2080s	7.77	2.43	12.80	2.22	17.87	2.04	1648.7	21.6
	RCP8.5	2040s	7.31	1.98	12.40	1.82	17.48	1.66	1600.5	19.2
		2080s	9.99	4.65	15.03	4.45	20.13	4.30	1524.8	15.2
Spring (Mar – May)	Baseline (1987~2010)		4.15	-	10.09	-	16.03	-	210.0	-
	RCP 4.5	2040s	5.96	1.81	11.57	1.48	17.20	1.17	366.9	42.8
		2080s	8.34	4.19	13.95	3.86	20.42	4.39	376.0	44.2
	RCP8.5	2040s	6.56	2.42	12.17	2.08	17.78	1.75	387.3	45.8
		2080s	9.03	4.88	14.64	4.55	20.22	4.19	384.1	45.3
Summer (Jun – Aug)	Baseline (1987~2010)		18.09	-	22.44	-	26.79	-	752.6	-
	RCP 4.5	2040s	19.03	0.93	23.67	1.23	28.22	1.43	771.5	2.5
		2080s	20.26	2.16	24.80	2.36	29.26	2.47	792.6	5.0
	RCP8.5	2040s	19.82	1.73	24.52	2.08	29.11	2.32	745.5	-1.0
		2080s	22.32	4.23	26.93	4.49	31.51	4.72	674.0	-11.7
Autumn (Sep –Nov)	Baseline (1987~2010)		6.55	-	12.04	-	17.54	-	253.7	-
	RCP 4.5	2040s	8.33	1.78	13.56	1.51	18.83	1.30	270.2	6.1
		2080s	9.42	2.86	14.54	2.49	19.74	2.20	308.6	17.8
	RCP8.5	2040s	8.82	2.27	13.97	1.93	19.19	1.65	303.1	16.3
		2080s	11.64	5.09	16.78	4.74	22.01	4.48	278.7	8.9
Winter (Dec – Feb)	Baseline (1987~2010)		-7.46	-	-2.26	-	2.95	-	76.6	-
	RCP 4.5	2040s	-6.37	1.09	-1.45	0.81	3.50	0.55	136.0	43.7
		2080s	-5.54	1.93	-0.69	1.56	4.26	1.31	147.3	48.0
	RCP8.5	2040s	-5.98	1.49	-1.09	1.17	3.85	0.90	164.7	53.5
		2080s	-3.04	4.42	1.76	4.01	6.78	3.83	188.0	59.3

Climate Change Impact on Snowmelt(Nov- Apr)

Change of future monthly snowmelt and streamflow

RCP 4.5 RCP 8.5



Snowmelt

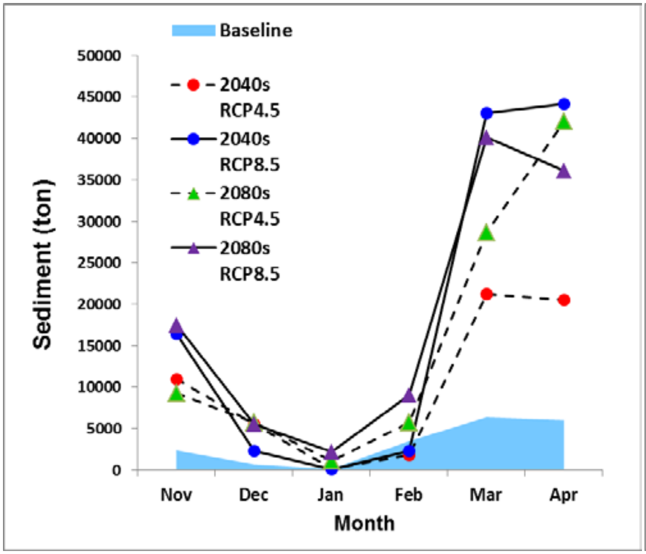
- Big change in 2040 March
- Advanced by the future temperature increase

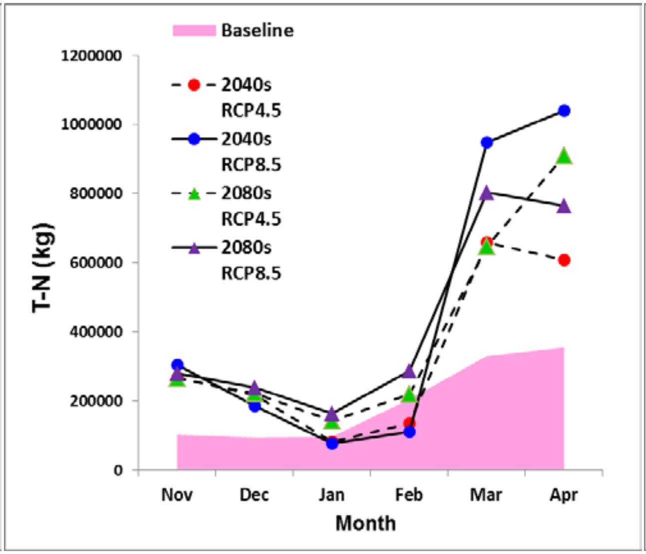
Streamflow

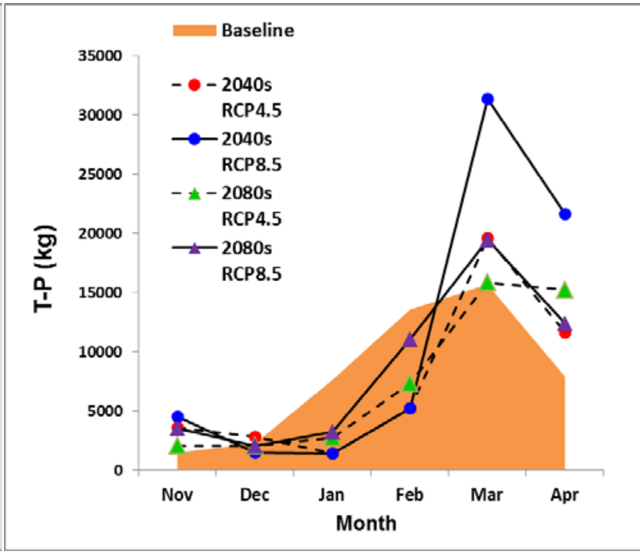
- Increased up to 55.4mm in 2040s RCP8.5 and 55.9mm in 2080s RCP8.5 scenario

Climate Change Impact on Water Quality

Runoff Characteristics of Nonpoint Source Pollution Loads







- The future sediment load showed general tendency of increase during snowmelt period.
- The future T-N & T-P loads showed clear increase in November, March, and April.
- Especially, the reason of future T-P decrease in Jan. and Feb. can be interpreted as follows:
- ➢ By the water temperature increase in the future, the soluble phosphorus concentration (solP) in the stream may be decreased by the uptake of inorganic P by algae. In addition, the organic phosphorus mineralization rate and the organic phosphorus settling rate can be adjusted to the water temperature in the direction of decreasing solP.

Summary and Conclusion

- This study tried to determine the SWAT snow depletion characteristics and assess future climate change impacts on snowmelt and the stream water quality for a mountainous watershed using SWAT
- The average value of SWAT SNO50COV was 0.47 in Chungju Dam watershed.
- The average runoff during snowmelt period (November-April) was 12.6 % for the full period (November to October).
- The future snowmelt and streamflow increased up to 141.0%, 154.7% respectively, and the future melt was advanced compared to present.
- The future SS, T-N, and T-P loads also increased except January and February of some scenarios.

“ Thank You “

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