Projection of Future Watershed Hydrology by applying SWAT through the Prediction of Vegetation Community under MIROC3.2 hires Climate Change Condition

6 August 2010

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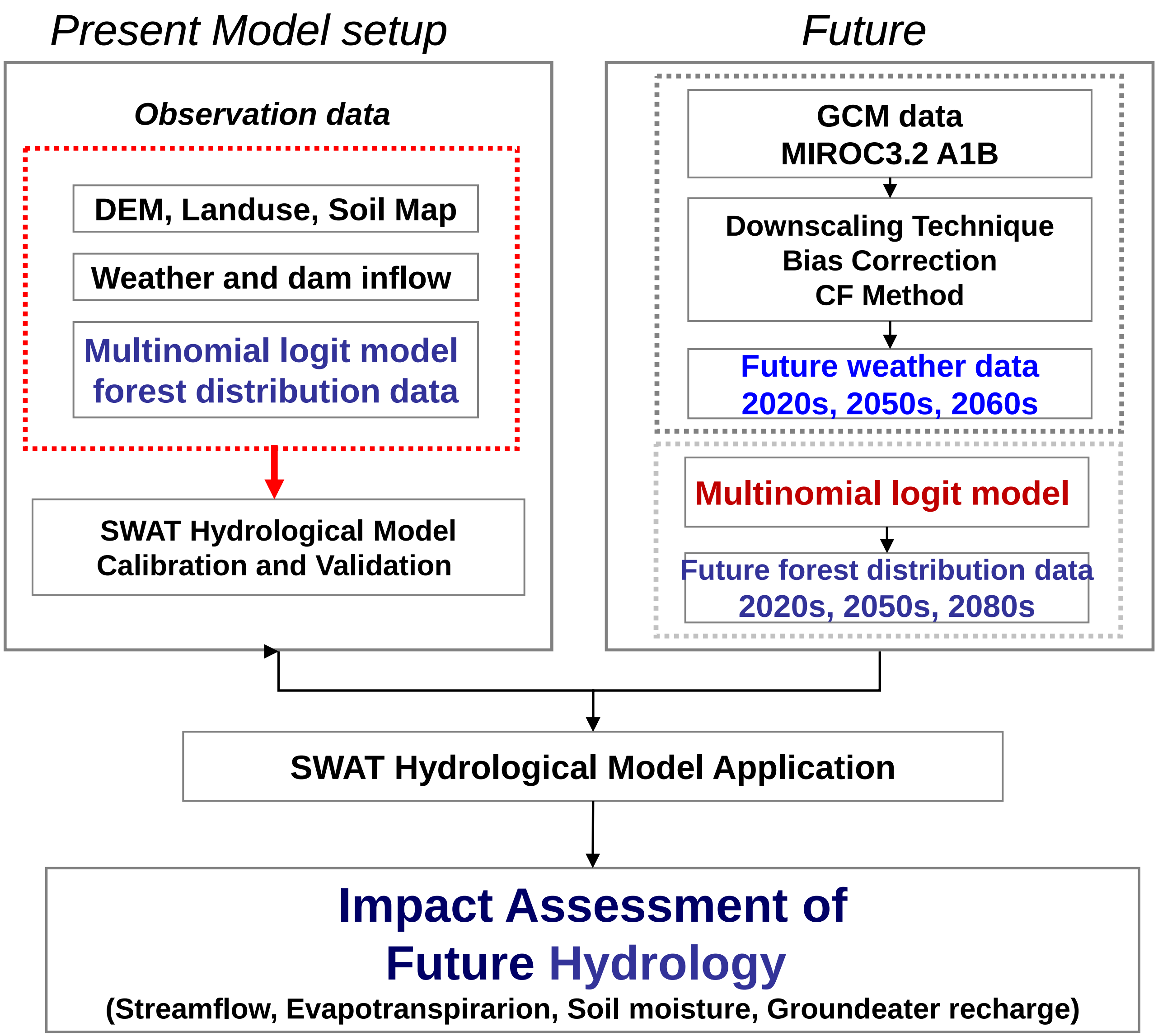
Introduction

- **By the climate change, the forest ecosystem is certainly expected to change and adjusted to the new temperature circumstances.**
- **Thus the assessment of the effects of climate change on the hydrologic cycle is critical for the proper management of water resources.**
- **The forest community change will firstly affect the evapotranspiration temporally and spatially which occupies the big weight among the hydrologic components.**
- **The evapotranspiration change of watershed successively affects other hydrological state variables, soil moisture and groundwater flow, and eventually the streamflow.**

- ***The objective***
  - ✓ **to assess the potential impact of future climate change on hydrology of a watershed by predicting future forest community. The future forest vegetation information was prepared by applying the multinomial logit model with environmental variables.**

Flowchart of Study



Model Description

- **SWAT (Arnold et al., 1998) is a well-established, distributed eco-hydrologic model operating on a daily time step.**

- **Water balance**

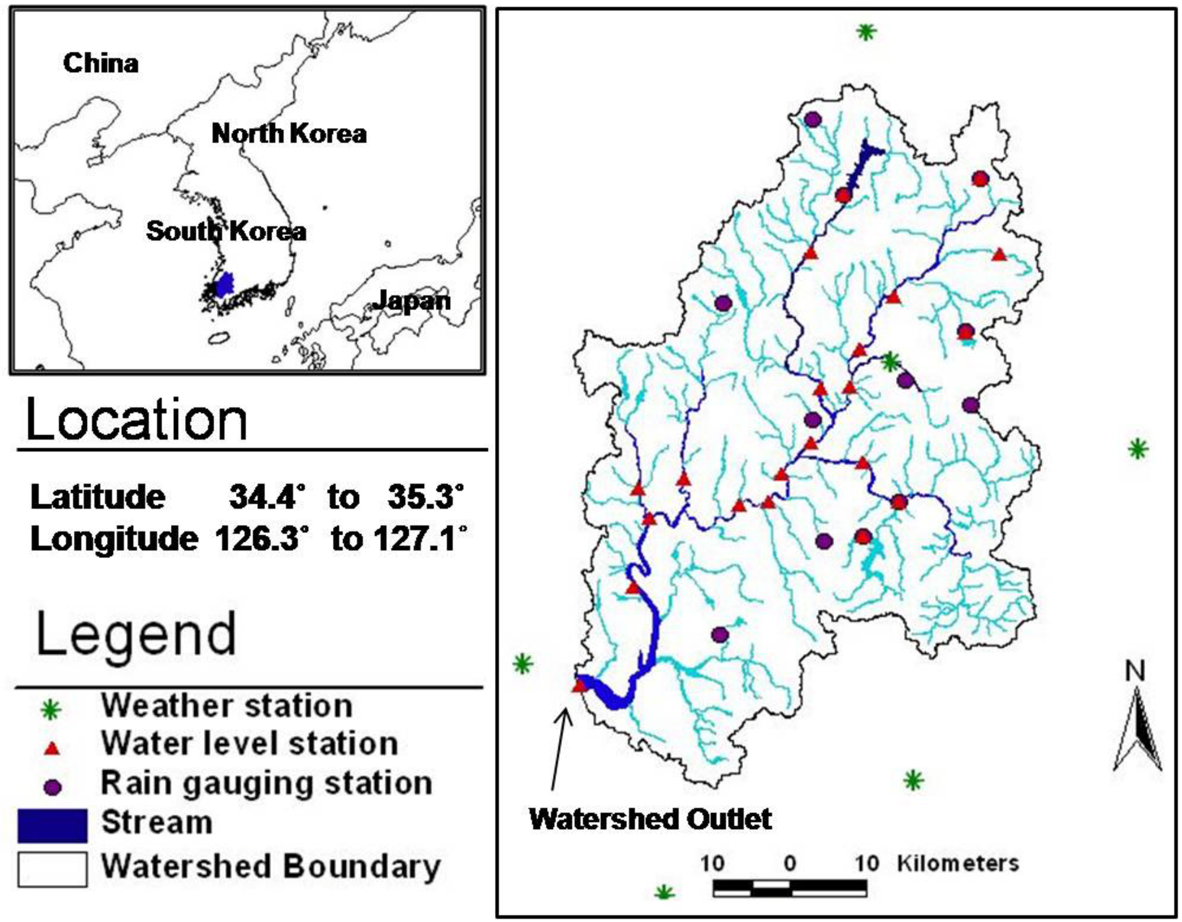
$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

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)

Study Watershed

❖ *Youngsangang watershed*

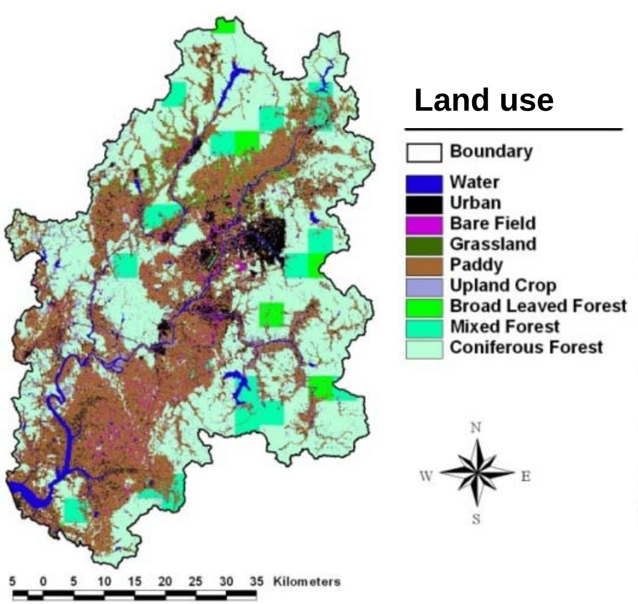
- ❖ Area: 3,455 km^2
- ❖ Forest area: 1,749 km^2 (51%)
- ❖ Stream length: 129.5 km
- ❖ Average elevation: 121.2 m
- ❖ Annual average precipitation : 1,338.5 mm
- ❖ Annual average temperature : 13.1 ℃



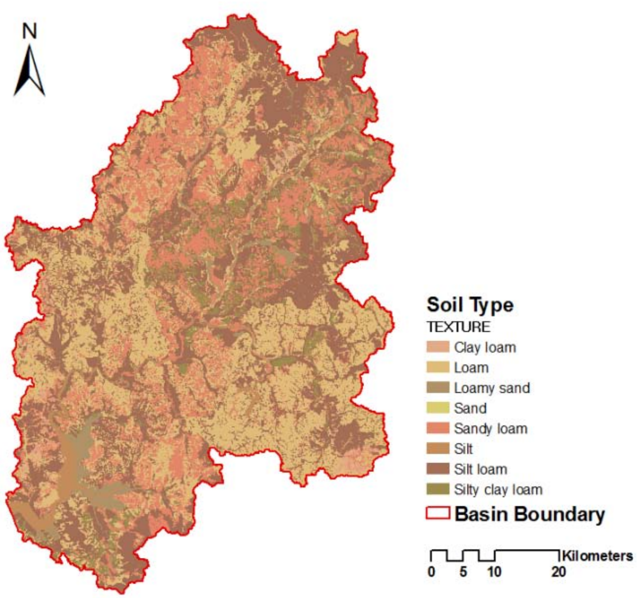
Elevation, Soil, Land Cover Data

Input data preparation

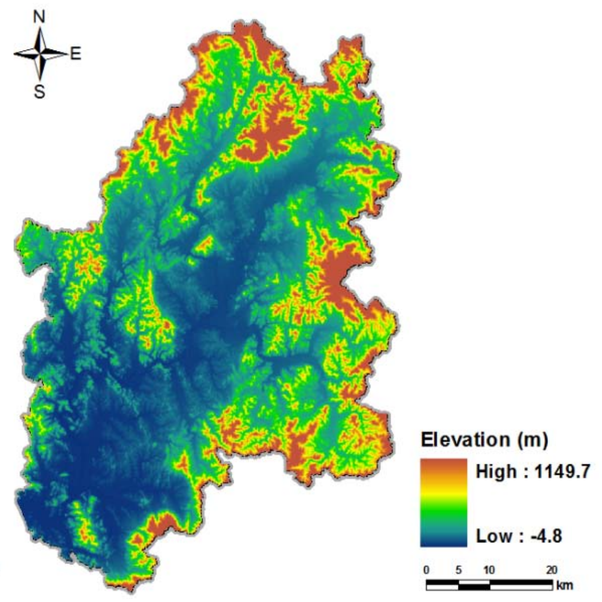
- ✓ Weather data of five weather stations closest to the watershed.
- ✓ Map data (Digital Elevation Model, Hydrologic Soil Type, Land use)



Land use (2000)



Soil



Elevation : -4.8 – 1,149m

Future Climate Data via the Bias-correction and Downscaling Technique

❖ Bias correction (1977-2006) (Droogers and Aerts, 2005)

For temperature

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

For precipitation

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

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

❖ Change Factor (CF) method

- ✓ **A relatively straightforward procedure for constructing regional climate change scenarios and has been widely used for rapid assessment of climate change impacts.**
- ✓ **Monthly mean changes in equivalent variables form the 30 years data (1977-2006, baseline period) of each weather station and the GCM simulations for three time periods (2020s, 2050s, 2060s)**

Future Climate Data via the Bias-correction and Downscaling Technique

❖ 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	320 × 160 (1.1° × 1.1°)

- ✓ 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.

A1B Scenario	Precipitation			Temperature		
	2020s	2050s	2080s	2020s	2050s	2080s
Winter (December – February)	**+102.0**	**+110.5**	**+75.0**	+2.9	+4.8	+6.1
Spring (March – May)	+95.9	+110.3	+165.0	+1.0	+2.4	+3.6
Summer (June – August)	**-263.4**	**-236.9**	**-241.1**	+1.4	+3.0	+4.3
Fall (September-November)	-21.3	+29.5	+21.8	+2.3	+3.9	+5.3
Annual	**-86.8**	**+13.4**	**+20.7**	**+1.9**	**+3.5**	**+4.8**

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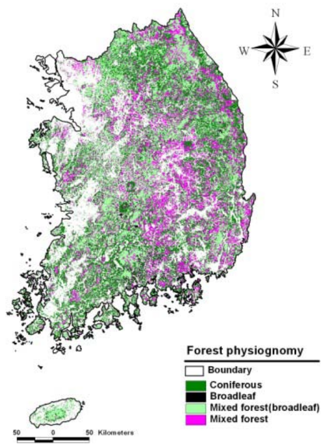
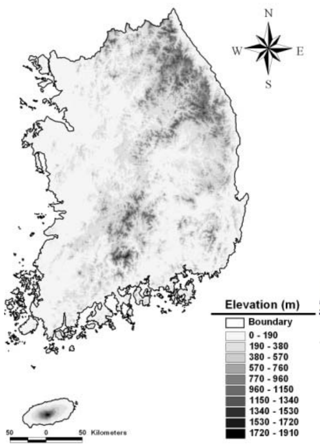
The Future forest distribution data

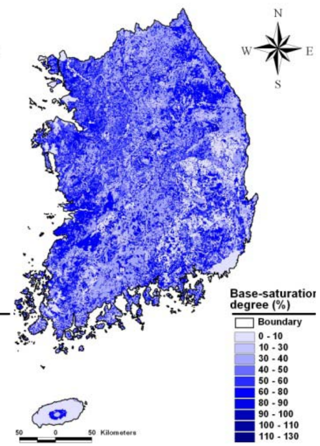
Data for multinomial logit modeling



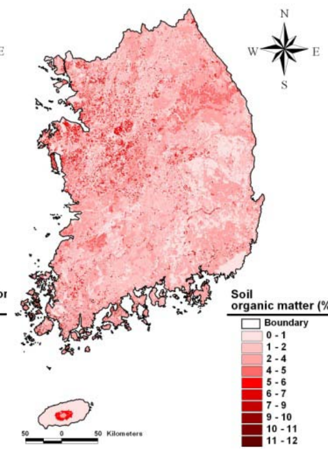
Forest community



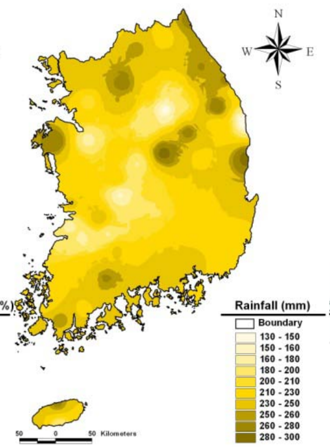
DEM



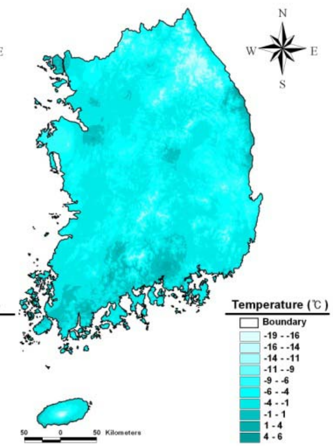
Degree of base saturation



Soil organic matter



Summer P



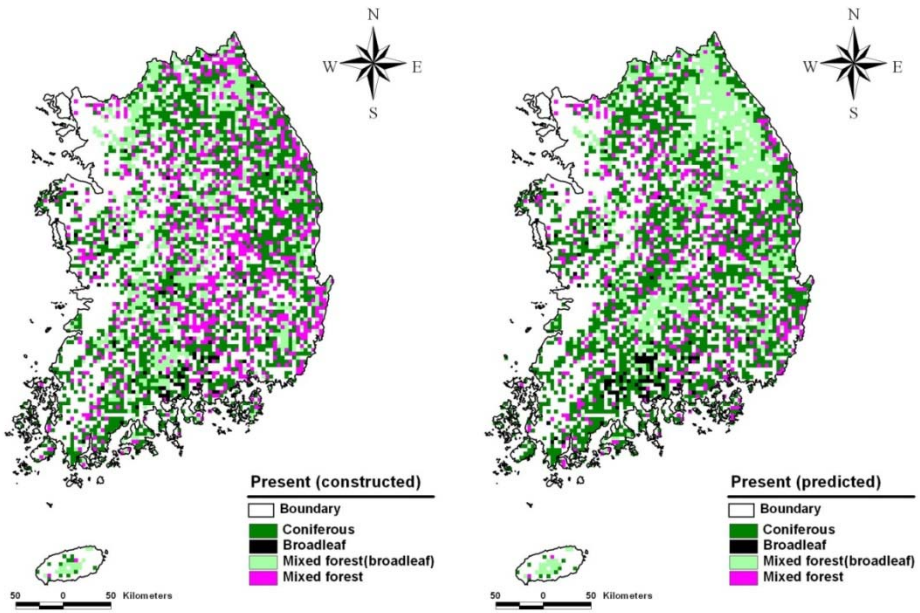
Coldest month T

The correlation coefficient between present forest community and environmental variables

Environmental variables	R^2	Environmental variables	R^2
DEM	*0.62*	*Coldest month temperature*	*- 0.69*
Warmest month temperature	- 0.58	Spring mean temperature	- 0.53
Summer mean temperature	- 0.54	Autumn mean temperature	- 0.54
Winter mean temperature	- 0.44	Yearly mean temperature	- 0.50
Degree of base saturation and soil organic matter	*0.55*	Spring precipitation	0.09
Summer precipitation	*0.38*	Autumn precipitation	0.08
Winter precipitation	0.01	Average annual precipitation	0.02

The Future forest distribution data

❖ The derived multinomial logit model of present forest community with environmental variables



❖ *Comparison of the forest area between present and model predicted results*

Forest type	Present (km^2)	Model results (km^2)	Difference
Coniferous	28,048	31,936	3,888 [13.8 %]
Deciduous	1,408	816	-240 [17.0 %]
Mixed (Dominant Deciduous)	13,376	12,676	-1,20 [8.9 %]
Mixed	15,536	4,800	-5,328 [4.3 %]

Forest type	Multinomial logit model					
Coniferous	- 5.8543	- 0.0032 A	- 0.0088 B	+ 0.0066 C	+ 0.0183 D	- 0.1158 E
Deciduous	- 7.6284	- 0.0069 A	+ 0.0728 B	+ 0.0077 C	+ 0.0181 D	+ 0.5555 E
Mixed (Dominant Deciduous)	- 6.7188	- 0.0076 A	+ 0.2214 B	+ 0.0090 C	+ 0.0096 D	- 0.3283 E
Mixed	- 7.0664	- 0.0106 A	+ 0.1545 B	+ 0.0073 C	+ 0.0194 D	- 0.1894 E

A: Degree of base saturation, B: Soil organic matter, C: DEM, D: Summer precipitation, E: The coldest month temperature

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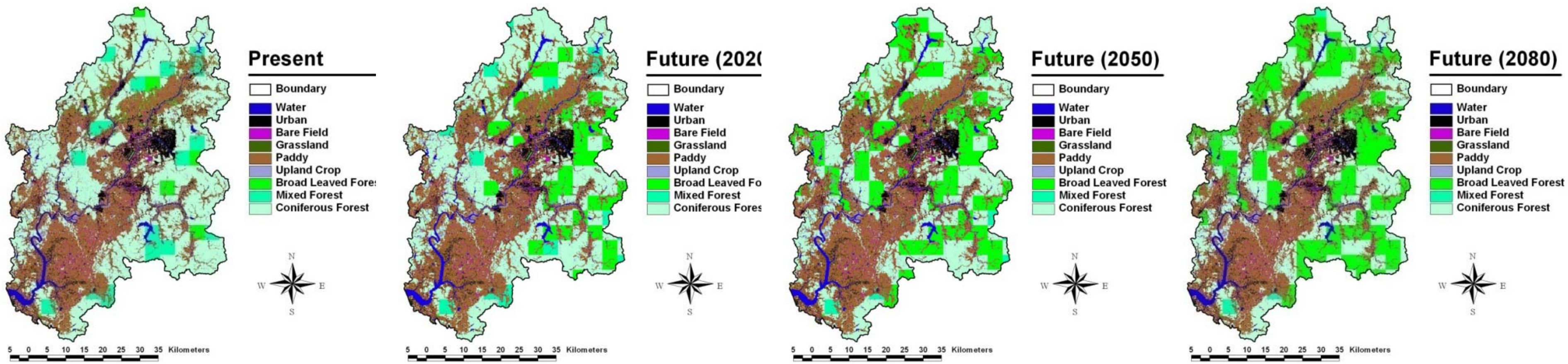
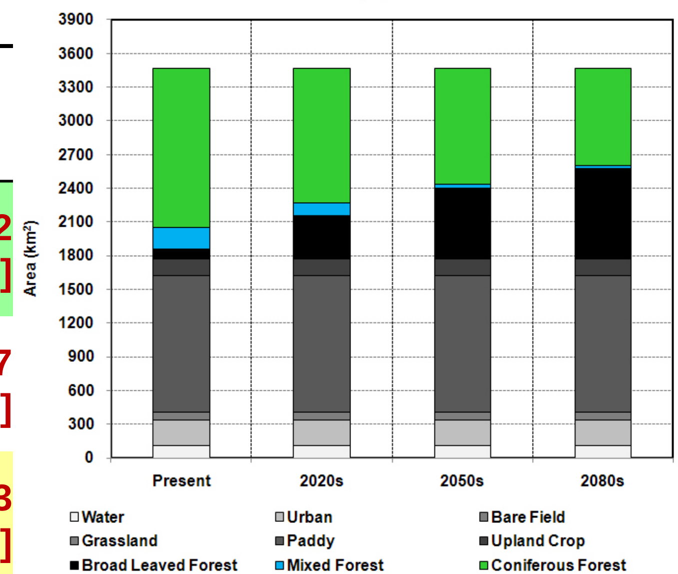
The Future forest distribution data

- ***The land uses of the study watershed considering predicted forest community by the multinomial logit model; (a) present, (b) 2020s, (c) 2050s, and (d) 2080s***

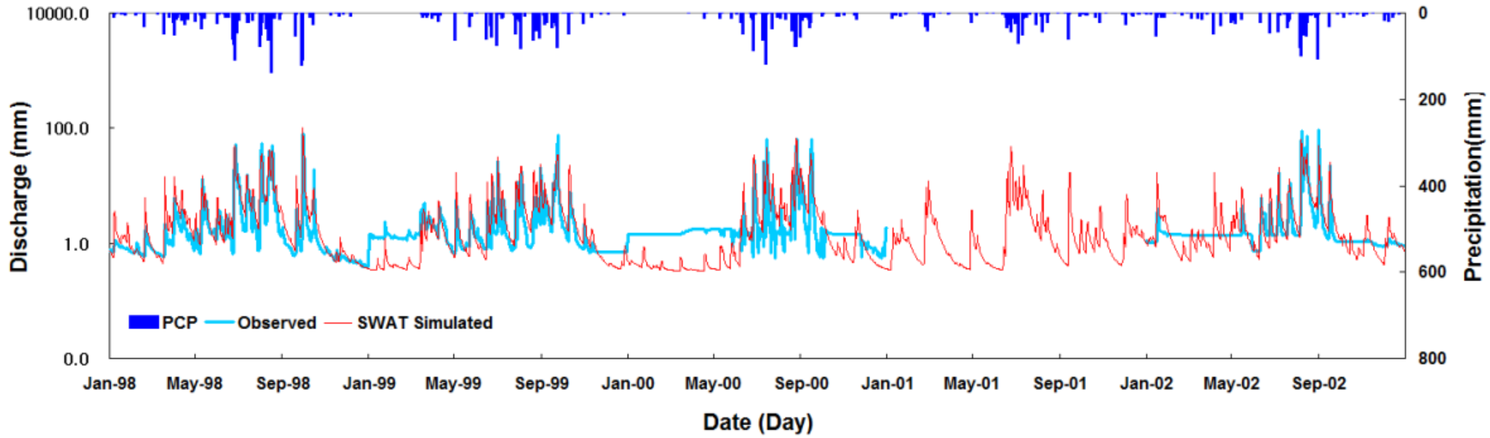


Forest type	Present (km^2)	2020s (km^2)	2050s (km^2)	2080s (km^2)
Deciduous	*85.0*	380.2 [+ 295.2]	632.7 [+ 547.7]	800.2 [+ 715.2]
Mixed	*194.8*	119.6 [- 75.2]	33.0 [- 161.8]	27.7 [- 167.1]
Coniferous	*1,413.4*	1,193.4 [- 220.0]	1,027.4 [- 386.0]	865.3 [- 548.1]

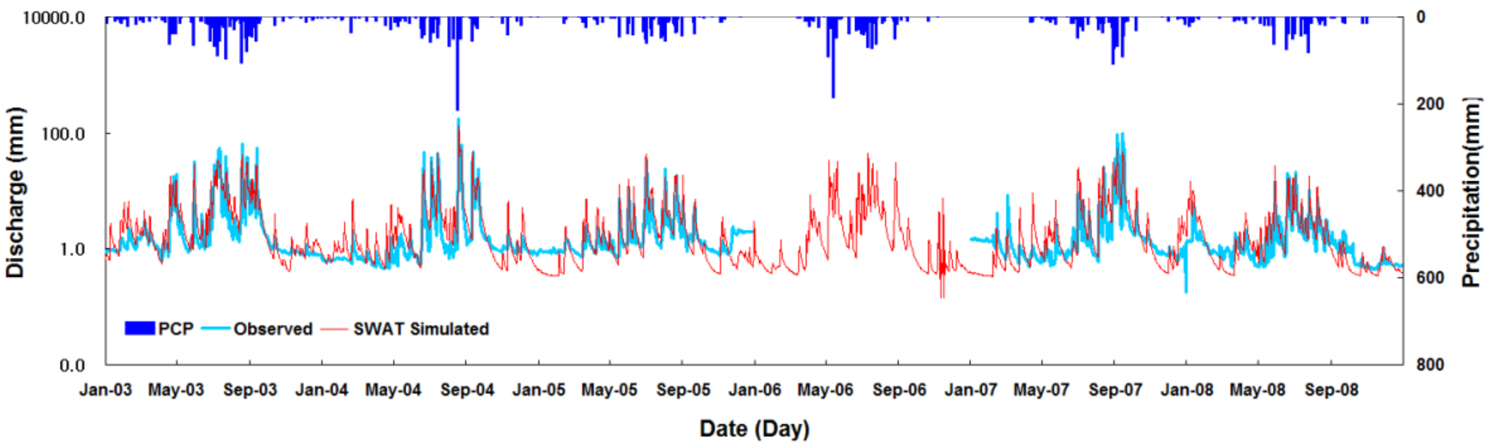


Model Calibration and Validation for the Study Watershed

Calibration period (1998-2002 excluding 2001)



Validation period (2003-2008 excluding 2006)



Year	RMSE (mm/day)	RMAE (mm/day)	R^2	ME
Calibration	4.19	0.87	0.64	0.62
Validation	3.96	0.62	0.75	0.62

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The evaluation of future climate change impact on watershed hydrology considering the change of future forest vegetation cover

Period	T (℃)	P (mm)	Forest cover unchanged				Considering future forest cover change			
			Q (mm) [V (%)]	QR (%)	ET (mm) [V (%)]	GW (mm)	Q (mm) [V (%)]	QR (%)	ET (mm) [V (%)]	GW (mm)
2005 [Baseline]										
Winter	-3.3	126.3	59.1	46.8	2.3	25.2	59.1	46.8	2.3	25.2
Spring	9.7	211.1	123.4	58.5	126.5	42.3	123.4	58.5	126.5	42.3
Summer	23.0	813.7	523.5	64.3	240.2	141.2	523.5	64.3	240.2	141.2
Fall	11.2	198.1	122.0	61.6	105.4	21.8	122.0	61.6	105.4	21.8
Annual	10.2	1349.2	**828.0**	**61.4**	**474.4**	**230.5**	**828.0**	**61.4**	**474.4**	**230.5**
A1B scenario – 2020s										
Winter	-0.3	228.2	147.5[149]	64.6	22.8[891]	68.2	147.1 [149]	64.4	22.8[891]	68.4
Spring	10.6	307.0	196.0 [58]	63.9	125.6 [-1]	65.9	200.2[62]	65.2	125.5[-1]	66.6
Summer	24.4	550.3	301.4[-42]	54.8	229.8 [-4]	87.4	299.3[-43]	54.4	229.0[-5]	87.0
Fall	13.5	176.9	92.3[-24]	52.2	113.2 [7]	15.4	92.1[-25]	52.1	112.4[7]	15.4
Annual	12.1	1262.4	**737.2[-11]**	**58.4**	**491.4[4]**	**236.9**	**738.6[-11]**	**58.5**	**489.7[3]**	**237.5**
A1B scenario – 2050s										
Winter	1.6	236.8	155.9[164]	65.8	32.2[1300]	72.0	155.8[164]	65.8	32.1 [1296]	72.5
Spring	12.1	321.3	179.4 [45]	55.8	148.7[18]	55.9	187.6[52]	58.4	148.4[17]	56.0
Summer	26.0	576.9	330.1[-37]	57.2	236.4[-2]	91.5	324.4[-38]	56.2	234.8[-2]	90.7
Fall	15.1	227.6	123.2 [1]	54.1	123.5[17]	22.9	123.5[1]	54.3	122.4[16]	23.3
Annual	13.7	1362.6	**788.6 [-5]**	**57.9**	**540.8[14]**	**242.3**	**791.3[-4]**	**58.1**	**537.8[13]**	**242.5**
A1B scenario – 2080s										
Winter	2.8	201.3	114.4 [94]	56.8	36.9[1504]	53.1	114.3[93]	56.8	36.9[1504]	53.6
Spring	13.3	376.1	211.6 [71]	56.3	158.0[25]	62.3	224.9[82]	59.8	157.5[25]	62.2
Summer	27.3	572.7	332.1[-37]	58.0	241.9[1]	90.1	322.6[-38]	56.3	238.6[-1]	88.3
Fall	16.5	219.9	114.3 [-6]	52.0	127.7 [21]	19.2	114.8[-6]	52.2	127.1[21]	19.7
Annual	15.0	1369.9	**772.3 [-7]**	**56.4**	**564.6[19]**	**224.7**	**776.7[-6]**	**56.7**	**560.0[18]**	**223.8**

Q: Streamflow, QR: Runoff ratio (Q/P), V: Variation, ET: Evapotranspiration, GW: Groundwater recharge, Winter: December – February, Spring: March – May, Summer: June – August, Fall: September-November

Summary and Conclusions

- This study tried to evaluate the future watershed hydrology under MIROC3.2 A1B climate change scenario.
- In this study, the multinomial logit model was adopted to predict the future vegetation cover.
- With the 5 selected environmental variables through the correlation analysis with the present forest distribution, the model of each forest cover was derived.
- The future change of + 4.1 ℃ temperature in 2080s predicted 715.2 km^2 increase of deciduous forest, 548.1 km^2 decrease of coniferous forest respectively.
- By applying the climate change and forest community scenario, the future watershed evaportanspiration of 2080s showed 85.7 mm/yr changes based on the 2005 evaportanspiration of 474.4 mm/yr.
- The impact of forest vegetation cover change was 1 % for the watershed evapotranspiration.
- In addition to the climate-vegetation dynamics, the vegetation-soil dynamics are necessary to understand and some factors to incorporate in the hydrologic model for the climate change study.

Thank you

This research was supported by a grant (code # 1-9-3) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program and by a grant from Construction Technology Innovation Program (CTIP) funded by Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korean government.

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