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International Water Resources Association (IWRA)

Assessment of Future Climate Change Impact on Groundwater Level using SWAT-MODFLOW in Geum River Basin of South Korea

International Water Resources Association
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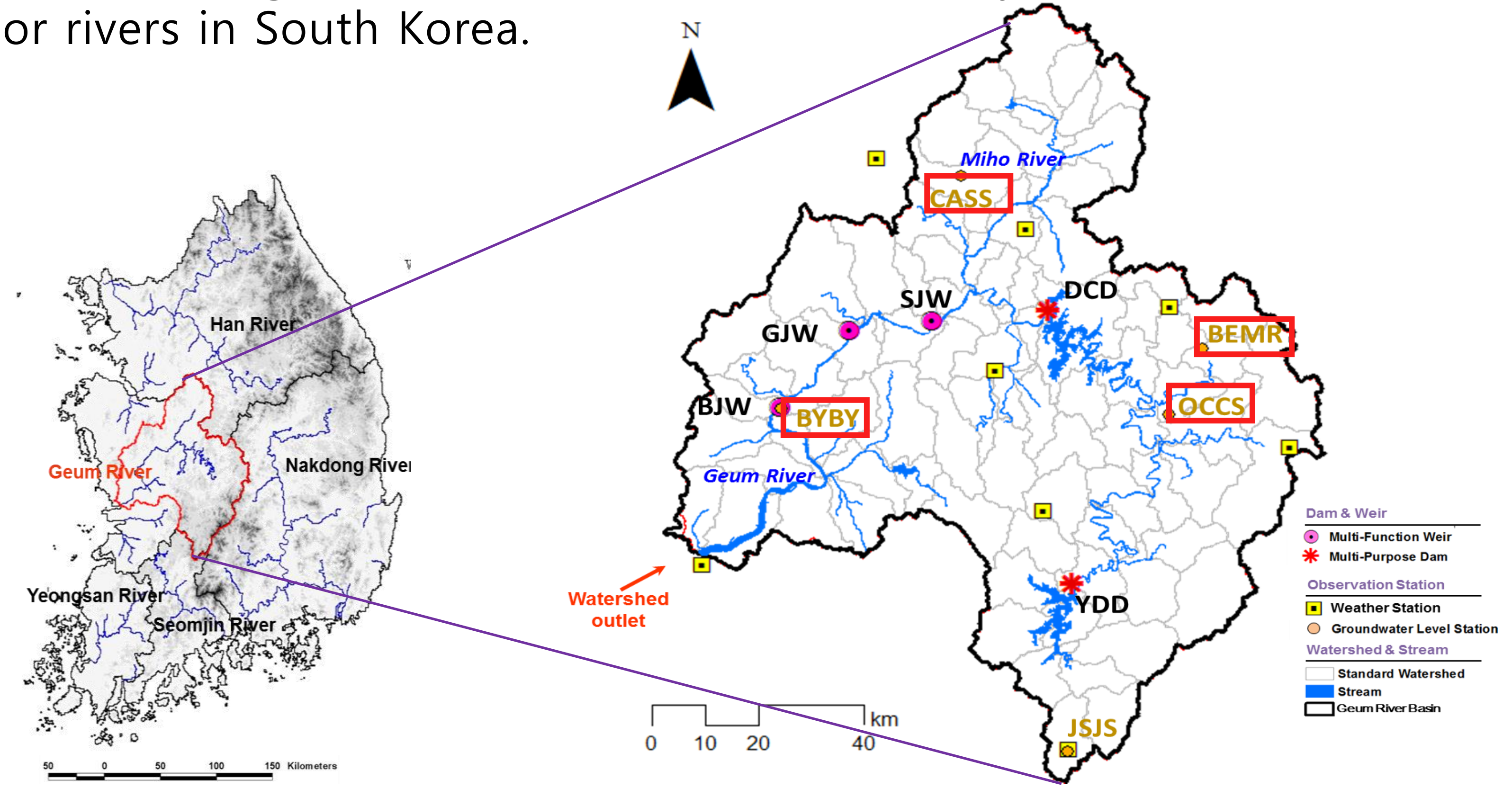
Purpose of this Study

- The annual groundwater use in South Korea is about 3.7 billion tons, which is about 10% of total water use and 35% of total developable groundwater resources. The groundwater use in Geum river basin (9,645.5 km^2) has been increased 11.6% even from 2005 to 2015.
- Nationally, The GWL are expected to decline by 0.58 m over the next 20 years. Attempts to quantify these groundwater changes have been continuously tried from the past.
- According to the IPCC 4th report (2007), changes in available water resources were selected as the weakest part due to future climate change. And The 5th IPCC Report (2014) especially recommends in Asia to regional coping strategies, diversification of water resources such as water recycling, and integrated water resource management.
- The purpose of this study is to conduct quantitative analysis of groundwater in Geum river basin using SWAT-MODFLOW(QSWATMOD).
- Additionally, for the efficient management of water resources according to climate change, a climate change scenario was used to estimate the hydrology and water quality of the watershed in future

Study Area

Geum river basin

- The total area of Geum river basin consist of 60% forest, 26% paddy and filed, 3~5% urban and bare field
- Average precipitation is 1221.8 mm and runoff is 838.5 mm (68.6%)
- The amount of groundwater used is 1808.3m^3/day/km^2, which is the second largest among the five major rivers in South Korea.



BYBY:	**alluvium** **Mixed forest, wetland**
CASS:	**alluvium** **Mixed forest, wetland**
BEMR:	**alluvium** **Deciduous forest, Field**
OCCS:	**alluvium** **Coniferous, Paddy**

Flow Chart

Model Input

Meteorological Data
- *Daily weather data (1984-2015)*
  - ✓*Precipitation (mm/day)*
  - ✓*Temperature (ºC)*
  - ✓*Wind speed (m/s)*
  - ✓*Solar radiation (MJ/m²)*
  - ✓*Relative humidity (%)*

GIS Data
- *Watershed boundary*
- *Digital Elevation Model (30m)*
- *Soil map (1:25000)*
- *Land Use Map*

Monitoring Data
- *Daily Streamflow data (1998-2015)*
- *Daily Groundwater Table (1998-2015)*

Climate change Scenario
- *Historical (HadGEM2-ES, INM-CM4)*
- *HadGEM2-ES (RCP 8.5 Wet scenario)*
- *INM-CM4 (RCP 8.5 Dry scenario)*

Model Calibration Process

SWAT Model
- *Model run (1998-2018)*
- *Warm-up (1998-2005)*
- *Calibration (2005-2009) and validation (2010-2015)*
  - ○*Daily Streamflow variation*
  - ○*Groundwater level variation*

QSWAT MODFLOW Apply

QSWAT MODFLOW
- *Apply MODFLOW with calibrated SWAT files*
  - *Specific Yield(Sy)*
  - *Specific storage(Ss)(1/m)*
  - *Soil Thickness(m)*
  - *Hydraulic Conductivity(K)(m/day)*
- *Groundwater Behavior Evaluation through Linked Model*
- *Geum river basin Groundwater Level & Behavior Evaluation*

Future Geum River Basin Groundwater Behavior Evaluation

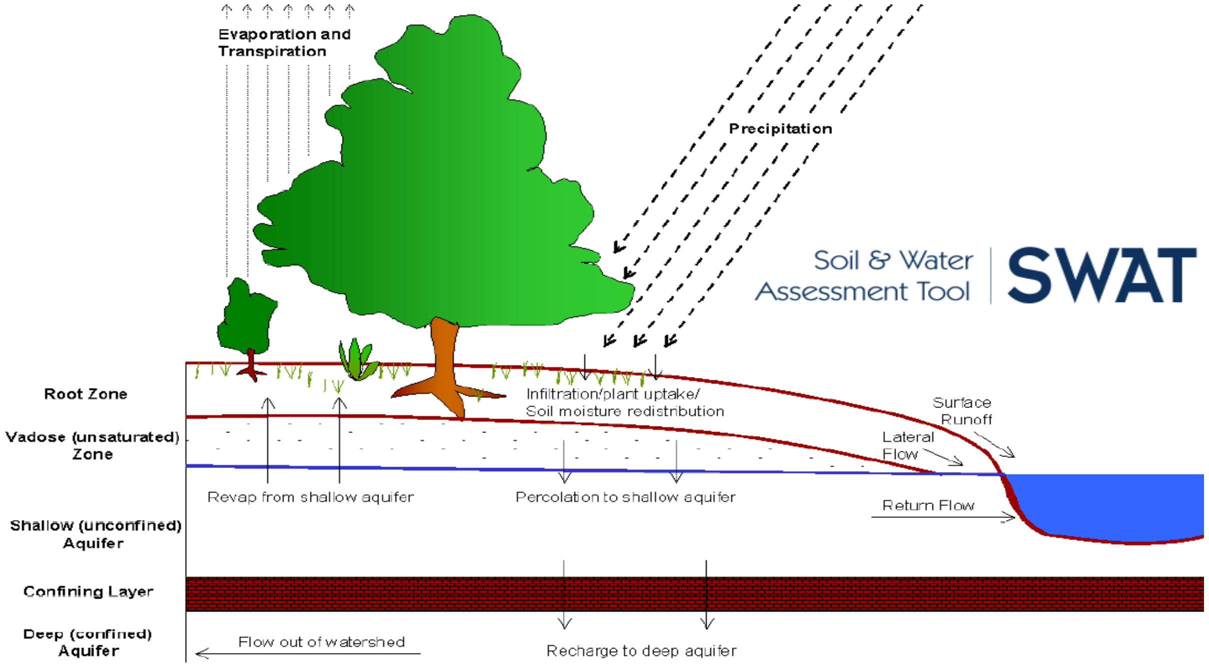
Material and Method

QSWATMOD, SWAT

- The SWAT model developed by the USDA is semi-distributed continuous long-term rainfall-runoff model based on Hydrologic Response Units (HRUs). The model considers all the effects of weather, evapotranspiration, growth of plants, and ground water.

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

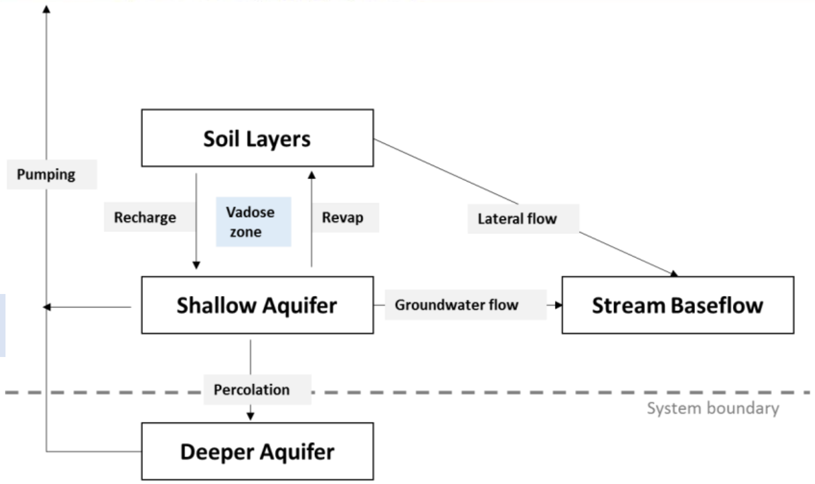
SW_t = Final soil water content (mm)
SW_0 = Initial soil water content on day i (mm)
R_{day} = Amount of precipitation on day i (mm)
Q_{surf} = Amount of surface runoff on day i (mm)
E_a = Amount of evapotranspiration on day i (mm)
W_{seep} = Amount of water entering the vadose zone from the soil profile on day i (mm)
Q_{gw} = Amount of return flow on day i (mm)



Material and Method

QSWATMOD, SWAT

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



Shallow aquifer

$$aq_{sh,i} = aq_{sh,i-1} + w_{rchrg,sh} - Q_{gw} - W_{revap} - W_{pump,sh}$$

$aq_{sh,i}$ = Amount of water stored in the shallow aquifer on day i (mm H_2O)
$aq_{sh,i-1}$ = Amount of water stored in the shallow aquifer on day i-1 (mm H_2O)
$W_{rchrg,sh}$ = Amount of recharge entering the shallow aquifer on day i (mm H_2O)
Q_{gw} = Groundwater flow or base flow into the main channel on day i (mm H_2O)
W_{revap} = Amount of water moving into the soil zone in response to water deficiencies on day i (mm H_2O)
W_{pump} = Amount of water removed from the shallow aquifer by pumping on day i (mm H_2O)

Groundwater flow / base flow

Q_{gw} = Groundwater flow or base flow into the main channel on day i (mm H_2O)
K_{sat} = hydraulic conductivity of the aquifer (mm/day)
L_{gw} = Distance from the ridge or sub-basin divide for the groundwater system to the main channel (m)
h_{wtbl} =water table height (m)

$$Q_{gw} = \frac{8000 \cdot K_{sat}}{L_{gw}^{2}} h_{wtbl}$$

> SWAT does not output groundwater level as a result

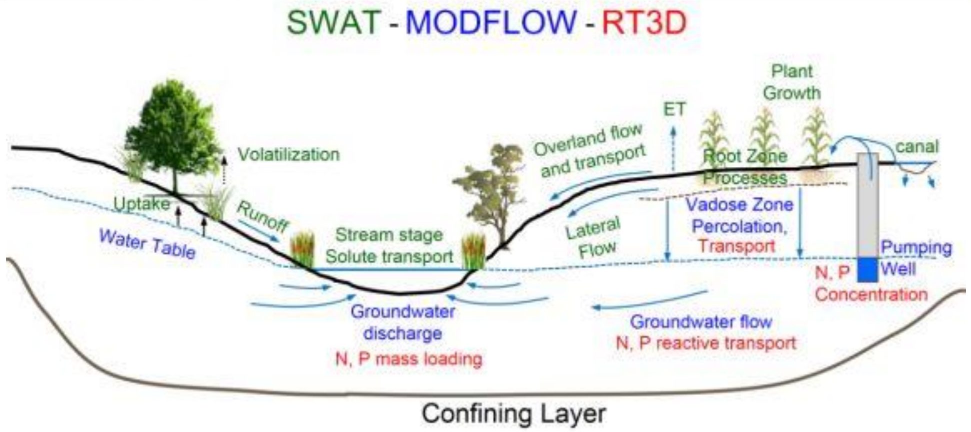
Extract HRU values at the point where groundwater observation is installed

- SA_ST – GWQMN = Ground water variation
- Observation average + (SA_ST – GWQMN) = Groundwater level

SA_ST: shallow aquifer storage (mm)
GWQMN: threshold water level in shallow aquifer for base flow (mm)

Material and Method

QSWATMOD



SWAT

Difficult to consider the distribution parameters of Groundwater and , spatial volatility of the groundwater level

With MODFLOW(3D groundwater distribution model)

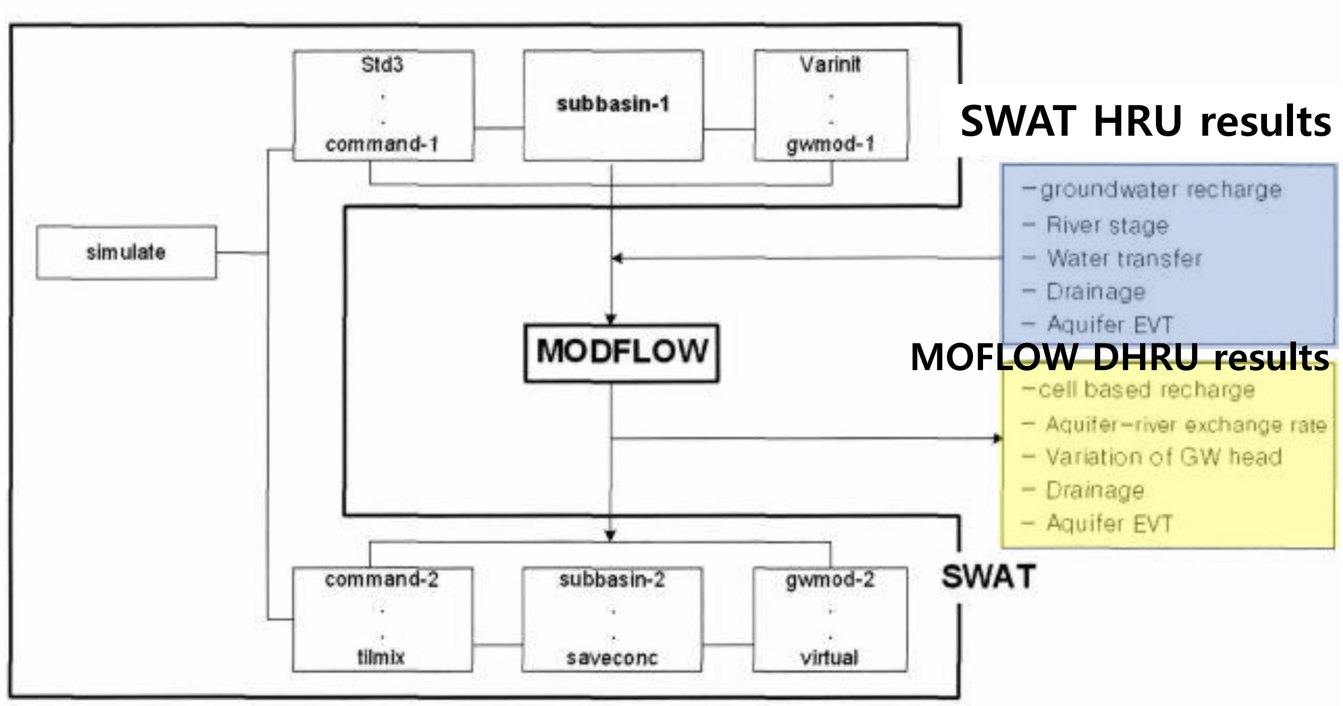
Cell based groundwater flow model with Tank Model, Complement the swat groundwater simulation and, also MODFLOW results more accurate with SWAT groundwater recharge

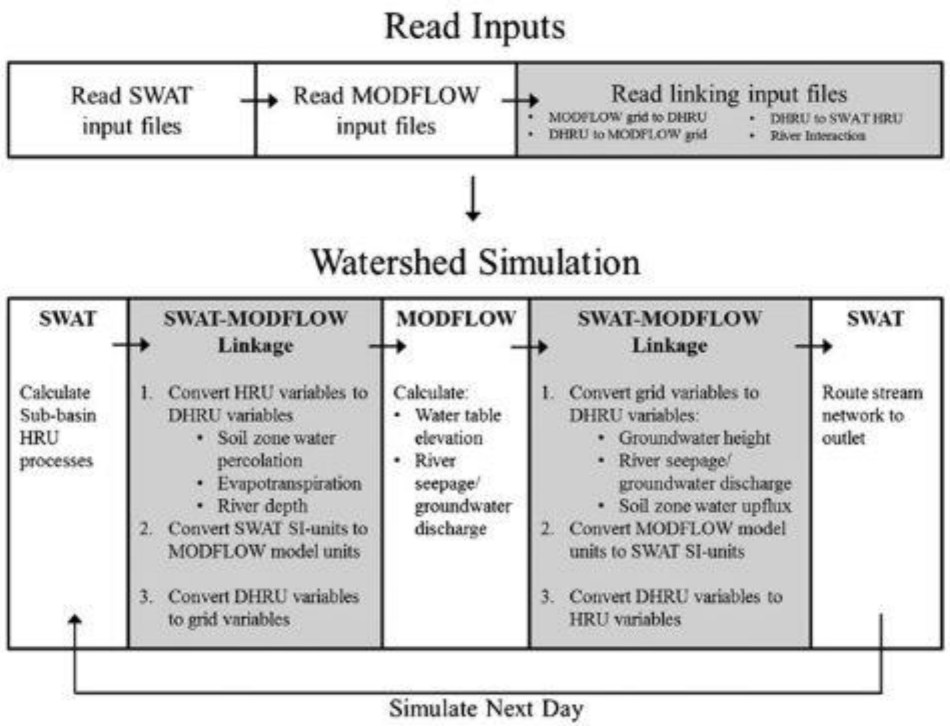
QSWATMOD

The model that link the above two models using QGIS, and that makes it easy to build input data and organize results.

Material and Method

QSWATMOD

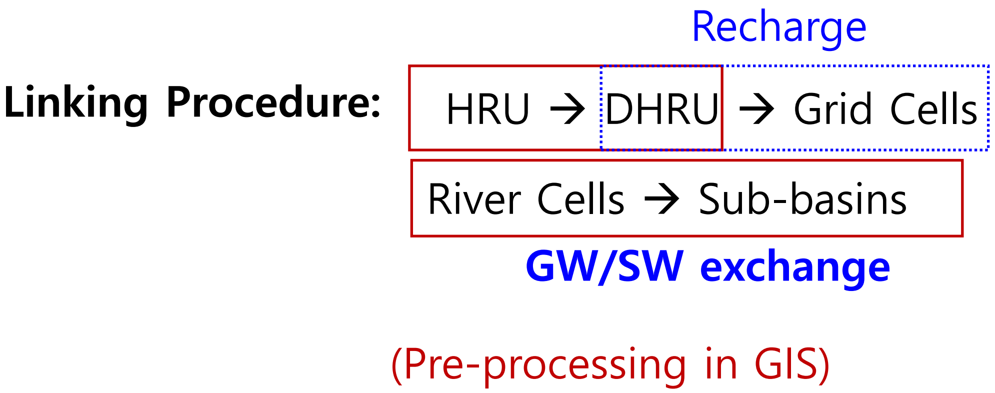


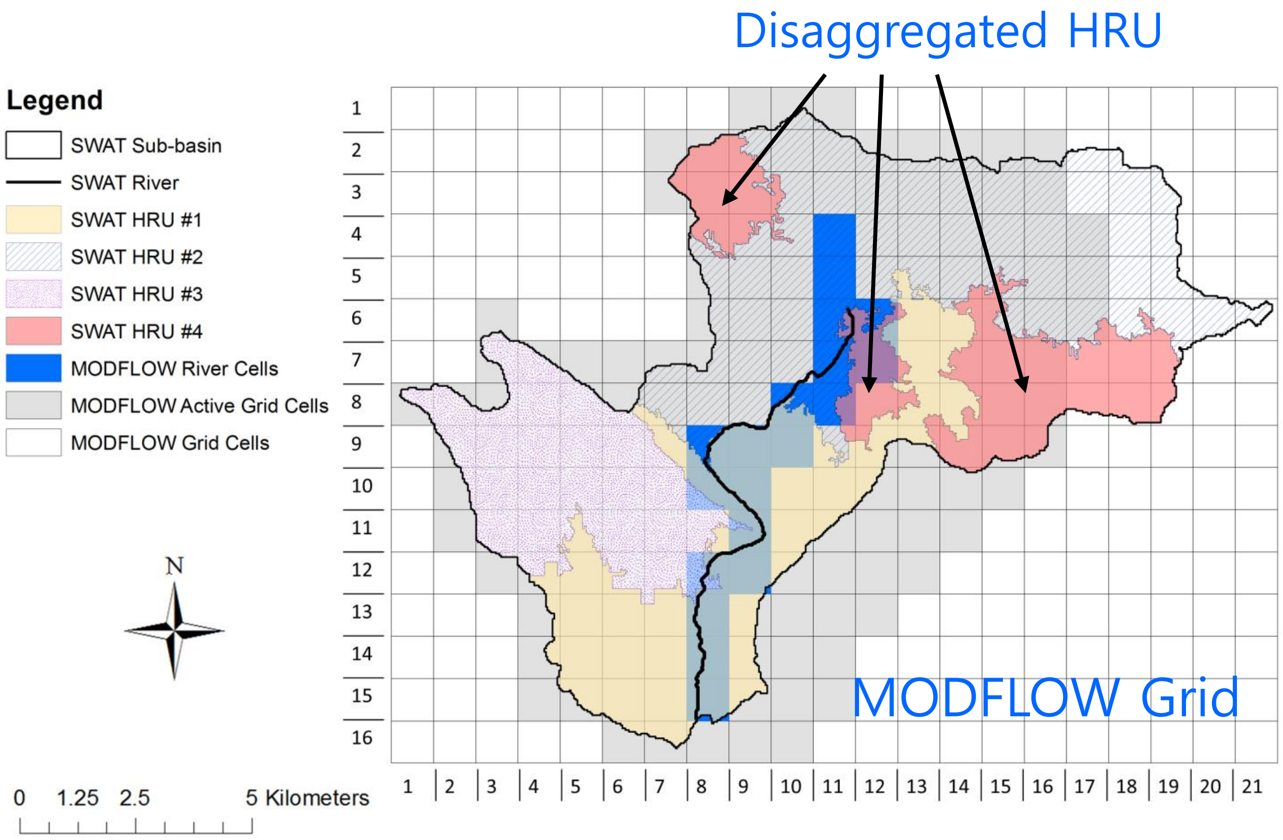


Material and Method

QSWATMOD

- Convert HRU from SWAT to DHRU (MODFLOW Linkage)
- MODFLOW Linkage process (DHRU) is created through combination with distribution parameters for Groundwater and HRU, same as HRU generation.

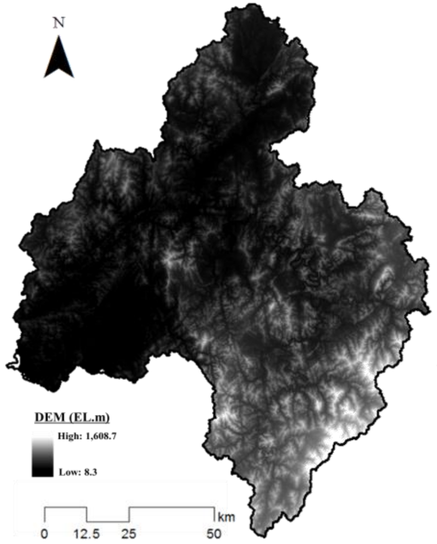




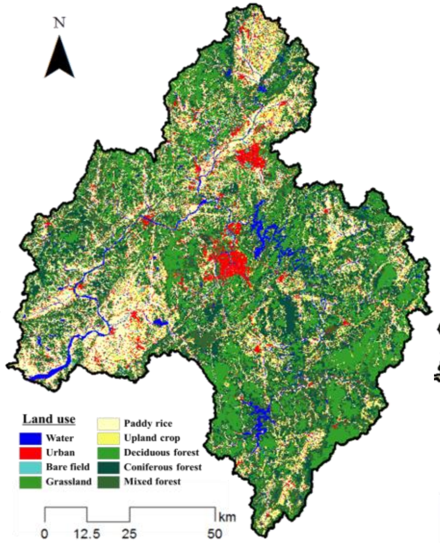
Model Apply (Calibration and Validation)

Input data (SWAT and MODFLOW)

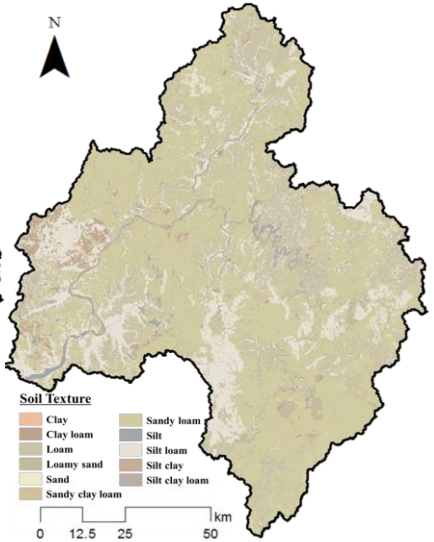
(a) DEM
Elevation : 8 – 1,608 m
(30m grid size)



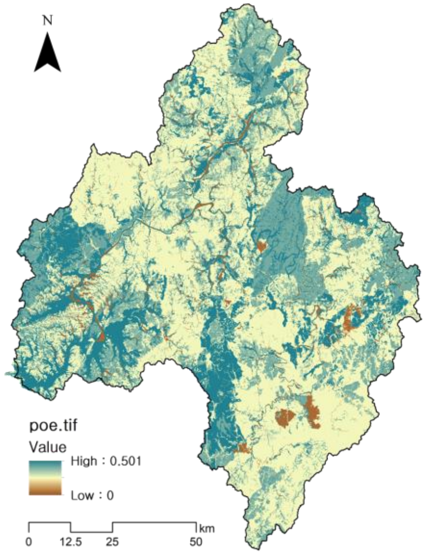
(b) Land cover
Land cover (2015) :
Forest (62%)
Paddy rice (15%)



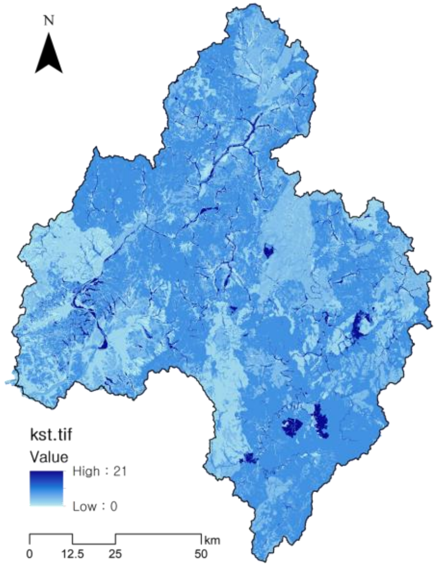
(c) soil
Soil :
Loam (24%)
Sandy Loam (58%)



(d) Specific yield



(e) Hydraulic Conductivity



Model Apply (Calibration and Validation)

SWAT Calibration

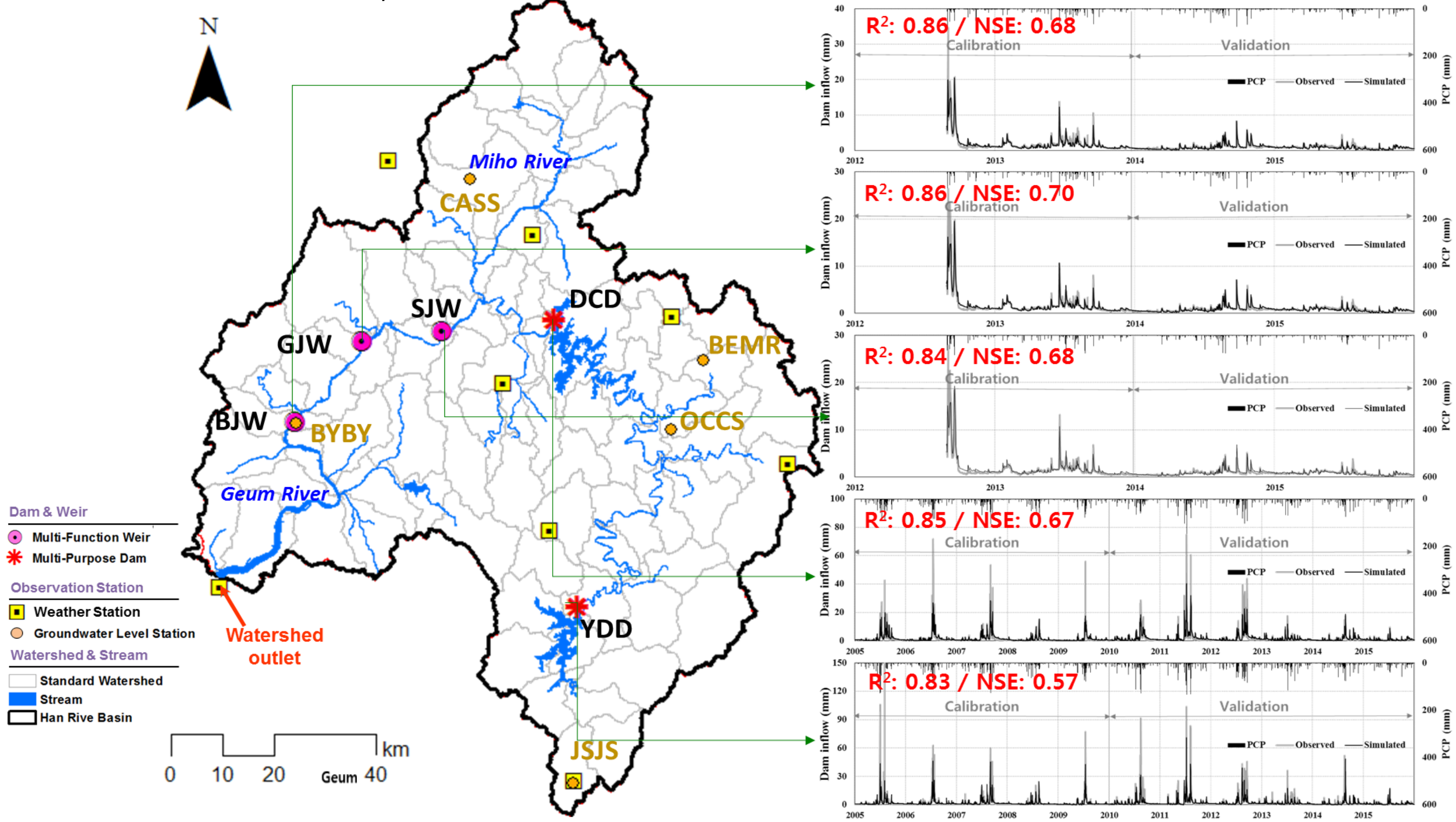
The SWAT model calibration period was set to 5 years (2005-2009) and the verification period was set to 6 years (2010-2015). But in case of SJW, GJW, BJW, since they were operated from August 2012, 2013yr as the calibration period and 2014~2015yr as the verification period were used.

Parameters	Definition	Range	Adjusted Value				
			YDD	DCD	SJW	GJW	BJW
Surface runoff							
CH_N(2)	Manning's "n" value for the tributary channel	0.01 to 30	0.16	0.01	0.014	0.014	0.014
Evapotranspiration							
ESCO	Soil evaporation compensation coefficient	0 to 1	0.95	0.95	0.95	0.95	0.95
Groundwater							
GW_DELAY	Delay time for aquifer recharge (days)	0 to 500	150	50	30	31	31
GWQMN	Threshold water level in shallow aquifer for base flow (mm)	0 to 5000	1,000	1,000	1,000	1,000	1,000
ALPHA_BF	Base flow recession constant	0 to 1	0.2	0.2	0.2	0.2	0.2
REVAPMN	Threshold water level in shallow aquifer for revap (mm)	0 to 1000	750	750	750	750	750
GW_REVAP	Groundwater revap coefficient	0.02 to 0.2	0.02	0.02	0.02	0.02	0.02
Reservoir							
RES_ESA	Reservoir surface area when the reservoir is filled to the emergency spillway (ha)	-	3700	7420	350	350	350
RES_EVOL	Volume of water needed to fill the reservoir to the emergency spillway (104 m3)	-	81500	149000	570	1560	2500
RES_PSA	Reservoir surface area when the reservoir is filled to the principal spillway (ha)	-	3390	6750	300	300	300
RES_PVOL	Volume of water needed to fill the reservoir to the principal spillway (104 m3)	-	74250	124160	565	1554	2471
RES_VOL	Initial reservoir volume(104 m3)	-	39821	76857	546	1550	2471
RES_K	Hydraulic conductivity of the reservoir bottom (mm/hr)	0 to 1	0.3	0.1	0.1	0.1	0.1
EVRSV	Lake evaporation coefficient	0 to 1	0.6	0.1	0.6	0.6	0.6

Model Apply (Calibration and Validation)

SWAT Calibration

- 2 Multi-purpose Dam & 3 Multi-functional weir; Calibration: 5 years (2005 ~ 2009) / Validation: 6 years (2010 ~ 2015)
- The figure and table shows the inflow and storage of five dams and weirs SWAT calibration and validation results.
- In YDD, DCD, SJW, and GJW, inflow and water storage were estimated to be slightly higher than the observation, while BJW was less, which is the influence of SJW and GJW inflow.



※ R^2 :0.83 ~ 0.85
NSE: 0.57 ~ 0.7

Model output	Evaluation criteria	YDD		DCD		SJW	
		Cal.*	Val.	Cal.	Val.	Cal.	Val.
Dam inflow (mm)	R^2	0.67	0.70	0.75	0.71	0.75	0.64
	NSE	0.55	0.58	0.70	0.64	0.69	0.64
	RMSE (mm/day)	1.58	1.74	1.60	1.26	1.18	0.46
	PBIAS (%)	10.48	-0.58	9.77	6.27	7.48	-0.94
Dam storage ($10^6 m^3$)	R2	0.68	0.78	0.65	0.68	0.55	0.70
	NSE	0.79	0.94	0.95	0.93	0.92	0.98
	RMSE (mm/day)	2.19	1.57	2.02	2.10	0.12	0.15
	PBIAS (%)	1.26	8.99	-16.99	-3.86	5.34	1.00

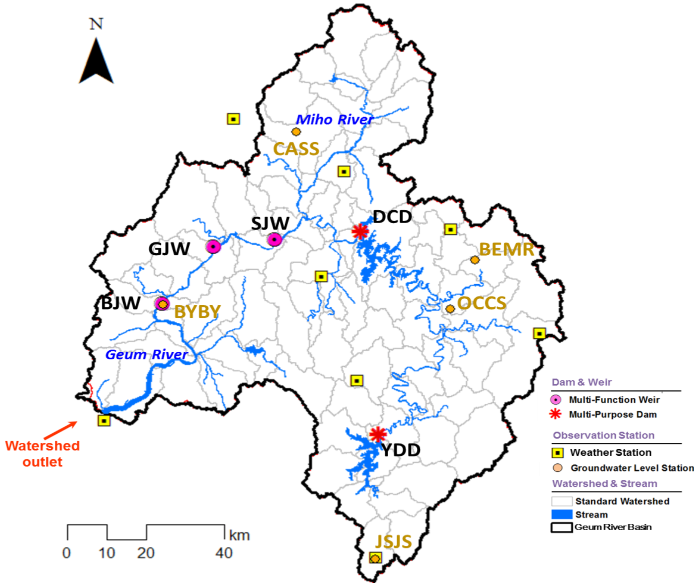
*Cal.: 2005~2009, Val: 2010~2015

Model output	Evaluation criteria	GJW		BJW	
		Cal.	Val.	Cal.	Val.
Dam inflow (mm)	R^2	0.80	0.61	0.81	0.62
	NSE	0.76	0.57	0.77	0.50
	RMSE (mm/day)	0.99	1.08	1.00	1.55
	PBIAS (%)	1.24	-12.53	-2.88	-0.41
Dam storage ($10^6 m^3$)	R2	0.55	0.72	0.57	0.31
	NSE	0.98	0.99	0.99	1.00
	RMSE (mm/day)	0.25	0.28	0.27	0.16
	PBIAS (%)	2.62	-0.93	-0.38	1.83

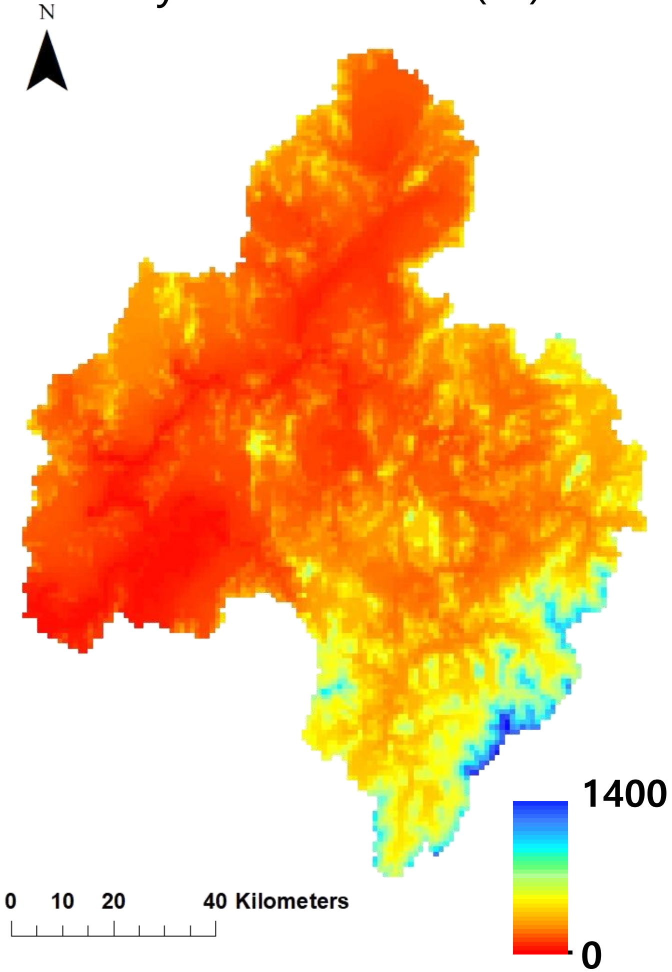
*Cal.: 2005~2009, Val: 2010~2015

Model Apply (Calibration and Validation)

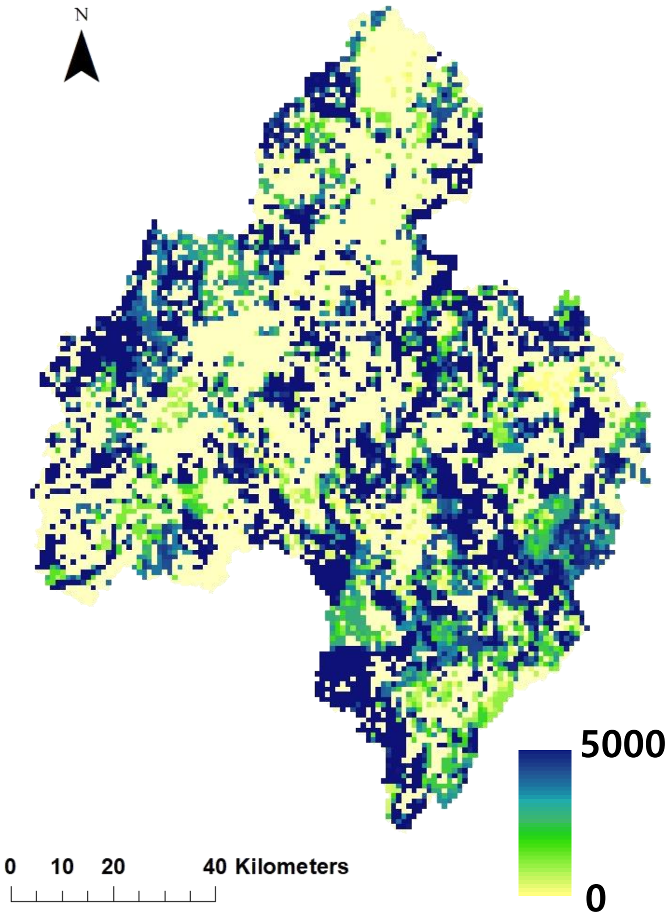
QSWATMOD APPLY



Hydraulic Head (m)

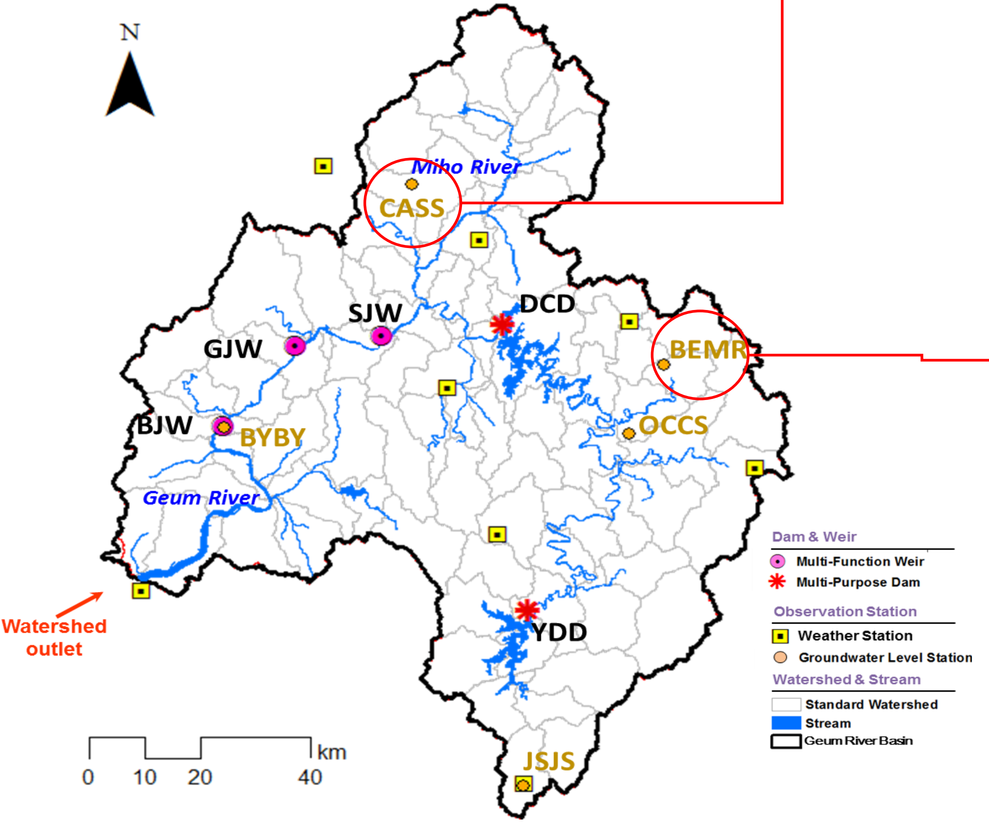


Recharge (m^3/day)

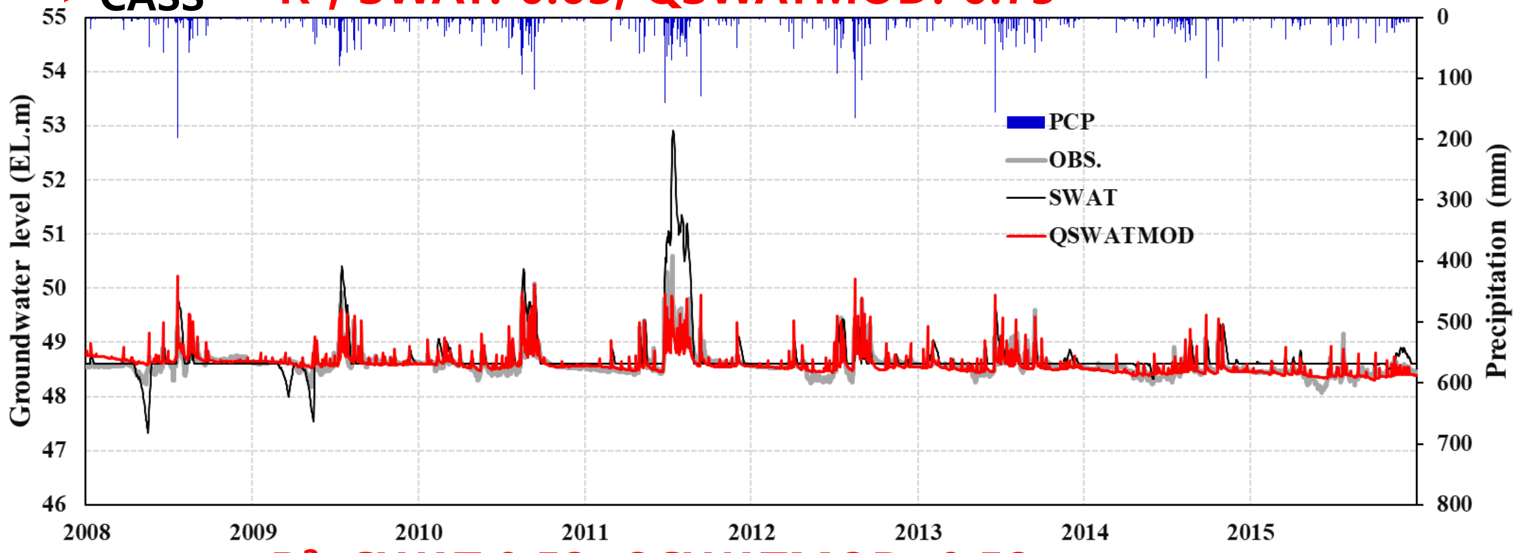


Model Apply (Calibration and Validation)

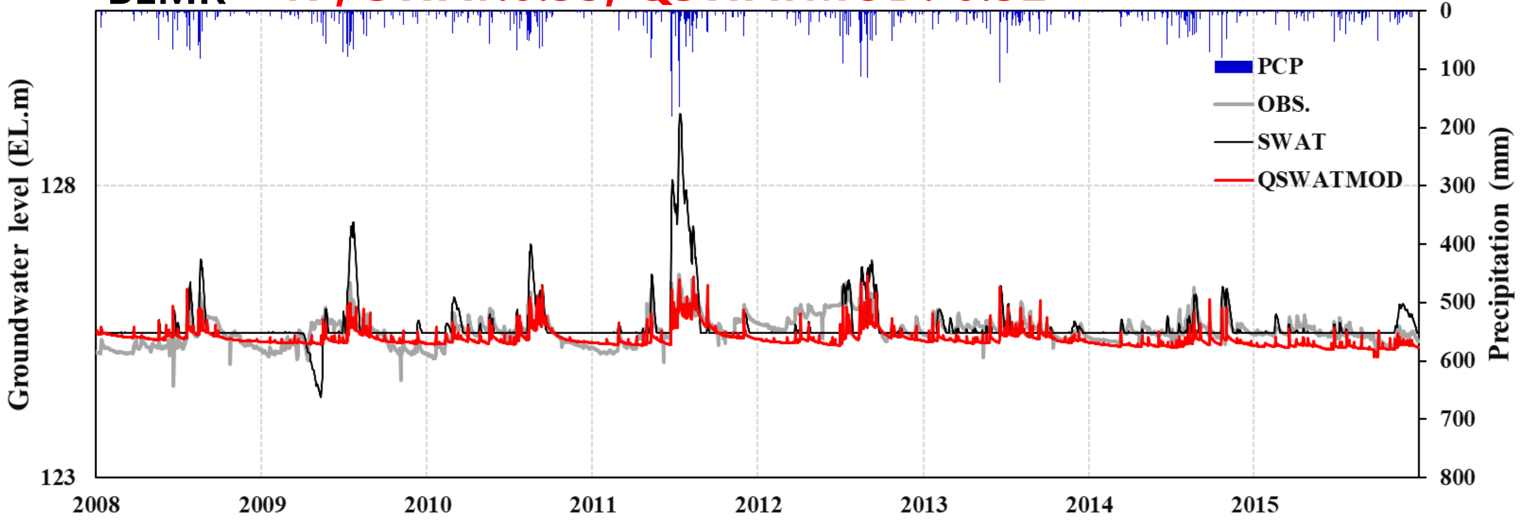
QSWATMOD GWL



CASS R^2; SWAT: 0.63, QSWATMOD: 0.75

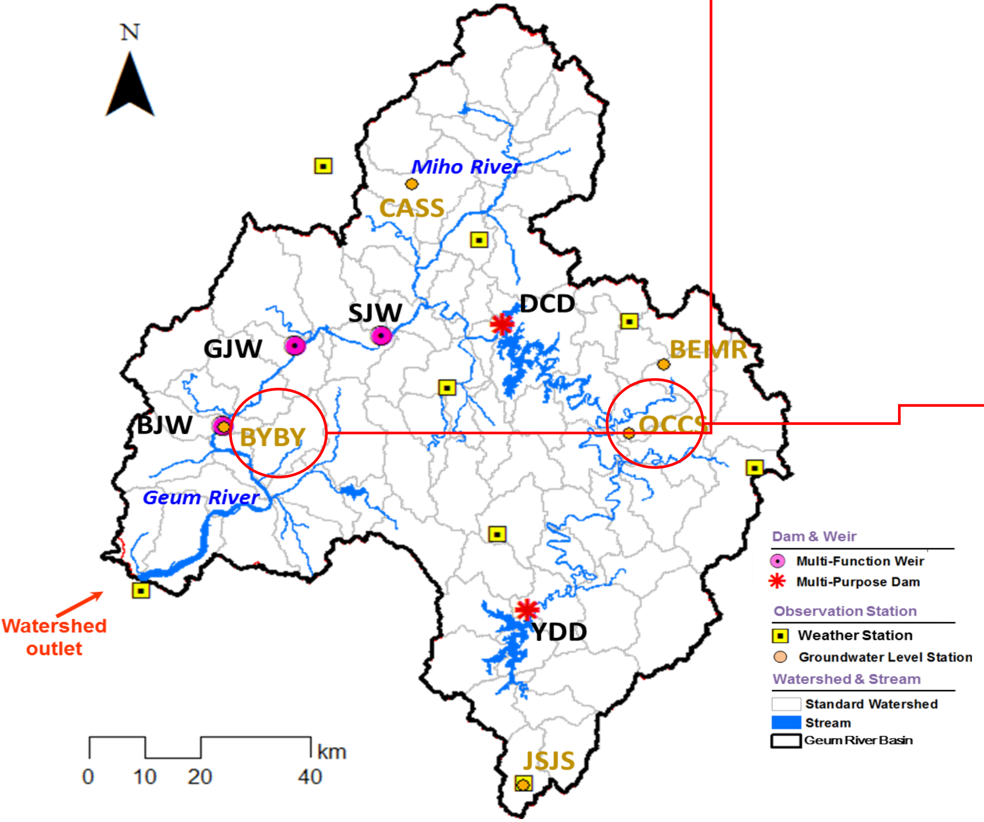


BEMR R^2; SWAT:0.53, QSWATMOD: 0.52

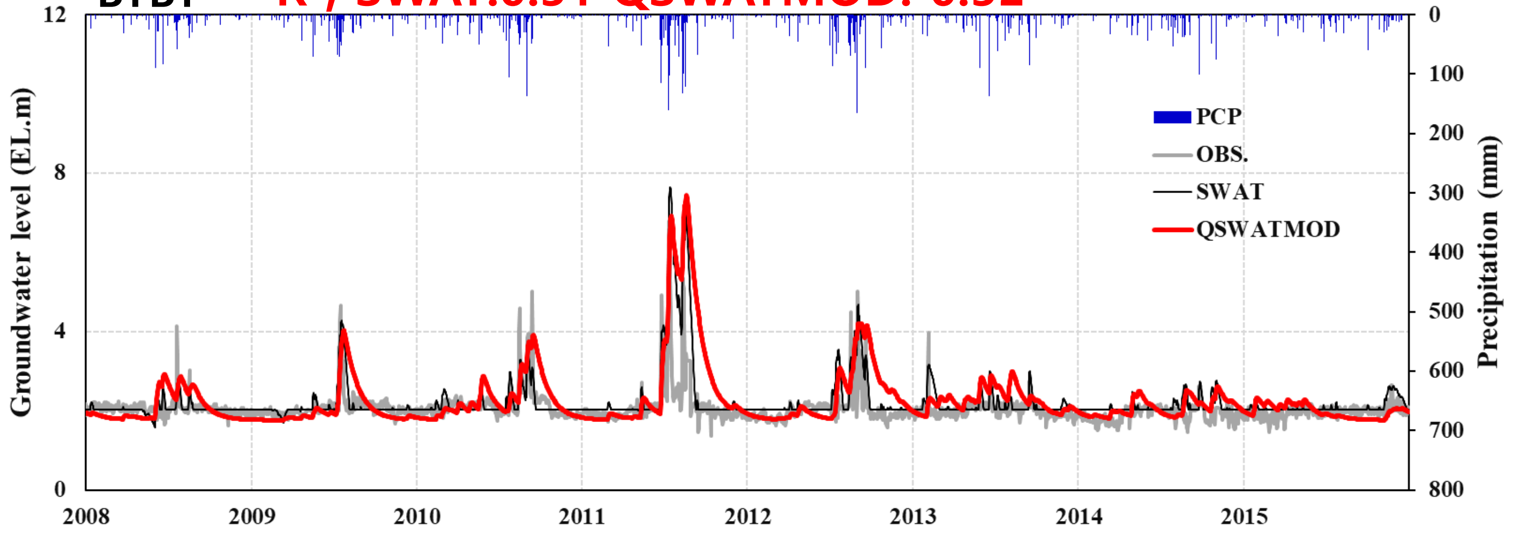


Model Apply (Calibration and Validation)

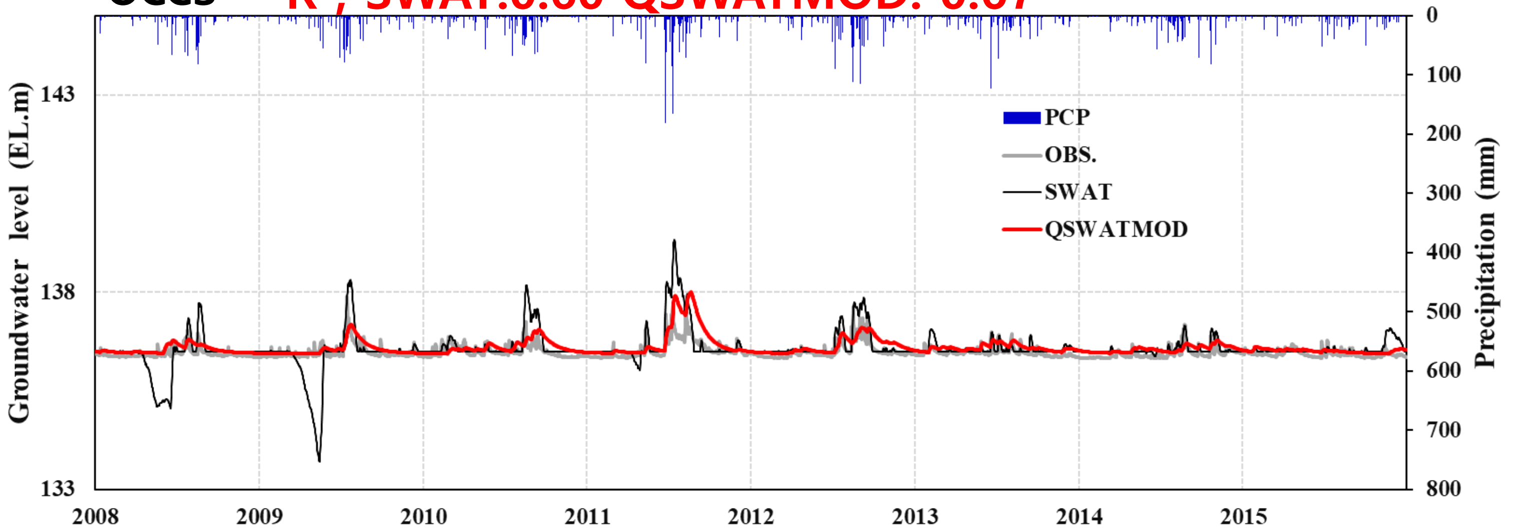
QSWATMOD GWL



BYBY R^2; SWAT:0.51 QSWATMOD: 0.52



OCCS R^2; SWAT:0.60 QSWATMOD: 0.67



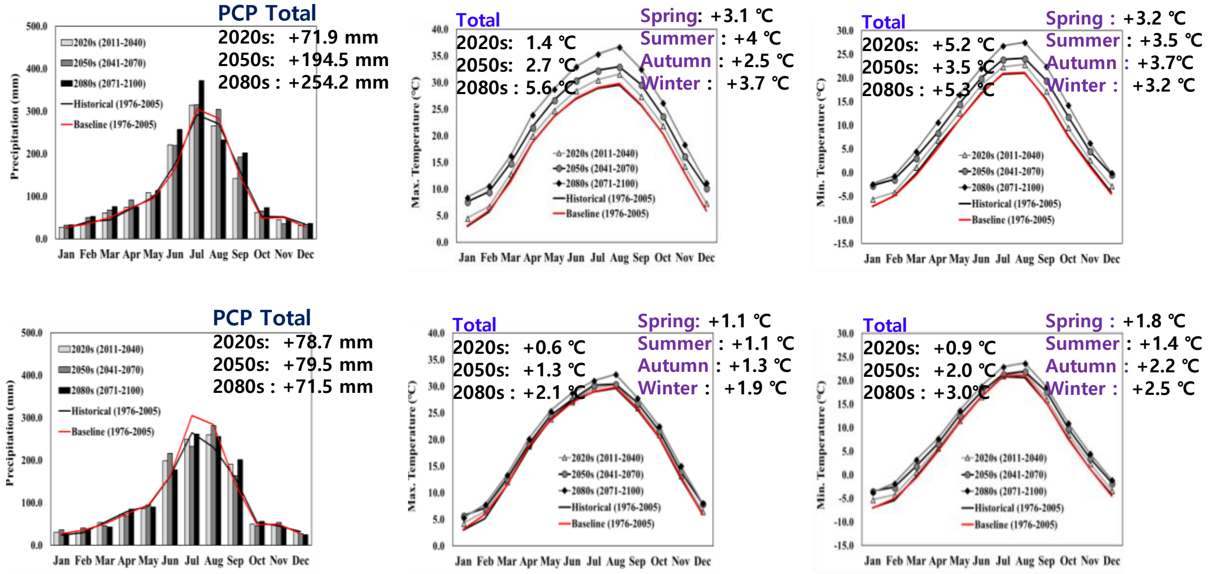
Assessment climate change on GWL

Climate change scenario

- Kim et al., (2018)* evaluated the impact of climate change on the Geum river basin by using climate scenario. To evaluate extreme climate change scneairos, Kim et al. (2018) used the extreme index as called STAtistical and Regional dynamical Down-scailing of Extremes (STARDEX) indices which were developed by STARDEX project. The wet, middle, and dry scenarios of the RCP 8.5 GCMs were selected by the STARDEX indices
- In this study, HadGEM2-ES in Wet scenario and INM-CM4 in Dry scenario were applied to confirm the change in groundwater pattern in the Geum river Basin.

HadGEM2-ES (Wet)

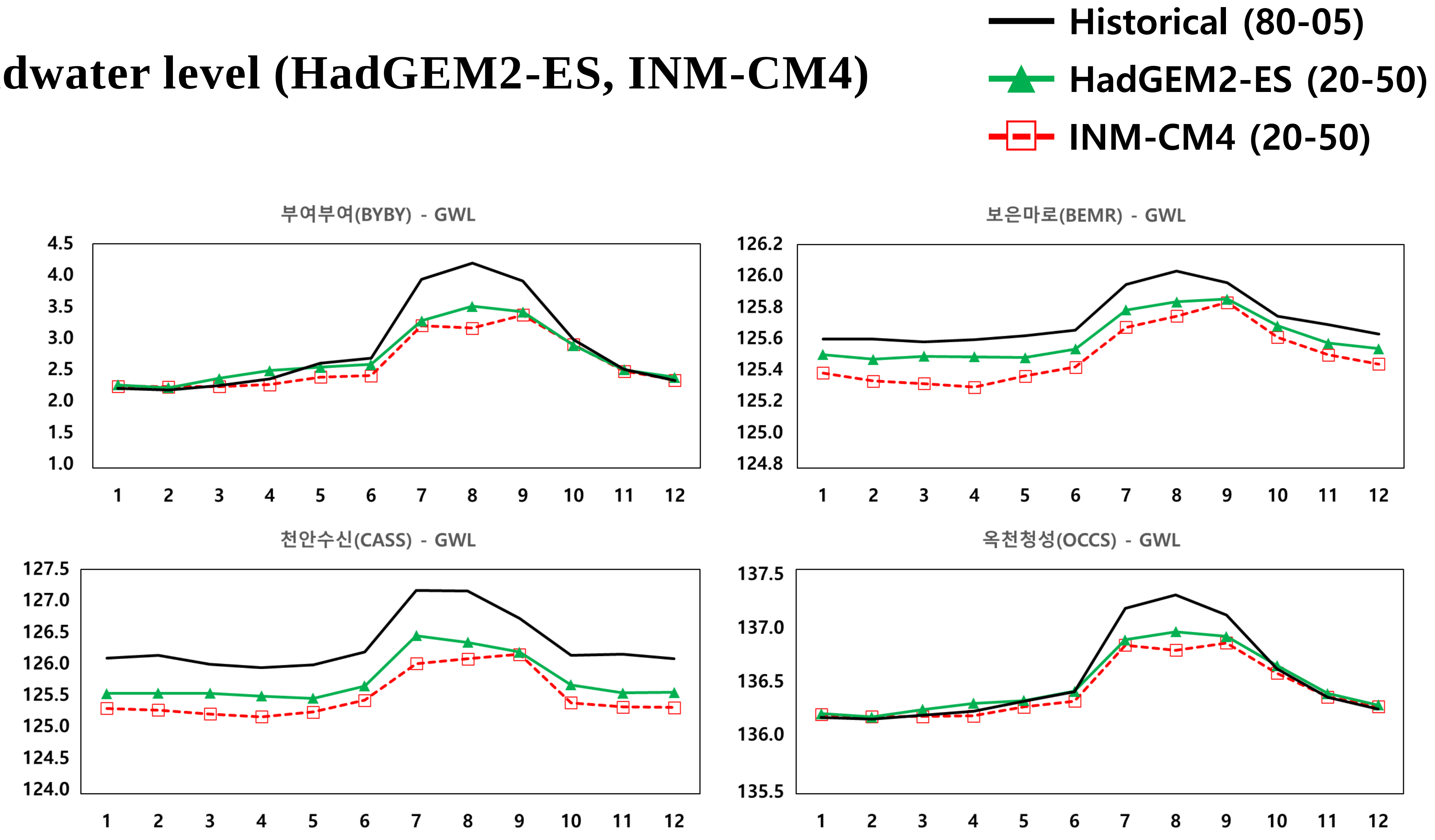
INM-CM4 (Dry)



*Y.W. Kim, J.W. Lee, S.J. Kim, Analysis of extreme cases of climate change impact on watershed hydrology and flow duration in Geum river basin using SWAT and STARDEX, Journal of Korea Water Resources Association, 51(10), 905-916, 2018.10

Assessment climate change on GWL

Groundwater level (HadGEM2-ES, INM-CM4)



Assessment climate change on GWL

Groundwater level (HadGEM2-ES, INM-CM4)

- At all groundwater level(GWL) observatories, it appears that the groundwater level tends to decrease depending on the both climate change scenario. In particular, in the Cheonan (CASS) and Boeun Maru (BEMR), the groundwater level tends to decrease significantly in summer.
- Also, GWL decreased in autumn and winter due to the effect of a dramatical decrease in summer.
- The dry scenario, INM-CM4, showed a more abrupt change in the GWL.

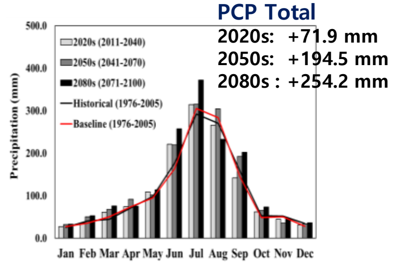
Average seasonal groundwater level change for each period(cm)

Stn	Season	HadGEM2-ES (Wet)			INM-CM4 (Dry)		
		20-30	30-40	40-50	20-30	30-40	40-50
BYBY	Spring	1.07	-0.33	0.34	-0.57	-0.39	-1.06
	Summer	-3.09	-1.83	-4.03	-3.99	-3.76	-4.92
	Autumn	-3.08	-0.97	0.45	-1.15	-2.54	-0.23
	Winter	0.12	0.25	0.52	-0.07	0.51	0.11
OCCS	Spring	0.86	-0.18	0.59	-0.34	-0.23	-0.47
	Summer	-2.10	-0.63	-3.27	-2.97	-2.78	-3.25
	Autumn	-2.60	-0.25	1.51	-0.71	-1.99	-0.14
	Winter	0.03	0.32	0.55	-0.02	0.51	0.18
CASS	Spring	-4.61	-15.24	-12.53	-16.20	-17.66	-18.01
	Summer	-13.64	-15.96	-16.84	-20.98	-23.34	-23.14
	Autumn	-11.72	-12.86	-11.94	-15.47	-16.20	-16.80
	Winter	-9.04	-15.77	-13.05	-16.77	-17.63	-20.13
BEMR	Spring	-1.65	-9.56	-7.91	-17.19	-12.97	-16.30
	Summer	-8.65	-7.31	-11.05	-14.76	-16.26	-13.63
	Autumn	-8.56	-4.09	-3.22	-11.16	-7.37	-6.76
	Winter	-5.39	-7.00	-5.82	-16.87	-8.38	-12.89

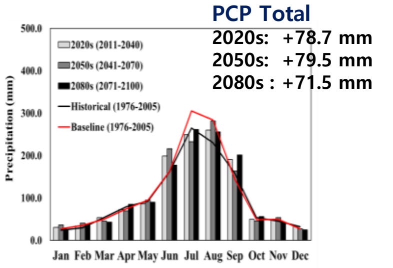
Assessment climate change on GWL

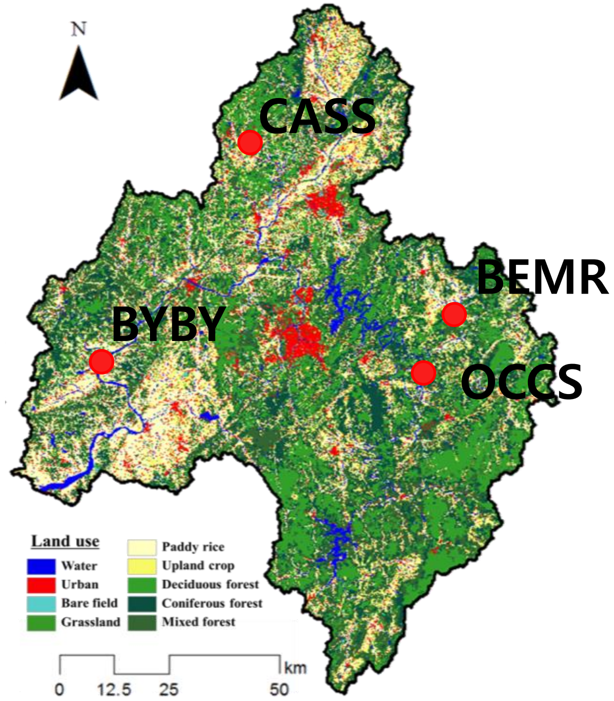
- The main land use of CASS and BEMR is mixed forest and broadleaf trees. Although precipitation increased, the total runoff and groundwater recharge is decreased. Because the water use efficiency of the forest changed due to the increase in evapotranspiration caused by temperature increment (average Increase of 3.0℃)
- As a result of scenario application, in addition to the summer groundwater level decrease, the range of the spring groundwater level decrease in May and June is gradually increasing, which is expected to accelerate the late spring drought.

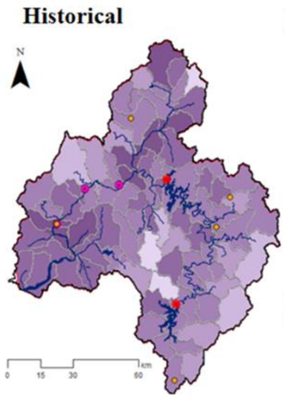
HadGEM2-ES (Wet)

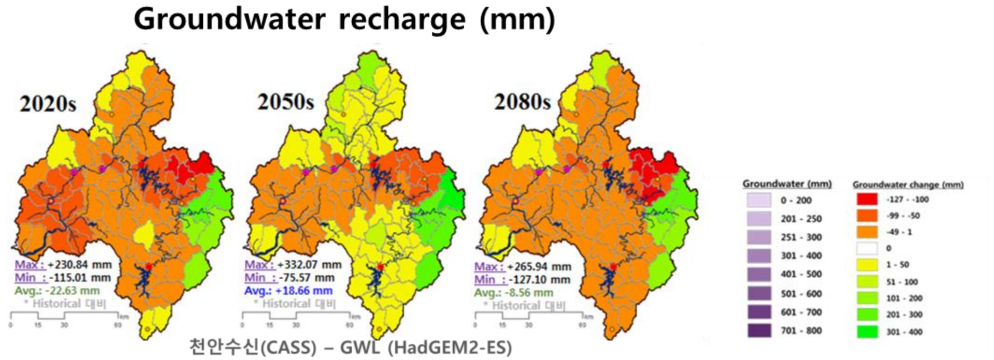


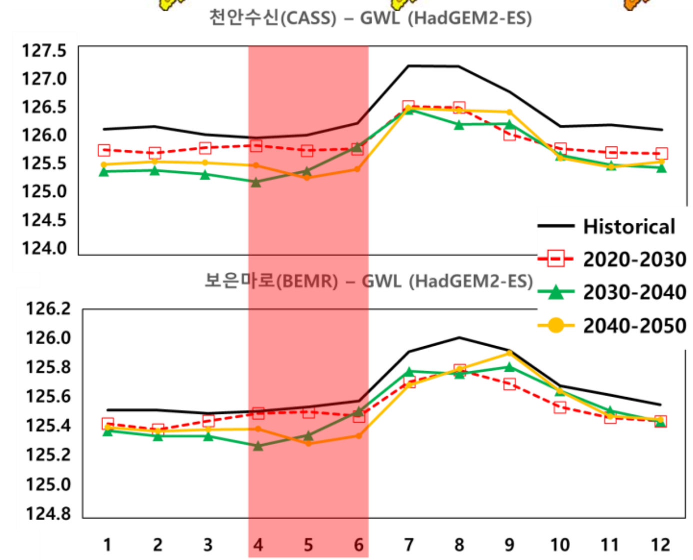
INM-CM4 (Dry)











Summary and Conclusion

- ✓ In this study, extreme climate change scenarios were applied to the QSWATMOD model, and the hydrological behavior of groundwater were evaluated in future (case of extreme event; HadGEM2-ES, INM-CM4)

- ✓ QSWATMOD overcomes the disadvantage that the SWAT model cannot express the detailed status of groundwater such as cell-based recharge, GW head distribution, Drainage. The groundwater level more accurately estimated through MODFLOW.

    - An increase in temperature has a greater effect than an increase in precipitation. Therefore, the GWL decreased due to the evapotranspiration of plants.
    - As a result of climate change, the groundwater level in spring (March to May) and summer (June to August) decreased. In autumn (September to November) and winter (December to February), the amount of groundwater recharge increased due to the precipitation increment, but the overall trend is decreasing.
    - As the groundwater level in the spring in May and June sharply decreases, the late spring drought is expected to accelerate.
    - The average annual groundwater level fluctuation was in the range of -16.84 to 1.57 cm (HadGEM2-ES) and -23.34 to 0.51 cm (INM-CM4) for each scenario.

- ✓ In this study, by estimating the behavior of the GWL in the Geum river basin for extreme scenarios and presenting statistical results by month/year/seasonal, it is expected to be utilized for prediction and efficient management of groundwater resources for adaptation to climate change.

- ✓ Improvements
    - Additional simulations of groundwater usage and future LU changes are needed.
    - QSWATMOD is under development, more detailed calibration in GW parameters and simulation for a long period(over 40 years) is difficult.
    - The results of models and extreme climate change scenarios contain many uncertainties.

Thank You!

For further information, please contact:)

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