Evaluation of stream flow and water quality impact of Yeongsan river basin by Inter-Basin Water Transfer(IBWT) using SWAT

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1. Introduction

- Currently, demand for water is expected to increase steadily because of the improvement in people's standard of living, but the water supply is not as good as that. To solve this problem, **the South Korea has been working on water supply using inter-basin water transfer (IBWT).**

- The IBWT is hydraulic method to solve water resources problems such as unbalanced water supply, demand and deterioration of water quality in watershed. **The IBWT is to transfer extra water by linking inter basins through the water conveyancing pipe or waterway from water-rich basin to water-poor basin in terms of water quantity.**

- **The water shortage problem causes water quality and water environmental problems** in the watershed or the stream and it can bring out the water disputes between water-rich basin and water-poor basin.

- Such water quantity problems are expected to affect the two river systems and increase difficulties in water resource planning and management.

- Therefore, it is necessary to establish the hydrologic model considering IBWT and to analyze the impact on streamflow and water quality changes by IBWT.

- **So, the purpose of this study is to establish the model considering IBWT and to evaluatethe impact on streamflow and water quality changes by IBWT about the water-poor basin.**

2. SWAT

SWAT Equation

• 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)

• Reservoir

$$V = V_{stored} + V_{flowin} - V_{flowout} + V_{PCP} - V_{evap} - V_{seep}$$

V = volume of water in the impoundment at the end of the day (m3H2O)

V_{stored} = volume of water stored in the water body at the beginning of the day (m3 H2O)

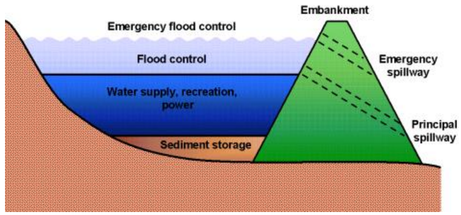
V_{flowin} = volume of water entering the water body during the day (m3 H2O)

V_{flwout} = volume of water flowing out of the water body during the day (m3 H2O)

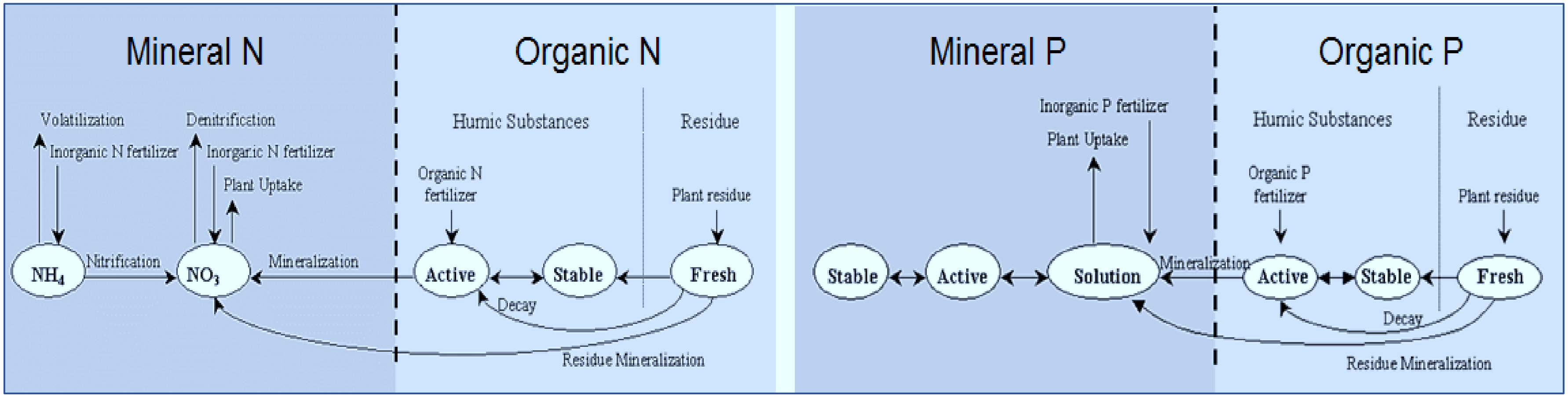
V_{pcp} = volume of precipitation falling on the water body during the day (m3 H2O)

V_{evap} = volume of water removed from the water body by evaporation during the day (m3 H2O)

V_{seep} =volume of water lost from the water body by seepage (m3 H2O).

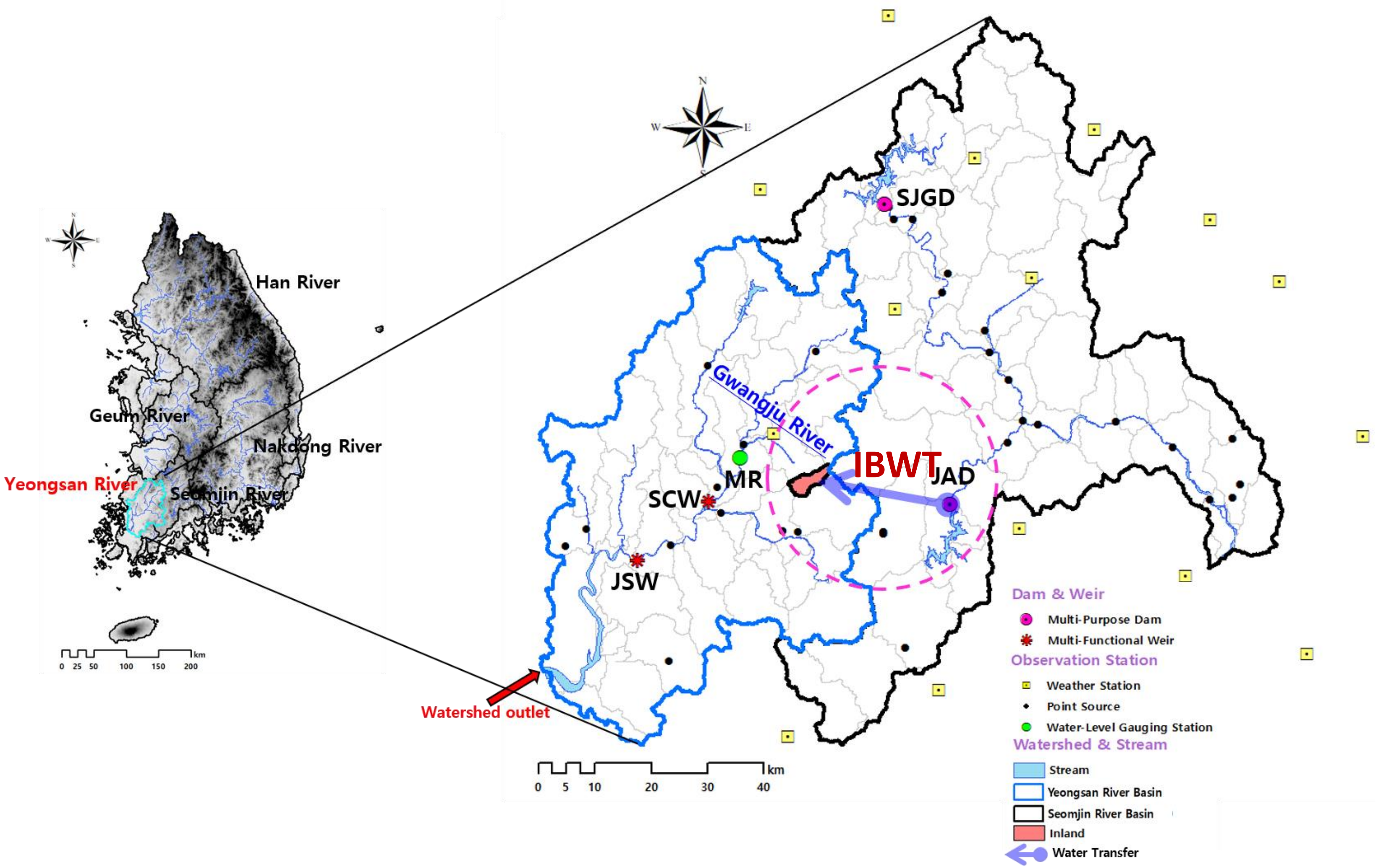


• Water Quality



2.1 Study Area

- **Yeongsan River Basin (3,371.7 km²)**
  - **Annual average precipitation: 1,293.0 mm (1981~2018)**
  - **Annual mean temperature: 14.0 ℃ (1981~2018)**
  - **Annual average daily IBWT amounts: 291,436.2 m^3/day (2005~2018)**



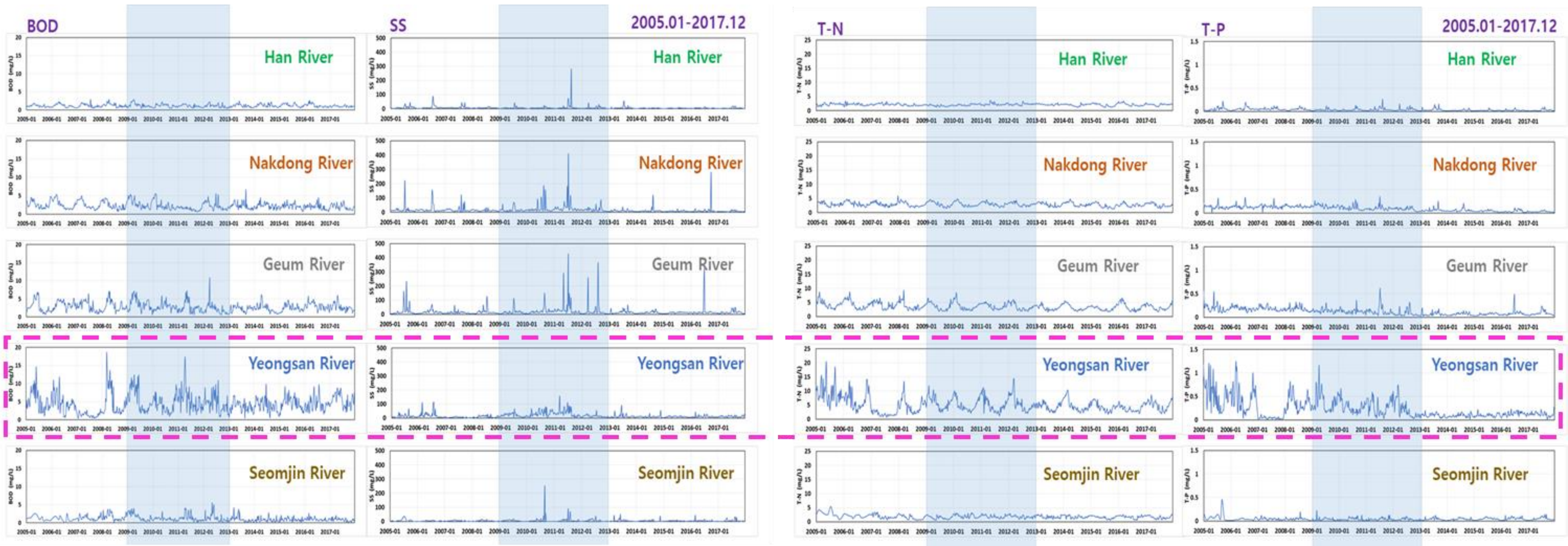
2.1 Study Area

- The annual amount of available water resources in the Yeongsan river basin is 5.7 billion m^3, which is the smallest of the five major rivers in the South Korea.

- Currently, the Yeongsan's deficient waters now come from the neighbor Seomjin river basin for about 27% of its water resources to upstream of Yeongsan river by government decision since 1991.

- Although the Yeongsan river has small amount of pollutant load due to its short channel length, its water quality is worst among the five major rivers in South Korea.

- Also, because it has small water quantities compared with other watersheds, it is vulnerable to small pollution source and the ratio of non-point source pollutant is twice higher than other watersheds in the South Korea.



2.2 Inlet Tool for IBWT

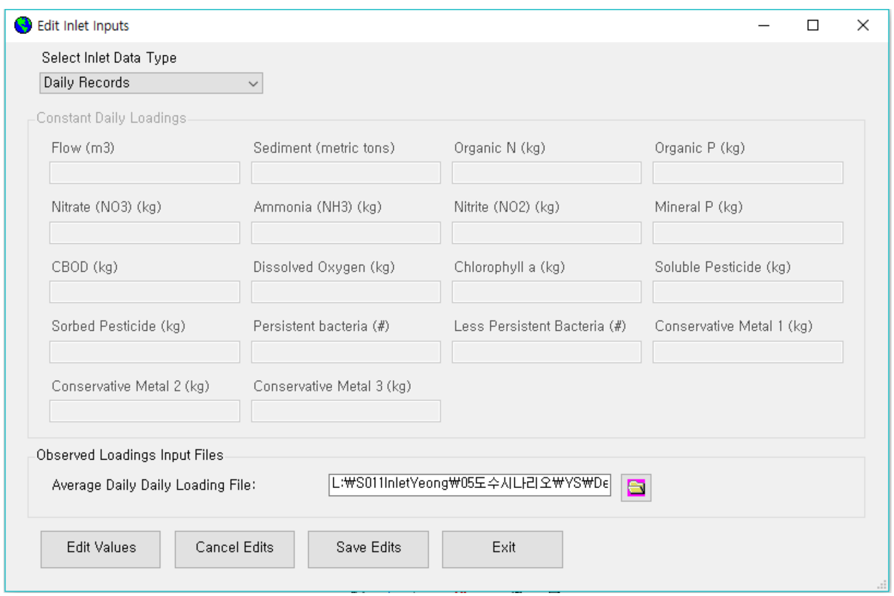
- **Inlet Tool**

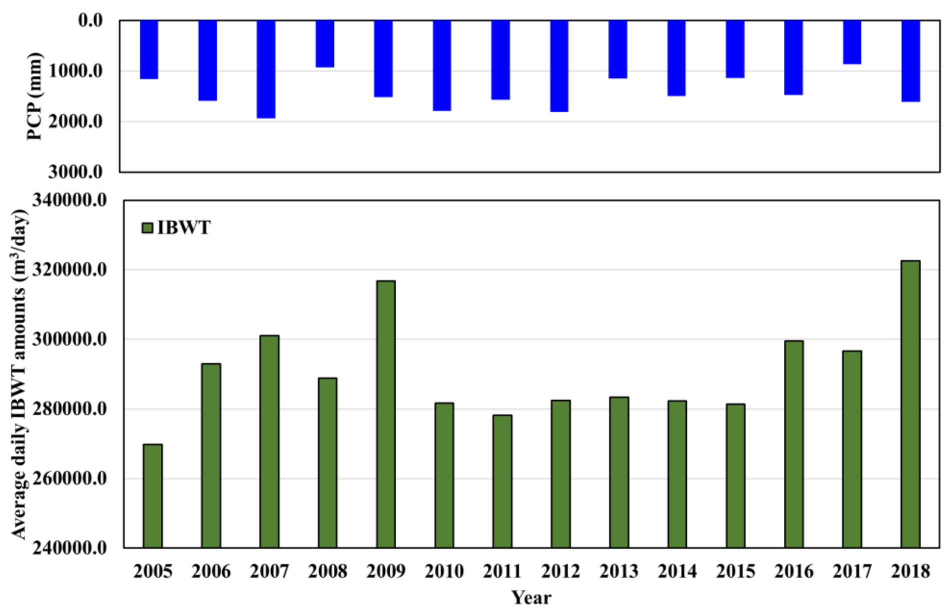
❖ **The Inlet tool in SWAT model was developed to add a new inlet and additional outlet** to the subbasin during the watershed delineation phase. => Inland creation

❖ **However, it has the limitation that the information on the upstream of inland will be disappeared when inland was created.**

❖ Select input data type among Constant, Annual, Monthly, Daily Records.

❖ **In this study, the daily observed data (2005~2018) were provided to build in form of inlet tool input data as daily records to consider IBWT from Juam dam in Seomjin river to Yeongsan river.**

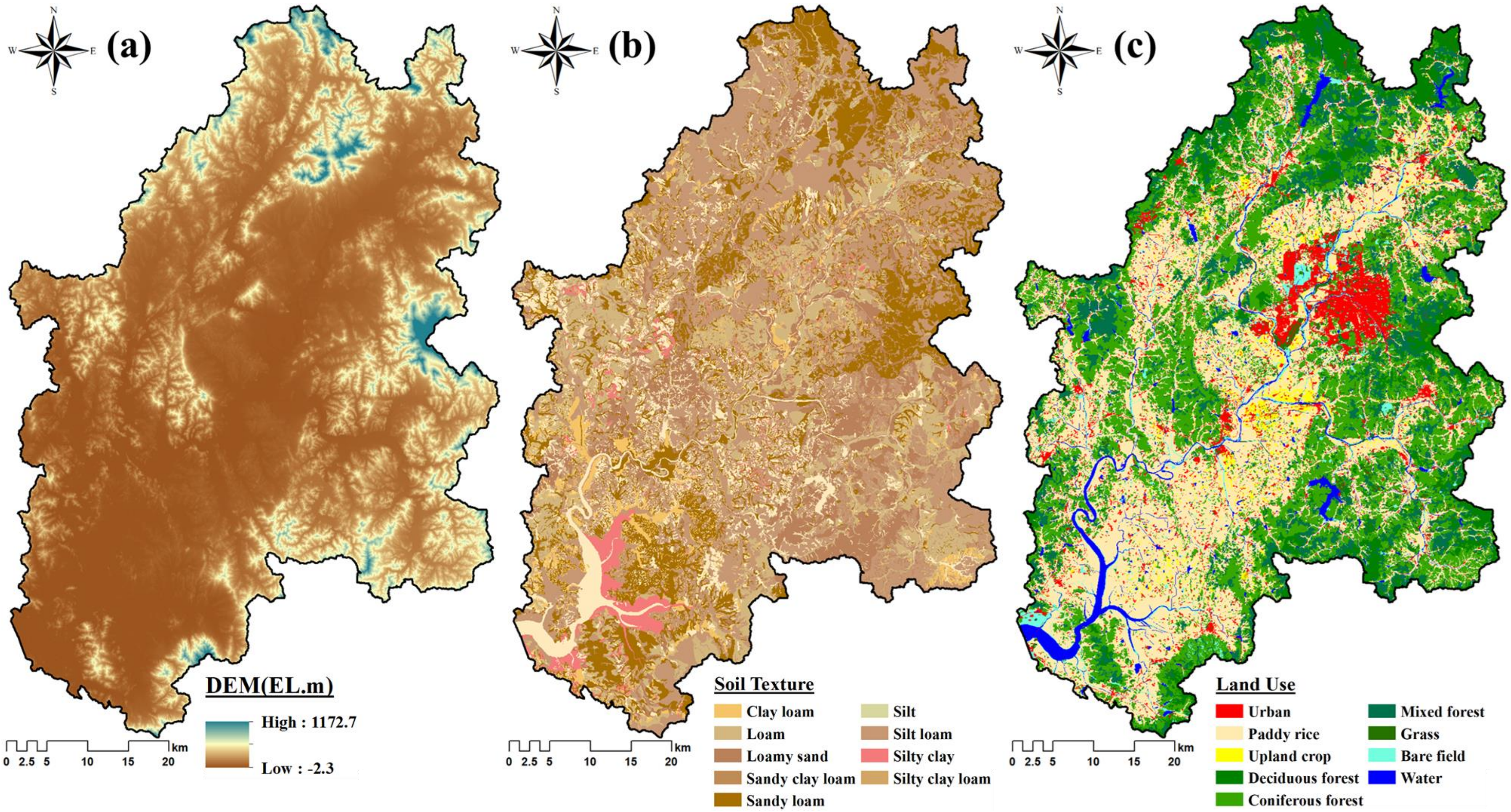




2.3 SWAT Input Data

❖ GIS Data

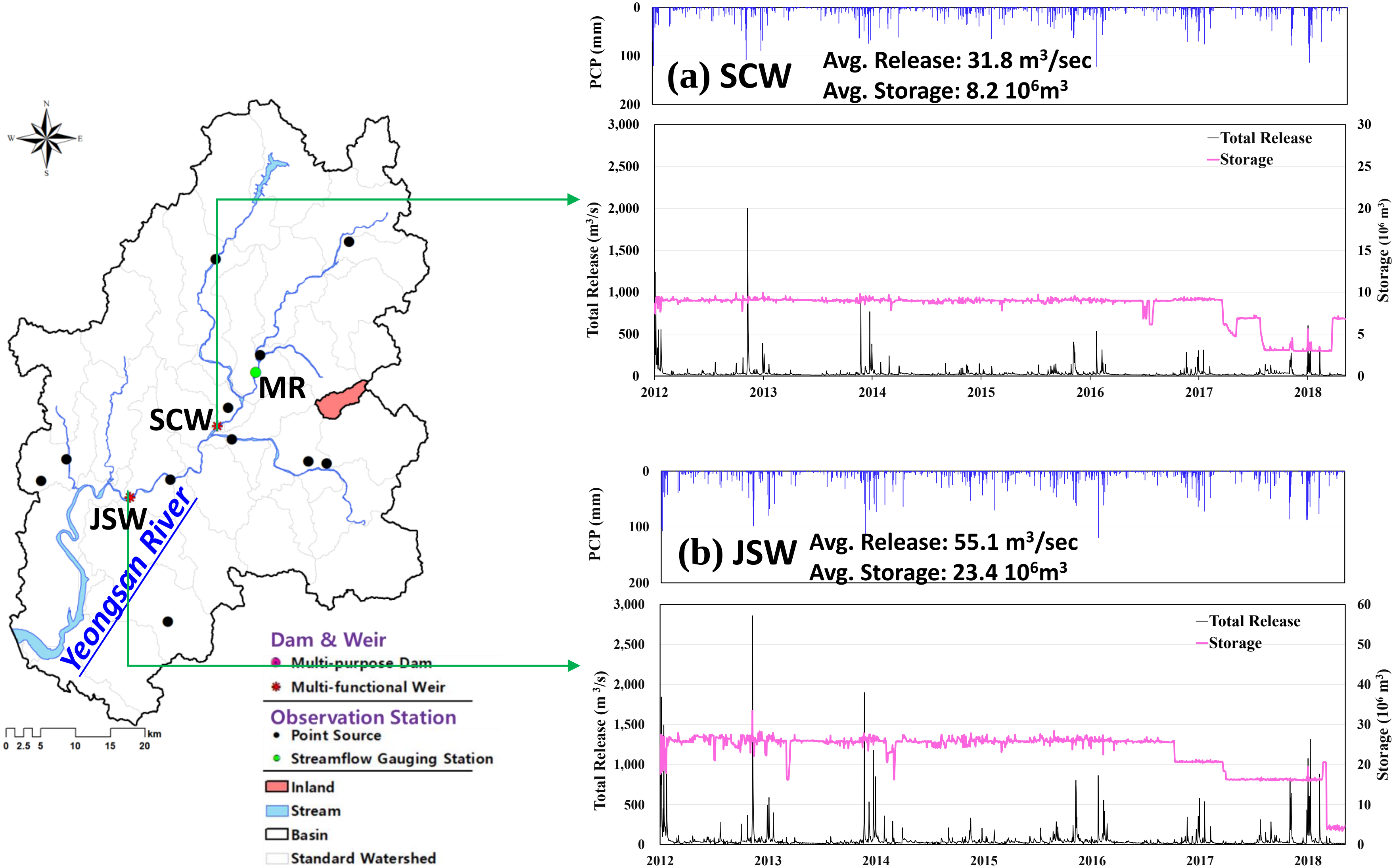
- ❖ (a) 30m DEM: -2.3 – 1,172.7 m
- ❖ (b) 1:25,000 Soil map: Silt loam 46.2%, Loam 18.9%
- ❖ (c) 1:25,000 Land use: Forest 45.6%



2.3 SWAT Input Data

❖ Operation Data (2012~2018)

- ❖ (a) Seungchon Multi-functional weir total release & storage data
- ❖ (b) Juksan Multi-functional weir total release & storage data



2.4 Calibration and Validation

❖ Adjusted SWAT Parameters – Hydrology and Water Quality

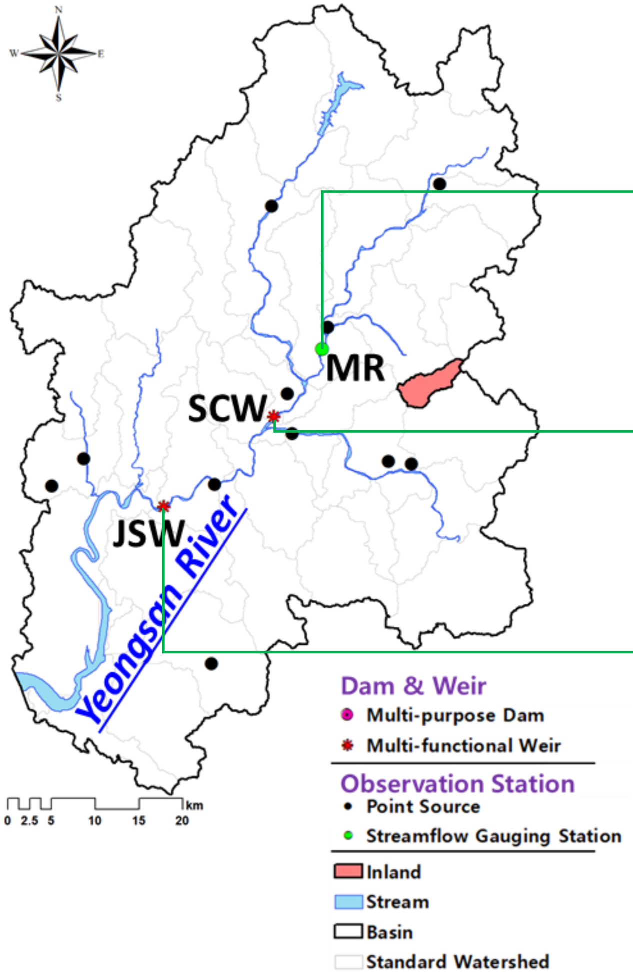
Parameters	Definition	Range	Adjusted Value		
			MR	SCW	JSW
Surface runoff					
CN2	SCS curve number for moisture condition	35 to 98	+10	+10	-10
Surlag	Surface runoff lag coefficient	0 to 7	4	4	4
CH_N(2)	Manning's "n" value for main channel	0.01 to 30	0.05	-	-
Evapotranspiration					
ESCO	Soil evaporation compensation coefficient	0 to 1	0.1	-	-
CANMX	Maximum canopy storage	0 to 100	-	7	-
SLOIL	Slope length of lateral subsurface flow (m)	0 to 150	15	-	-
LAT_TIME	Lateral flow travel time (days)	0 to 180	20	-	-
Groundwater					
GW_DELAY	Delay time for aquifer recharge (days)	0 to 500	-	-	-
GWQMN	Threshold water level in shallow aquifer for base flow (mm)	0 to 5000	5000	-	-
ALPHA_BF	Base flow recession constant	0 to 1	-	-	-
Reservoir					
RES_ESA	Reservoir surface area when the reservoir is filled to the emergency spillway (ha)	-		338	312
RES_EVOL	Volume of water needed to fill the reservoir to the emergency spillway (10^4 m^3)	-		893	2586.1
RES_PSA	Reservoir surface area when the reservoir is filled to the principal spillway (ha)	-		250	235
RES_PVOL	Volume of water needed to fill the reservoir to the principal spillway (10^4 m^3)	-		759	2256.4
RES_VOL	Initial reservoir volume(10^4 m^3)	-		837	2425.3

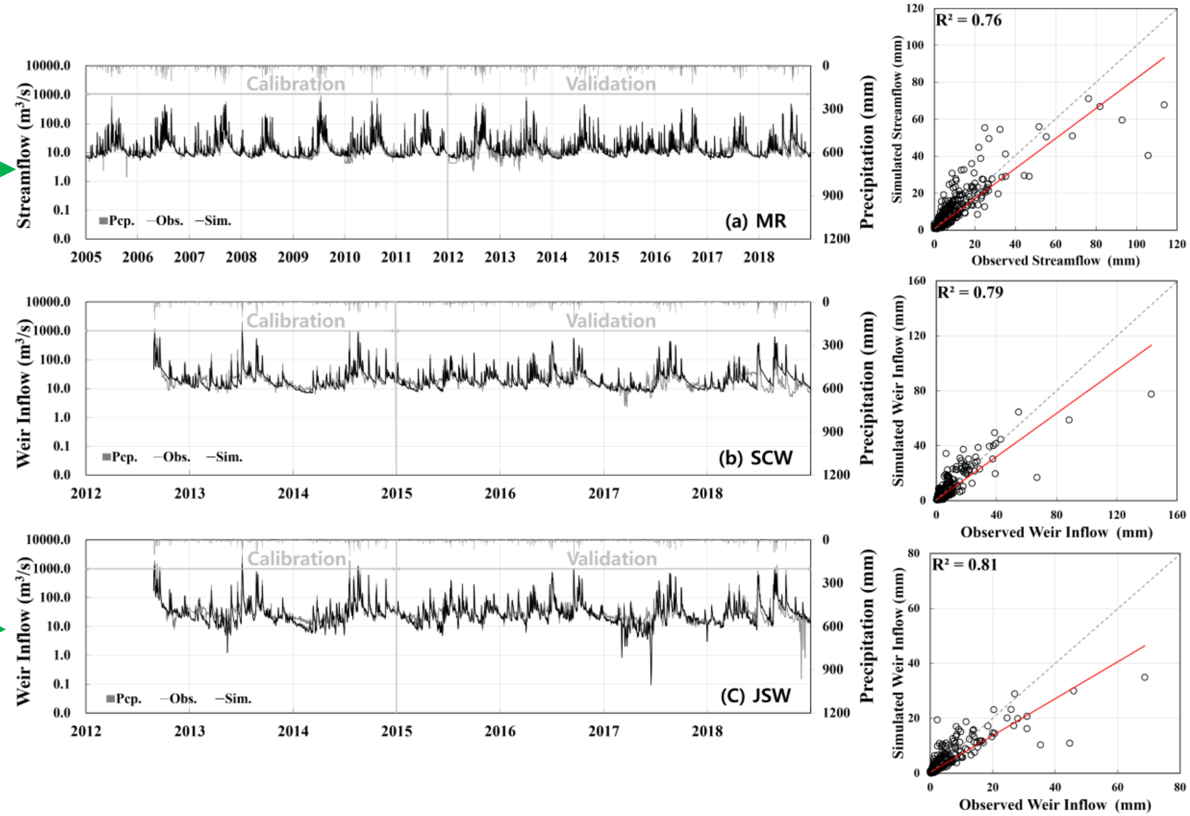
Parameters	Definition	Range	Adjusted Value		
			MR	SCW	JSW
Suspended Soild					
USLE_P	USLE equation support practice factor	0 to 1	-	0.8	0.75
SPCON	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	0.0001 to 0.01	0.001	0.001	0.001
SPEXP	Exponent parameter for calculating sediment reentrained in channel sediment routing	1 to 1.5	1.5	1.5	1.5
Evapotranspiration					
SHALLST	Initial depth of water in the shallow aquifer (mm)	0 to 5000	-	-	-
LAT_ORGN	Organic N in the baseflow (mg/l)	0 to 200	1.5	3.3	1.5
NPERCO	Nitrate percolation coefficient	0 to 1	-	-	-
SDNCO	Threshold value of nutrient cycling water factor for denitrification to occur	0 to 1	-	-	-
RAMMO_SUB	Atmospheric deposition of ammonium	0 to 1	-	-	-
RCN_SUB	Atmospheric deposition of nitrate	0 to 2	-	-	-
Groundwater					
GWSOLP	Reservoir surface area when the reservoir is filled to the emergency spillway (ha)	0 to 1000	2	0.1	0.25
LAT_ORGP	Volume of water needed to fill the reservoir to the emergency spillway (10^4 m^3)	0 to 200	0.05	0.1	0.2

2.4 Calibration and Validation

❖ SWAT Streamflow and Weir Inflow Calibration Results

- ❖ **Calibration: 7 years (2005~2011) / Validation: 7 years (2012~2018)**
- ❖ **Avg. R^2: 0.76~0.81 (Good) / NSE: 0.65~0.74 (Satisfactory) / RMSE: -8.3 ~ +7.6 mm/day**





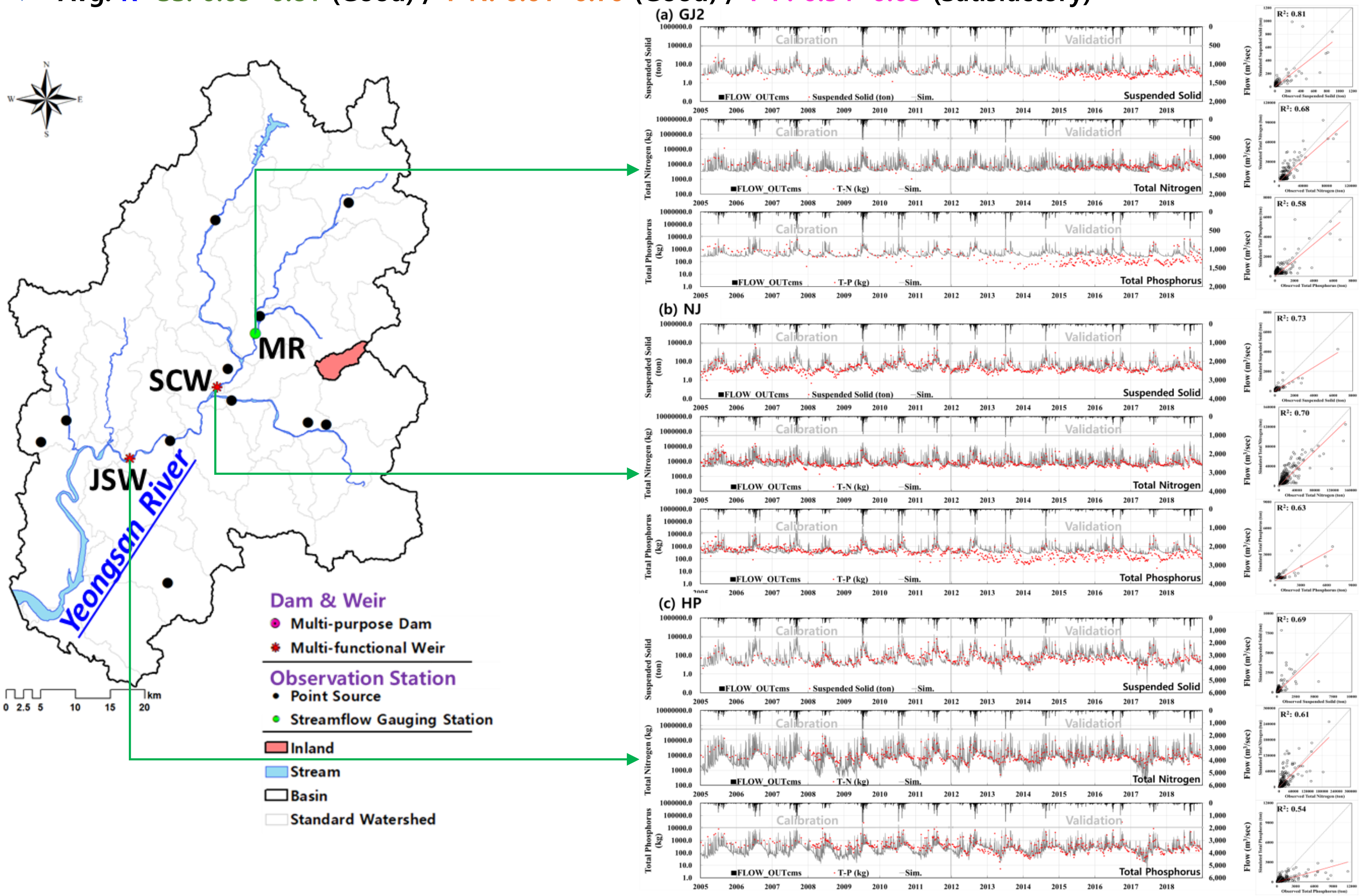
(Moriasi et al., 2015)

Criteria	Output Response	Temporal Scale	Performance Evaluation Criteria			
			Very Good	Good	Satisfactory	Not Satisfactory
R^2	Flow	Daily	$R^2 > 0.85$	$0.75 < R^2 \le 0.85$	$0.60 < R^2 \le 0.75$	$R^2 \le 0.60$
	SS & P	Monthly	$R^2 > 0.80$	$0.65 < R^2 \le 0.80$	$0.40 < R^2 \le 0.65$	$R^2 \le 0.40$
	N	Monthly	$R^2 > 0.70$	$0.60 < R^2 \le 0.70$	$0.30 < R^2 \le 0.60$	$R^2 \le 0.30$
NSE	Flow	Daily	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.70	NSE ≤ 0.50

2.4 Calibration and Validation

❖ SWAT Water Quality Calibration Results

- ❖ Calibration: 7 years (2005~2011) / Validation: 7 years (2012~2018)
- ❖ Avg. R^2-SS: 0.69~0.81 (Good) / T-N: 0.61~0.70 (Good) / T-P: 0.54~0.63 (Satisfactory)



3.1 IBWT Scenarios

❖ IBWT Scenarios

- Recently, the scenario planning that can support planning through research and analysis of various future conditions and changes in a hypothetical scenario has been widely applied globally.

- **The scenario planning is not predicting the future changes, but is establishing adaptation and response strategies on future changes**(Van der Heijden, 2005)**.**

- In this study, the hypothetical IBWT scenarios were constructed to evaluate the streamflow and water quality changes on IBWT amounts change from Juam Dam in the Seomjin river basin.

- **The hypothetical IBWT scenarios were consisted of an increase scenarios in which the IBWT amounts increase from the Seomjin river basin and a decrease scenarios in which IBWT amounts decrease from the Seomjin river basin.**

3.1 IBWT Scenarios

❖ IBWT Scenario Description

- The hypothetical IBWT scenarios were consisted of a total 6 scenarios (3 increase scenarios, and 3 decrease scenarios).

- **The IBWT scenario 1, 2, and 3 were consisted of +10%, +30%, and +50% increasing of the present IBWT amounts (100%), respectively.**

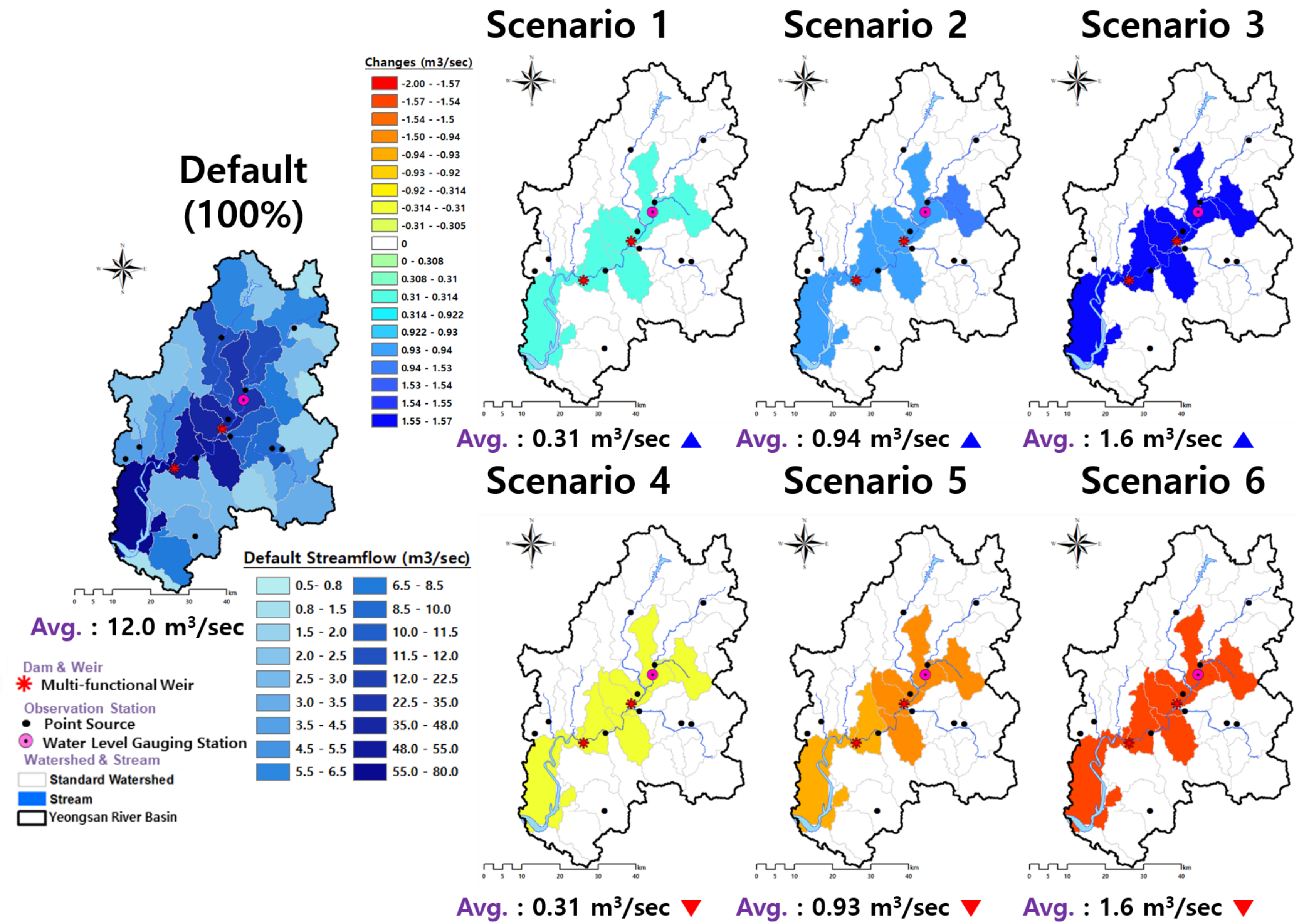
- **On the contrary, the IBWT scenario 4, 5, and 6 were consisted of -10%, -30%, and -50% decreasing of the present IBWT amount (100%), respectively.**

- **These scenarios were applied to SWAT to evaluate the IBWT impact on the streamflow and water quality of the Yeongsan river basin.**

IBWT Scenario	IBWT Condition from the Seomjin River Basin	Change Rate
Scenario 1	110% of the present IBWT amounts	+10%
Scenario 2	130% of the present IBWT amounts	+30%
Scenario 3	150% of the present IBWT amounts	+50%
Scenario 4	90% of the present IBWT amounts	-10%
Scenario 5	70% of the present IBWT amounts	-30%
Scenario 6	50% of the present IBWT amounts	-50%

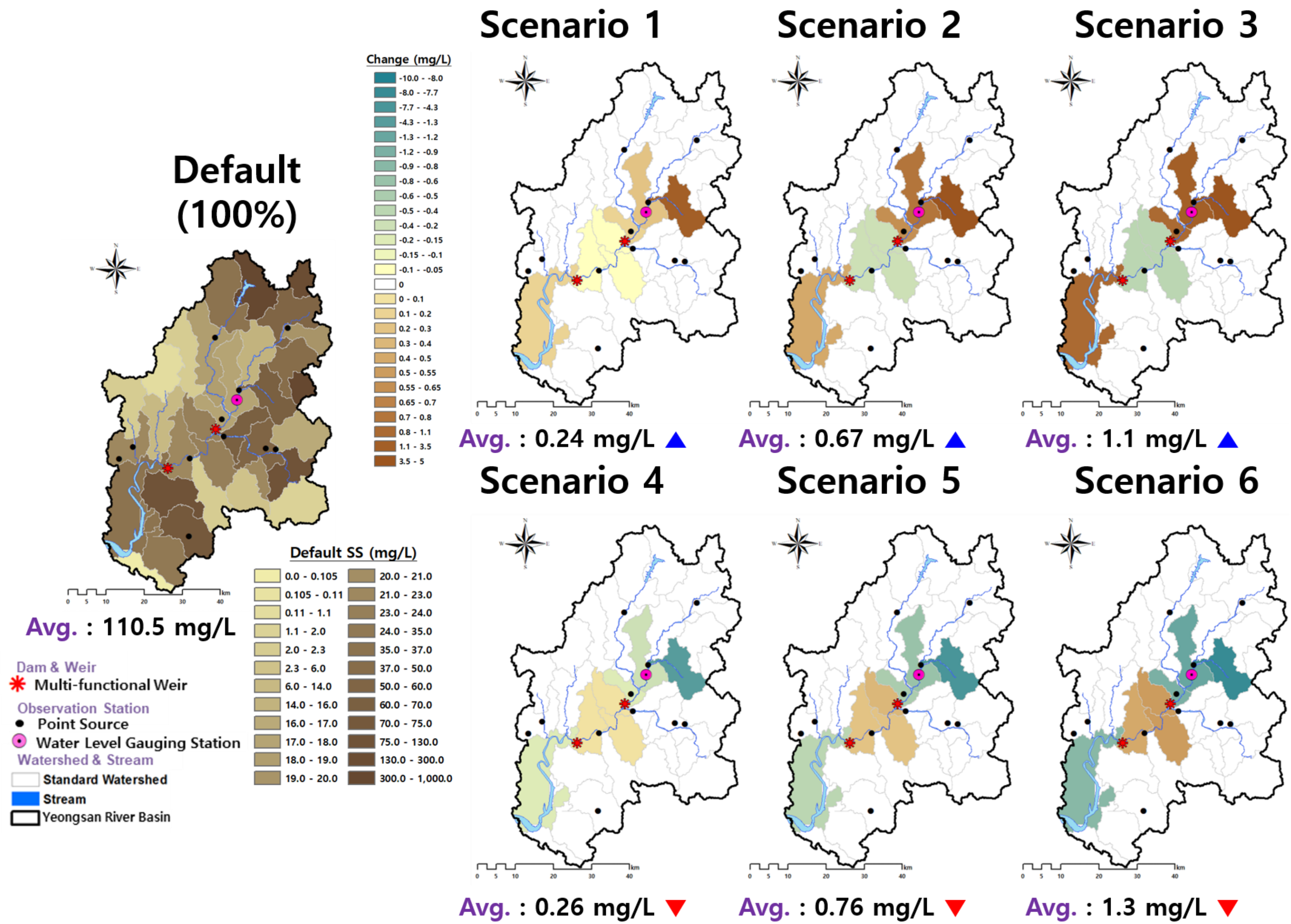
3.2 Streamflow Changes

❖ IBWT Impact on the Streamflow



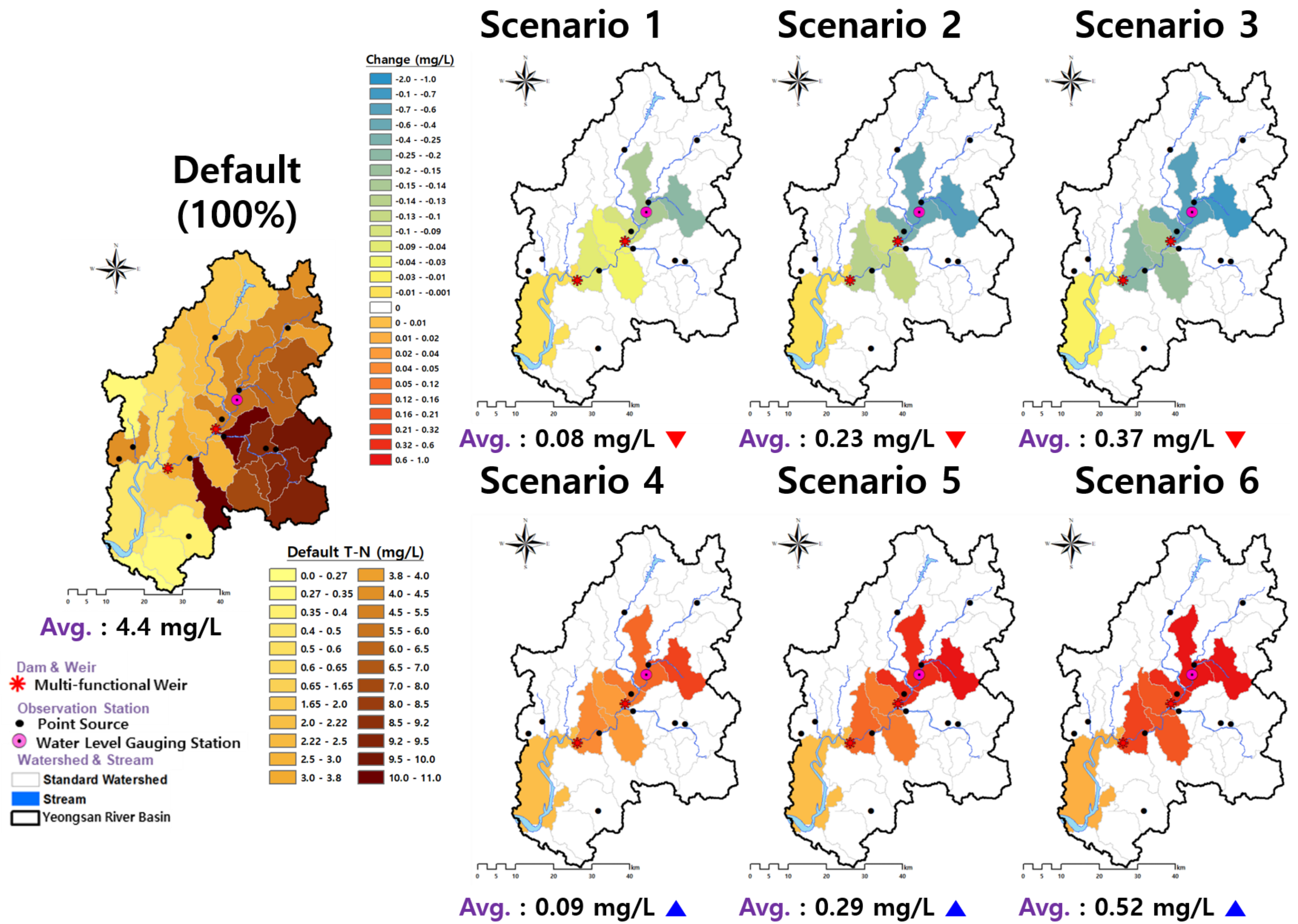
3.3 Water Quality Changes

❖ IBWT Impact on the Stream Water Quality – Suspended Soild



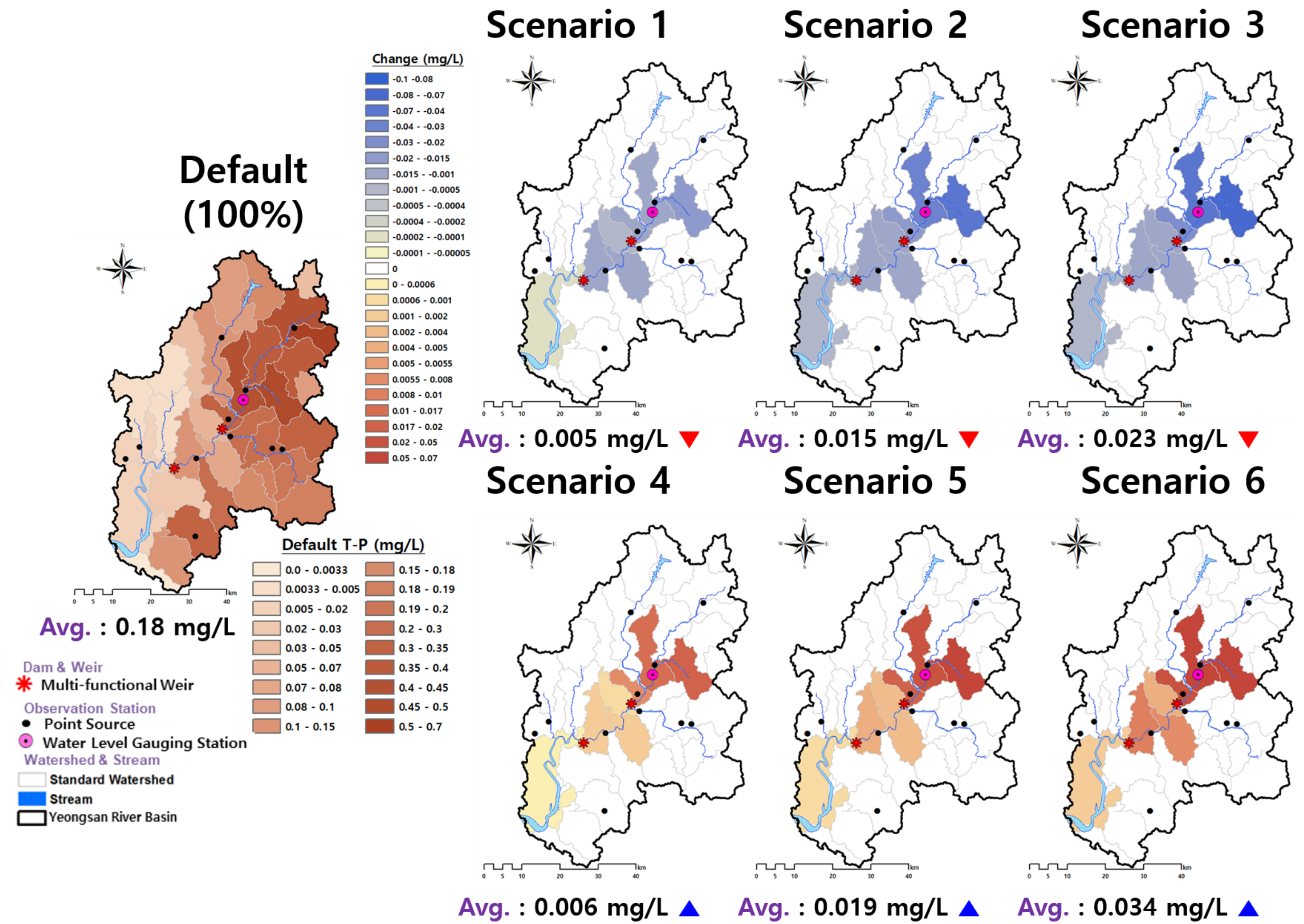
3.3 Water Quality Changes

❖ IBWT Impact on the Stream Water Quality – Total Nitrogen



3.3 Water Quality Changes

❖ IBWT Impact on the Stream Water Quality – Total Phosphorus



4. Summary and Conclusion

- **This study was performed to evaluate the IBWT impact on the streamflow and water quality of the Yeongsan river basin.**
  - The Yeongsan river basin (3,371.7 km^2) has been suffered water deficit and water quality problem.
  - **The deficient waters now come from the neighbor Seomjin river basin for about 27% of its water resources to upstream of the Yeongsan river by government decision since 1991.**
  - Annual average daily IBWT amounts: 291,436.2 m^3/day

- **The SWAT was established to consider the IBWT using Inlet tool in the watershed delineation phase.**
  - The inlet tool was developed to add a new inlet and additional outlet to the subbasins. => Inland creation.
  - But, the information on the upstream of inland will be disappeared when inland was created.

- **The daily observed IBWT data (2005~2018) were provided to build in form of inlet tool input data as daily records.**

- **The SWAT was calibrated and validated the weir inflows, streamflow, and water quality during the 14 years (2005~2018).**
  - Calibration: 7 years (2005~2011) / Validation: 7 years (2012~2018)
  - **The streamflow and weir inflows => Avg. R^2: 0.76 ~ 0.81 (Good), NSE: 0.65 ~ 0.74 (Satisfactory), RMSE: -8.3 ~ +7.6 mm/day**
  - **The stream water quality => Avg. R^2-SS: 0.69 ~ 0.81 (Good) / T-N: 0.61 ~ 0.70) (Good) / T-P: 0.54 ~ 0.63 (Satisfactory)**

- **To evaluate the impact of IBWT on the streamflow and water quality, the hypothetical IBWT scenarios were constructed.**
  - The IBWT scenarios were consisted of an increase scenarios in which the IBWT amounts increase from the Seomjin river basin and a decrease scenarios in which IBWT amounts decrease from the Seomjin river basin.
  - **The IBWT scenarios were consisted of a total 6 scenarios (3 increase scenarios, and 3 decrease scenarios).**
  - **The IBWT scenarios 1, 2, and 3 were consisted of +10%, +30%, and +50% increasing of the present IBWT amounts (100%).**
  - **The IBWT scenarios 4, 5, and 6 were consisted of -10%, -30%, and -50% decreasing of the present IBWT amounts (100%).**

4. Summary and Conclusion

- **The impact of IBWT on streamflow and water quality were evaluated using the 6 hypothetical IBWT scenarios.**
  - **The average streamflow of Yeongsan river during 14 years (2005~2018) is 12.0 m^3/sec.**
    - The IBWT scenario 1, 2, and 3 → the streamflow was increased steadly 12.31(+2.6%), 12.94(+7.8%), and 13.6(+13.3%) m^3/sec respectively.
    - The IBWT scenario 4, 5, and 6 → the streamflow was decreased steadly 11.69(-2.6%), 11.07(-7.8%), and 10.4(-13.3%) m^3/sec respectively.

  - **The average SS, T-N, and T-P of Yeongsan river during 14 years (2005~2018) is 110.5, 4.4, and 0.18 mg/L, respectively.**
    - **SS**
    - The IBWT scenario 1, 2, and 3 → the suspended solid was increased 110.76(+0.2%), 111.26(+0.7%), and 111.8(+1.2%) mg/L respectively.
    - The IBWT scenario 4, 5, and 6 → the suspended solid was decreased 110.24(-0.2%), 109.74(-0.7%), and 109.2(-1.2%) mg/L respectively.
    - **T-N**
    - The IBWT scenario 1, 2, and 3 → the T-N was decreased 4.32(-1.8%), 4.17(-5.2%), and 4.05(-8.0%) mg/L respectively.
    - The IBWT scenario 4, 5, and 6 → the T-N was increased 4.49(+2.0%), 4.68(+6.4%), and 4.91(+11.6%) mg/L respectively.
    - **T-P**
    - The IBWT scenario 1, 2, and 3 → the T-P was decreased 0.175(-2.8%), 0.165(-8.3%), and 0.157(-12.8%) mg/L respectively.
    - The IBWT scenario 4, 5, and 6 → the T-P was increased 0.186(+3.3%), 0.199(+10.6%), and 0.214(+18.9%) mg/L respectively.

- **These results indicated that the IBWT causes direct changes on river environment and water resources capacity in available water resources of basins. it also indicated that because the streamflow and water quality of watershed were sensitive to the amount of IBWT, the controlling of the amount of IBWT is the essential consideration in the establishement of the watershed environment and water resource management plan.**

Thank You

For further information, please contact☺

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