Evaluation of Groundwater Use Impact on the Drying Stream by Modifying SWAT Groundwater Balance Equation

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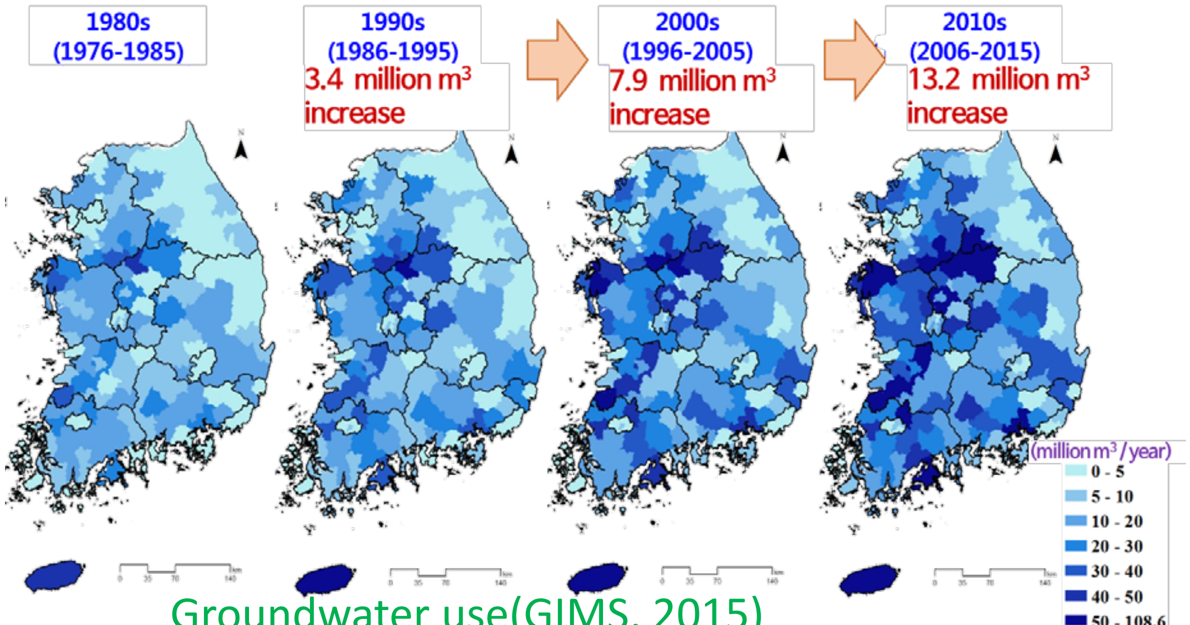
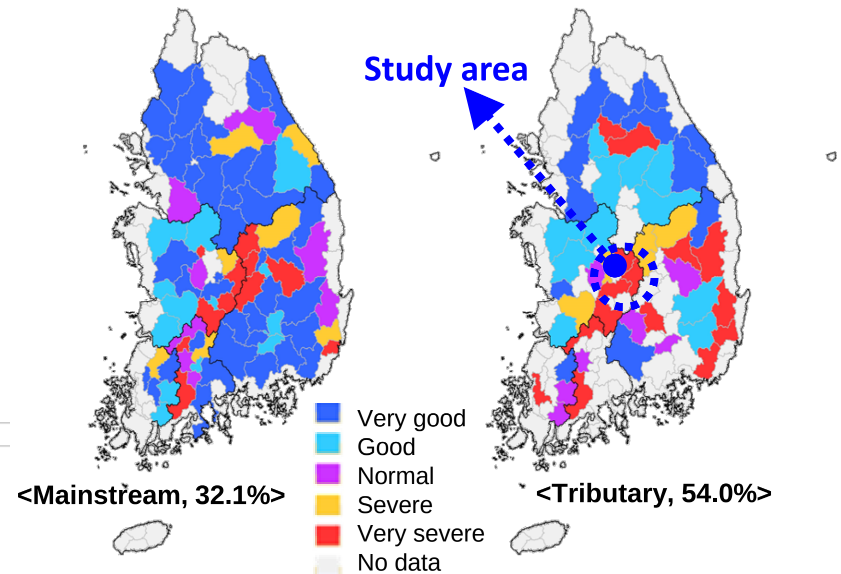
Background and purpose

- Recently in South Korea, it was reported that **84 %** of total small streams showed the **drying stream phenomena** (Rural research institute, 2006).
  - The 7,917 groundwater wells have been developed to obtain more agricultural and drinking water in rural areas near streams since 1980.
  - The **pumping water use** in 2007 was about 3,735 million m^3/year occupying **10 %** of total national water use (K-water 2008).



Groundwater use(GIMS, 2015)

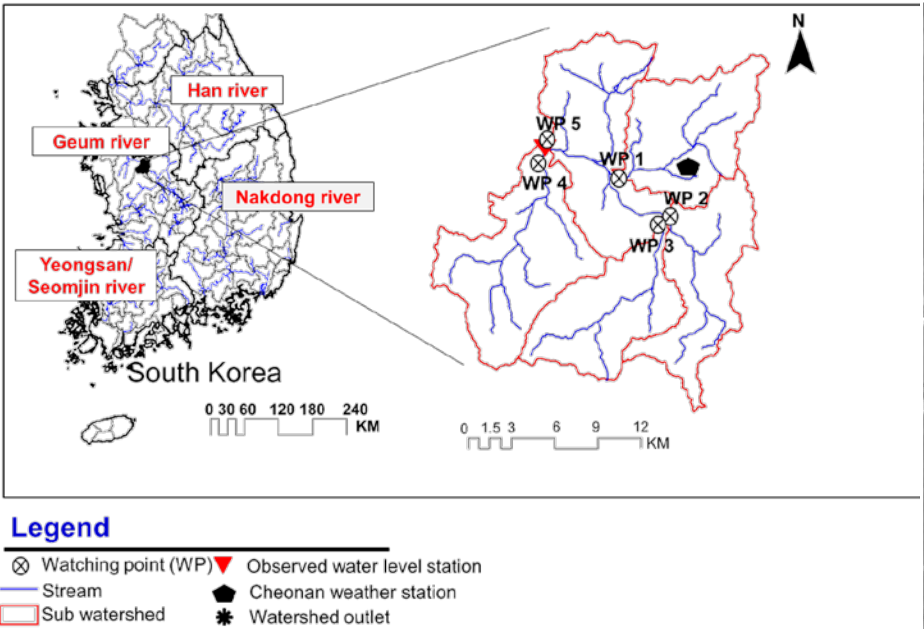


Drying stream status survey(K-water, 2010)

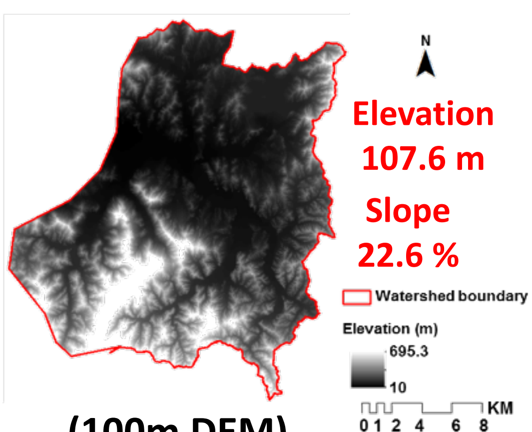
- The objective of this study is to identify the **drying stream phenomena** through tracing the **flow decrease** by **SWAT model** groundwater equation under **groundwater use and return flow conditions**.

Study area

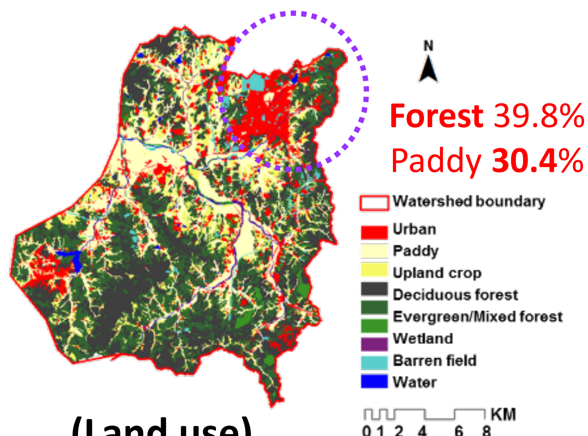
Actual drying stream area



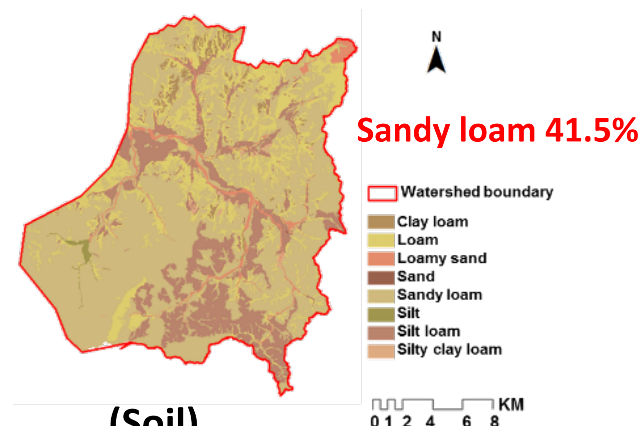
- Area : 358.8 km²
- Discharge station : Hannadaegyo
- Study area : Sapgyocheon upstream watershed
- Annual average precipitation: 1362.3 mm for 20years
- annual average temperature : 12.0 ℃ for 20 years
- Forest area : 39.8 %



(100m DEM)



(Land use)



(Soil)

Materials and Methods

SWAT model groundwater use equation (Shallow aquifer equation)

- SWAT model is a continuous, long-term, and distributed-parameter model designed to predict the impact of land management practices on the hydrology and water-quality and contaminant transport in agricultural watersheds.
- SWAT simulates two aquifers in each subbasin. The shallow aquifer is an unconfined aquifer that contributes to flow in the main channel or reach of the subbasin.
- The water balance for the **shallow aquifer** as follows :

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

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

Materials and Methods

Drying stream definition

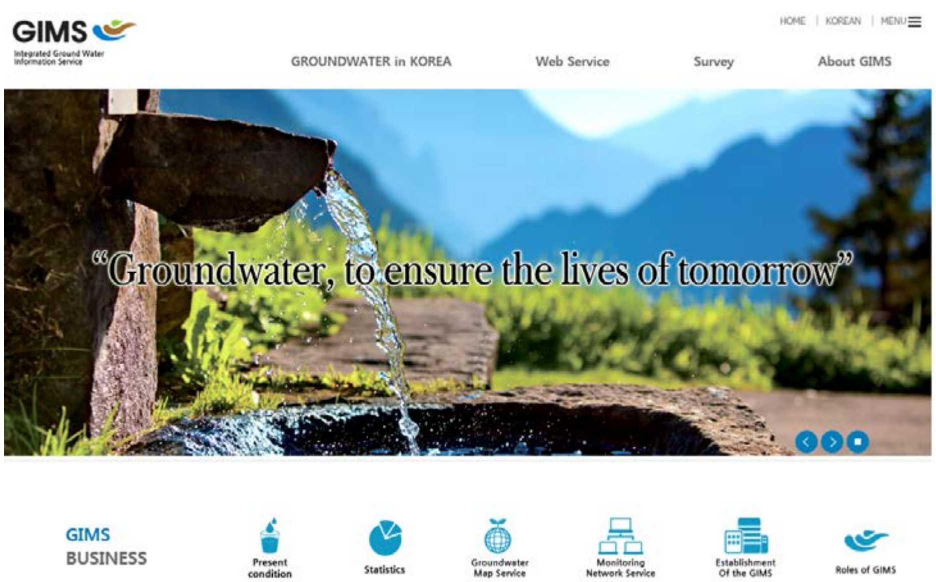
- The phenomenon defined that the river is almost dry enough to see the bottom of the river as a normal stream (Gyeonggi Research institute, 2003).
- The phenomenon defined that flow is seriously **reduced by anthropogenic factors** (Ministry of Land, Infrastructure and Transport, 2009).
- In this study, the **10 day minimum flow (Q355)** change was evaluated as the standard criteria suggested by Ministry of Land, Infrastructure, and Transport (Ministry of Land, Infrastructure and Transport, 2009).
- To estimate the drying stream, the volume of streamflow were evaluated.

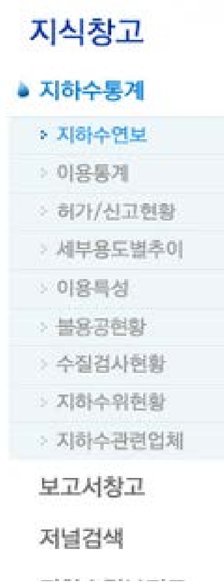
Method	Parameter	Description
Volume	Discharge change of 10 day minimum flow (Q355)	The discharge difference between 10 day minimum flow using the flow duration analysis between the present and ground use conditions

Materials and Methods

Groundwater use data

- **Groundwater use data** are available on the website of **National Groundwater Information Center (NGIC).**
- The NGIC provides **monthly and yearly groundwater use data** at watersheds and administrative districts.
- In this study, monthly groundwater from 2000 to 2015 use was divided into living, industrial, and agricultural use.





〈표〉 국가지하수 정보센터 보유자료 현황

조사자료	전국 약 48,000 공에 대한 시추, 착정, 양수시험, 전기탐사, 수질자료 등
관측자료	전국 320개 지하수 관측소의 관측자료 일평균
이용실태자료	전국 지자체의 지하수 이용통계 및 시설현황 자료 약 130만

〈표〉 이용실태 제공정보 세부항목

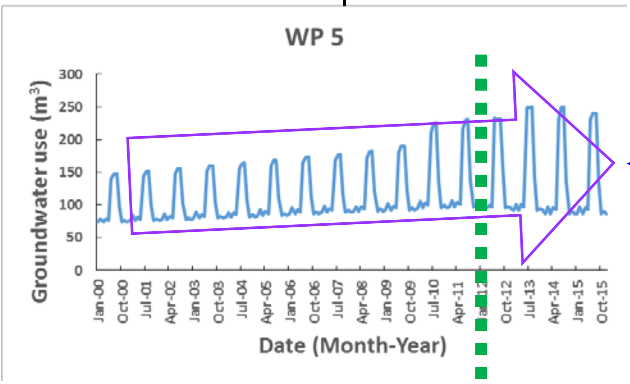
구성	항목	세부항목	비고
지하수 통계	지하수 연보	지하수 조사연보, 지하수 관측연보	홈페이지 정보
	이용통계	지역별 현황, 세부용도별 현황, 유역별 현황, 당해연도 개발	
	허가/신고 현황	-	
	세부용도별 추이	지역별 이용현황추이, 용도별 이용현황추이, 유역별 이용현황 추이	
	이용특성	개발가능량대비, 개발밀도, 공당지하수, 양수능력별, 정호형태별, 토출관직경별, 정호구경별, 정호심도별	
	불용공현황	-	
	수질검사현황	정기수질검사현황, 환경부수질측정망	
	[illegible]	[illegible]연도수위, 연도별 수위	
	[illegible]	[illegible]하수개발·이용 시공업체, 정화업체, 영향조사기관	

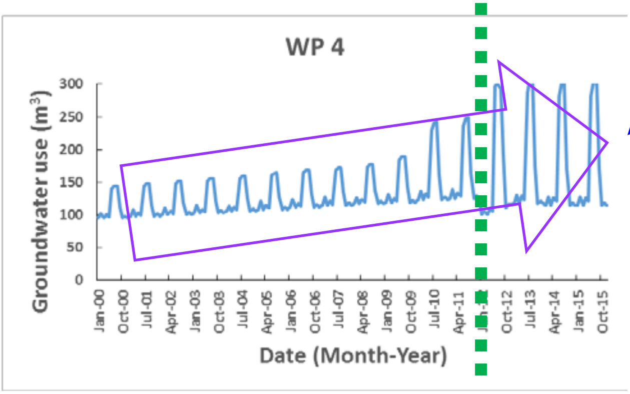
GIMS website (http://www.gims.go.kr)

Materials and Methods

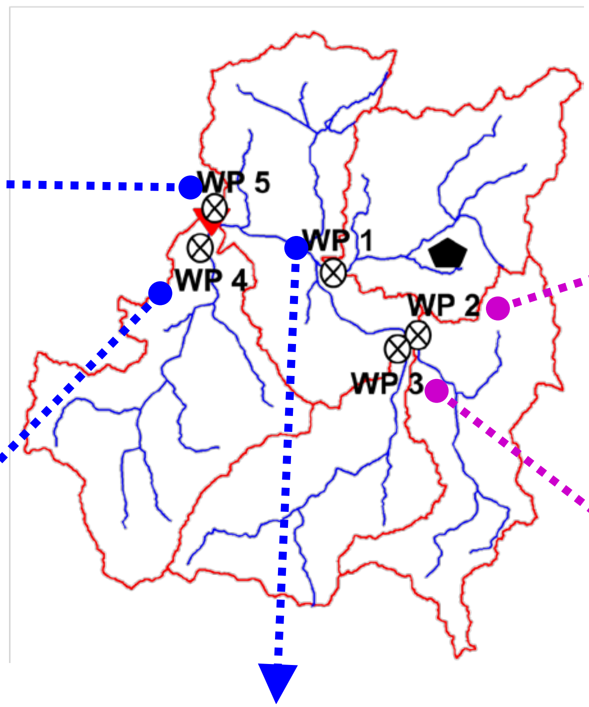
Groundwater use

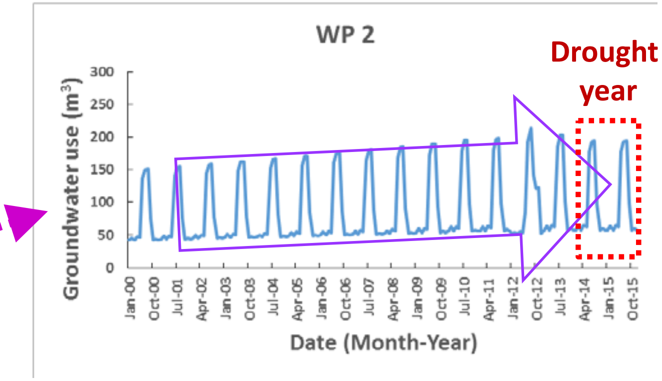
- Using monthly groundwater use records at watching points (WP).
- Data period: 2000-2015

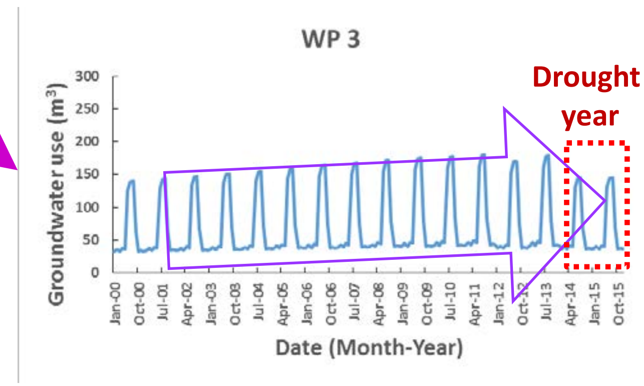


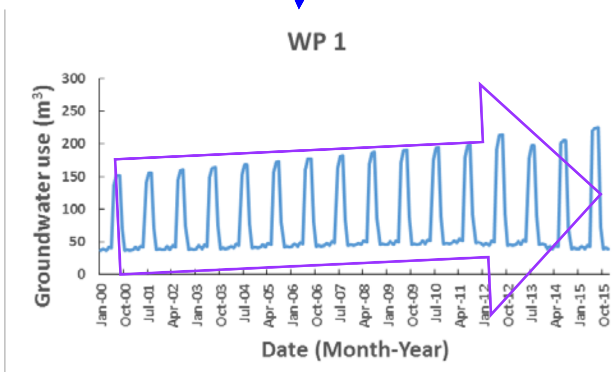


Water curtain house farming increase









Materials and Methods

Return flow

- Return flow is defined as the quantity of water that can be used again and returned to the stream.
- The rate of return has been used in the past as a practice.
- Recently, a lot of research is underway to directly estimate the return flow as planned observation of groundwater facilities and sewage facilities are possible.
- **From domestic and industrial water statistics report, domestic and industrial return flow was calculated in South Korea.**
- **The agricultural return flow rate used recent experimental study in South Korea.**

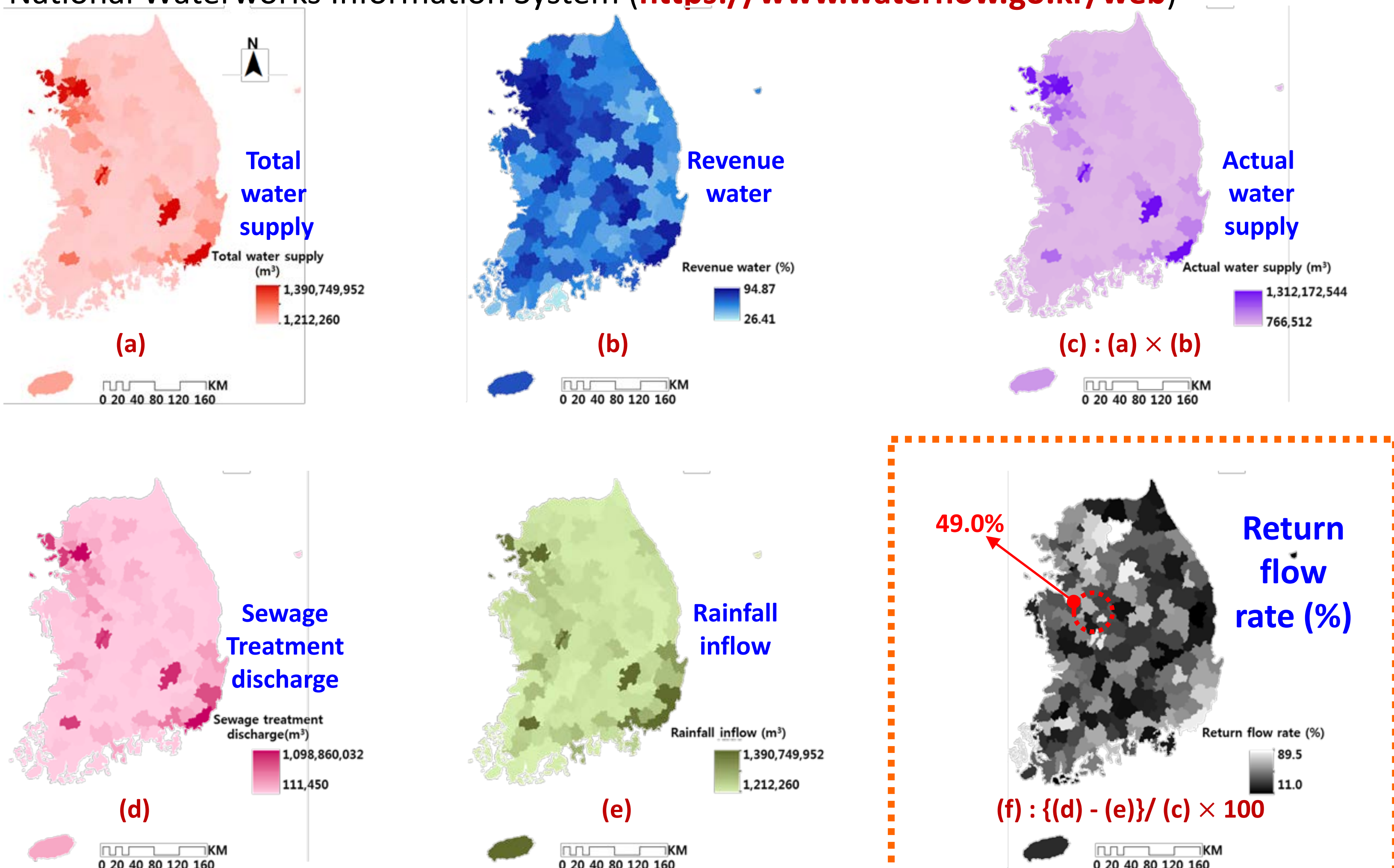
Institution	Site	Period	Experimental plot area (ha)	Agricultural return flow rate (%)
Daejeon Regional Office of Construction Management	Gongju	2003.04 – 2003.09	70.3	40.0
	Yeongi		171.0	38.1
Kangwon University	Eumseong	2002.05 – 2002.09	14.8	18.0
	Chungju		10.6	66.3
	Chuncheon1		7.1	70.8
	Chuncheon2		1.5	53.3

This study area

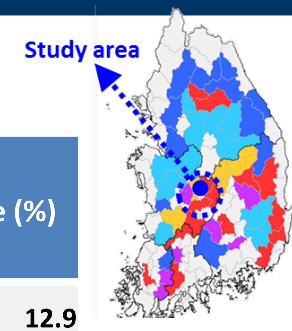
Results

Return flow rate (Domestic water)

- We use **waterworks statistics and sewer statistics reports**.
- National Waterworks Information System (**https://www.waternow.go.kr/web**)



Results



Return flow rate (Industrial water)

Administrative district	Water use (m³)			Wastewater discharge (m³)	Return flow rate (%)
	Waterworks	Groundwater	Stream	Waterworks	
Seoul	31,377,650	3,679,908	464,583,476	64,462,650	12.9
Pusan	82,180,778	3,554,846	194,310,247	177,328,680	63.3
Daegu	57,485,803	12,413,619	355,543,660	144,394,000	33.9
Inchon	63,582,970	1,689,912	84,313,908	28,820,035	19.3
Gwangju	11,018,885	6,427,860	169,274,634	22,736,580	12.2
Ulsan	26,786,046	3,444,919	188,625,217	39,399,925	18.0
Dajeon	227,431,572	7,722,140	239,968,958	288,560,240	60.7
Gyeonggi-do	286,671,196	88,934,980	1,253,848,020	703,467,420	43.2
Kangwon-do	11,394,986	22,086,196	121,308,885	89,001,600	57.5
Chungcheongbuk-do	34,023,577	24,205,935	87,293,956	69,239,405	47.6
Chungcheongnam-do	213,715,258	35,883,425	369,716,069	339,224,430	54.8
Jeollabuk-do	67,726,008	19,072,659	218,176,915	172,520,900	56.6
Jeollanam-do	323,879,232	114,357,578	852,265,437	236,392,615	18.3
Gyeongsangbuk-do	197,374,448	32,269,068	263,928,192	437,038,590	88.5
Gyeongsangnam-do	47,695,013	29,251,090	458,566,536	127,826,285	23.9

study area

Results

Modification of SWAT model code

- We add the **return flow rate (*Rate$_{returnflow}$*)** by **domestic, industrial, and agricultural water** in shallow aquifer equation.

$$aq_{sh,i} = aq_{sh,i-1} + w_{rchrg} - Q_{gw} - w_{revap} - w_{pump,sh} \times \boldsymbol{Rate_{returnflow}}$$

- The modified code can read **groundwater use** text file by domestic, industrial, and agricultural water files.
- SWAT simulates average monthly water use (wus file).
- In this study, we modified **readwus file** for applying **monthly groundwater use per year**.

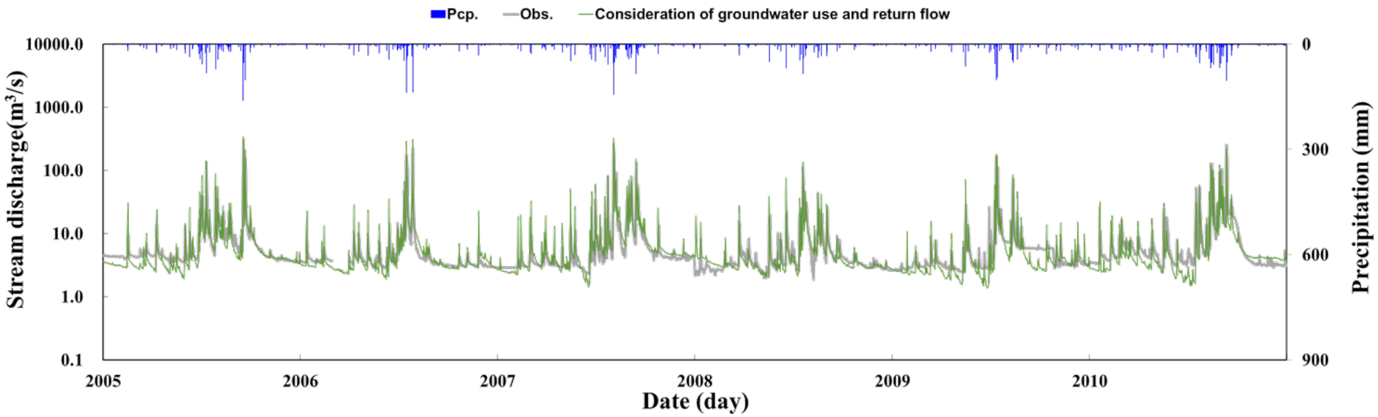
```
if (yrs == 0) then
    do j = 1, hrutot(i)
        ihru = 0
        ihru = nhru + j
        do mon = 1, 12
            wushal(mon,ihru) = swush(mon)
        end do
    end do
else if (yrs == 1) then
    do j = 1, hrutot(i)
        ihru = 0
        ihru = nhru + j
            do mon = 1, 12
                wushal(mon,ihru) = swush(mon+12)
            end do
    end do
else if (yrs == 2) then
    do j = 1, hrutot(i)
        ihru = 0
        ihru = nhru + j
            do mon = 1, 12
                wushal(mon,ihru) = swush(mon+24)
            end do
    end do
```

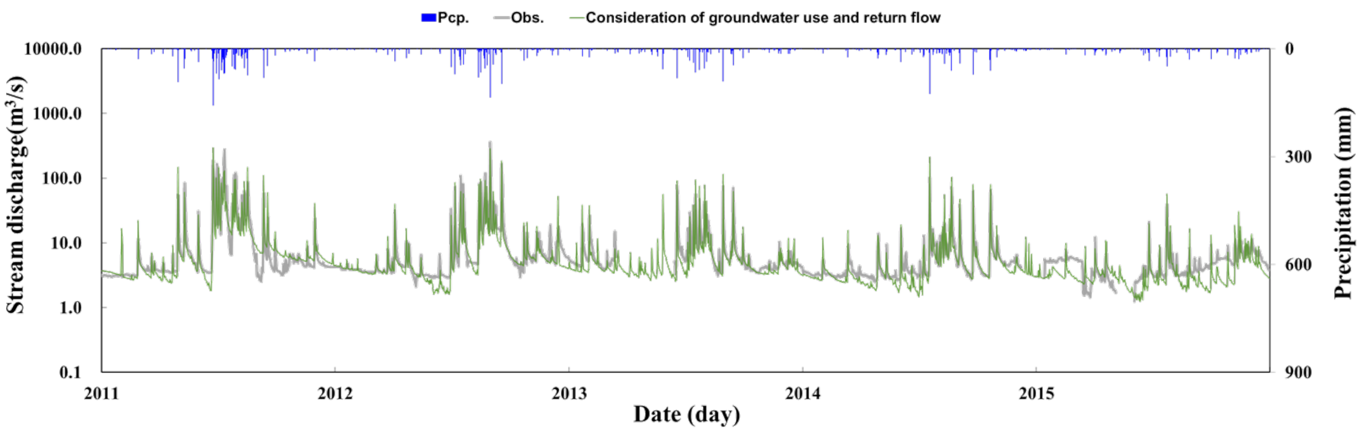
Add code

Results

Model simulation for streamflow

- Using daily discharge records at outlet **with groundwater use and return flow rate**.
- Calibration period: **2005-2010** / Verification period: **2011-2015**



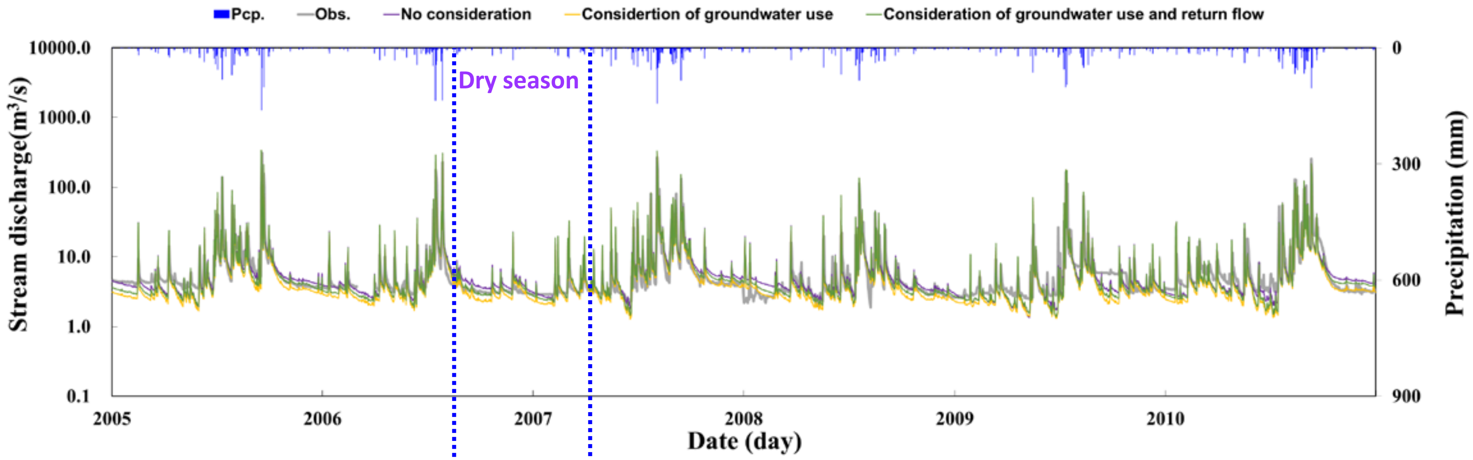


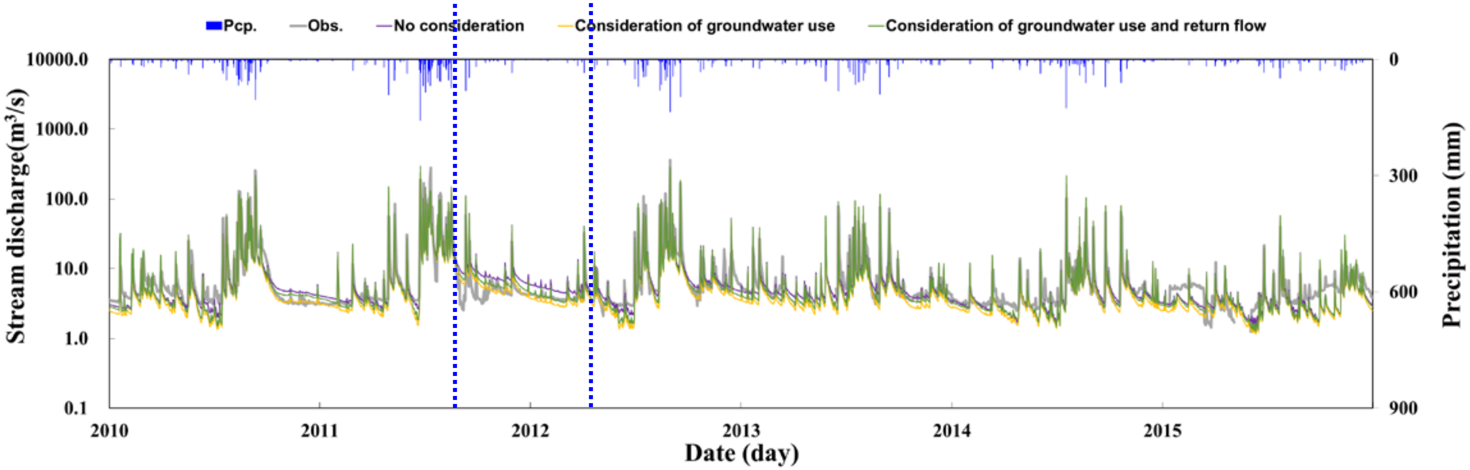
Year	Runoff rate (%)		R^2	NSE	RMSE (mm/day)
	Obs.	Sim.			
2005	70.7	68.7	0.59	0.55	1.38
2006	63.0	68.7	0.86	0.75	3.28
2007	56.9	65.5	0.73	0.67	7.03
2008	66.7	68.2	0.77	0.70	0.70
2009	65.5	61.3	0.72	0.60	2.19
2010	78.9	67.0	0.88	0.87	8.64
2011	78.3	71.1	0.63	0.61	6.96
2012	85.6	71.0	0.85	0.83	10.29
2013	59.9	64.7	0.70	0.55	2.80
2014	59.5	60.4	0.80	0.66	1.01
2015	60.7	55.0	0.70	0.60	1.47
Mean	64.6	66.5	0.73	0.67	2.92

Results

Comparison of streamflow

- No consideration of groundwater use and return flow (**scenario1**).
- Consideration of groundwater use (**scenario2**).
- **Consideration of groundwater use and return flow** (**scenario3**).





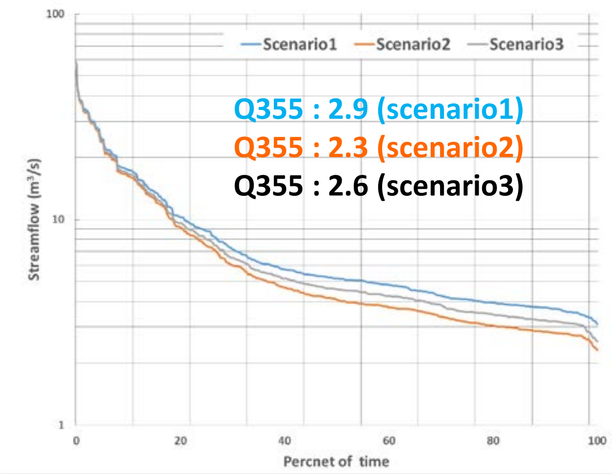
Scenario	R^2	NSE	RMSE (mm/day)
Scenario1	0.70	0.62	4.14
Scenario2	0.68	0.24	3.96
Scenario3	0.73	0.65	2.92

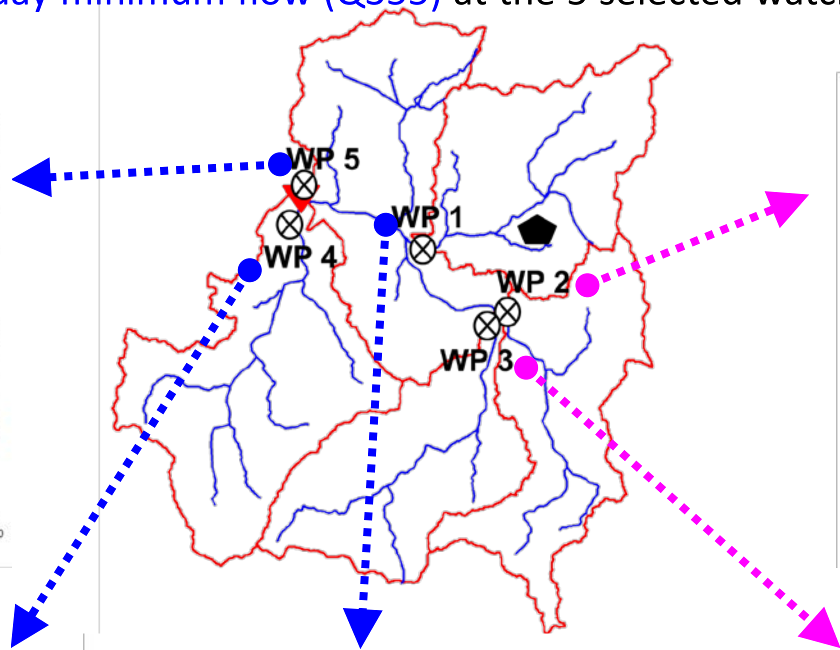
Results

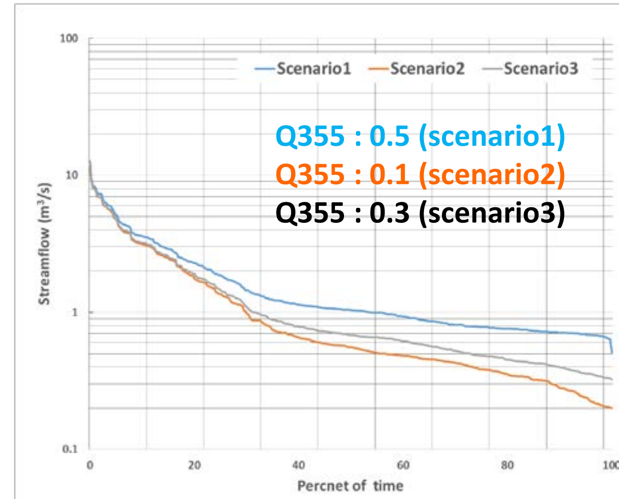
Evaluation of flow duration analysis

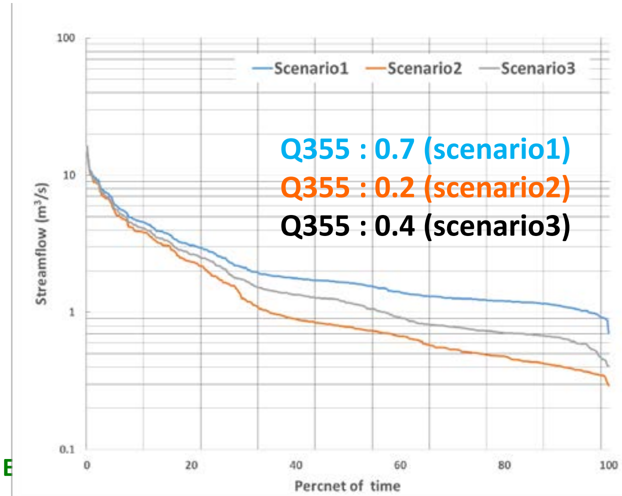
- No consideration of groundwater use and return flow (scenario1).
- Consideration of groundwater use (scenario2).
- Consideration of groundwater use and return flow (scenario3).

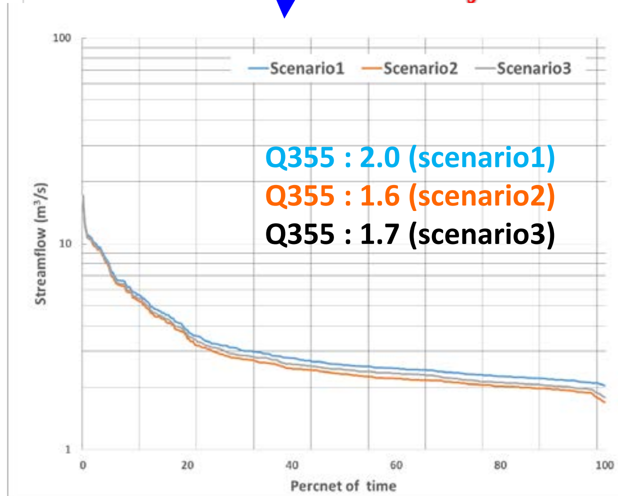
❖ Volume change of 10 day minimum flow (Q355) at the 5 selected watching points between through the flow duration analysis.

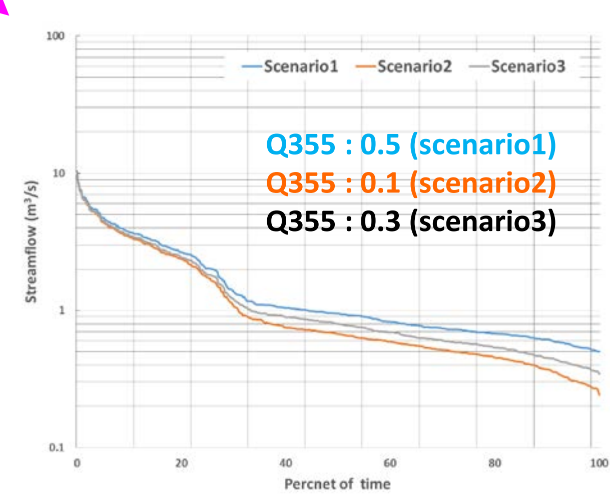












Results

Estimation index of drying stream progress

- Evaluation of drying stream severity was suggested by **drying stream index (DSI)**.
- It can shows **simply current states of drying stream**.
- The **10 day minimum flow (Q355) when groundwater use and return flow didn't considered** was defined as **standard flow (scenario 1)**.
- Calculate the **number of flow occurrences** that is **less than the standard flow** for each scenario.

DSI	Drying Stream Progress	Condition	Comments
1	D≤10	Normal	-
2	10<D≤30	Weak	Concern monitoring
3	10<D≤30	Warning	Keep watch carefully
4	60<D≤90	Severe	Require short-term improvement
5	90<D	Very severe	Require long-term improvement

Results

Estimation of DSI Scenario 2 : consideration of groundwater use / Scenario 3 : consideration of groundwater use and return flow

Date	DSI at WP 1		DSI at WP 2		DSI at WP 3		DSI at WP 4		DSI at WP 5	
	Sce.2	Sce.3	Sce.2	Sce.3	Sce.2	Sce.3	Sce.2	Sce.3	Sce.2	Sce.3
2005	5	3	5	3	4	2	5	2	5	3
2006	5	4	5	5	5	3	5	3	5	4
2007	5	5	4	3	3	3	5	4	4	4
2008	5	4	5	4	5	3	5	3	5	4
2009	5	5	5	5	5	5	5	5	5	5
2010	5	5	5	4	4	3	5	4	5	4
2011	4	3	5	3	3	2	5	2	4	3
2012	3	3	5	2	3	2	4	2	3	3
2013	4	2	5	1	2	1	4	1	4	2
2014	5	5	5	5	5	4	5	5	5	5
2015	5	5	5	5	5	5	5	5	5	5

Results

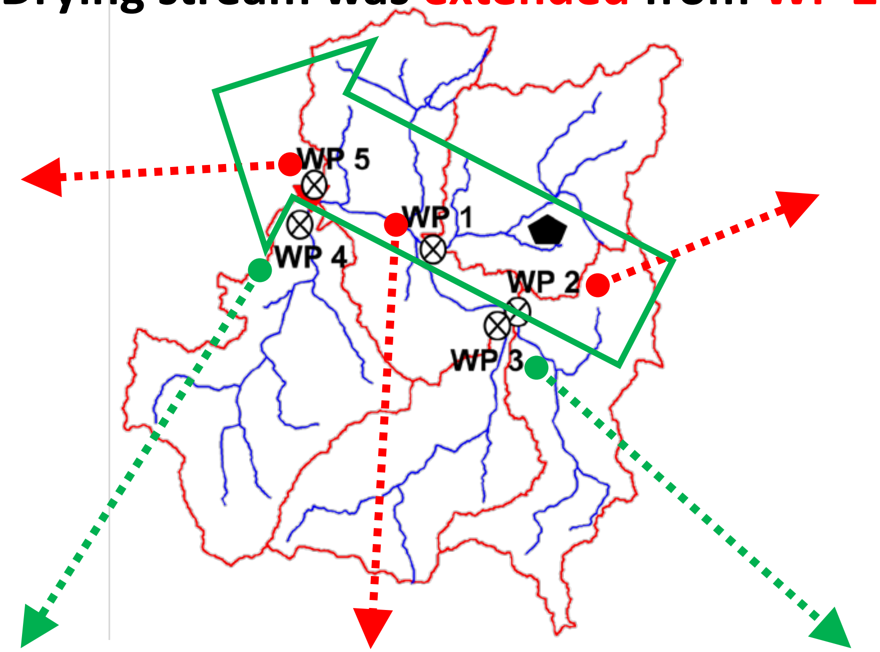
Estimation of DSI

- No consideration of groundwater use and return flow (scenario1).
- Consideration of groundwater use (scenario2).
- Consideration of groundwater use and return flow (scenario3).

Drying stream was extended from WP 2

Date	DSI		
	Sce.1	Sce.2	Sce.3
Mean (2005-2015)	3	5	4

Date	DSI		
	Sce.1	Sce.2	Sce.3
Mean (2005-2015)	1	5	4



Date	DSI		
	Sce.1	Sce.2	Sce.3
Mean (2005-2015)	1	5	3

Date	DSI		
	Sce.1	Sce.2	Sce.3
Mean (2005-2015)	2	5	4

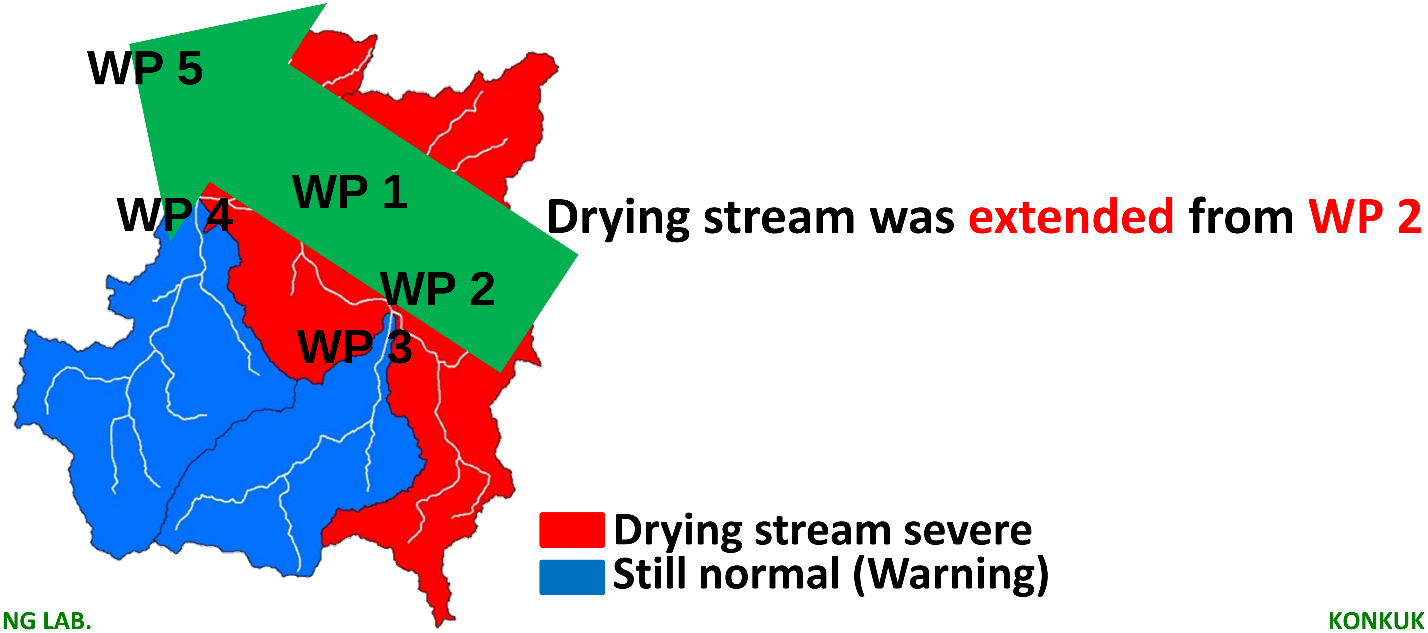
Date	DSI		
	Sce.1	Sce.2	Sce.3
Mean (2005-2015)	2	4	3

Summary and Conclusion

- This study tried to identify the drying stream phenomena through tracing the flow decrease by continuous long-term hydrologic routing under groundwater use conditions.

- From the results of the SWAT model, the specific locations and streams affected by groundwater use and return flow impact are to be identified.

- The SWAT was calibrated for 6 year (2005-2010) daily streamflow data at actual drying stream area and verified with another 5 years (2011-2015) data with consideration of groundwater use and return flow.
  - The average coefficient of determination (R^2; Legates and McCabe, 1999) and the Nash-Sutcliffe model efficiency (NSE; Nash and Sutcliffe, 1970) for streamflow were 0.73 and 0.67 respectively.



Thank you

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