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Improvement and Application of SWAT Model for Irrigation Water Supply in Agricultural Reservoir of South Korea

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Jong-Yoon Park / Rim Ha / So-Ra Ahn / Sang-Ho Kim / Seong-Joon Kim*

Earth Information Engineering Laboratory
Department of Civil and Environmental System Engineering
Konkuk University, Republic of Korea

Outline

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    - Improvement of SWAT2009 reservoir module
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4. **SWAT Application**
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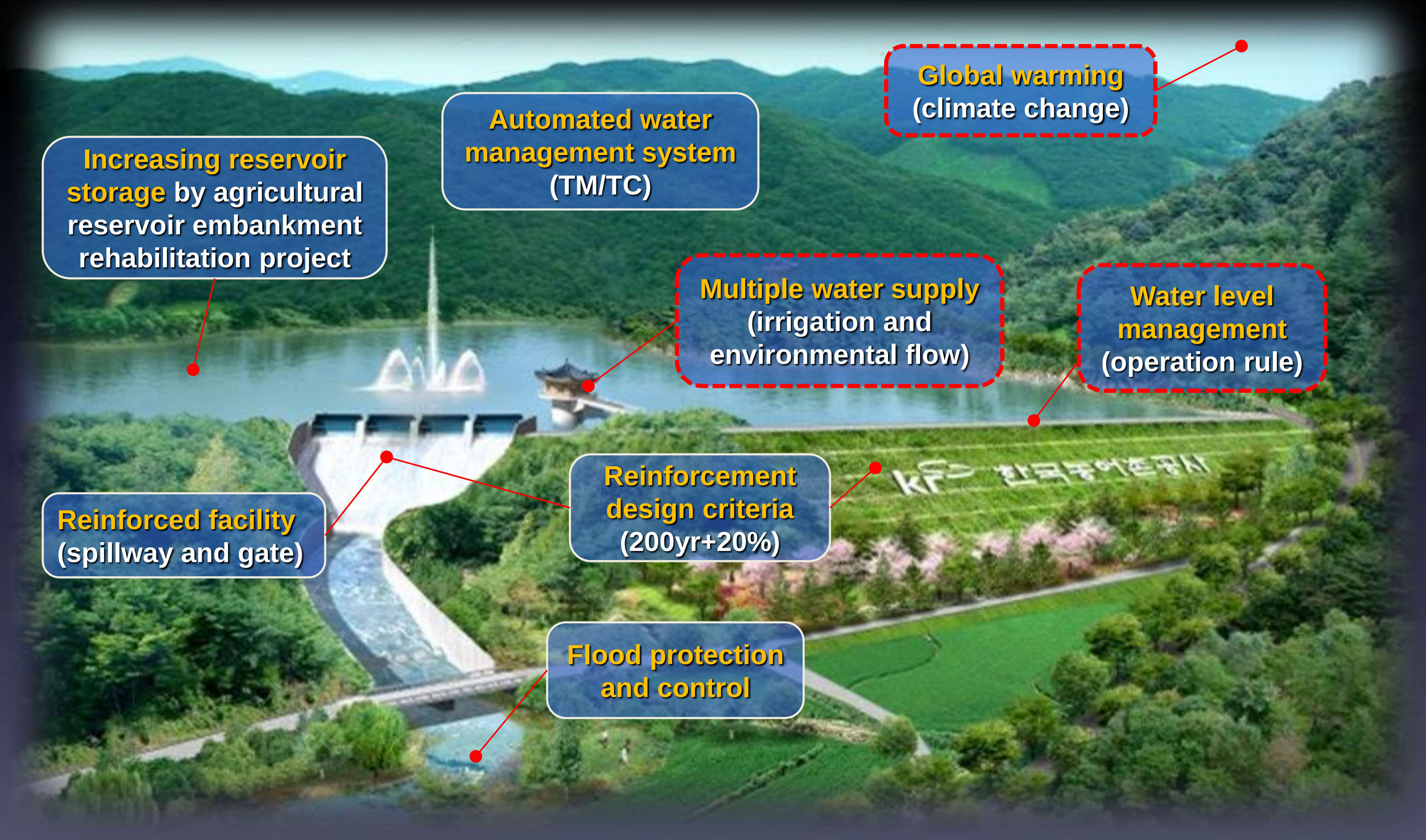
    - Model calibration and validation
    - Applications to climate change adaptation and new opportunity

      - rice phenology, storage reallocation, operating rule curve, environmental flow
5. **Concluding Remarks**

Key issue

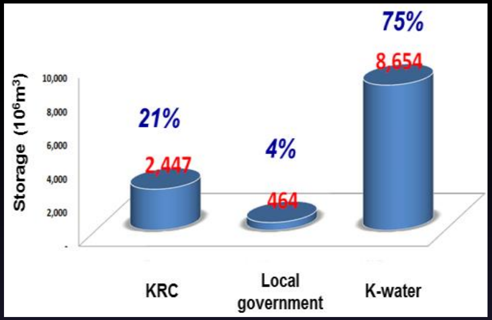
✓ Changing paradigm in water management of agricultural reservoir

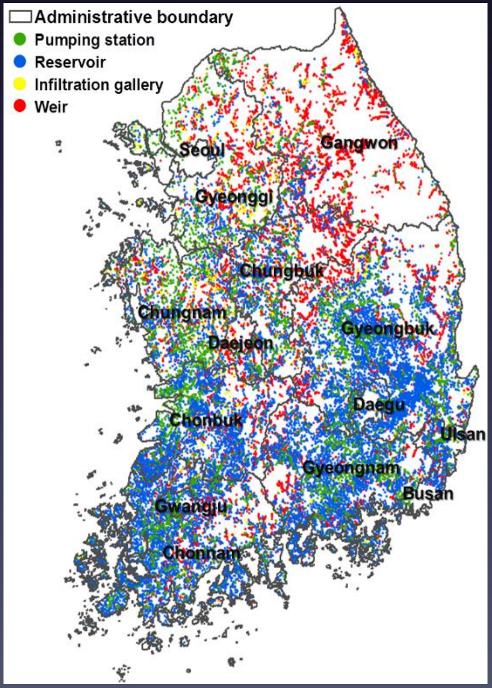


Background

✓ **Key issues in our agricultural water resources can be summarized as follows:**

- South Korea has a high dependency on fresh water resources such as reservoirs and lakes.
- Climate change will affect Korean water resources through its impact on the quantity, variability, timing, form, and intensity of precipitation.
- In terms of agriculture, climate change will affect irrigation water demand of rice via changes in rice physiology and phenology, soil water balances, evapotranspiration, and effective rainfall.
- The agricultural reservoir needs a new operation strategy and water management for the both irrigation water and environmental flow.
- In order to assess the climate change impact on watershed hydrology, integrated watershed models such as SWAT are needed to apply irrigation systems by reservoir operation.





Objective

✓ SWAT2009

- Using the study case of an agricultural reservoir watershed, it was shown that the current original SWAT2009 version is not able to appropriately evaluate the reservoir performance in such a system when it worked as a multiple purpose to supply water for irrigation and environmental flow
- Application of the original version in agricultural reservoir watersheds using farmer's irrigation practices was not possible because the excess irrigation depths are returned to the stream through the drainage canal system

✓ The purpose of this study is…

- to add the reservoir simulation option in the current reservoir simulation module of the SWAT2009 version for correctly simulating the multiple water supply system of agricultural reservoir based on operating rule

IWRM development

✓ Irrigation Water Requirement Model (IWRM)

- IWRM was developed for the purpose of calculating the daily-based irrigation water requirement in rice paddy fields.
- IWRM is a computer program for the calculation of crop water requirements and irrigation requirements based on climate, crop, soil, and water loss condition.
- The program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.
- IWRM can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both irrigated and partially irrigated conditions.

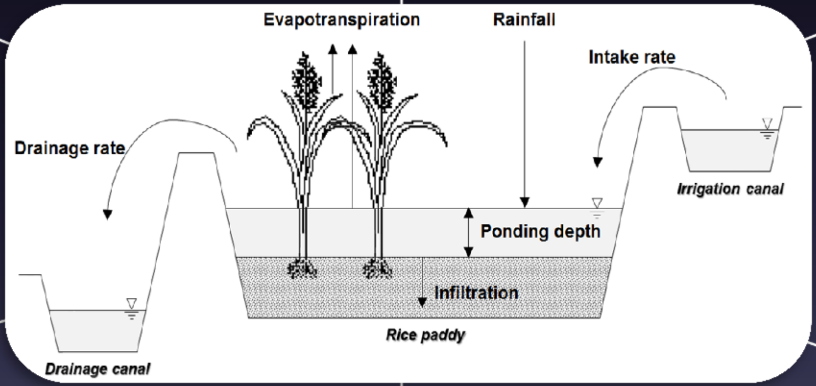
IWRM components

✓ **Irrigation water requirement in paddy fields**

Evapotranspiration
(Penman–Monteith method)

Infiltration
(paddy field)

Crop coefficient
(for rice paddy)

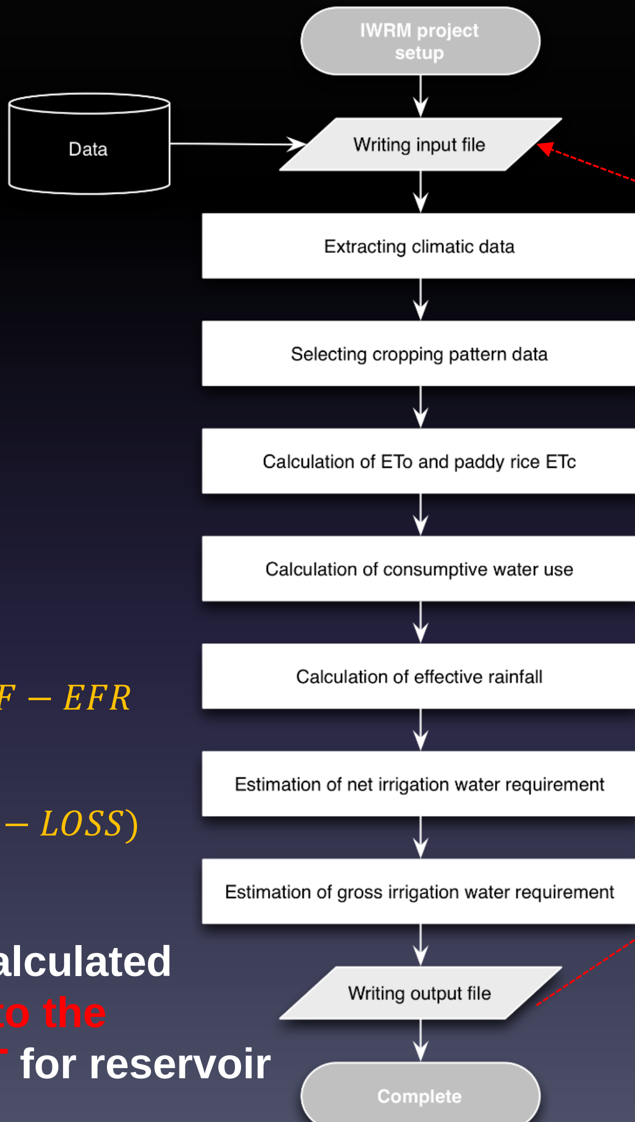


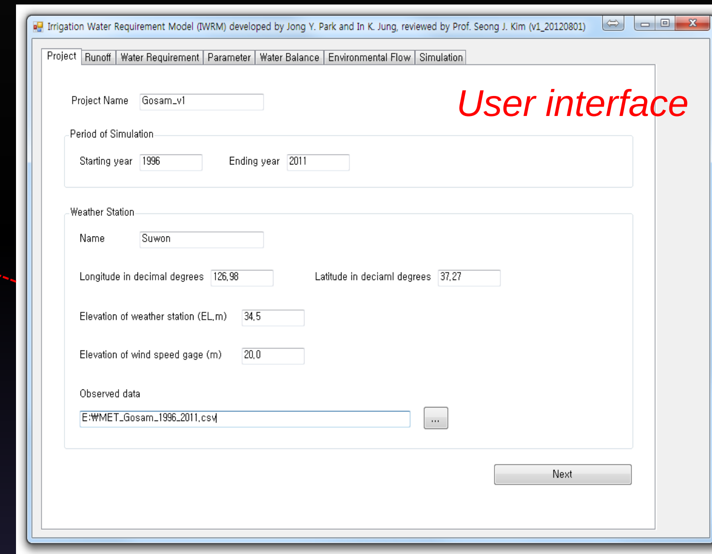
Loss rate
(conveyence, management)

Rice phenology
(irrigation schedule)

Cultivation and
management water

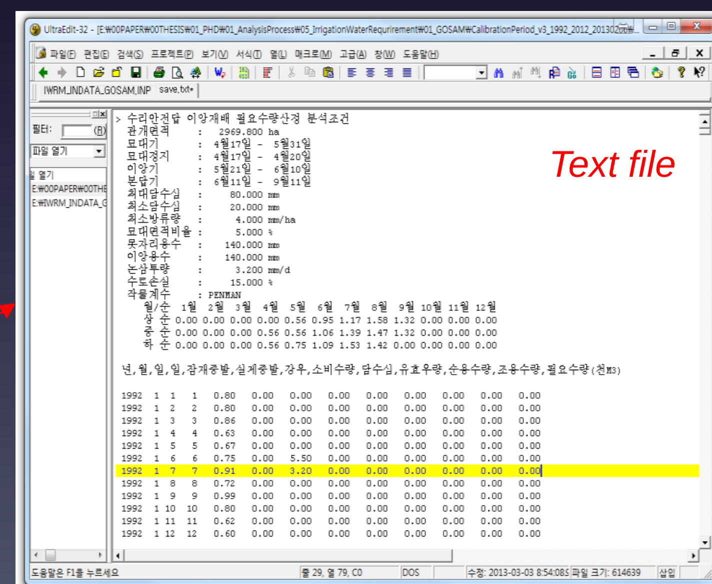
IWRM simulation





$$NIWR = ET_c + INF - EFR$$

$$GIWR = NIWR/(1 - LOSS)$$



The resulting calculated GIWR inputs into the improved SWAT for reservoir simulation

SWAT improvement

✓ **The improvement of SWAT in order to suit the actual situation in agricultural reservoir watersheds of South Korea contains four aspects:**

1) simulating the auto-irrigation according to the SWAT coupling with the calculated irrigation water from irrigation water requirement model (IWRM)
2) applying the restricted water level (RWL) for multiple water supply
3) incorporating the operation rules of the reservoir such as order, timing and volume of water supplies into the reservoir module of SWAT
4) considering the irrigation return flow that contribute to streamflow

SWAT improvement

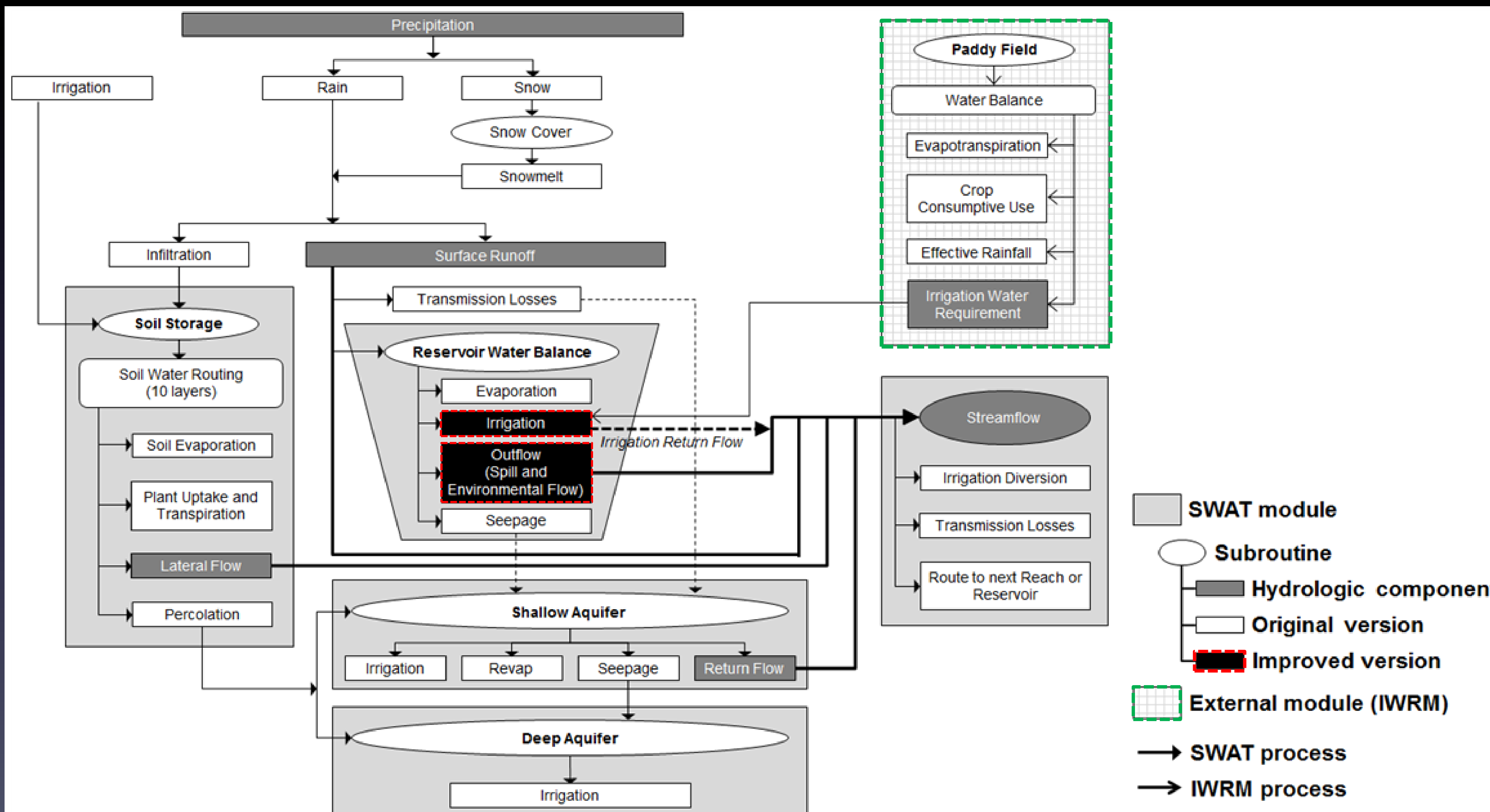
✓ Reservoir control module

- For the multiple water supply, a new method is needed in the reservoir control module of the model.
- The volume of outflow may be calculated using one of four different methods in the reservoir control module (IRESCO) of the original SWAT model.

Method	IRESCO	Requirement
Existing (original ver.)	0	compute outflow for uncontrolled reservoir with average annual release rate (m^3/s)
	1	measured monthly outflow (m^3/s)
	2	simulated controlled outflow-target release (m^3/s)
	3	measured daily outflow (m^3/s)
Added (improved ver.)	4	calculated daily irrigation water requirement (10^3m^3), and environmental flow rate (m^3/s)

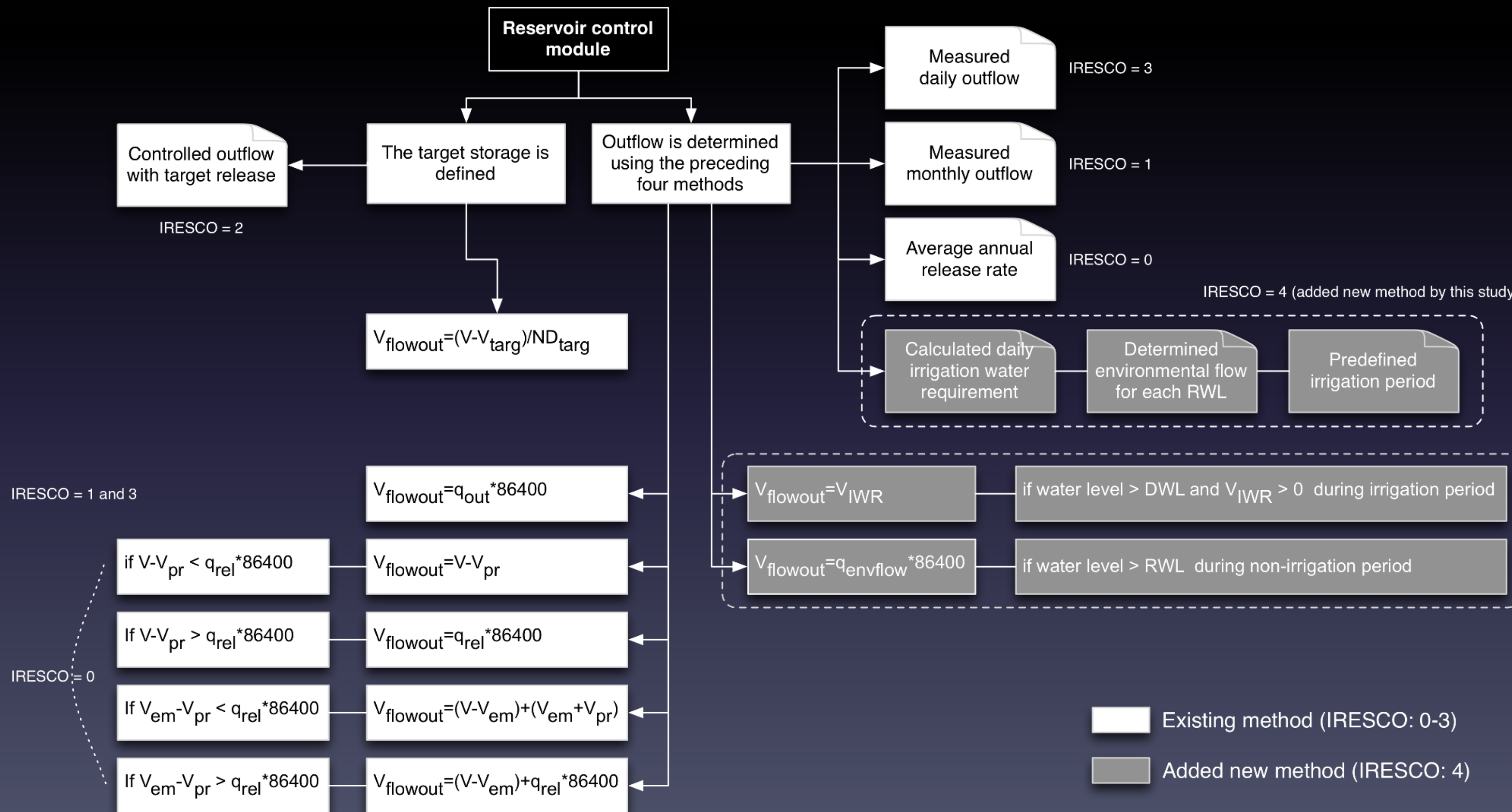
SWAT improvement

✓ **Paddy water movement in SWAT**



SWAT reservoir simulation

✓ **Volume of outflow**



SWAT reservoir simulation

- ✓ **Irrigation period**

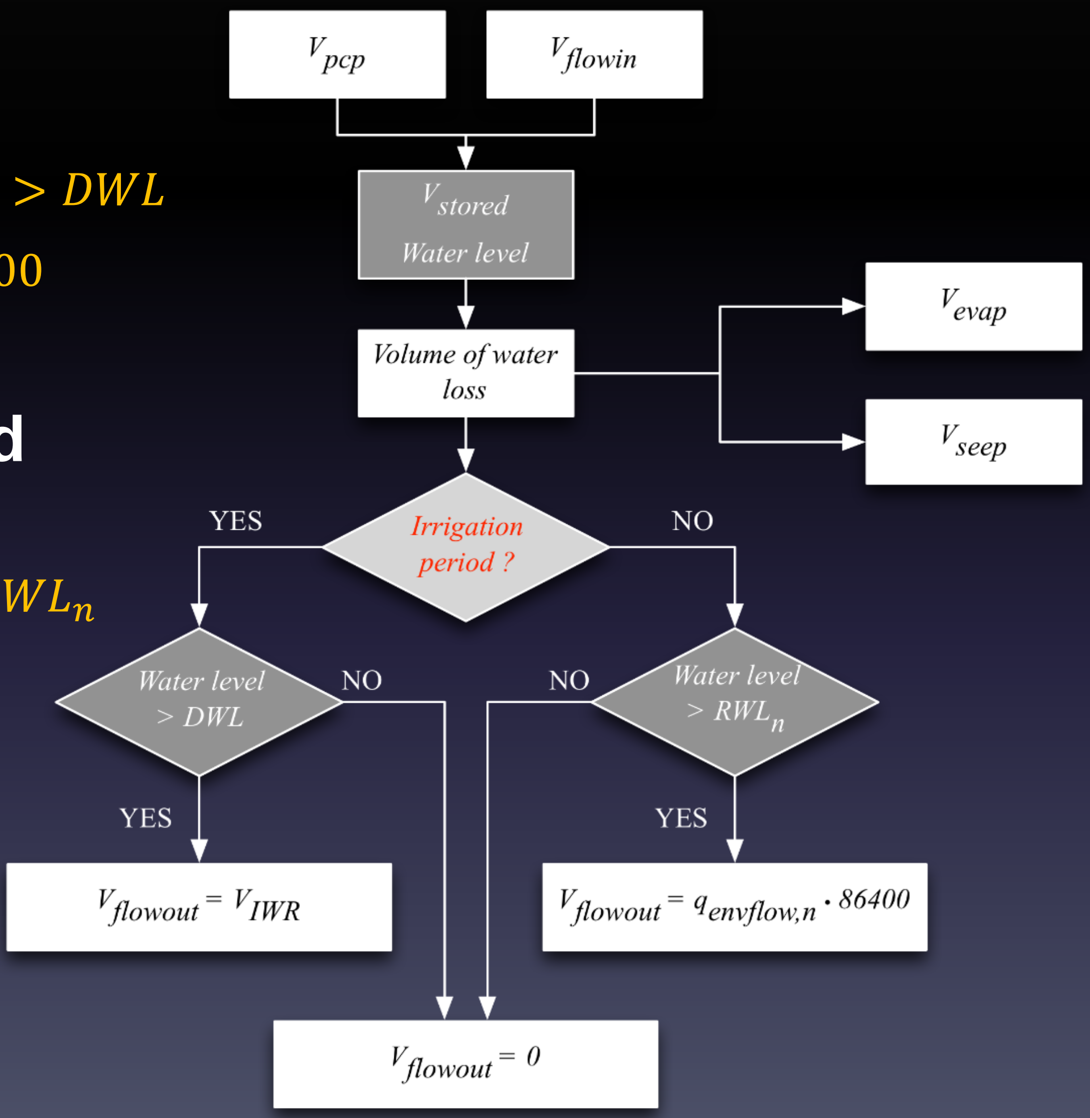
$$V_{flowout} = V_{IWR} \quad if\ water\ level\ > DWL$$

$$q_{IWR,return} = (V_{IWR} \cdot IWR_k)/86400$$

- ✓ **Non-irrigation period**

$$V_{flowout} = q_{envflow,n} \cdot 86400 \quad if\ water\ level\ > RWL_n$$

RWL_n is the restricted water level (EL.m) for environmental water supply, which is possible to set up to five by user within the range from DWL to HWL

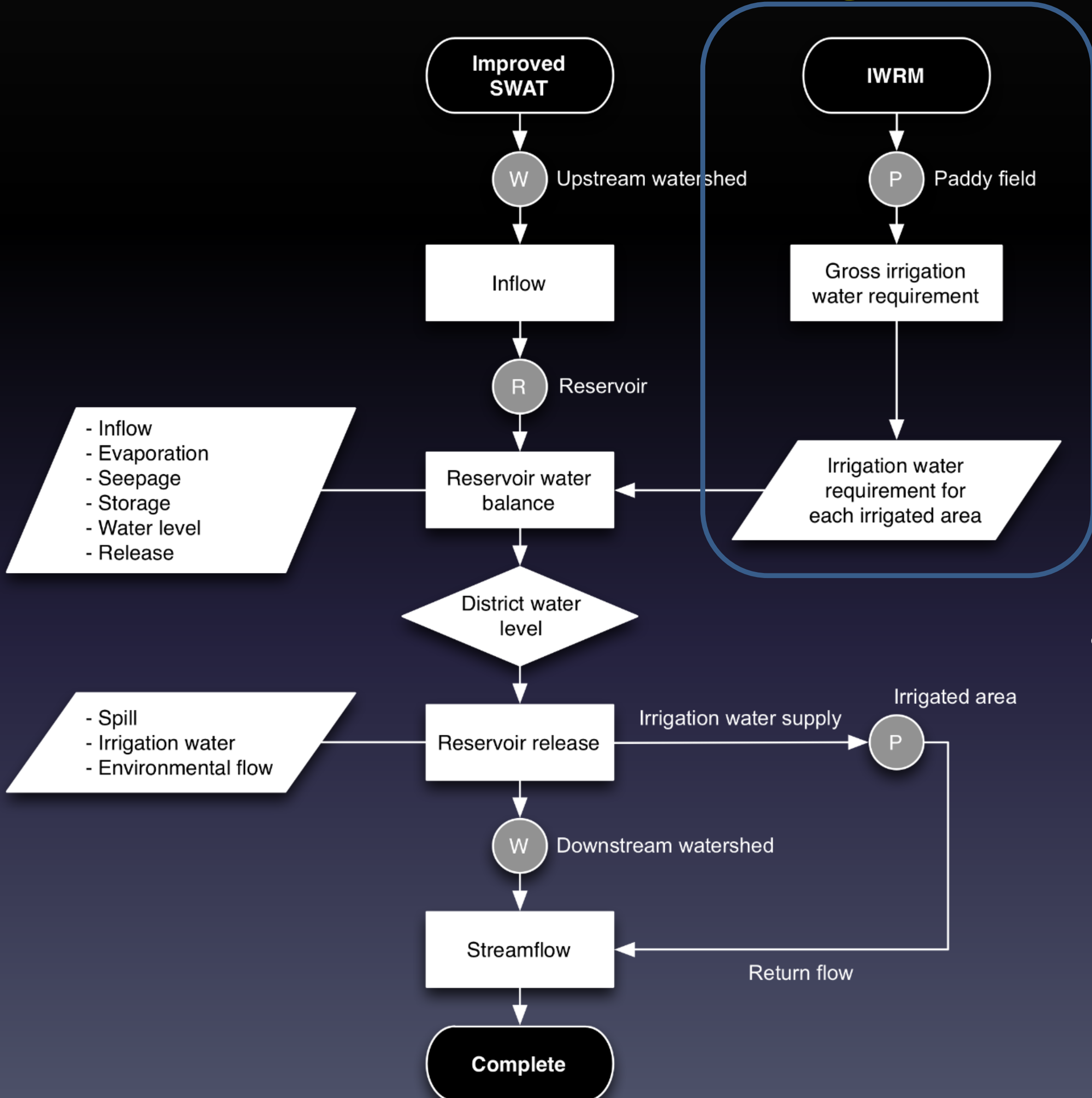


SWAT new parameters

✓ **Input and output data sets of reservoir module in the improved SWAT model**

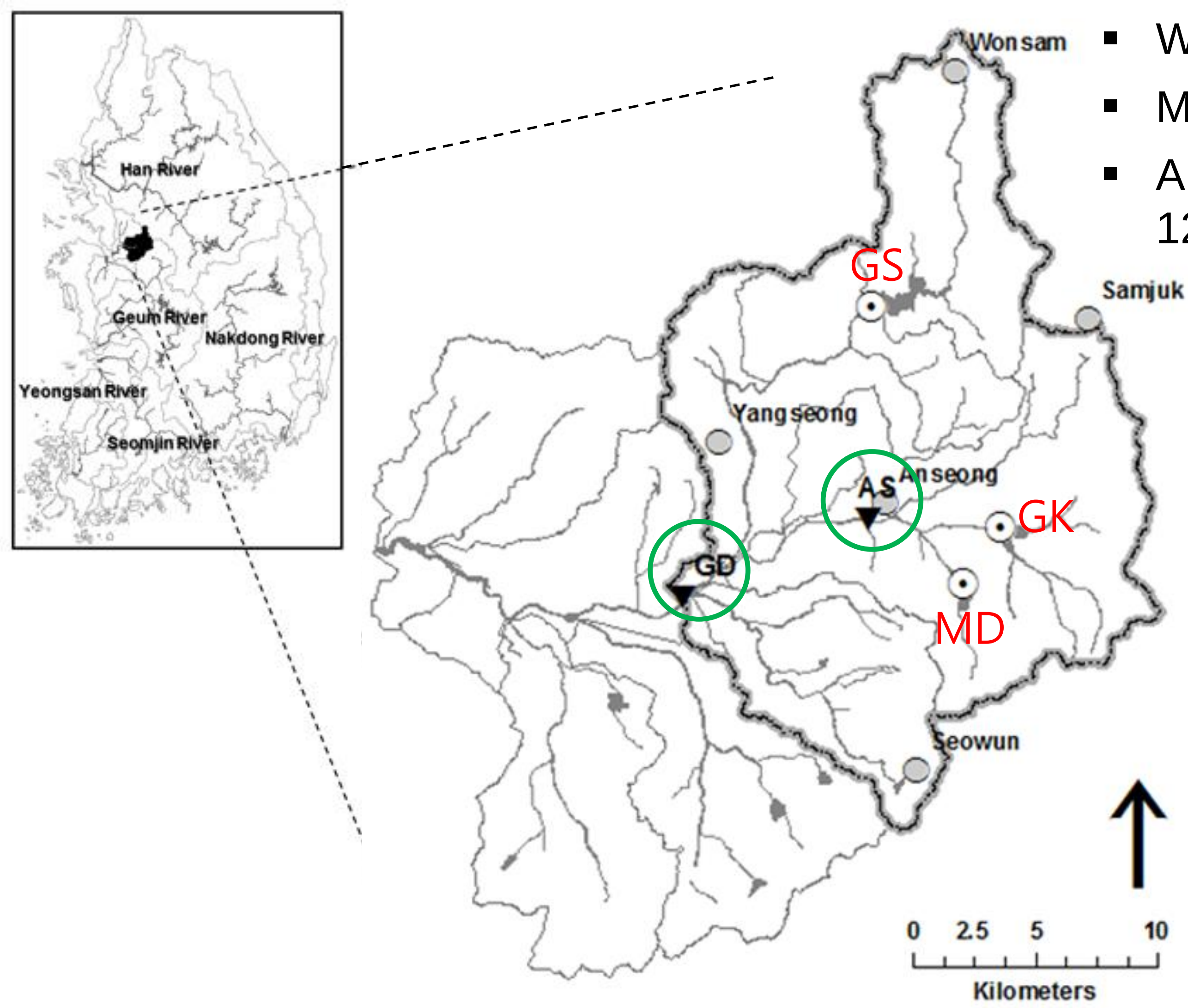
Data	Added input	Added output
Reservoir characteristics	▪ Relation curve between water level (EL.m) and storage capacity ($10^3 m^3$) ▪ HWL and DWL (EL.m)	▪ Water level on day (EL.m) ▪ Irrigation water requirement on day (m^3) ▪ Irrigation return flow on day (m^3/s) ▪ Environmental flow on day (m^3)
Irrigation water	▪ beginning and ending dates of irrigation period (mm/dd-mm/dd) ▪ Daily irrigation water requirement ($10^3 m^3$) calculated by IWRM ▪ Irrigation return flow fraction (0-1)	
Environmental flow	▪ RWL (EL,m) ▪ Environmental flow rate for each RWL	

SWAT modeling approach



- Watershed water balance using improved SWAT coupled with the IWRM models is performed by considering the relationship between upstream, downstream, and reservoir
- The improved SWAT and IWRM models were linked so that output from the IWRM became input for the improved SWAT model

Study area



- Watershed area: 364 km^2
- Mean temperature: 11.5℃
- Annual mean precipitation: 1295.1 mm

Paddy: 24.7%
Upland crop: 14.1%
Forest: 44.7%

Agricultural reservoirs

✓ **The reservoirs physical characteristics data**

Characteristics		Unit	Reservoir		
			Gosam (GS)	**Geumkwang (GK)**	**Madun (MD)**
Area	Watershed area	ha	7,100	4,830	1,240
	Irrigated area	ha	2,970	1,906	530
	Area of full water	ha	230	138.4	40.5
Storage	Gross storage	10^3m^3	16,105	12,095	3,496
	Effective storage	10^3m^3	15,217	12,047	3,486
	Dead storage	10^3m^3	888	48	10
Water level	FWL	EL.m	54.1	67.7	120.8
	HWL	EL.m	52.4	67.0	119.1
	DWL	EL.m	40.8	51.5	102.0
Dam	Constructed year	-	1963	1961	1975
	Type	-	Fill dam	Fill dam	Fill dam

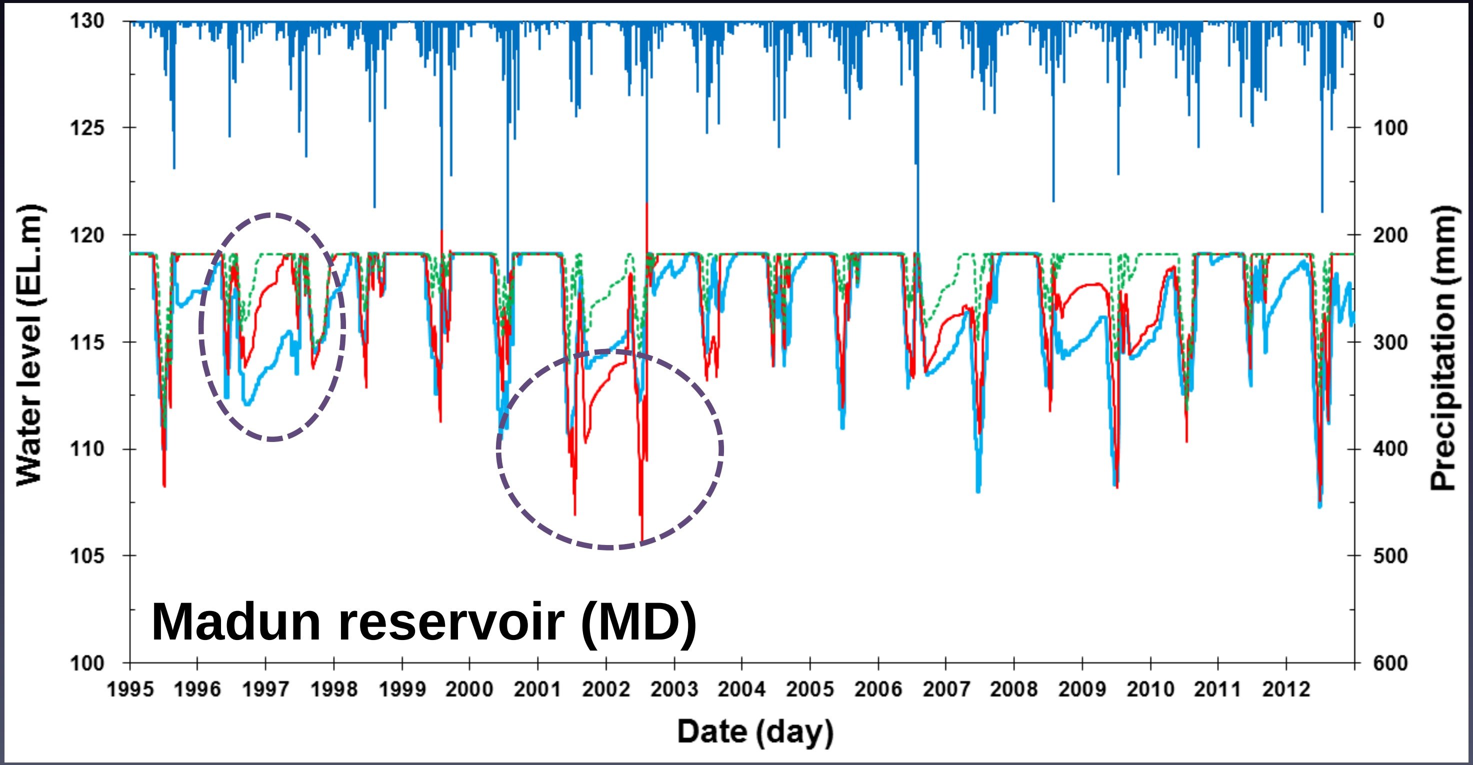
Data for SWAT evaluation

Data	R/S/P	Description	Source
Geographical data			
Topography	30 m	Digital elevation model (DEM)	KNGI
Land use	1:25,000	Landsat land use classification (seven classes)	KME
Soil	1:25,000	Soil classification and physical properties, e.g., texture, porosity, field capacity, wilting point, saturated conductivity, and depth	KRDA
Measured data			
Weather	1980-2012	Daily precipitation (mm), minimum and maximum temperature (℃), mean wind speed (m/s), and relative humidity (%) data	KMA
Rainfall	1980-2012	Daily precipitation data (mm)	WAMIS
Reservoir water level	1995-2012	Daily reservoir water level data (EL.m) and it was converted to storage volumes (m^3)	KRC
Discharge	1998-2012	Daily water level data (EL.m) and it was converted to streamflow (m^3/s)	HRFCO

SWAT reservoir simulation results

✓ Evaluation of reservoir operation

- The Hydrological Operation Model for Water Resources System (HOMWRS) which developed by the Korea Rural Community Corporation (1998) was adopted for the comparison of reservoir operation.



SWAT reservoir simulation results

✓ **Water balance**

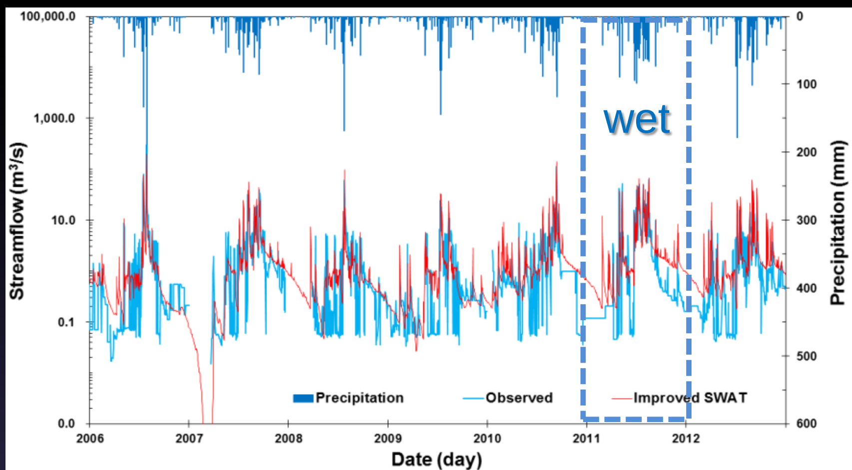
Reservoir	Model	Reservoir water balance ($10^3 m^3$)			
		INFLOW	IWR	WB	SPILL
Gosam	HOMWRS	67,719	20,716	47,003	50,465
	Improved SWAT	65,156	18,311	46,845	35,792
		(-3.8)	(-11.6)	(-0.3)	(-29.1)
Geumkwang	HOMWRS	42,075	9,750	32,325	35,066
	Improved SWAT	43,319	12,109	31,211	22,335
		(+3.0)	(+24.2)	(-3.4)	(-36.3)
Madun	HOMWRS	9,672	3,685	5,987	6,565
	Improved SWAT	9,905	3,408	6,908	7,987
		(+2.4)	(-7.5)	(+15.4)	(+21.7)

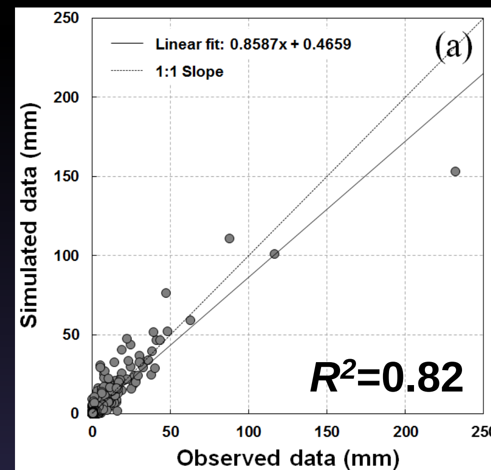
SWAT reservoir simulation results

Reservoir	Evaluation criteria	Observed	Simulated	
			HOMWRS	Improved SWAT
Gosam	Mean storage, *V*	0.81	0.94	0.89
	Mean *V* at 1 Apr.	0.97	1.00	0.99
	Mean *V* at 30 Sep.	0.76	0.92	0.87
	NSE		0.05	0.50
	R^2		0.50	0.68
Geumkwang	Mean storage, *V*	0.73	0.97	0.86
	Mean *V* at 1 Apr.	0.89	1.00	0.95
	Mean *V* at 30 Sep.	0.70	0.96	0.85
	NSE		-0.98	0.23
	R^2		0.36	0.61
Madun	Mean storage, *V*	0.75	0.93	0.82
	Mean *V* at 1 Apr.	0.90	0.99	0.94
	Mean *V* at 30 Sep.	0.73	0.91	0.83
	NSE		-0.20	0.62
	R^2		0.50	0.74

SWAT model calibration results

✓ **Streamflow at AS station**





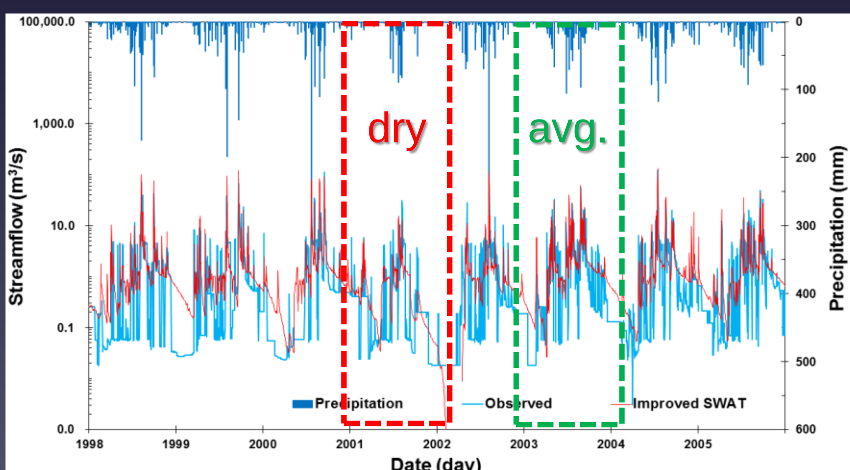
Calibration period

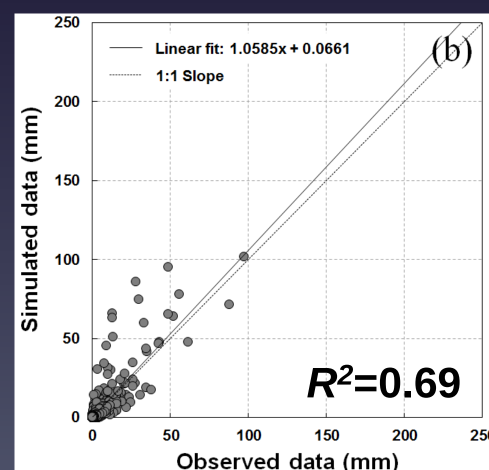
: 2006-2012 (7yrs)

Runoff ratio (%)

: 43.0 (obs.)

: 48.7 (sim.)





Validation period

: 1998-2005 (8yrs)

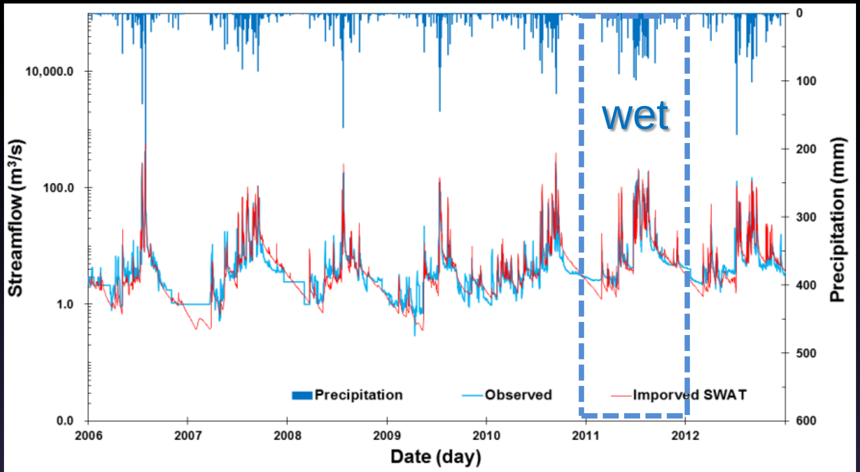
Runoff ratio (%)

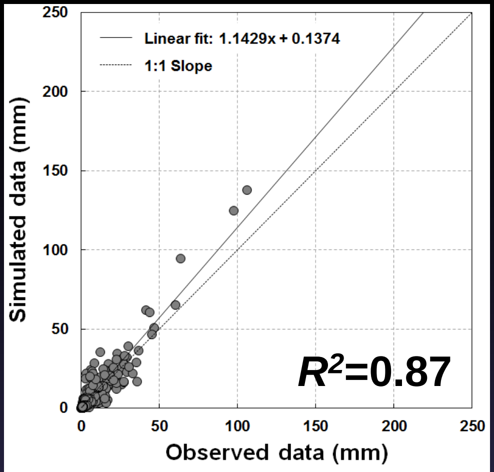
: 40.6 (obs.)

: 44.3 (sim.)

SWAT model calibration results

✓ Streamflow at GD station (watershed outlet)





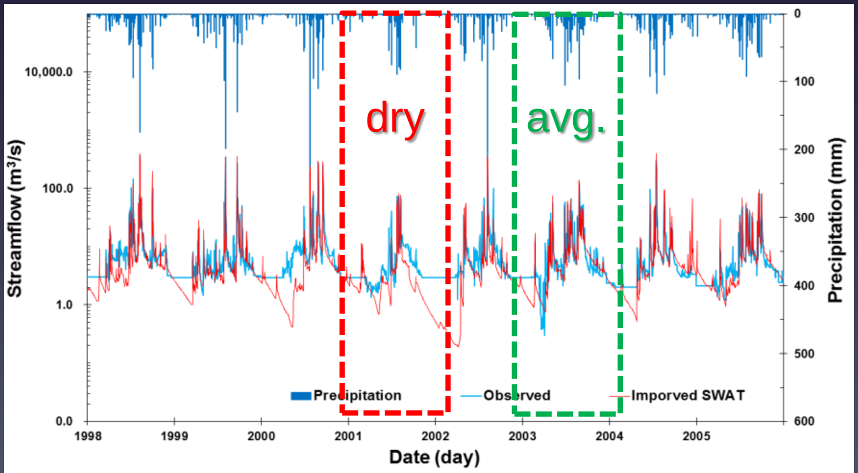
Calibration period

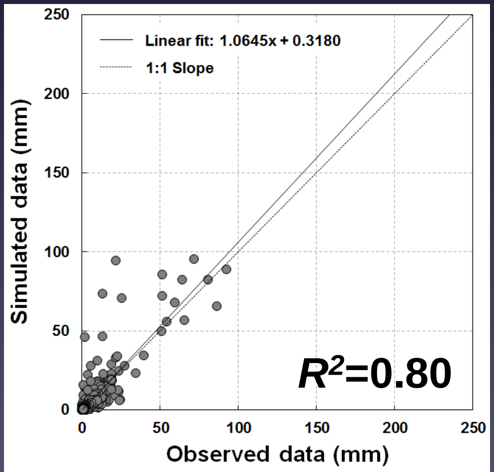
: 2006-2012 (7yrs)

Runoff ratio (%)

: 49.2 (obs.)

: 52.8 (sim.)





Validation period

: 1998-2005 (8yrs)

Runoff ratio (%)

: 57.4 (obs.)

: 51.6 (sim.)

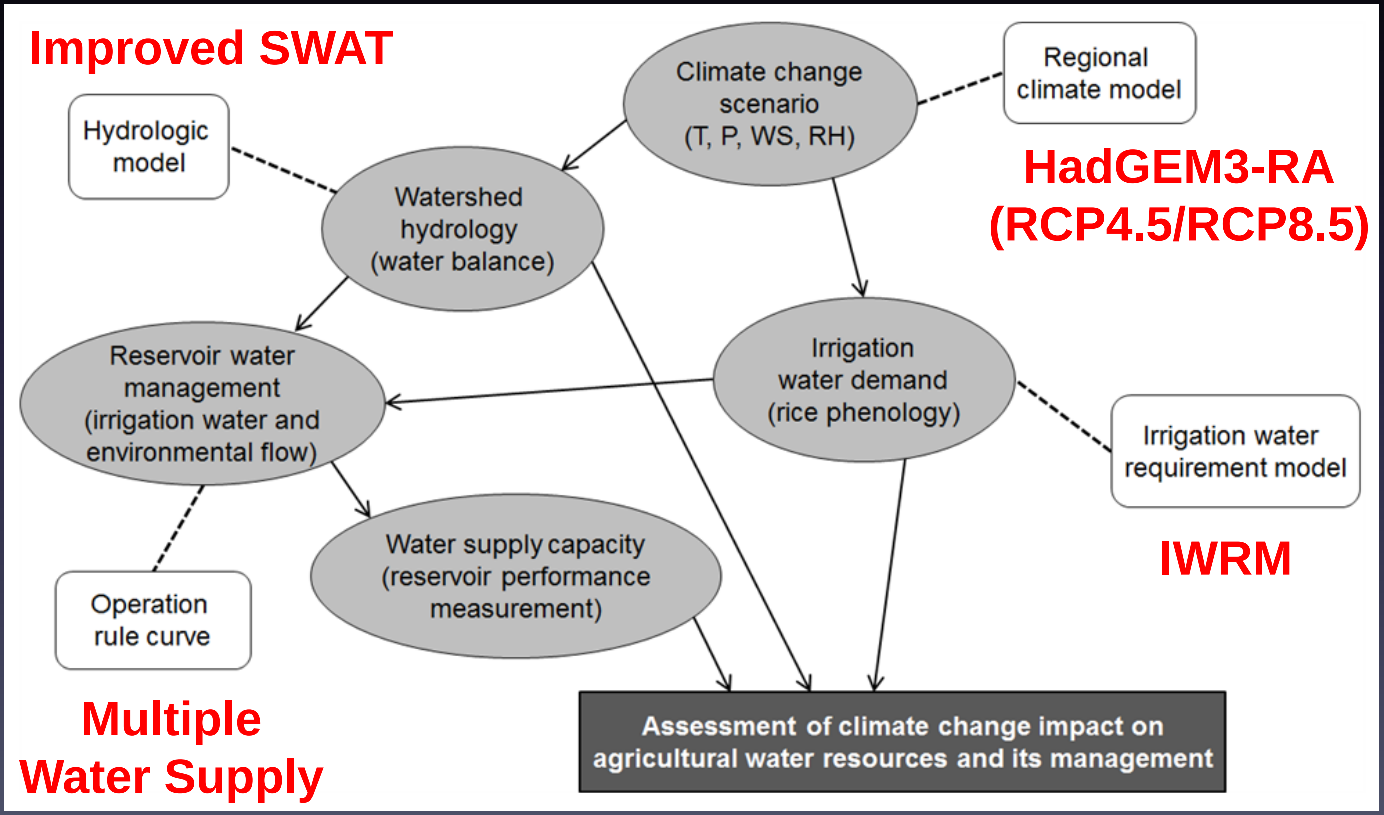
SWAT statistical summary

Gauging station	Static		Calibration	Validation	All data
Precipitation (mm/yr)			**1327.5**	**1306.8**	**1316.5**
Anseong (AS)	Runoff ratio (%)	Obs.	43.0	40.6	41.7
		Sim.	48.7	44.3	46.3
	Evaluation criteria	R^2	0.82	0.69	0.75
		NSE	0.60	0.53	0.56
		RMSE	2.50	2.93	2.73
Gongdo (GD)	Runoff ratio (%)	Obs.	49.2	57.4	53.6
		Sim.	52.8	51.6	52.2
	Evaluation criteria	R^2	0.87	0.80	0.83
		NSE	0.72	0.68	0.70
		RMSE	2.03	2.56	2.31

- The peak runoff errors may be caused by poor simulation of anthropogenic effects on runoff mechanisms in paddy fields (24.7% of the total area).
- Unlike typical runoff mechanisms, rice paddy hydrology is managed with irrigation scheduling and levee height adjustment, which increase the difficulty of simulating water budgets.
- During paddy cultivation periods, farmers artificially control levee heights for their own water management.

SWAT application

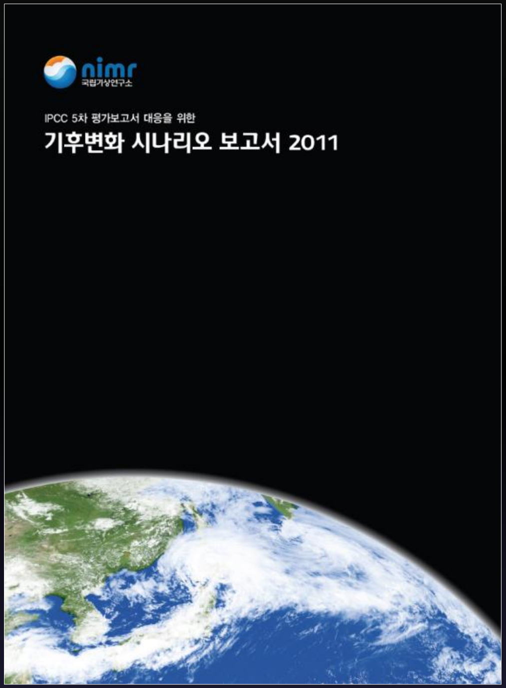
✓ **Application of the improved SWAT model for agricultural water management adapting climate change**

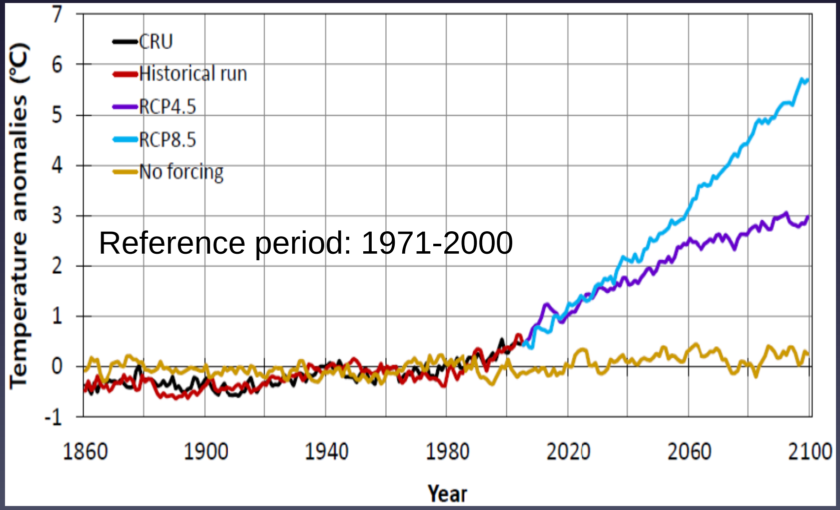


RCM projection

✓ **Downscaled HadGEM3-RA data**

- Source: NIMR/KMA (2011)
- Scenario: RCP4.5, RCP8.5
- Period: 2006-2099
- Time step: daily
- Variable: T, PCP, RH, WS



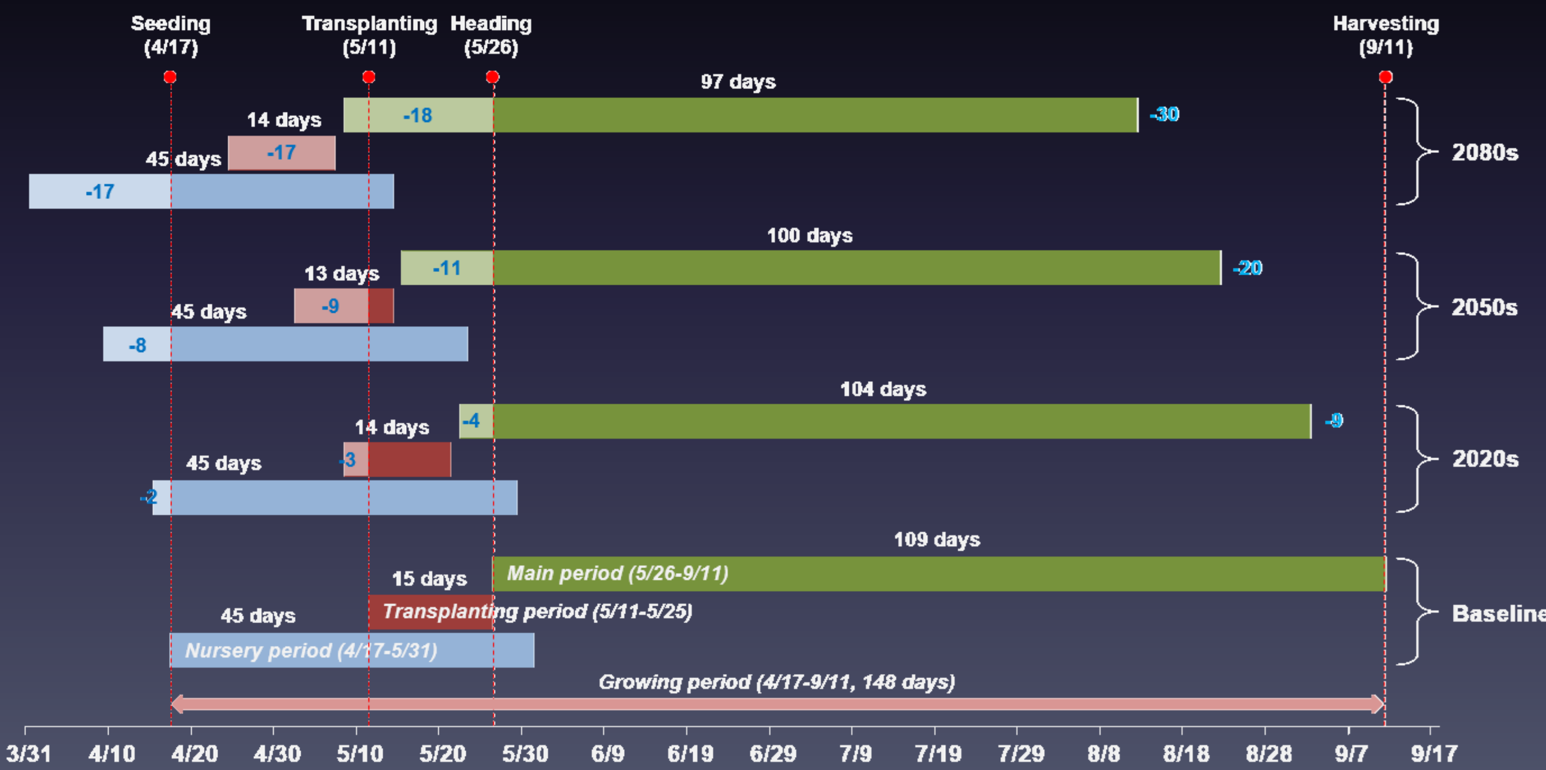


2100		RCP2.6	RCP4.5	RCP6.0	RCP8.5
Temp. (℃)	Global Scale	1.4	2.4	2.9	4.7
	Korea Peninsula	-	3.4	-	6.0
Prec. (%)	Global Scale	3.0	4.6	5.0	7.2
	Korea Peninsula	-	17.3	-	20.4

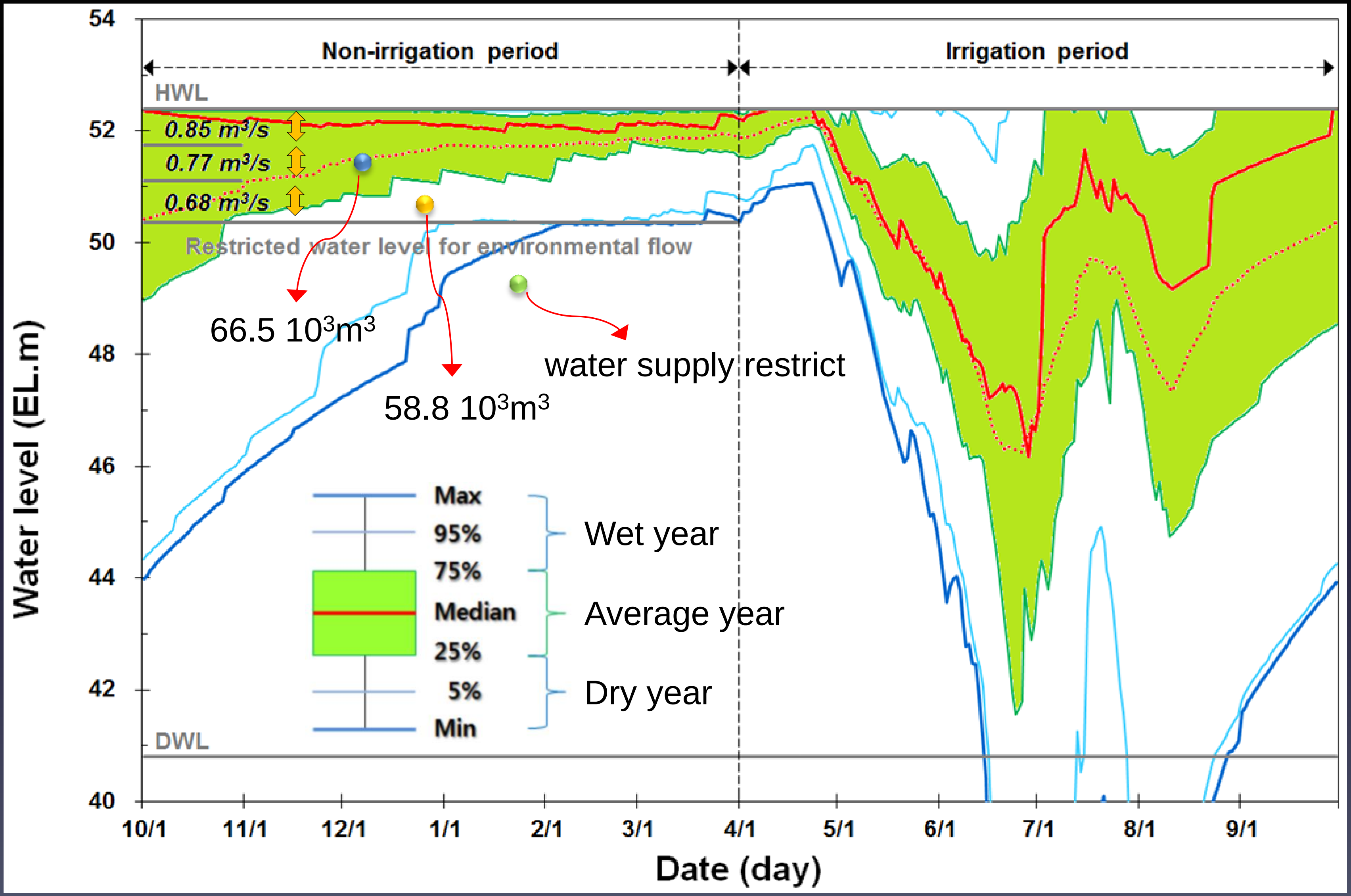
Change of rice phenology

- ✓ For climate change adaptation of future paddy irrigation, the rice growing period can be shifted 17 days earlier without increasing the IWR (Park, 2013).
- ✓ Such a shift can significantly reduce the risk of rice plant damage due to water shortage of the agricultural reservoir.

under the RCP8.5 scenario



Reservoir operating rule curve



Effects of multiple water supply

- ✓ **Streamflow at the watershed outlet (GD) using the improved SWAT**

Scenario		Precipitation (mm)	Streamflow (mm)		
			Impact	Adaptation	Multiple water supply
	Baseline	1227.8	601.0		
RCP4.5	2020s	1255.8 (+2.3)	594.6 (-1.1)	598.2 (-0.5)	598.7 (-0.4)
	2050s	1379.7 (+12.4)	707.1 (+17.7)	715.0 (+19.0)	715.9 (+19.1)
	2080s	1425.5 (+16.1)	741.7 (+23.4)	750.5 (+24.9)	751.4 (+25.0)
RCP8.5	2020s	1256.6 (+2.3)	603.5 (+0.4)	607.2 (+1.0)	607.8 (+1.1)
	2050s	1459.9 (+18.9)	764.2 (+27.2)	770.2 (+28.2)	771.4 (+28.4)
	2080s	1499.7 (+22.1)	778.3 (+29.5)	792.6 (+31.9)	794.1 (+32.1)

Concluding remarks

- The main objective of this study is to assess the future climate change impact and adaptation on agricultural water resources to manage reservoir and its watershed in the irrigated agricultural region of South Korea.
- Improved SWAT coupled with IWRM reproduced long-term water quantity and reservoir operation better in an agricultural reservoir watershed.
- This study provides a good reference to understand the variation of agricultural water resources in highly reservoir watershed, and is expected to technically support the assessment of multiple water supply capacity.
- Although the applicability of this results is limited, they can be used as basic tools in the development of agricultural water resources, particularly in the estimation of capacity and capability.
- Also, to mitigate negative hydrologic impacts and utilize positive impacts, climate change should be considered in water resource planning for the agricultural reservoir watershed.

Thank you

Q&A

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