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The Contribution of Paddy Return Flow to Streamflow in Rice-Paddy Areas through SWAT-SWMM Integration

Soil & Water Assessment Tool | SWAT

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**Master course of Reg. Environ. Eng.
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Table of Contents

PART 1

Introduction

❖ **Agricultural Water Use in South Korea**

| 7.1% (1.6 billion) |
| Agricultural water |
| Domestic water |
| Industrial water |

33.1% (7.4 billion)

68.8% (743,603 ha)

<Proportion of Water Use by Category in South Korea>
(Ministry of Environment, 2021)

| 2% (0.3 billion) |
| Paddy water |
| Field water |
| Livestock water |

13% (2 billion)

85% (13.1 billion)

<Proportion of Each Agricultural Water Type in South Korea>
(Water Commission Support Department, 2018)

| Paddy Area |
| Field Area |

49.4% (743,603 ha)

50.6% (761,011 ha)

<Proportion of Cultivated Land Area in South Korea>
(Statistics Korea, 2024)

- **Agricultural water** accounts for approximately **68.8% of total water use** in South Korea
- The proportions of paddy and Field are similar, accounting for 50.6% and 49.4%, respectively
- However, **Paddy Water consumes** approximately **85%** of the **total agricultural water usage**

❖ **Characteristics of Agricultural Water Supply**

<Current Paddy Water Supply System in South Korea>
(the 1st National Water Management Basic Plan, 2021)

- **In South Korea, most Paddy water supply systems use open channels**
- **Research has confirmed that approximately 52% of paddy water is not delivered through this system**

❖ **Paddy Return Flow**

- **Paddy return flow is routed through multiple pathways, including surface water bodies such as rivers and subsurface routes such as groundwater**
- **As returned Paddy water plays a role in sustaining streamflow, it is necessary to investigate the volume of Paddy return flow to evaluate its ecological impacts on rivers and nearby ecosystems**
- **However, quantitative evaluations of the effects of Paddy return flow on streamflow are still insufficient**

❖ Necessity of Integrating SWAT and SWMM

<SWAT>
- Paddy ponding simulation not available

<SWAT-PADDY>
- While simulation of paddy field ponding is feasible, it is considered at the Hydrologic Response Unit (HRU) level

<EPA-SWMM>
- Both paddy field ponding simulation and the representation of actual irrigation canal networks are supported

- **Soil and Water Assessment Tool** (SWAT) **lacks** the capability **to simulate paddy field ponding**
- To address this, **SWAT-PADDY** was developed for paddy field simulation, but its **HRU-based structure limits** accurate estimation of return flow reflecting **actual canal networks**
- **Storm Water Management Model** (SWMM) can simulate Paddy return flow based on actual canal networks. However, it **has limitations in simulating streamflow**
- Therefore, **linking SWAT and SWMM is** necessary **to evaluate the impact of Paddy return flow on streamflow**

Introduction

❖ **Purpose of This Study**

✓ **Estimation of Paddy return flow from paddy rice cultivation using SWMM**

✓ **The estimated Paddy return flow is used as a point source input in SWAT**

✓ **Flow Duration Curve analysis comparing SWAT results with and without SWMM-derived Paddy return flow to assess changes in streamflow characteristics**

The impact of Paddy return flow on streamflow was analyzed using the original SWAT model and Flow Duration Curve (FDC) evaluation

PART 2

Methodology

❖ Soil Water Assessment Tool(SWAT)

National Oceanic and Atmospheric Administration(https://www.noaa.gov/jetstream/atmosphere/hydro)

- **SWAT, developed by USDA-ARS, is a semi-distributed, long-term watershed model that simulates runoff, erosion, and agricultural nonpoint source pollution based on climate, topography, soil, and land use data.**

❖ Storm Water Management Model(SWMM)

Category	SWMM Function
Reservoir	Storage
Inflow sluice gate	Orifice
Drainage sluice gate	Weir
Paddy field	Subcatchment / Storage
Water channel	Conduit
Sluice management	Control rule

- **Storm Water Management Model(SWMM), developed by the US EPA, simulates flow and water quality in urban watershed sewers, focusing on rainfall runoff estimation.**

- **While designed for urban watersheds, SWMM's capabilities in runoff, groundwater, and evaporation analysis make it suitable for rural watersheds and Paddy water studies**

- **SWMM simulates paddy fields, channel networks, paddy's depth management and hydraulic structures using features like Subcatchments, Storage Units, Conduits, Control rules, Orifices and Weirs.**

❖ Study Area: Watershed - SWAT

Watershed Area: 149.22km²

Bogangcheon Watershed

We are here!

SWAT Simulation Area

SWMM Simulation Area

- **The Bogangcheon Watershed is located in Chungcheongbuk-do, South Korea, encompassing parts of Goesan-gun, Jeungpyeong-gun, and Jincheon-gun**
- **The region exhibits irregular runoff characteristics influenced by paddy field irrigation and drainage, along with complex hydraulic structures in small streams**

❖ Study Area: Baekma Reservoir, Baekma 1 region - SWMM

SWAT Simulation Area

<Study Area>
(Baekma Reservoir, Baekma 1 region)

Baekma 1 region

Field Type	Count	Area(ha)
Paddy	**218**	**50.02**
Orchard	1	8.51
Facility	18	0.47
Upland	102	2.06
Total	**339**	**61.06**

<Based on Farm-map of the Baekma 1 region>

- Baekma Reservoir has a storage capacity of 891,650 m³ and serves a 140.2 ha divided into Baekma 1 and Baekma 2 regions.

- In this study, SWMM was built for the Baekma 1 region to simulate Paddy water supply. This region includes 218 paddy fields over 50.02 ha.

❖ Data Collection for SWAT Setup: Weather Data

▶ Data Period: 1/1/2018~12/31/2022

- **Weather data from the Korea Meteorological Administration (KMA) were used from the Cheongju, Eumseong, and Jeungpyeong weather stations, including daily precipitation, temperature, wind speed, solar radiation, and relative humidity**

❖ **Data Collection for SWAT Setup: DEM, Soil, Land use**

DEM

Soil

Land use

- **A 30 m × 30 m DEM was generated using digital maps from the National Geographic Information Institute (NGII)**
- **A detailed soil map was sourced from the National Institute of Agricultural Sciences (NIAS), Rural Development Administration (RDA)**
- **Land use data (medium classification) were obtained from the Environmental Spatial Information Service**

15

❖ **Data Collection for SWMM Setup: GPS Coordinates**

<Measuring GPS Coordinates>

<GPS Coordinates>

- **GPS measurements were conducted to collect elevation data for input data into SWMM.**

❖ **Data Collection for SWMM Setup: Current status of rice Cultivation and Water supply**

<Field Survey>

Ministry of Agriculture, Food and Rural Affairs

Unchanged paddy field
New paddy field
Removed paddy field

<Update Farm-map data>

Channel
Inflow Gate
Outflow Gate

<Water Supply Status for Each Paddy Field>
(example)

- **To Build SWMM for each paddy field, a Field survey was conducted on the current status of rice cultivation and water supply for each paddy field.**

❖ **Data Collection for SWMM Setup: Channel Dimensions**

Development of SWMM Input Data Based on Field Survey Data

<Measuring Channel>   <Channel DB>   <Channel DB input in SWMM>

- **The channel dimensions (depth/width) were measured to setup the channel network in the study area.**

❖ **Data Collection for SWMM Setup: Weather and Water supply amount data**

- The data period from April 1, 2022, to October 31, 2022, during which the Paddy water supply amounted to 749,600 m³, and the rainfall totaled 1,144 mm.

Observation Station of the Korea Meteorological Administration.

PART

3

Results

❖ Simulation Results of Paddy Water Irrigation and Return Flow

Simulation Results of Irrigation Water and Return Flow

- The irrigation water applied to paddy fields refers to **the total amount of Paddy water entering through the inlet structures, excluding rainfall**
- Return flow was calculated as the total inflow to downstream outfalls in SWMM, including ineffective discharge and rainfall-induced paddy runoff
- Based on the SWMM simulation, 283,976 m³ of water was applied to paddy fields through irrigation, and 704,340 m³ of water was returned to the river

❖ Results Comparison: Original SWAT vs. SWAT-SWMM

Data Period: 4/1/2022~10/31/2022

Flow Duration Curve

— SWAT — SWAT_SWMM

- **Compared to the original SWAT model, the SWAT simulation incorporating Paddy return flow derived from SWMM produced higher streamflow values in the Dry conditions and Low flows**

22

❖ **Limitations**

✓ **This study faced limitations in validating SWAT and SWMM simulation results due to the absence of direct flow measurements, relying instead on assumptions for water loss, evaporation, and seepage, which may not accurately capture real-world variability.**

✓ **Future research should include direct measurements for improved accuracy.**

✓ **Additionally, since the SWMM simulation period was relatively short (approximately 7 months), further analysis is needed by extending the simulation period with additional reservoir supply data to assess the year-to-year impact of Paddy return flow.**

04 Limitations & Conclusions

❖ **Conclusions**

- ✓ **This study confirmed that Paddy return flow from paddy fields can influence streamflow, particularly during low-flow periods.**

- ✓ **The SWAT-SWMM integrated modeling approach used in this study can serve as a foundational tool for investigating hydrological interactions between Paddy water supply and streamflow.**

- ✓ **In particular, it is expected to be useful for quantitatively analyzing streamflow changes resulting from efficient Paddy water use in paddy-dominated agricultural watersheds.**

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Thank you

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