Discussion on the Suitability of SWAT Model Applied to Hydrological Simulation of Paddy Field in Taiwan

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Content

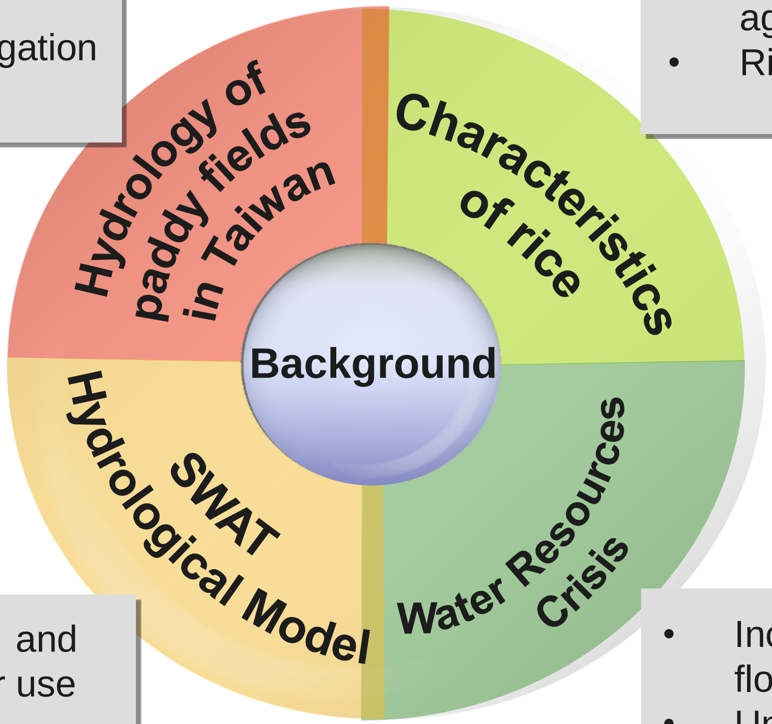
Introduction (1/4)

Hydrology of paddy fields in Taiwan

- The climate and geographical conditions in Taiwan
- Agricultural management for irrigation and drainage operations

Characteristics of rice

- Plentiful rainfall in Taiwan leads agricultural advantage
- Rice is the staple food in Taiwan



Hydrological Model

- Simulation of water supply and demand for optimizing total water use
- Streamflow simulation at different temporal scales

Water Resources Crisis

- Increasing and intensifying drought and flood
- Unstable irrigation water for paddy

Introduction (2/4)

- Irrigation Methods

Continuous irrigation
- Interval irrigation
- Continuous irrigation with water drainage

Rotational irrigation
- Standard rotational irrigation
- Precision rotational irrigation
- Large area rotational irrigation

Special rotational irrigation
- Method of reduced water depth
- Method of extended interval
- Method of reduced irrigation area

Traditional Methods

Introduction (3/4)

- Paddy Field Models

- Kamruzzaman et al. (2020) used APEX-Paddy to assess the impact of BMPs on paddy fields due to climate change.
  - Jeon et al. (2007) compared changes in water quality of paddy fields using HSPF-Paddy of different scales.
- Yan et al. (2016) analyzed the effectiveness of water resources management with improved WALRUS-Paddy.
  - Janssen et al. (2010) developed the PADDY-FLUX model to assess the impact of water resources management on infiltration.
- Kang et al. (2016) evaluated the simulation results of reservoir water level with COMFARM.

Advantage of SWAT model:
The SWAT model can be simulated and verified by adjusting relevant parameters. Compared with other hydrological models, it has advantageous features such as continuously simulating watershed at a fine spatial scales over a long-term period.

Introduction (4/4)

- Objectives

Integration of paddy land use

- Development of the land use classification and integration method to reflect the actual irrigated area of paddy fields.

Evaluate the applicability of simulation

- Examine the irrigation/drainage mechanism of paddy in the SWAT model, and analyze the HRU water balance of paddy fields to evaluate the applicability of SWAT model in paddy field simulation.

Study Area (1/2)

- Nankan River Basin

Geographic information

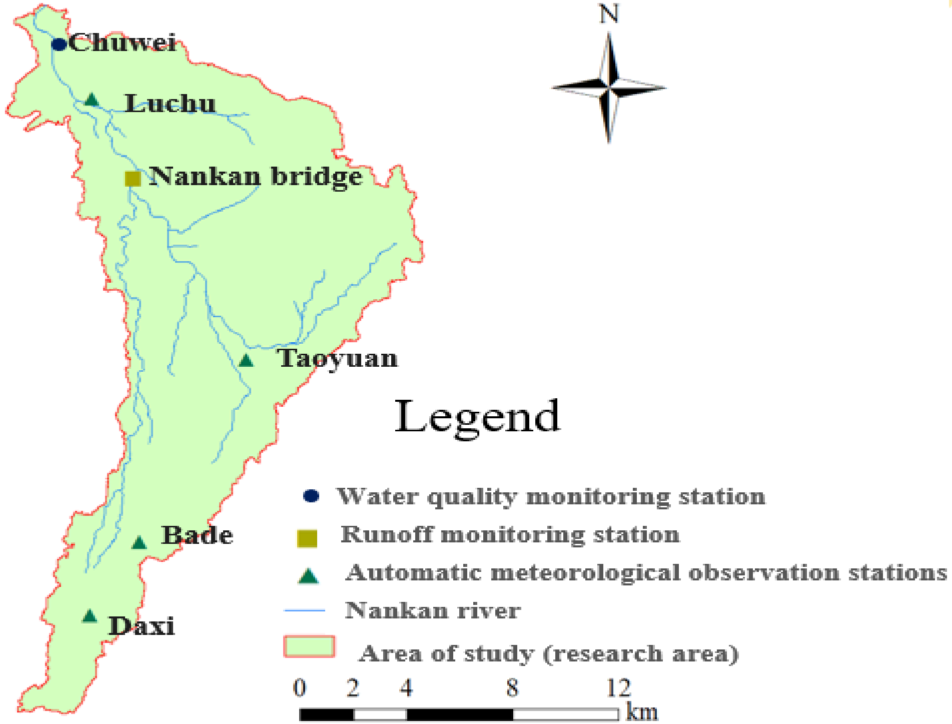
- Originates from: Pingding plateau in Taoyuan
- Total length of Nankan river: 30.7 km
- Drainage area: 214.7 km^2
- Average slope: 1/186

Water quality information

- Average RPI (1999 ~ 2014): 4.35
- Historical severe contamination: 7.3 at the Chuwei bridge monitoring station in September 2019

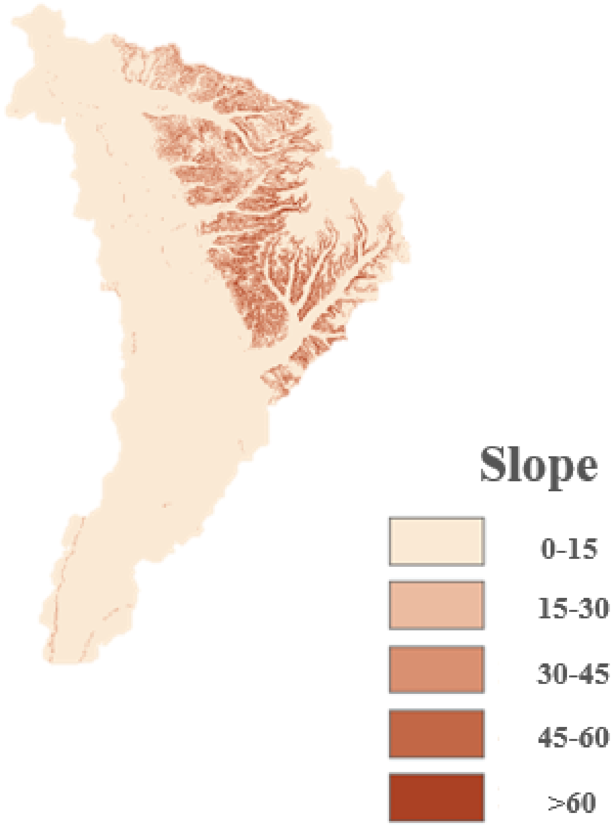
Irrigation information

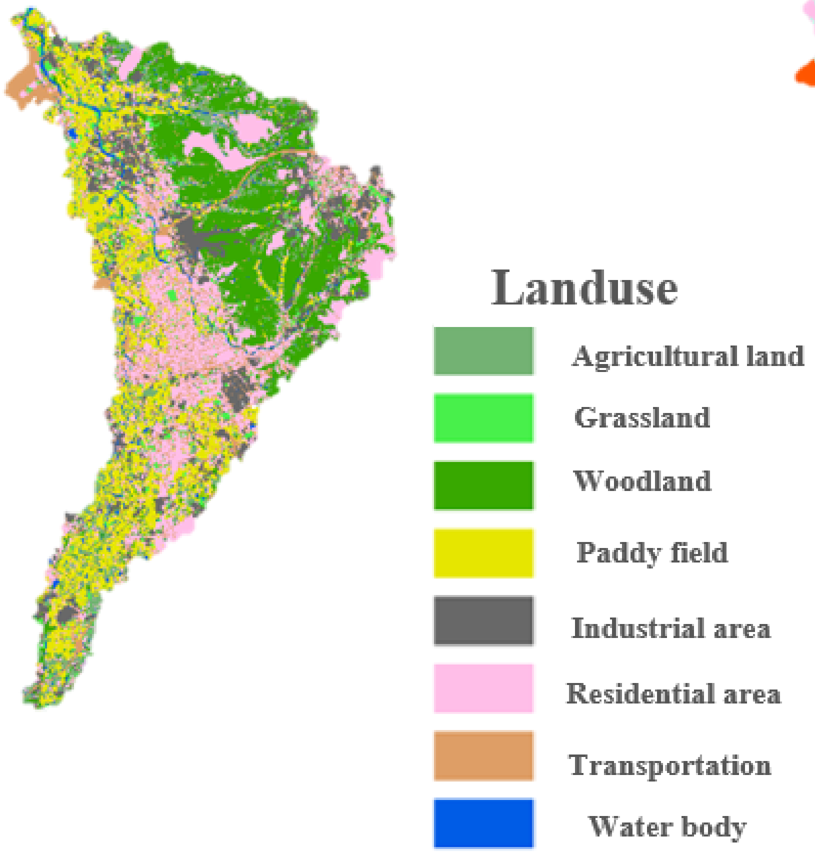
- Governed by: Taoyuan and Shimen Management Offices
- Irrigation supply: 40% ~ 44% from river, 56% ~ 60% from reservoir or/and ponds

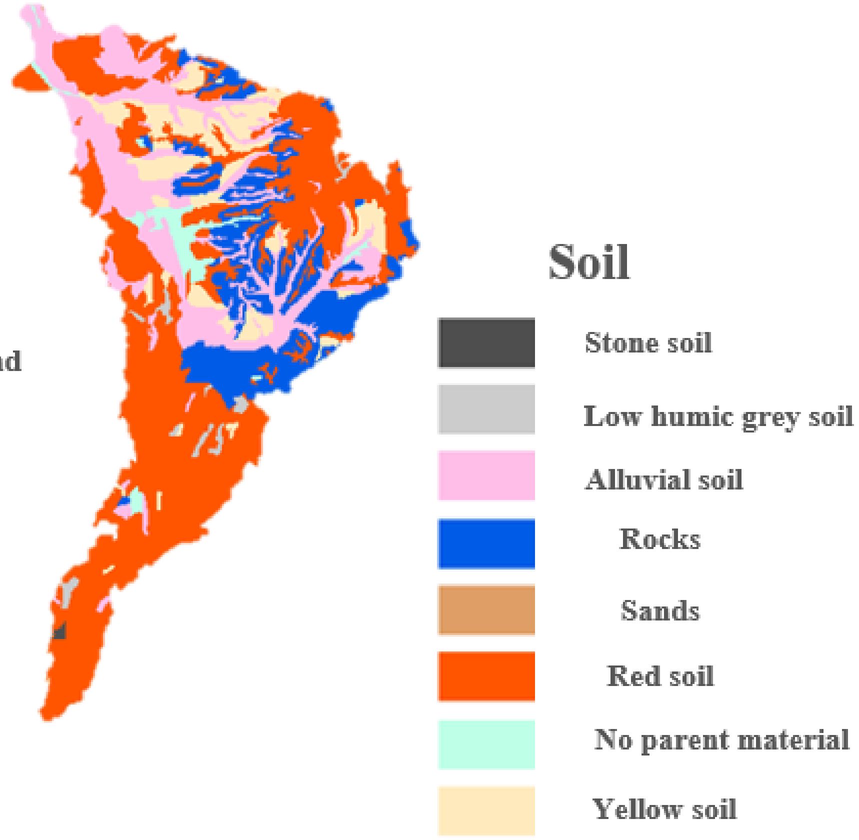


Degree of Contamination	Uncontaminated/ Slightly contaminated	Mild contamination	Medium contamination	Severe contamination
RPI	< 2.0	2.0 - 3.0	3.1 - 6.0	> 6.0

Study Area (2/2)







0-15%:78.29%
15-30%:11.00%
Others: 10.71%

Woodland: 21.70%
Residential area: 23.75%
Paddy fields: 18.11%
Others: 36.44%

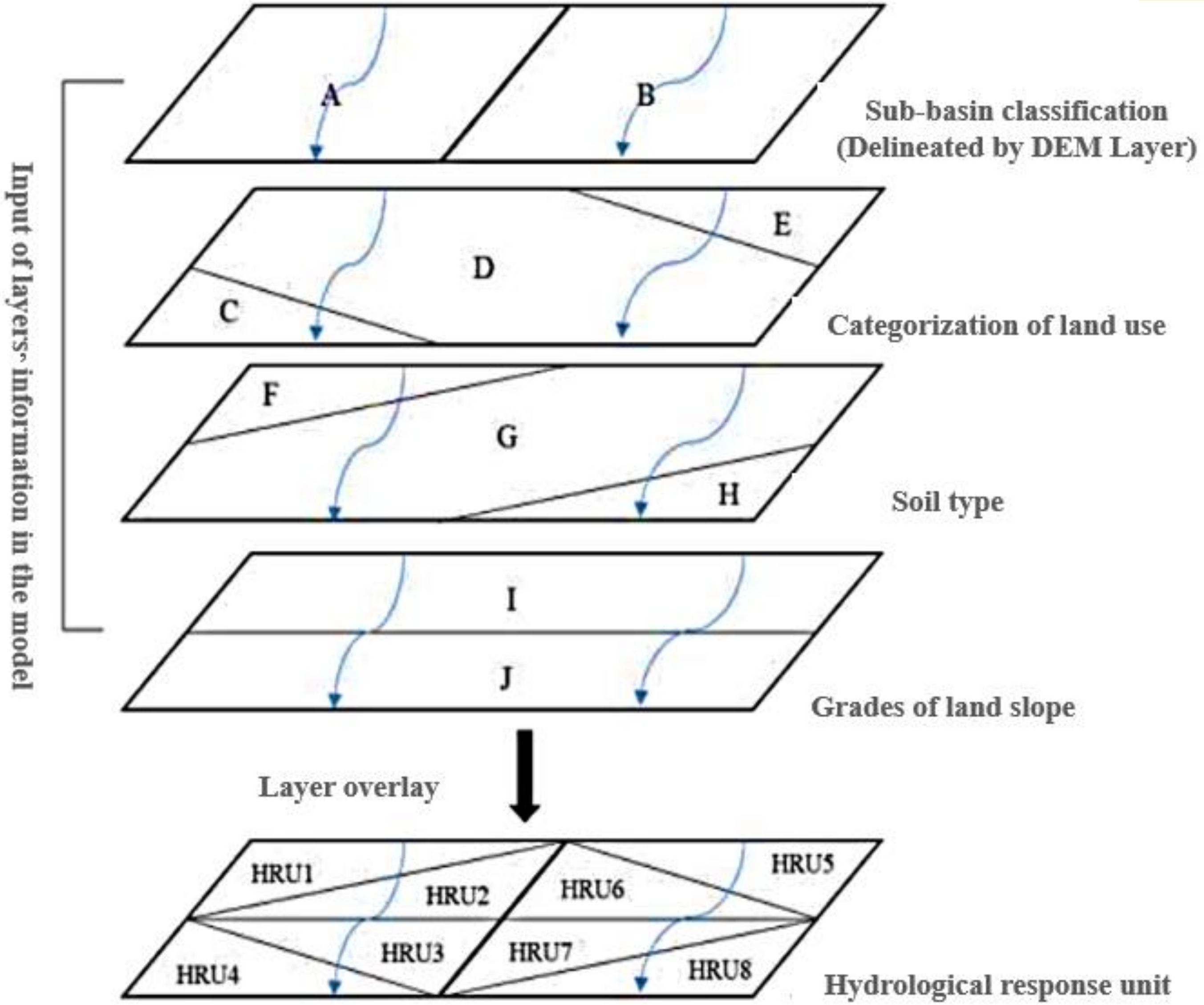
Red soil: 47.40%
Alluvial soil: 20.98%
Yellow soil: 11.34%
Others: 20.28%

Methodology (1/8)

- SWAT Model

SWAT model can simulates hydrological and water quality features of river tributaries and the subbasins at various spatio-temporal scales.

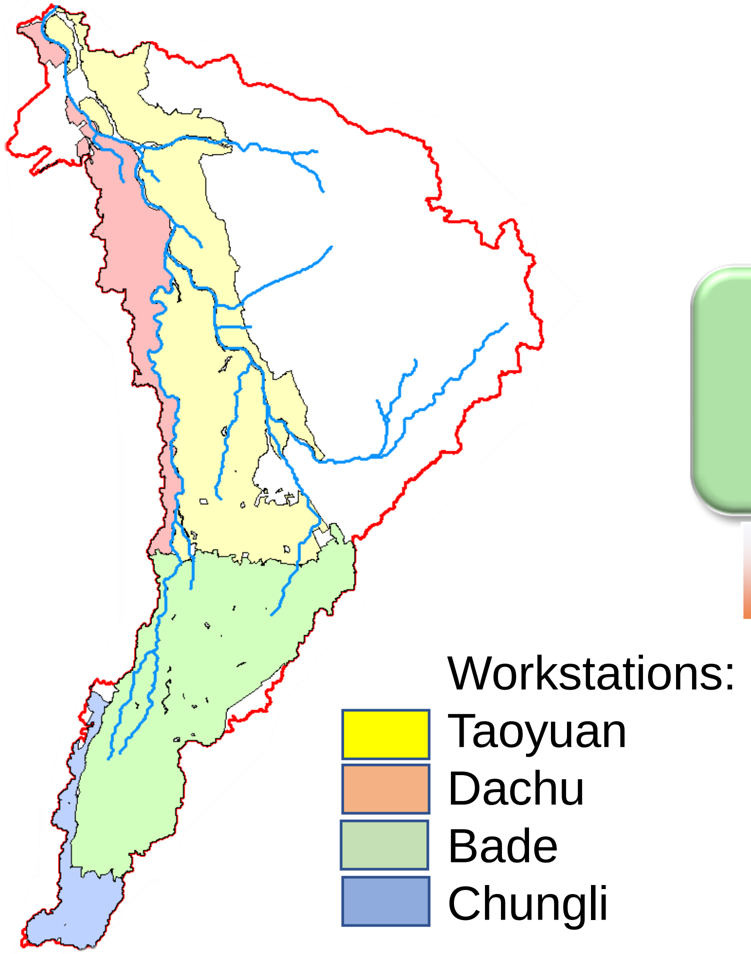
SWAT subdivides the watershed into smaller subbasins according to the distribution of the tributaries of the river and the monitoring points, then further classify the smallest calculation units: Hydrological Response Unit (HRU), which is an unique combination of land use, soil type and land slope in each subbasin area.



Methodology (4/8)

- Reclassification of Paddy field

Data source	Year of the Data
Construction and Planning Agency, Ministry of the Interior	Digital map, the 2nd Land Survey in 2015
Taoyuan and Shimen Management Offices	Statistical data, planned paddy irrigation area in 2020



Distribution of Workstations

Type 1
> 75% of paddy field coverage

- Target: In 2015 Land Survey, the land use type of "paddy field" was over 75%.
- Action: Keep the "paddy field"

Type 2
> 50% of paddy field coverage

- Target: Left from Type 1
- Action: Reclassify "dry land" into "paddy field"

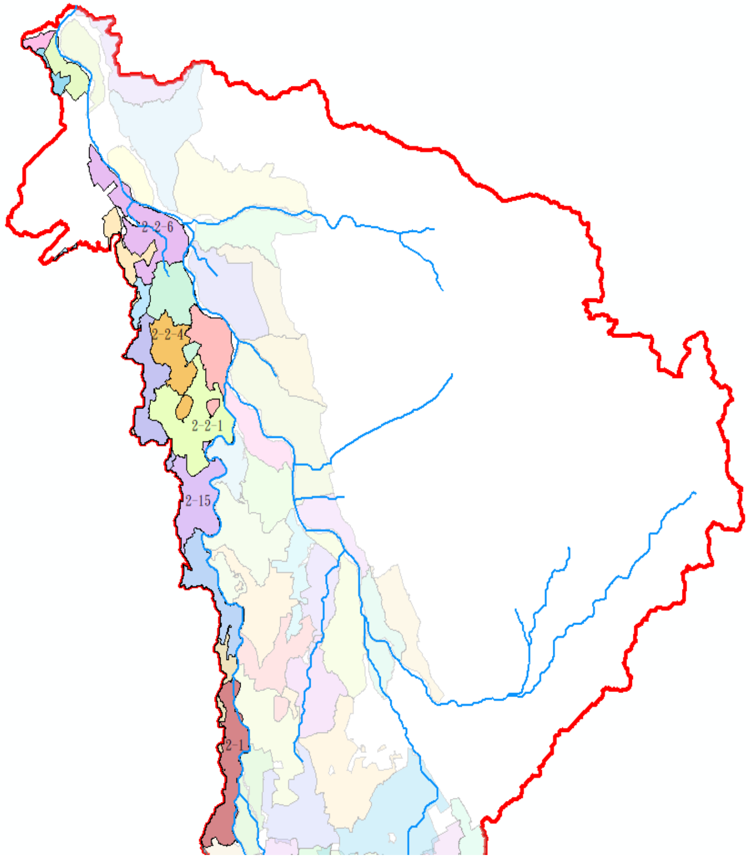
Type 3
Others

- Target: Left from Type 2
- Action: Sequentially reclassify vegetated land use types and other land use types of high water content

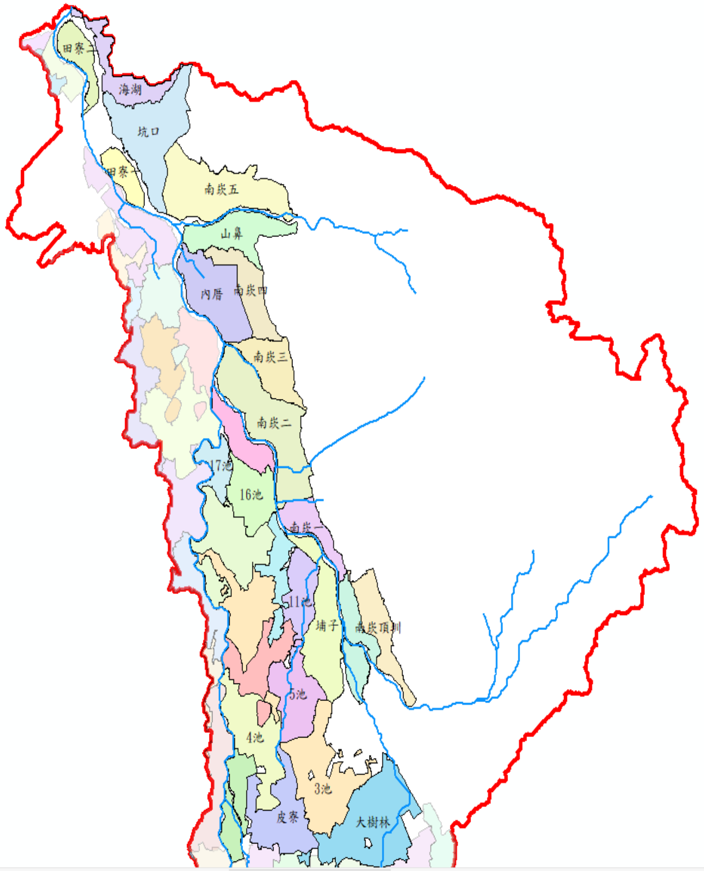
Methodology (5/8)

- Workstations and Groups

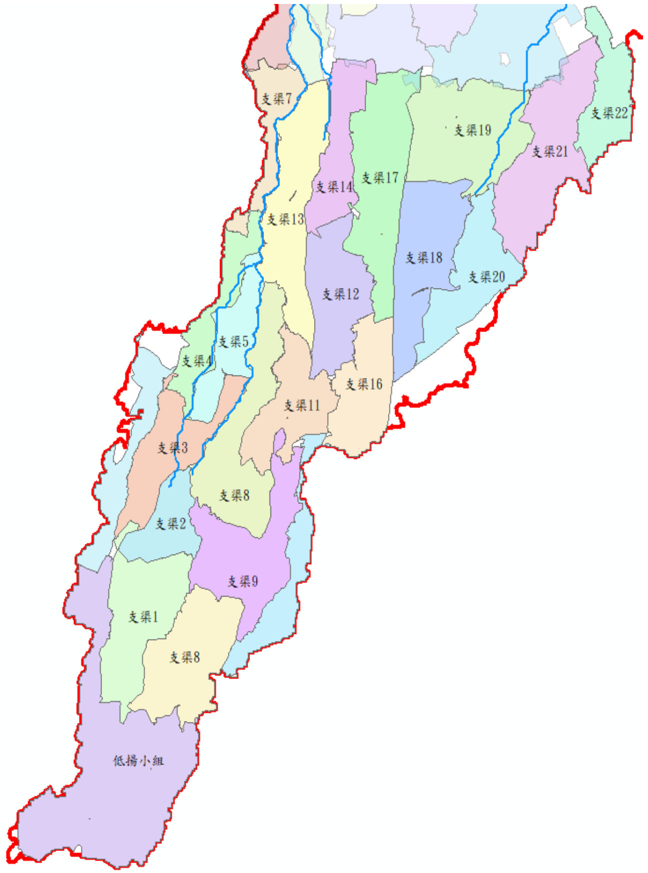
Dachu Workstation
16 Groups



Taoyuan Workstation
28 Groups



Bade Workstation
22 Groups
Chungli Workstation
2 Groups



Methodology (7/8)

- Scenarios 1: Plowsole depths

Scenario 1A

The depth of the soil as the depth of plowsole

The depths of the soil layers
- Alluvial soil: 20 mm
- Yellow soil: 30 mm
- Other soil layers: 120 mm

Scenario 1B

Fixed depth at 6000mm as the depth of plowsole

as the default values for plowsole of HRU paddy fields

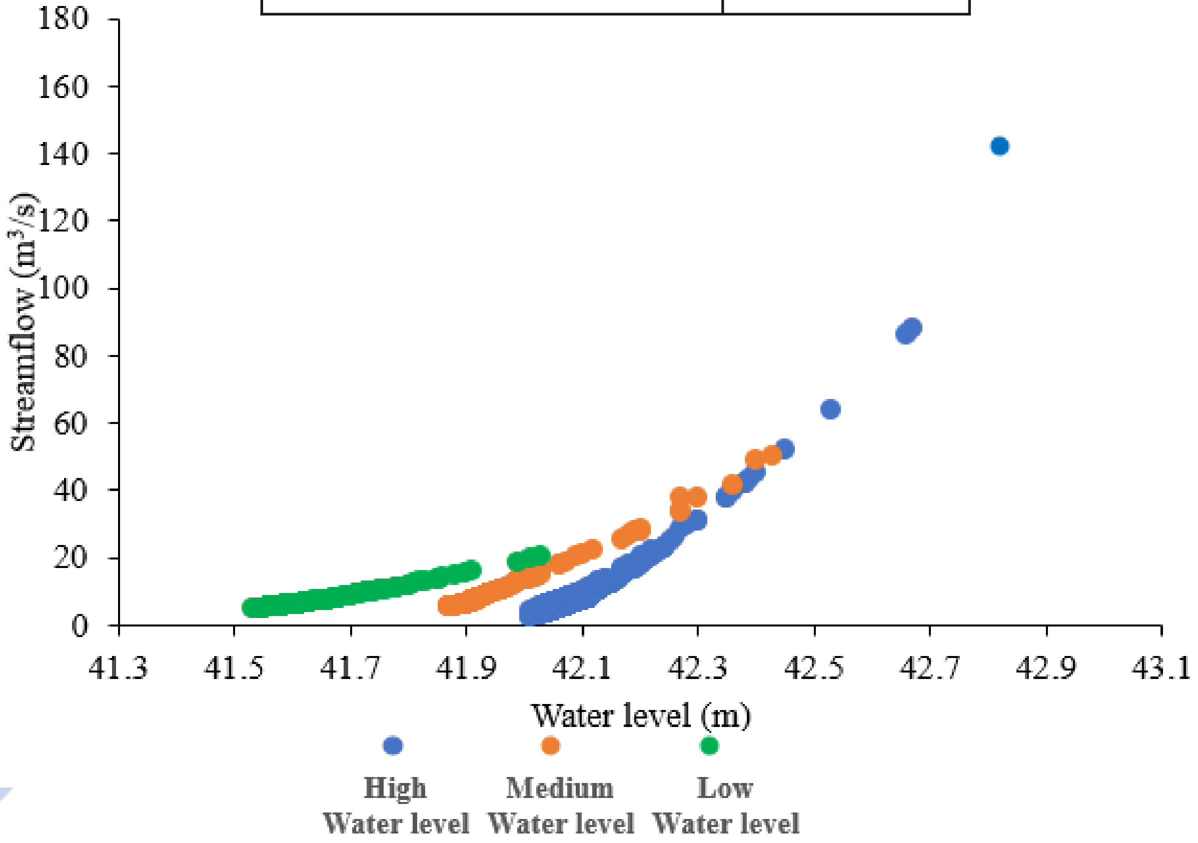
Set HRU36 (alluvial soil) as an example, test the following simulations:
- Analyze its hydrological characteristics
- Compare the hydrological change in water quantity

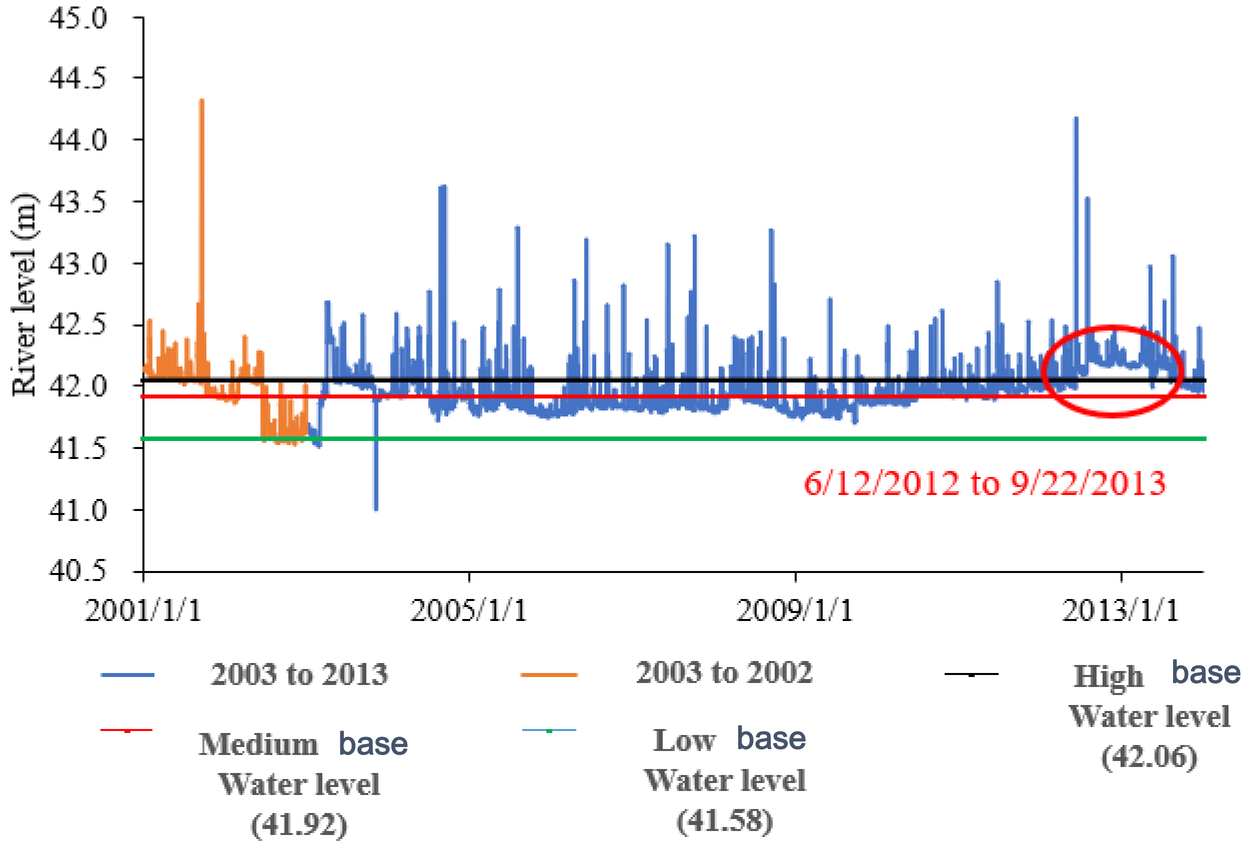
Select appropriate plowsole depths for further calibration and validation.

Methodology (6/8)

- Estimation of Streamflow

Observed hydrological data	Year
Water level	2001 ~ 2013
Streamflow	1982 ~ 2002





Methodology (8/8)

- Model Calibration and Validation

Uncertainty Analysis → Sensitivity Analysis → Calibration Process → Validation Process

SUFI-2

- 500 simulations
- P-value < 0.05 was regarded as an adjustable sensitivity parameter.

Evaluation of model simulation results

Performance of model simulation \ Statistical value	NSE	PBIAS (%) Streamflow	RSR
Very good	0.75 < NSE ≤ 1.00	|PBIAS|<10	0.00 ≤ RSR ≤ 0.50
Good	0.65 < NSE ≤ 0.75	10≤|PBIAS|<15	0.50 < RSR ≤ 0.60
Satisfactory	0.50 < NSE ≤ 0.65	15≤|PBIAS|<25	0.60 < RSR ≤ 0.70
Unsatisfactory	NSE≤0.50	|PBIAS|≥25	RSR>0.70

→ The calibrated SWAT model with scheduled irrigation was further applied to simulate the auto-irrigation.

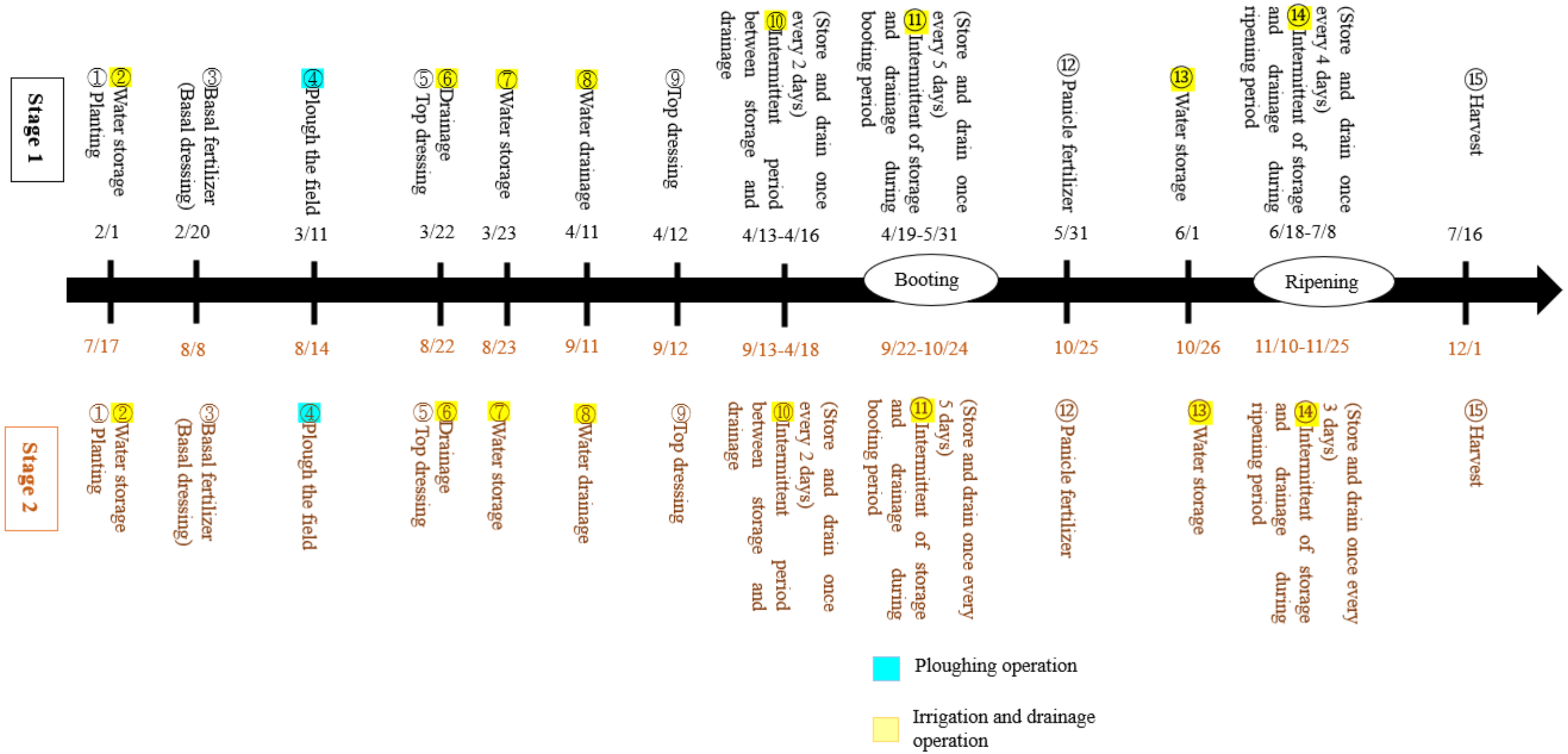
Methodology (2/8)

- Scenario 2: Irrigation operations

Scenario 2A:

Auto-irrigation is the system mode to determine the water demand of crops and automatically supply the amount of proper irrigation, in which a threshold of severe water shortage is set by user (AUTO_WSTR) as the trigger criteria for irrigation. When the system detects that the soil water content (SW) < field water content (FC) in HRU, the AUTO_WSTR is triggered and the irrigation process starts until the field is saturated with proper water content (Neitsch et al., 2011).

Scenario 2B:
Traditional (Scheduled) irrigation



Methodology (3/8)

- Traditional (Scheduled) Irrigation

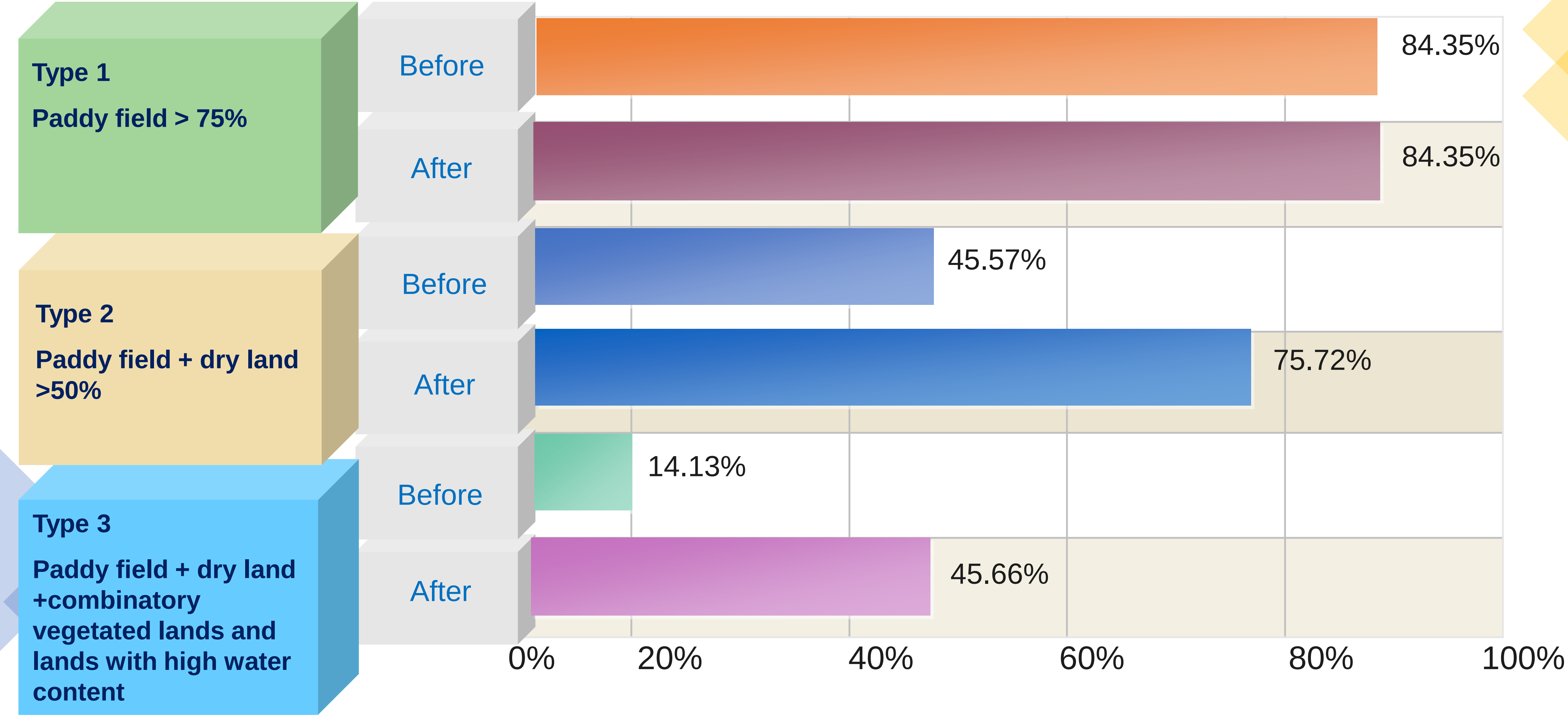
The average water quantity (m^3/s) of scheduled irrigation provided by the Irrigation Agency were used to calculate the amount of irrigation per unit area (mm/day).

$$\text{Fixed irrigation per unit area}\left(\frac{\text{mm}}{\text{day}}\right) = \frac{\text{Average of scheduled irrigation}\left(\frac{\text{m}^3}{\text{s}}\right) * 86400}{\text{Irrigation area (ha)} * 10}$$

Group's irrigation area (ha)	Fixed irrigation per unit area (mm/day)
Range: 0.27-170.28 ha Average: 63.29 ha	Range: 5.51-19.55 mm/day Average: 9.59 mm/day

Results and Discussion (1/12)

- Reclassify of paddy fields



Results and Discussion (2/12)

Scenario 1

The soil depth as the plowsole depth

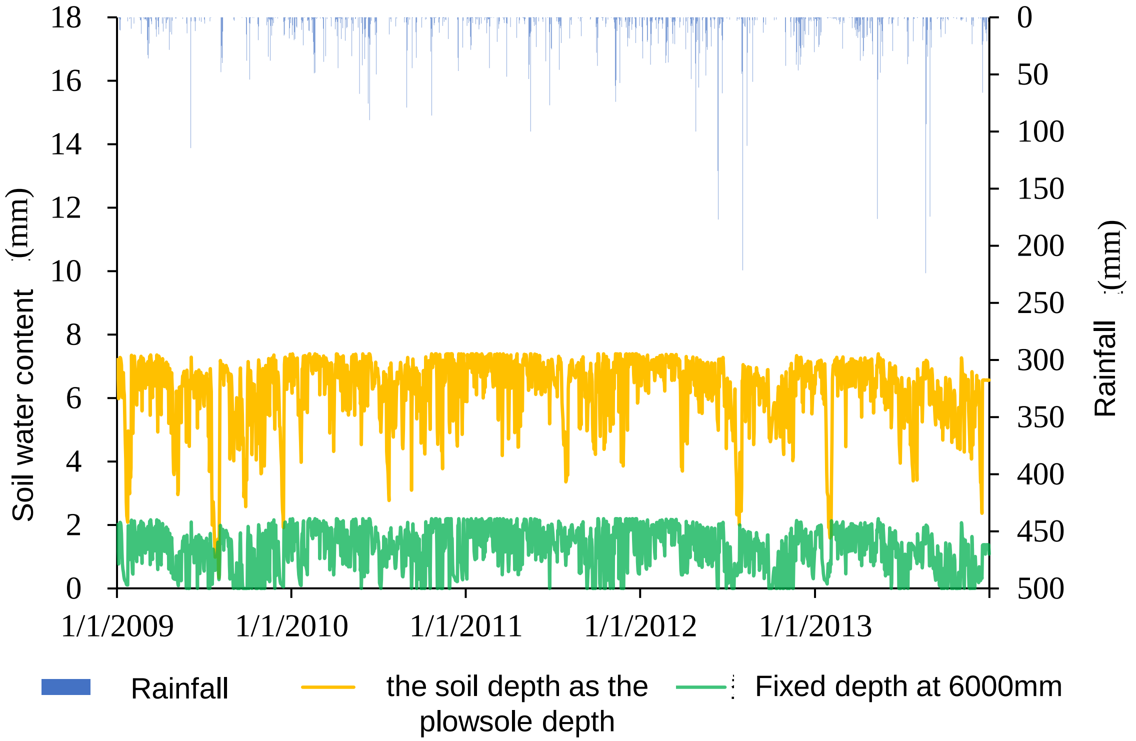
vs.

Fixed depth at 6000mm as the plowsole depth

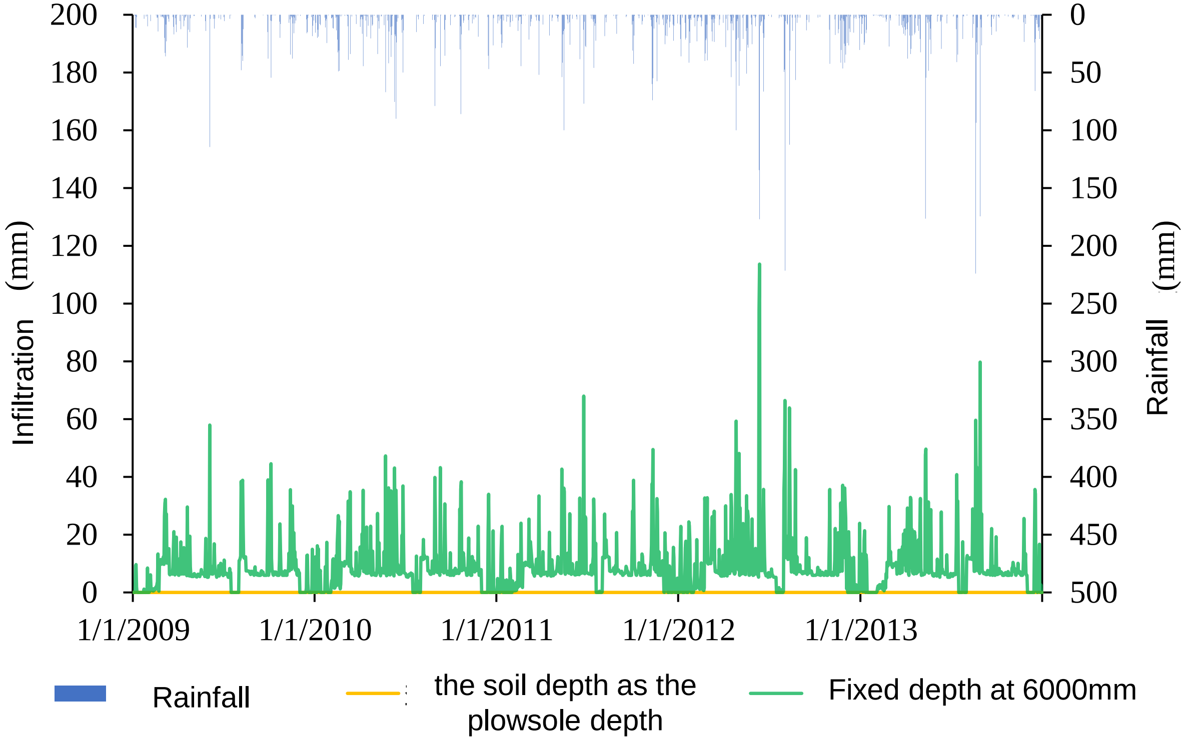
Results and Discussion (3/12)

- Comparison of plowsole depths: soil water content, infiltration, storage in paddy, and drainage from paddy

Soil water content (m^3)



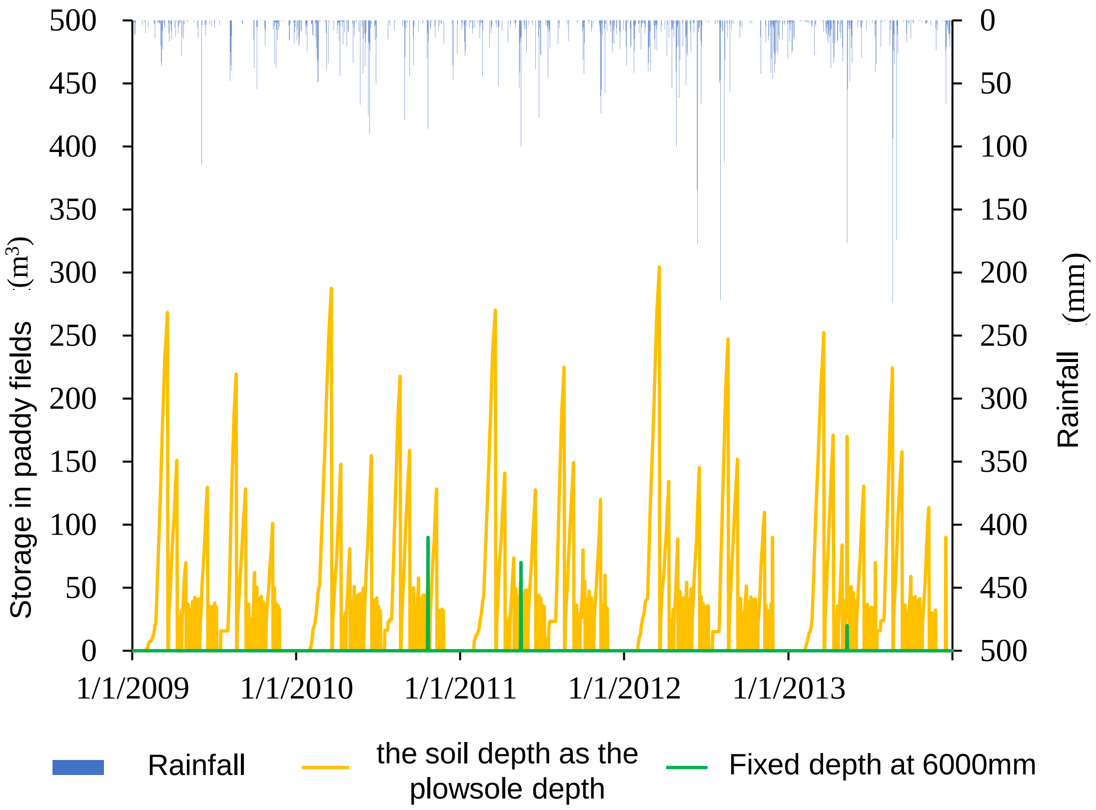
Infiltration (m^3)



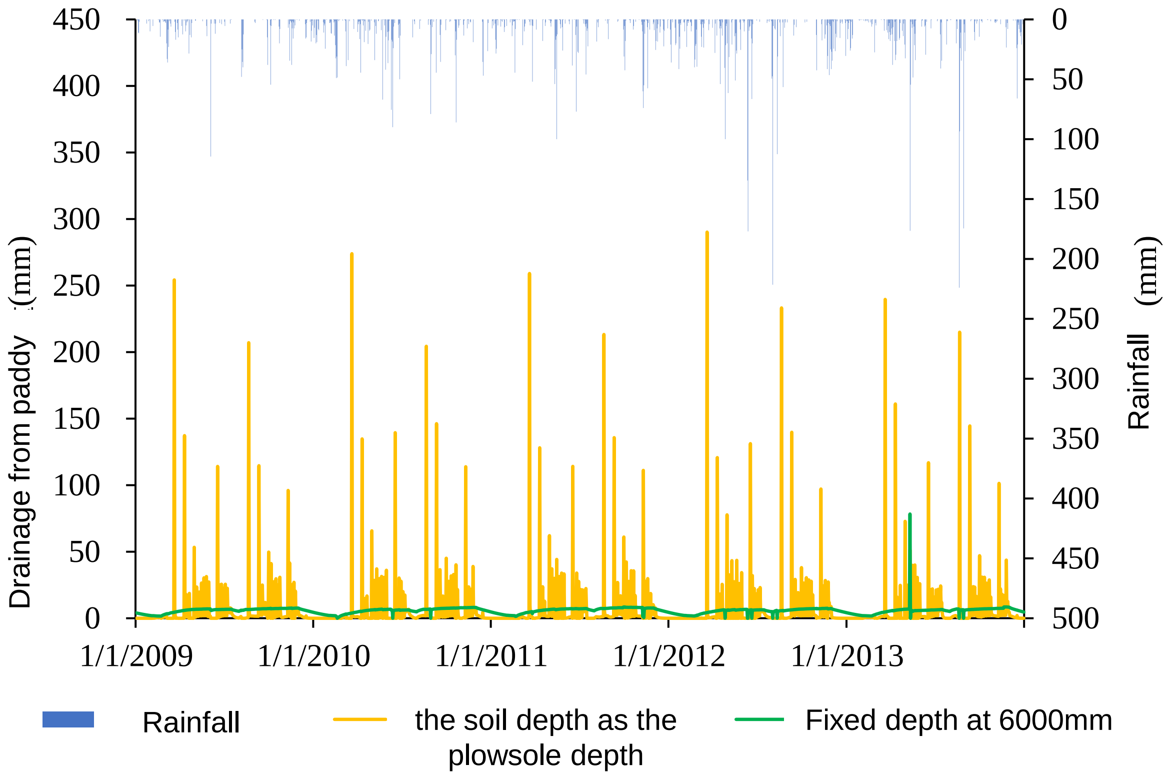
Results and Discussion (4/12)

- Comparison of plowsole depths: soil water content, infiltration, storage in paddy, and drainage from paddy

Storage in paddy fields (m^3)

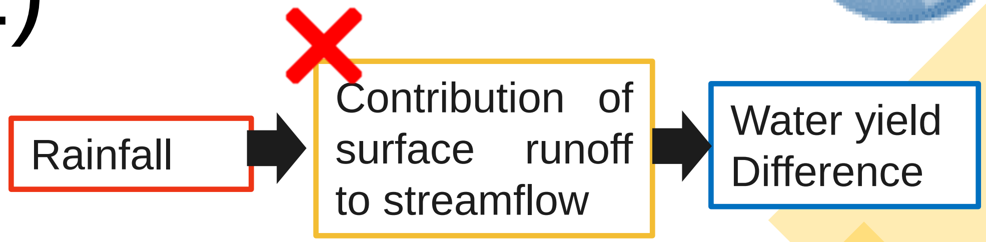


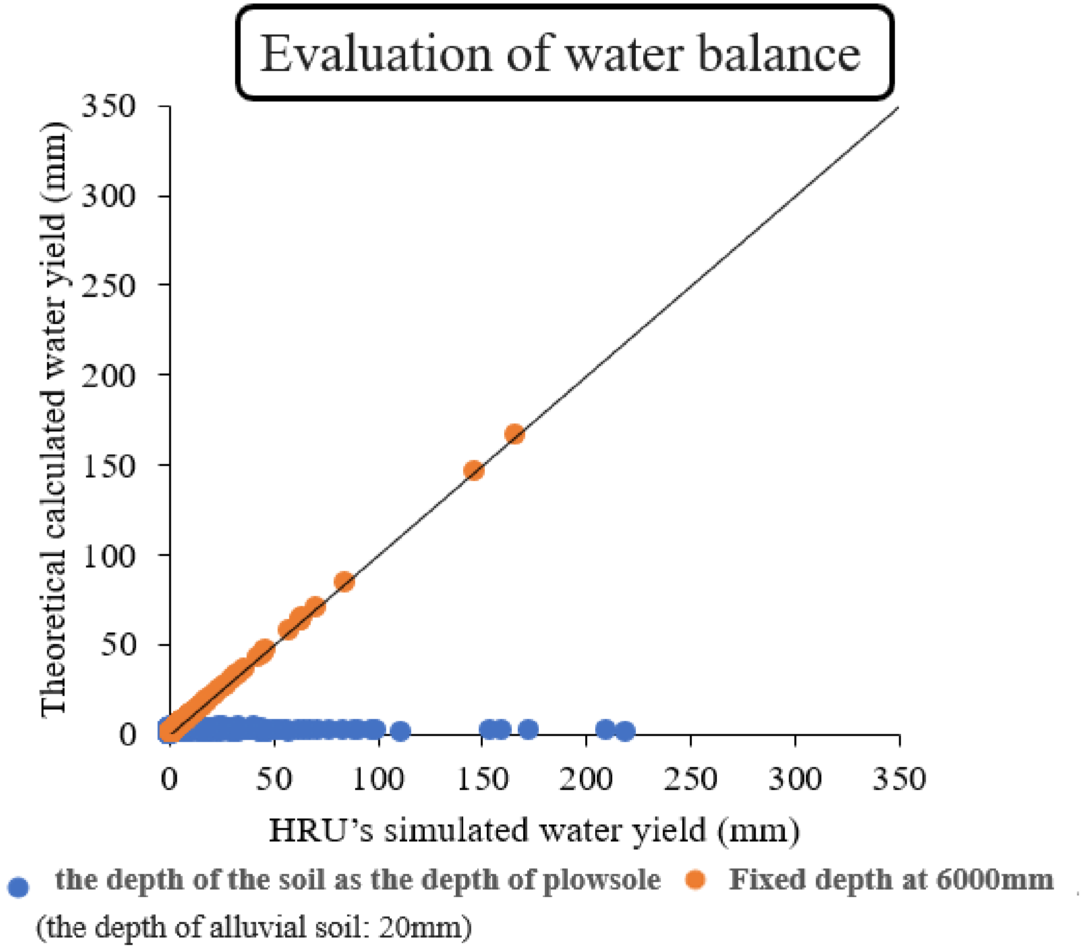
Drainage from paddy (m^3)

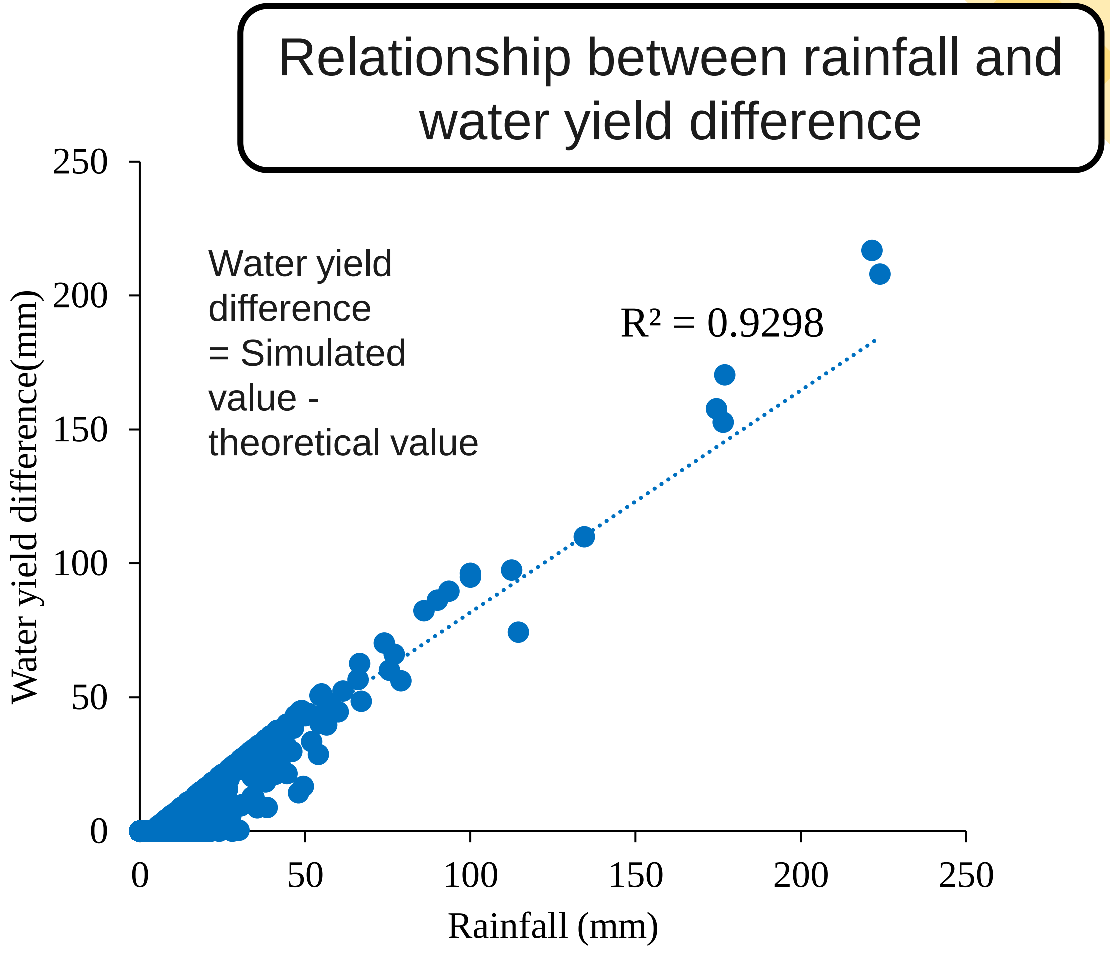


Results and Discussion (5/12)

- Analysis of Water Yield at HRUs
  - Verification of simulated and theoretical water yields



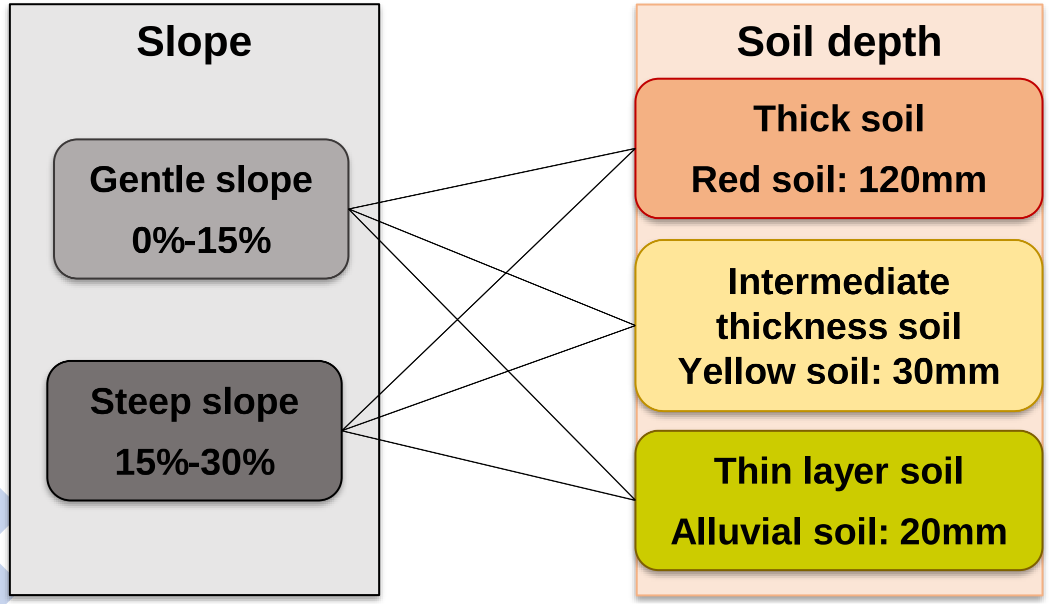


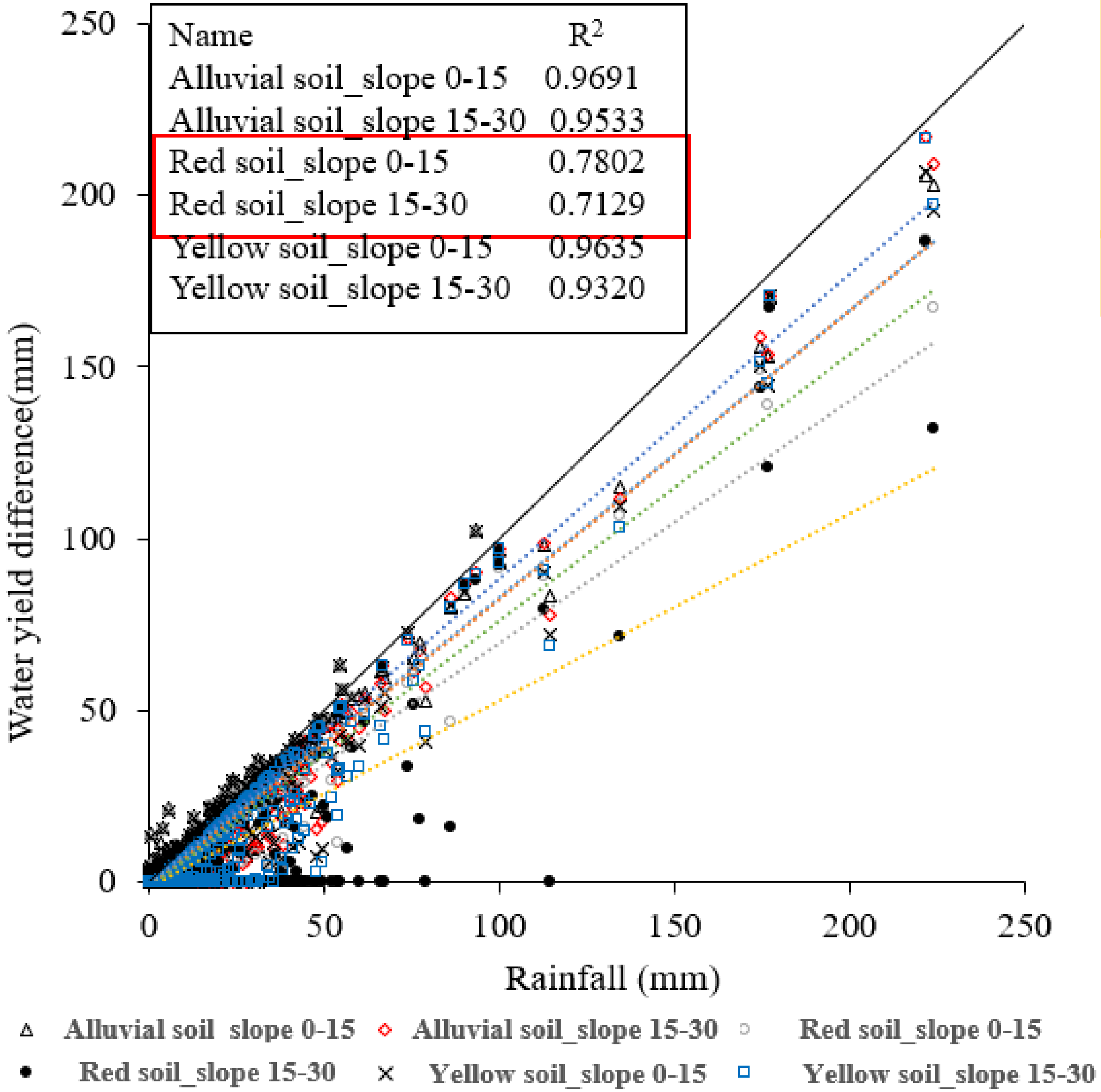


Results and Discussion (6/12)

- Analysis of Water Yield at HRUs
  - Impacts of slope and soil depths

Combinations of Slop and Soil depths (as plowsole depths)





Results and Discussion (7/12)

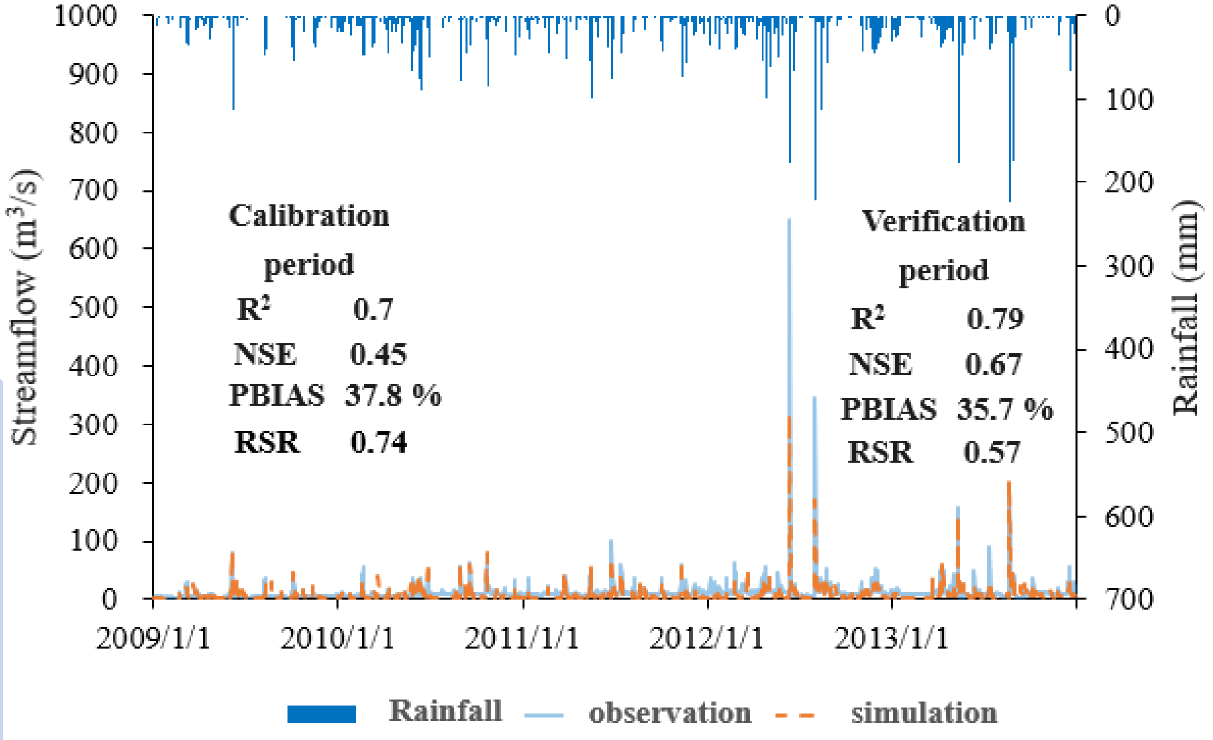
Scenario 2

Traditional Irrigation vs. Auto-Irrigation

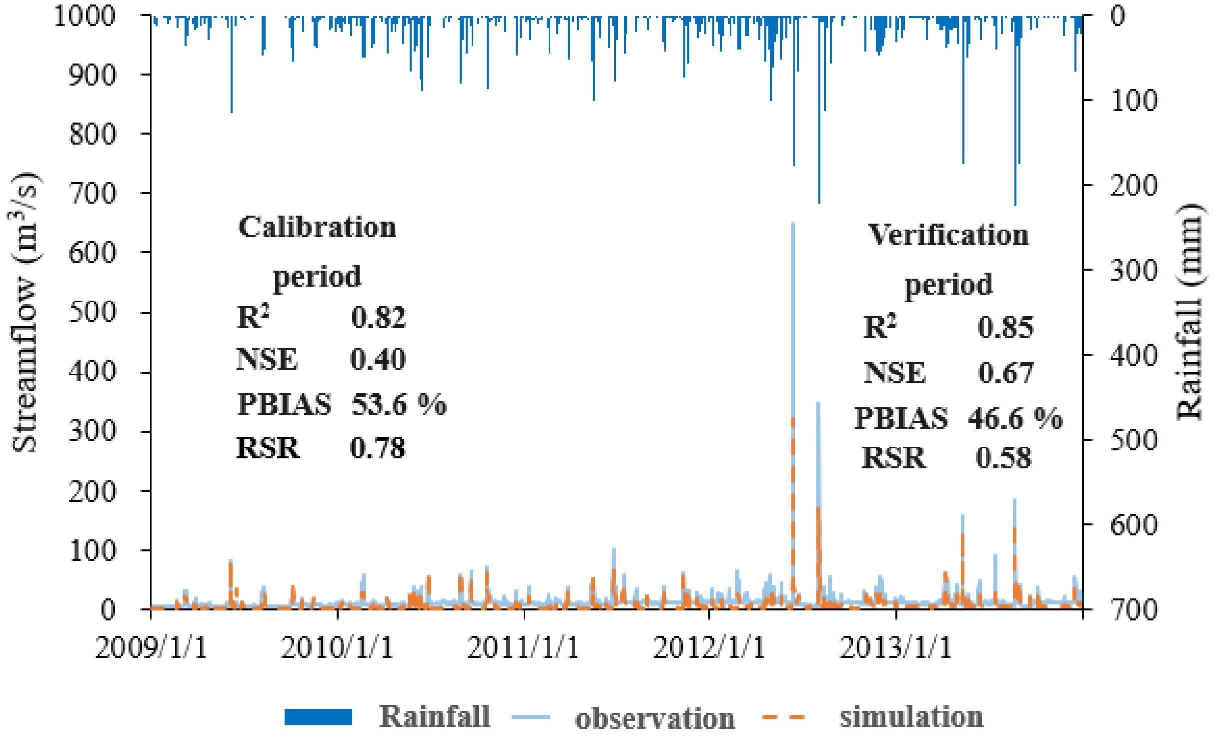
Results and Discussion (8/12)

- Model Calibration and Validation
  - Traditional irrigation vs. Auto-irrigation

Traditional Irrigation

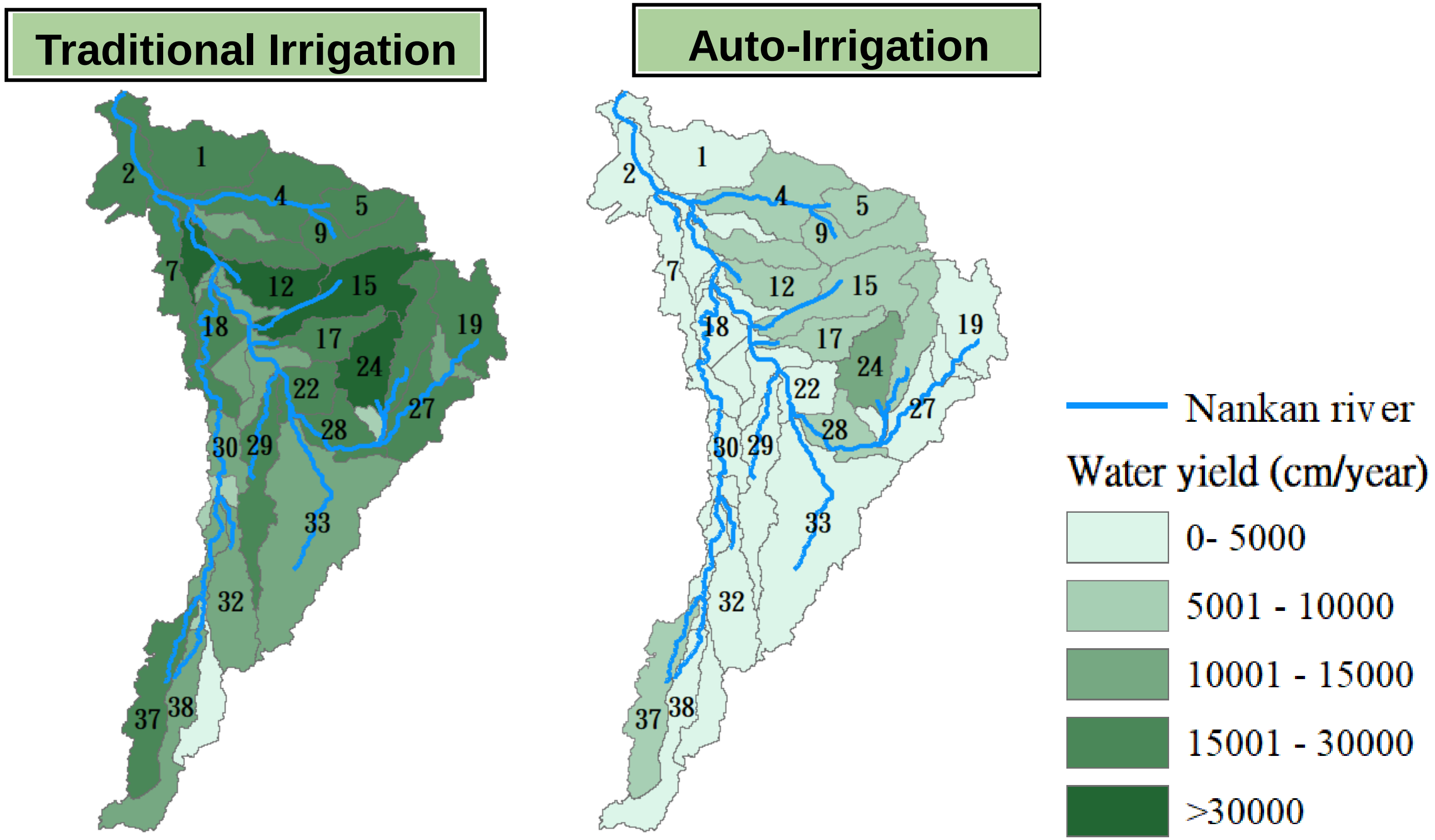


Auto-Irrigation



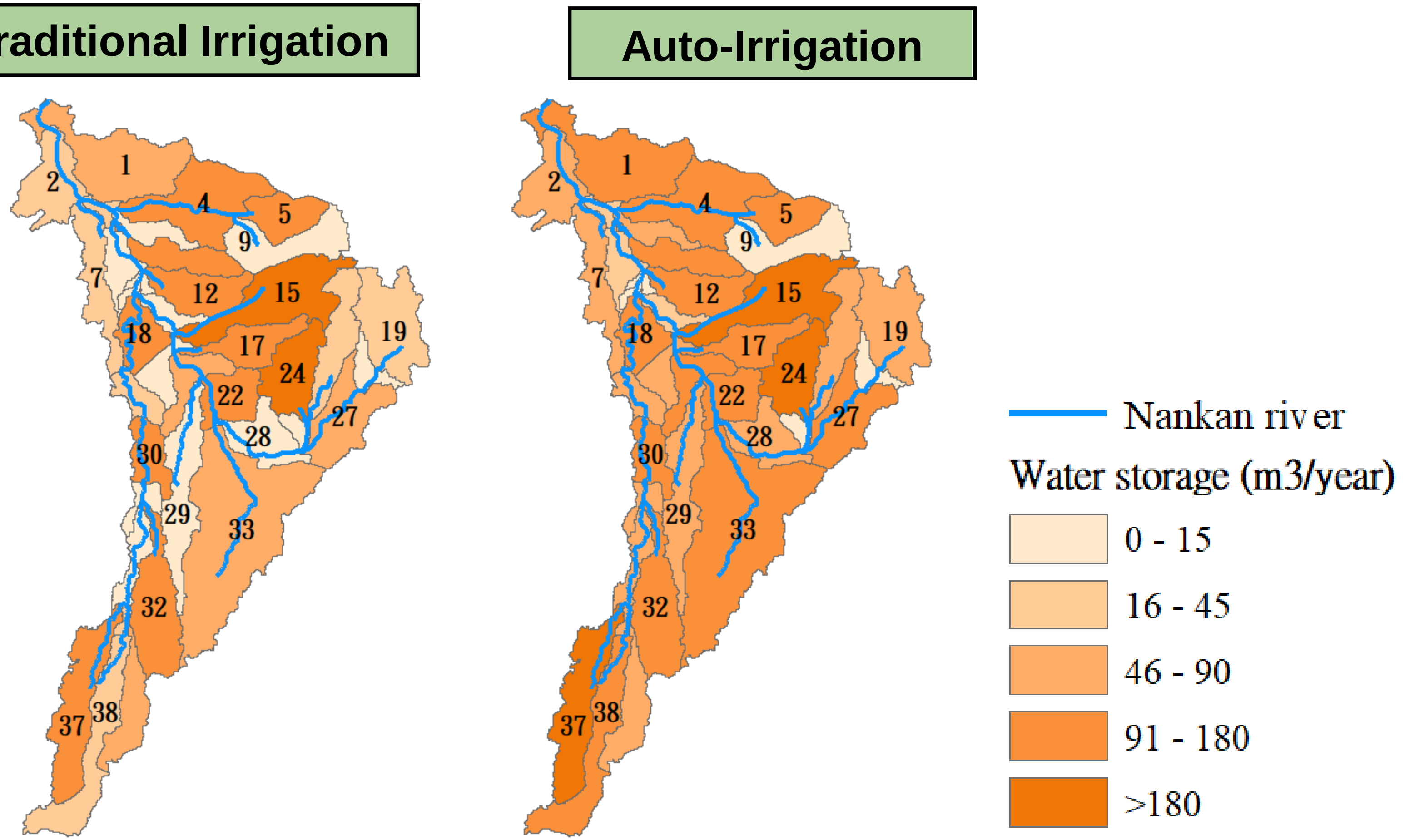
Results and Discussion (9/12)

- Traditional irrigation vs. Auto-irrigation
  - Annual average water yield of paddy HRU at subbasins



Results and Discussion (10/12)

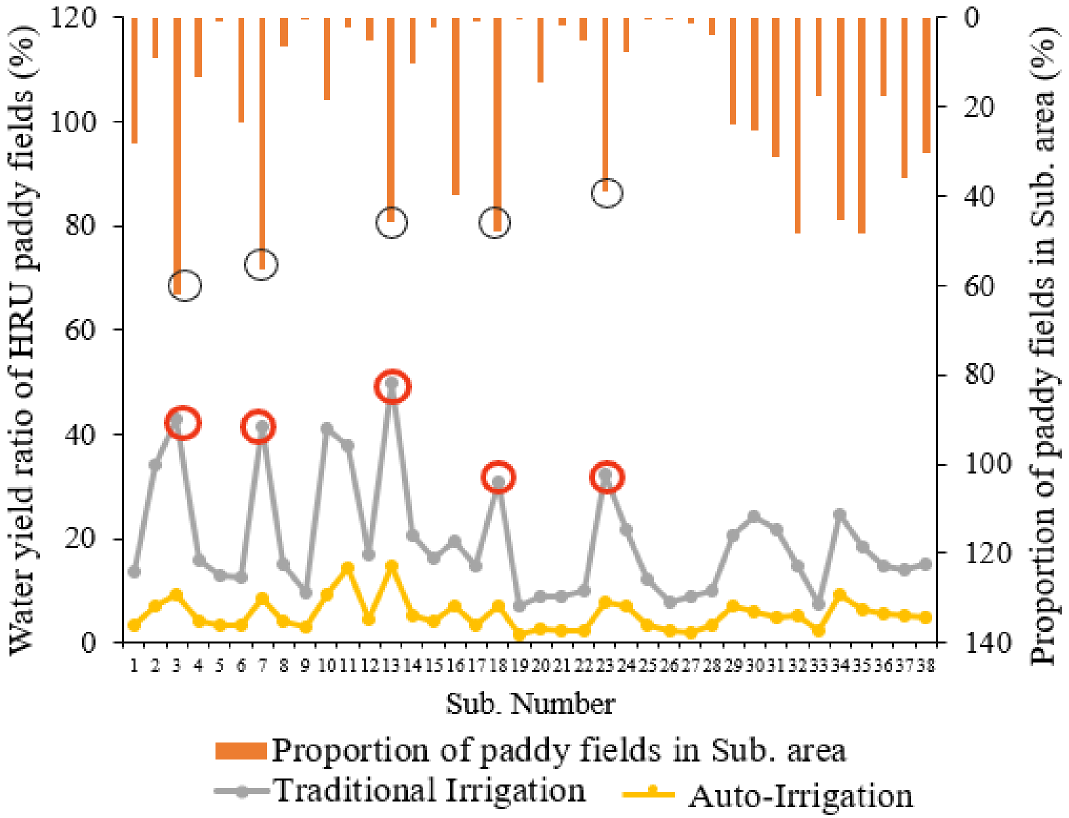
- Traditional irrigation vs. Auto-irrigation
  - Annual average water storage of paddy at subbasins



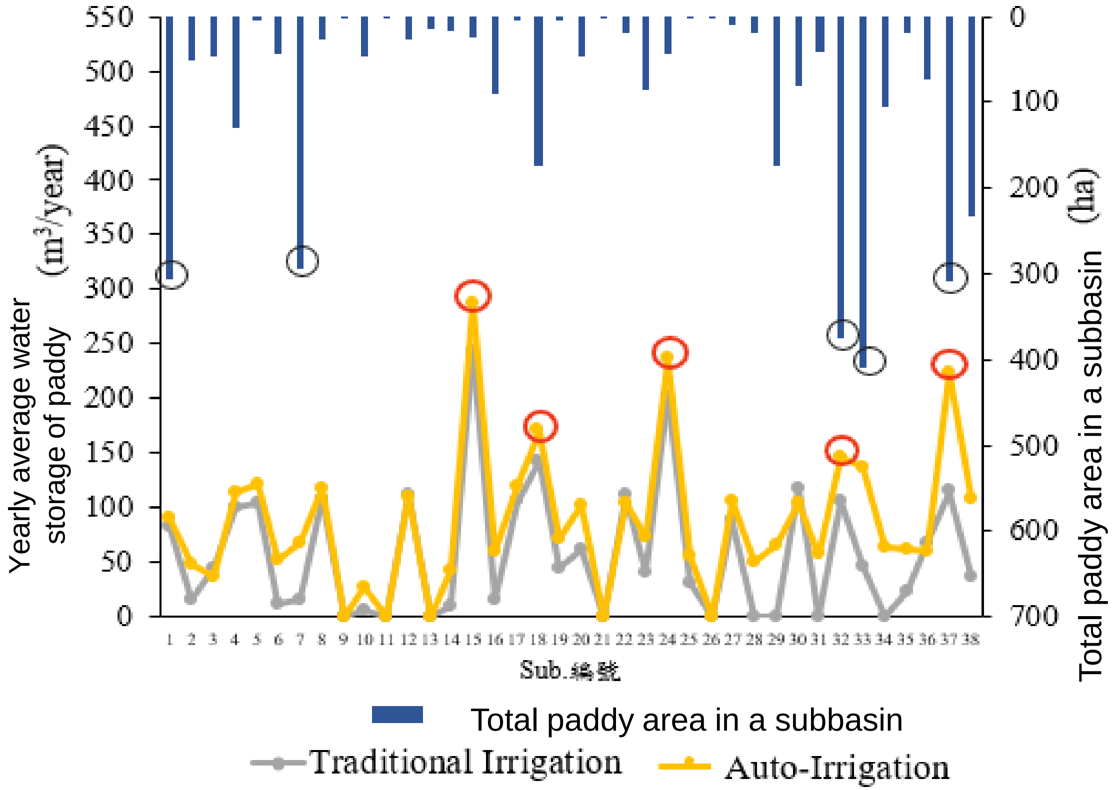
Results and Discussion (11/12)

- Traditional irrigation vs. Auto-irrigation
  - Paddy HRU contribution to total water yield of a subbasin vs. Area percentage of paddy in a subbasin
  - Yearly average water storage of paddy vs. Total paddy area in a subbasin

HRU Water Yield



Water storage of paddy



Results and Discussion (12/12)

- Traditional irrigation vs. Auto-irrigation
  - Daily average water yield of paddy HRU and water storage of paddy

Daily average water yield of paddy HRU (mm/day)			Insight
Irrigation operations	Range (2009-2013)	Average (2009-2013)	• Traditional irrigation allows water stored in paddy fields to release as a way to increase water yield of paddy HRU. • As for auto-irrigation to meet the water demand by crops, the model tends to retain more water storage in paddy fields. Thus, water drained as water yield of paddy HRU become less.
Traditional Irrigation	1902.5 - 2200.7	2038.0	
Auto-irrigation	318.9 - 624.5	480.4	
Daily average water storage of paddy (m^3/day)			
Irrigation operations	Range (2009-2013)	Average (2009-2013)	
Traditional Irrigation	4.24 - 7.29	6.08	
Auto-irrigation	3.17 - 12.26	9.01	

Conclusion

- Integration and proper classification of land use could effectively improve the irrigation coverage of paddy fields (by an average of 25%), reaching a total coverage of approximately 70%, and R^2 value of paddy field coverage increased from 0.52 to 0.82.
- By setting the soil depth as the plowsole depth, all hydrological characteristics of paddy fields were clearly presented, while soil infiltration would be enhanced when setting the plowsole with a fixed depth of 6000mm.
- Under the condition of shallow soil depth and slow slope, the difference between simulated and theoretical water yields is closely correlated with rainfall.
- Auto-irrigation operation is suggested for storing more water in paddy fields and resulting less return water out of paddy fields.

Thank you for your listening.