Developing optimal diffuse pollution management strategies in an agricultural watershed under future climate change

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Outline

1 Introduction

2 Methodology

3 Results

4 Conclusions

Introduction

Agricultural practices

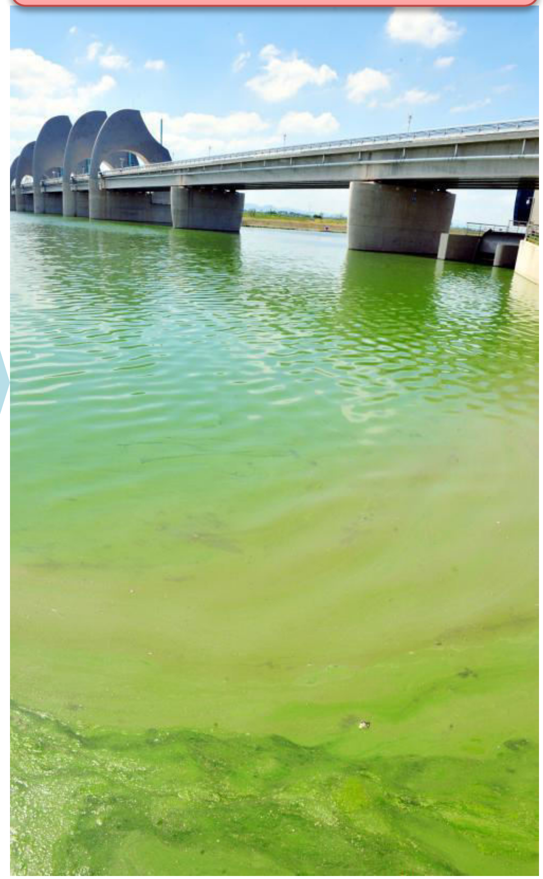
Tillage practices

Fertilizer scattering

Agricultural area in Yeongsan-river watershed : **40 %**

NPS pollutants runoff

Algal blooms

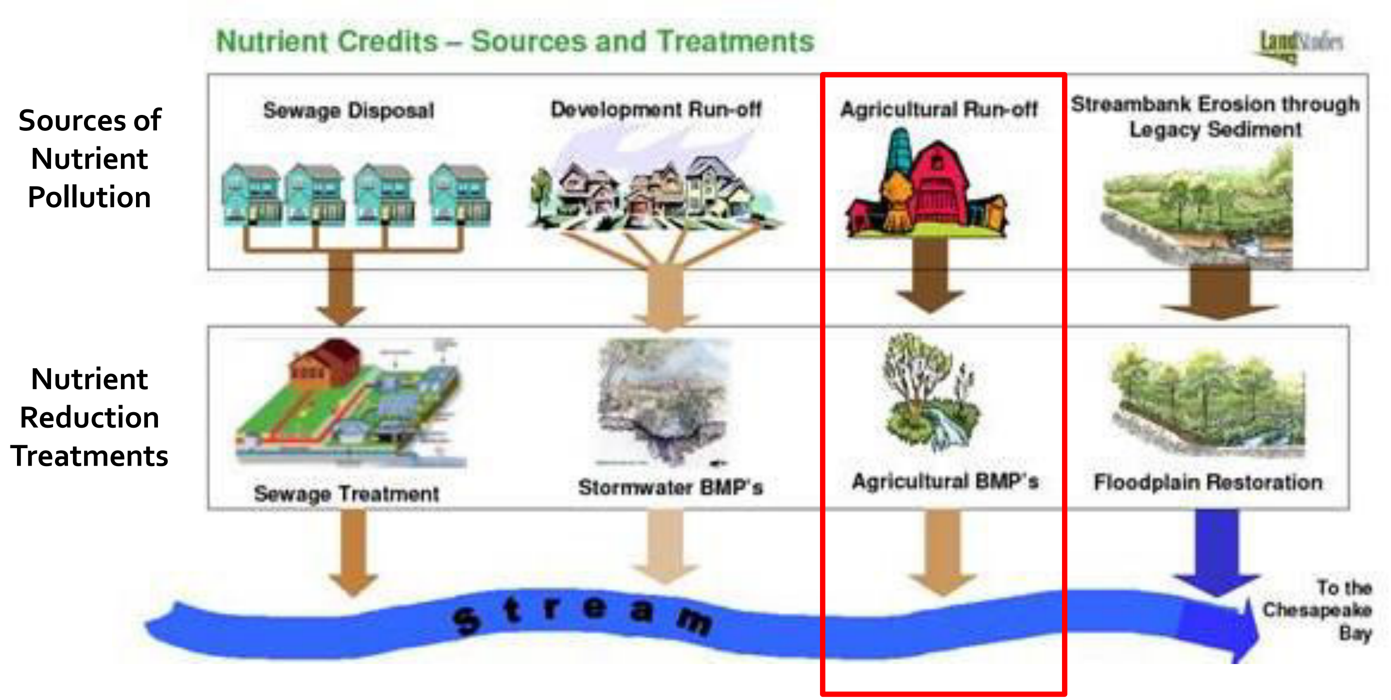


How to reduce the NPS pollutants efficiently?

- ✓ Algae blooms in large rivers in Korea have been a big problem every year
- ✓ Eutrophication of freshwater can be lead to the algae blooms

Introduction Background

➢ **Solution : To suggest the best management practices (BMPs)**

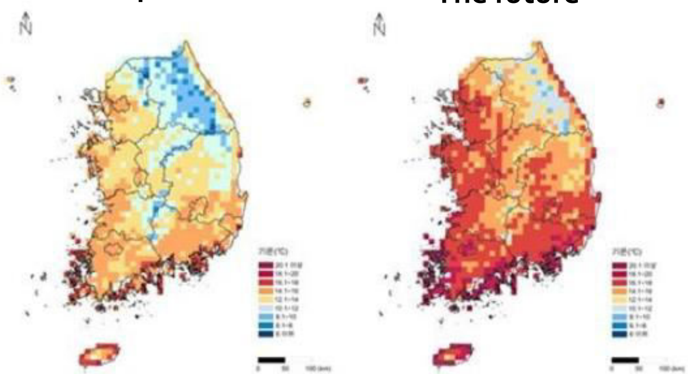


✓ An alternative way to moderate nonpoint sources loading and improve water quality by controlling runoff, sediments and nutrients, in agricultural watersheds.

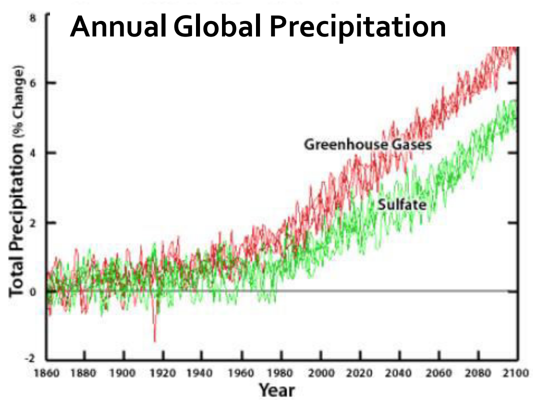
Introduction Background

Climate Change

The present The future

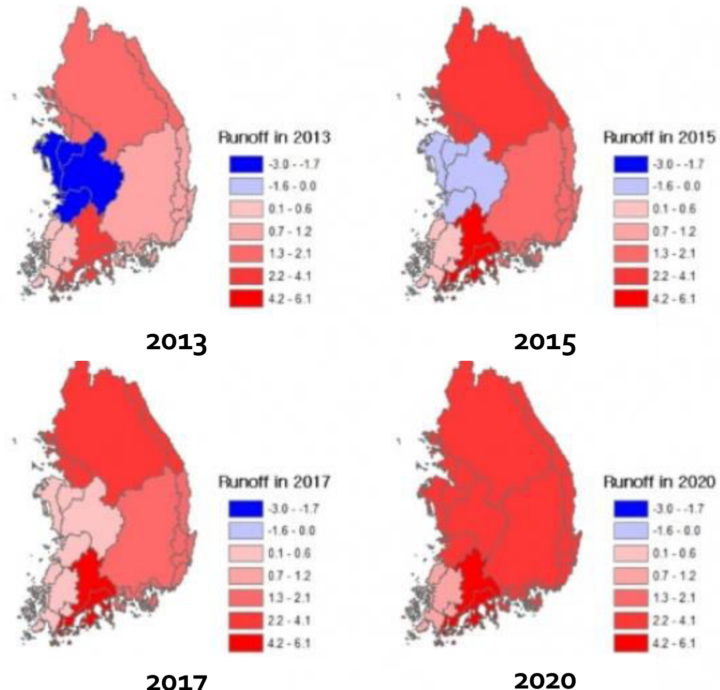


(ref. Jong-Suk Kim, 2011)



(ref. EPA)

Runoff Change



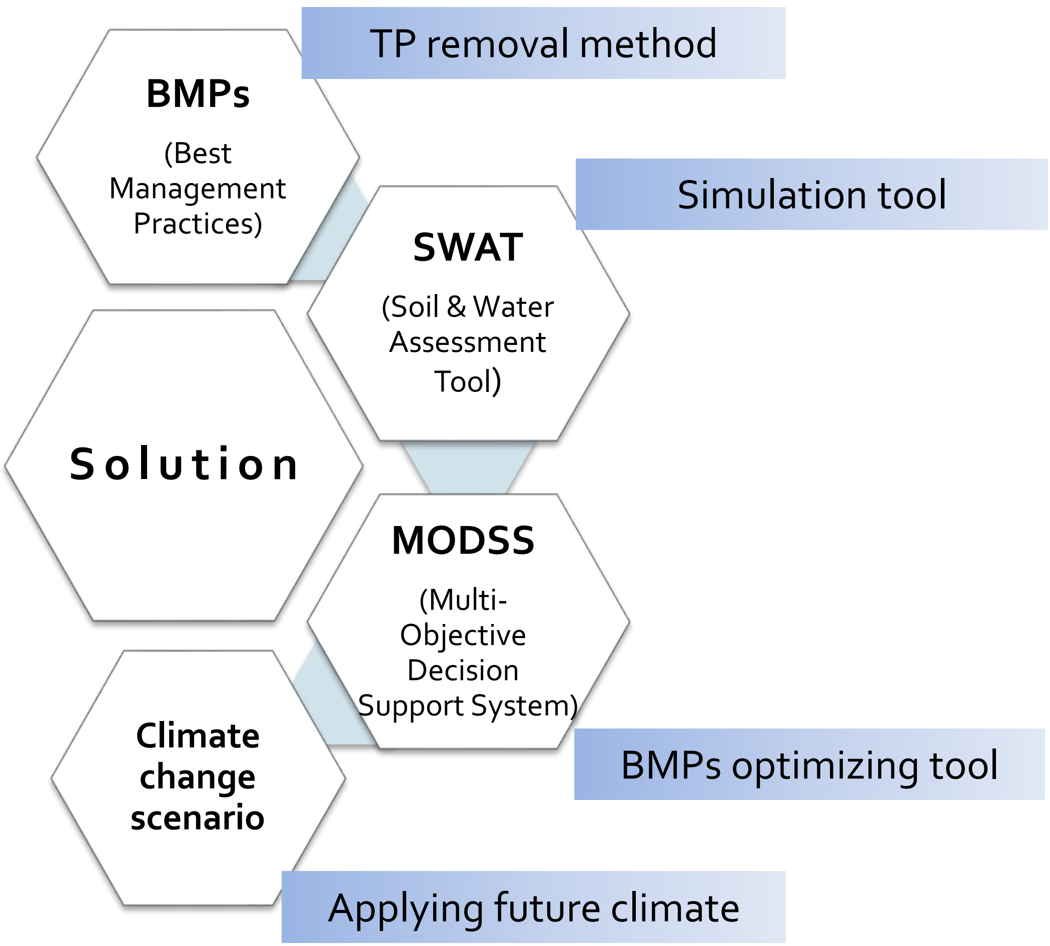
(ref. Hyun Suk Shin, 2012)

BMPs can be changed

✓ Climate change impacts on runoff change, also BMPs can be changed with runoff change

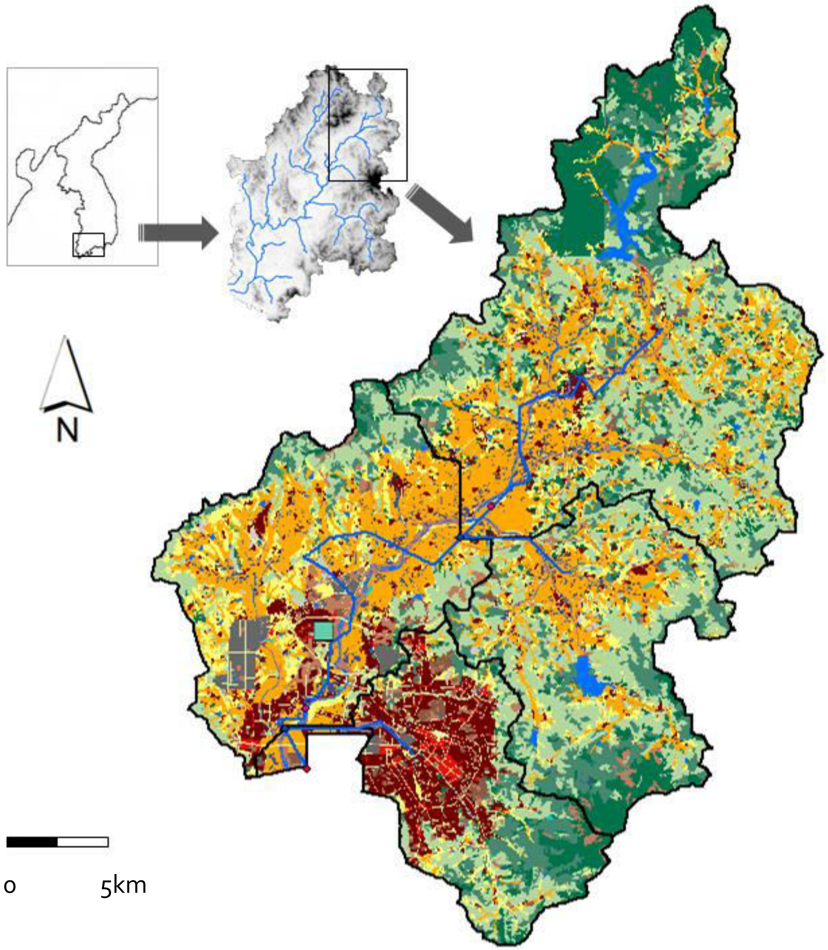
Objective

- ✓ To develop a hydrologic model for forecasting the flow, sediment, and TP in Yeongsan River
- ✓ To estimate the TP removal efficiency of BMPs using hydrologic model
- ✓ To analyze the variation of optimized BMPs according to climate change



Methodology

Methodology   Site Description

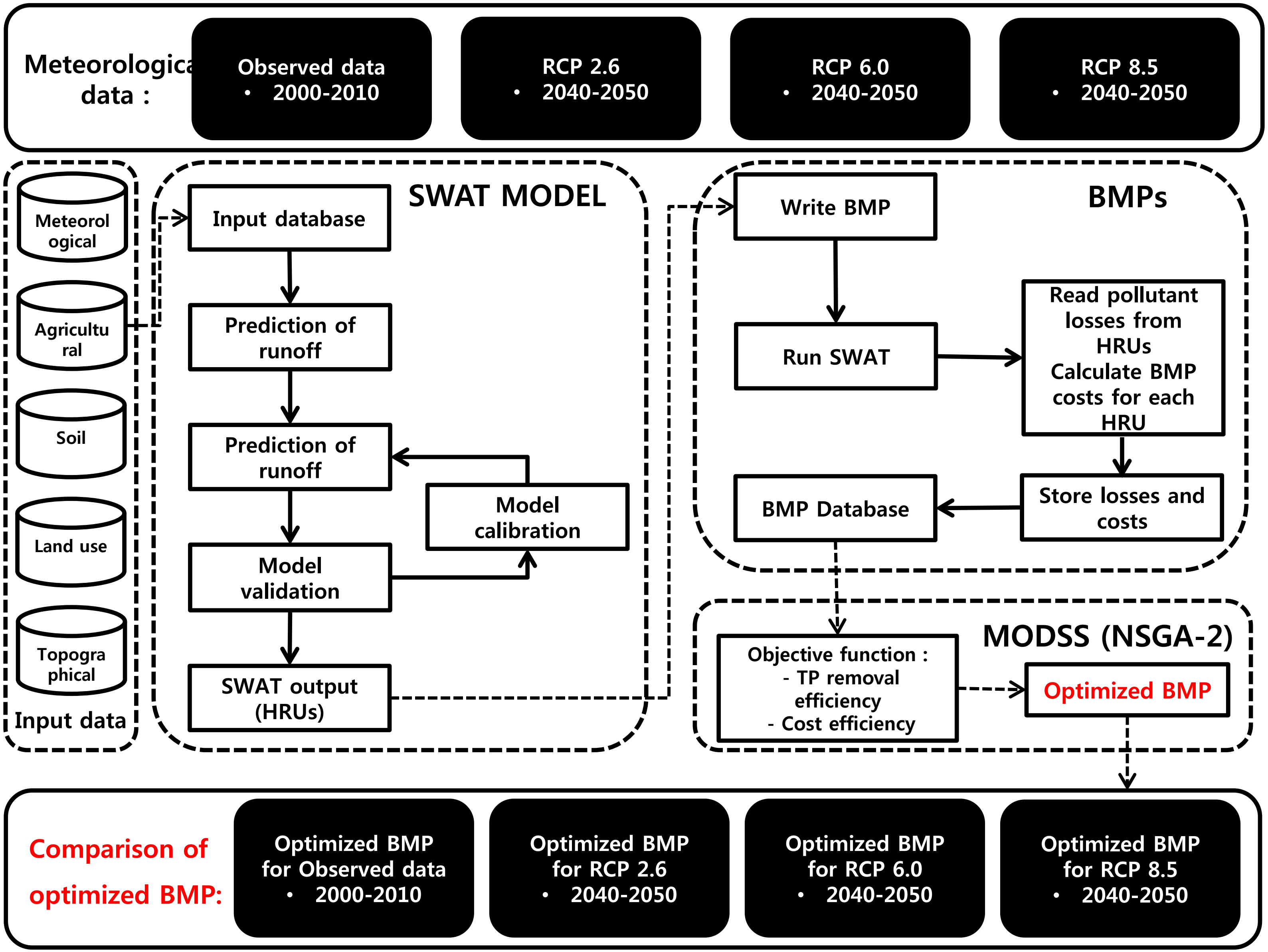


- Area [km²] : 724.37
- The number of sub-basins : **9**
- The number of agricultural HRU : 98
- The number of Rice HRU : 39
- The number of Soybean HRU : 59

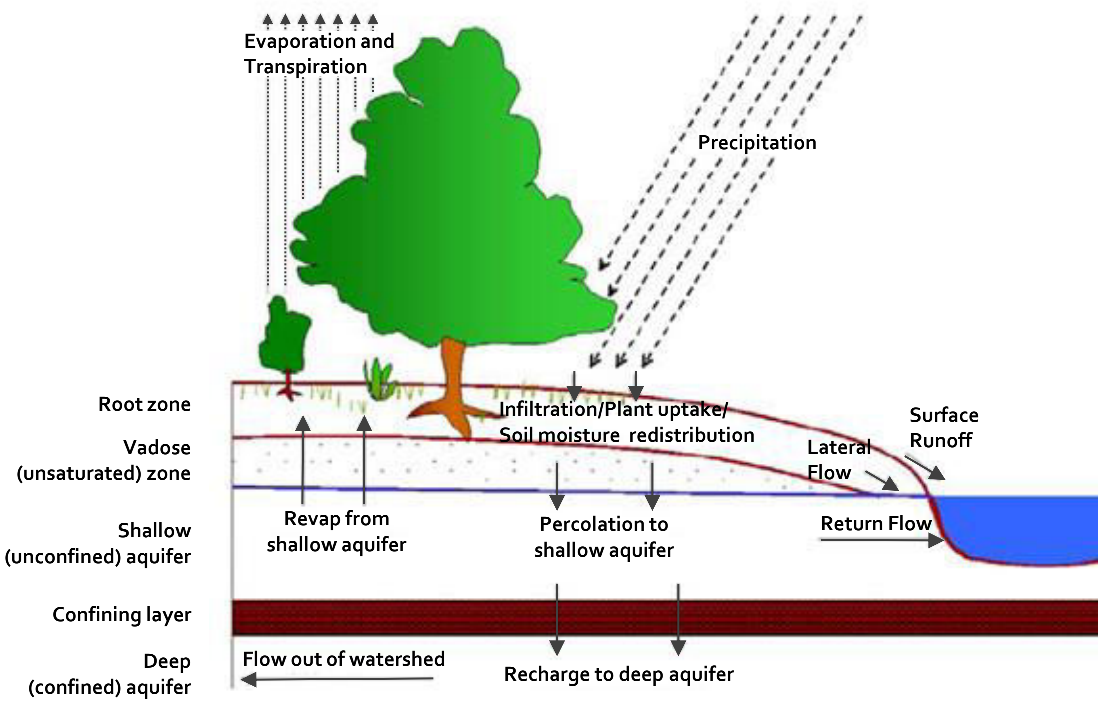
Land Use	Area (%)
Forest-Evergreen	24.85
Rice	**21.08**
Forest-Mixed	12.34
Forest-Deciduous	10.94
Soybean	**8.66**
Residential-High Density	7.87

✓ HRU(Hydrologic Response Unit) is classified by land use, slope, and soil component

Methodology Flow Chart



Methodology SWAT model



- ✓ SWAT is a basin-scale and continuous-time hydrologic model with GIS interface
- ✓ Water balance equation : $SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$

SW_t: final soil water content, ***SW_o***: initial soil water content, ***t***: time, ***i***: day,
R_{day}: amount of precipitation, ***Q_{surf}***: amount of surface runoff, ***E_a***: amount of evapotranspiration,
w_{seep}: amonut of water entering the vadose zone from the soil profile, ***Q_{gw}***: amount of return flow

Methodology SWAT model

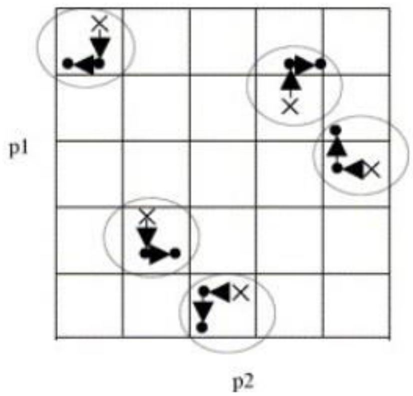
- **Simulation Period : 11 years (2000 – 2010)**

2000-2002	2003-2006	2007-2010
Spin Up	Calibration	Validation

- **Sensitivity analysis : LH-OAT (**Latin hypercube one-factor-at-a-time)

✓To process by performing the LH samples in the role of initial points for a OAT design.

✓The method to comprehend efficiently global sensitivity about the whole boundary of parameter.



- **Calibration/Validation**

✓ Procedure : Flow discharge -> Sediment -> TP

✓Flow discharge : SCE-UA(Shuffled complex evolution at university of Arizona) method was used to analyze optimization in a single run.

✓ Sediment, TP : Pattern search using MATLAB

Methodology BMPs

List of representation of simulated BMPs

✓ Rice area

	BMP type	Cost ($/ha)
1	**Conservation Tillage (CT)**	**0**
2	**Parallel Terrace (PT)**	**74.9**
3	**contour Cropping (CC)**	**16.8**
4	**Detention Pond (DP)**	**99**
5	CT/PT	74.9
6	CT/CC	16.8
7	CT/DP	99
8	CT/PT/DP	173.9
9	CT/CC/DP	115.8

✓ Soybean area

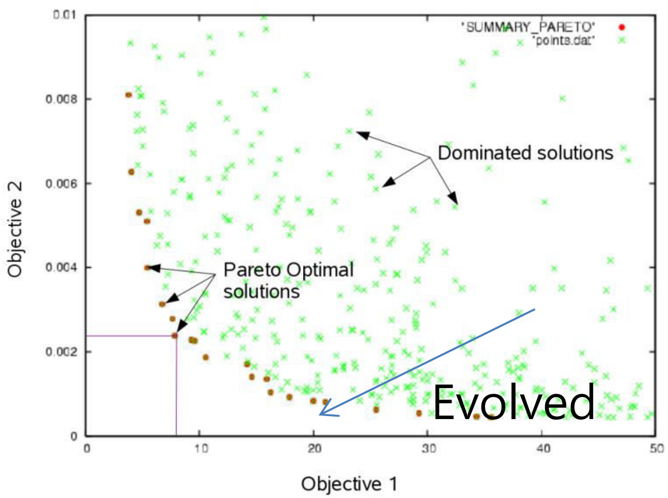
	BMP type	Cost ($/ha)
10	**Conservation Tillage (CT)**	**0**
11	**No Tillage (NT)**	**17.25**
12	**Parallel Terrace (PT)**	**74.9**
13	**Contour Cropping (CC)**	**16.8**
14	**Detention Pond (DP)**	**99**
15	**Riparian Buffers (RB) 10m**	**29.35**
16	CT/PT	74.9
17	CT/CC	16.8
18	CT/DP	99
19	CT/RB	29.35
20	NT/PT	92.15
21	NT/CC	34.05
22	NT/DP	116.25
23	NT/RB	46.6
24	CT/PT/DP	173.9
25	CT/CC/DP	115.8
26	CT/PT/RB	104.25
27	CT/CC/RB	46.15
28	NT/PT/DP	191.15
29	NT/CC/DP	133.05
30	NT/PT/RB	121.5
31	NT/CC/RB	63.4

✓ Simulated BMPs by SWAT

BMP	Parameter	Value
Conservation Tillage (CT)	Till ID: 3 CN2 OV_N	 CN2-2 0.30
Parallel Terrace (PT)	CN2 P-factor	CN2-5 0.1 if slope = 1 to 2% 0.12 if slope = 3 to 8%
Contour Cropping (CC)	CN2 P-factor	CN2-3 0.5 if slope = 1 to 2% 0.6 if slope = 3 to 8%
Detention Pond (DP)	pnd_k pnd_fr pnd_ESA	0 0.01 0.75
Nutrient Management (NM)	Amount of fertilizer	-25%
Riparian Buffers (RB)	FILTERW	10

- **NSGA-2 (Non-dominated Sorting Genetic Algorithm-2)**

✓ Pareto-optimal front (Non-dominated sorting)



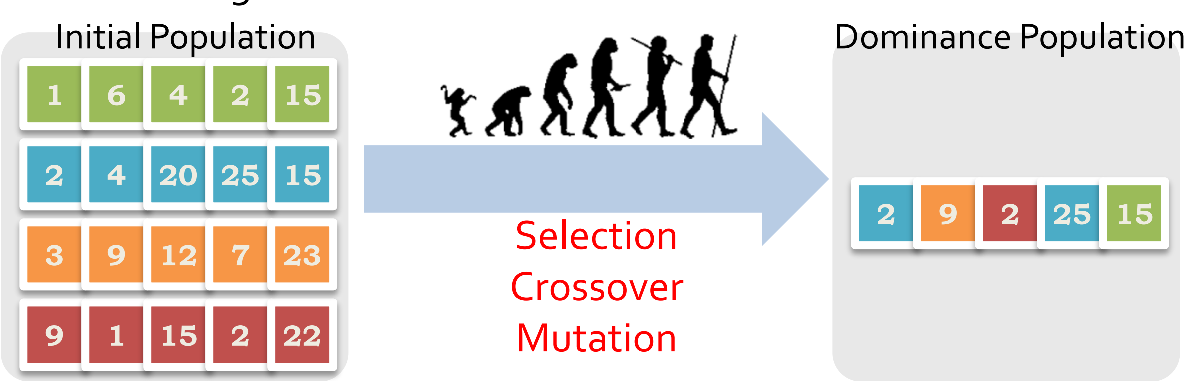
In multi-objective optimization, when the different objectives are contradictory, an optimal solution is said Pareto optimal when it is not possible to improve an objective without degrading the others.

✓ Objective function

1) Minimizing TP loads

2) Minimizing cost for implementing BMPs

✓ Principle of Genetic Algorithms



Methodology Climate change

➢ Scenario information

Climate change scenarios → RCP (IPCC 5th Report) → Greenhouse gases scenarios → HadGEM2-AO → HadGEM3-RA → PRISM

Greenhouse gases scenarios

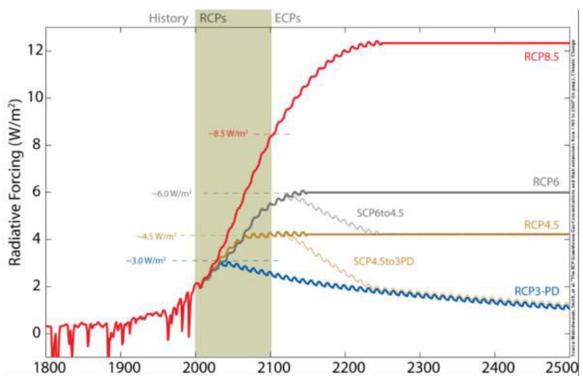
- RCP 2.6
- RCP 4.5
- RCP 6.0
- RCP 8.5

HadGEM2-AO: Global model applying artificial climate change
- Size: 135km

HadGEM3-RA: Region climate model
- Size: 12.5km

PRISM: Specification using the observed data
- Size: 1km

➢ RCP Scenario



RCP	Definition
2.6	Earth overcome the impact from human activity by one self.
4.5	Greenhouse gas reduction policy was realized considerably.
6.0	Greenhouse gas reduction policy was realized in some degree
8.5	Greenhouse gas was emitted without reduction

✓The more RCP number increase, greenhouse gas is much more emitted .

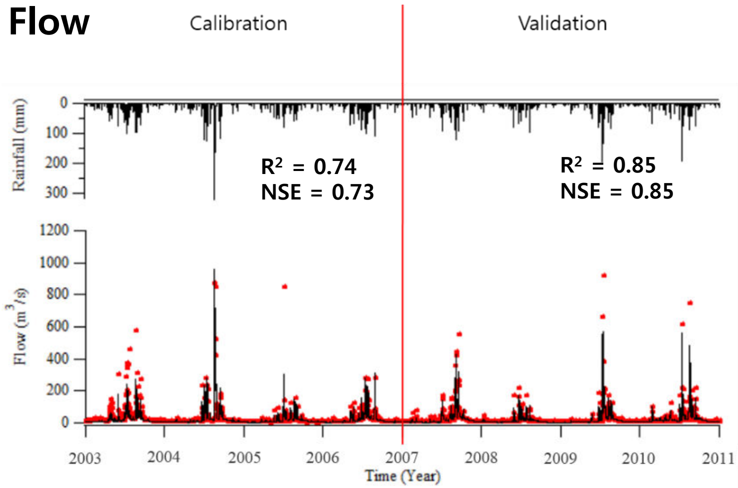
Results

Results SWAT Model Calibration/Validation

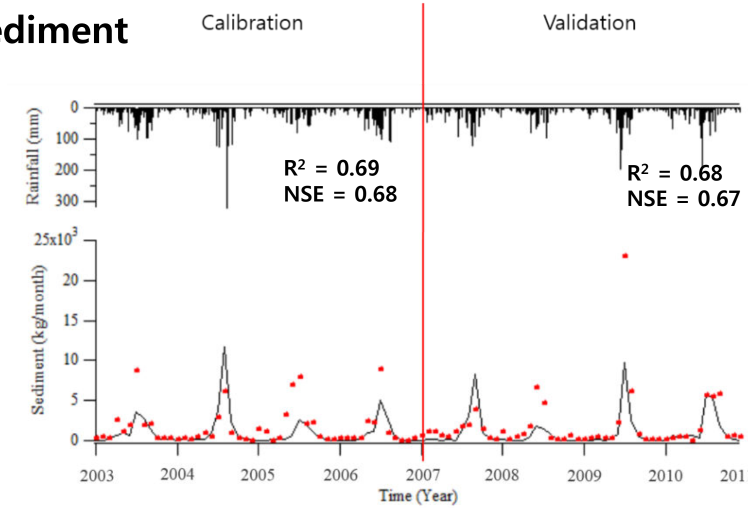
● Observation
—— Simulation

➢ Simulation results

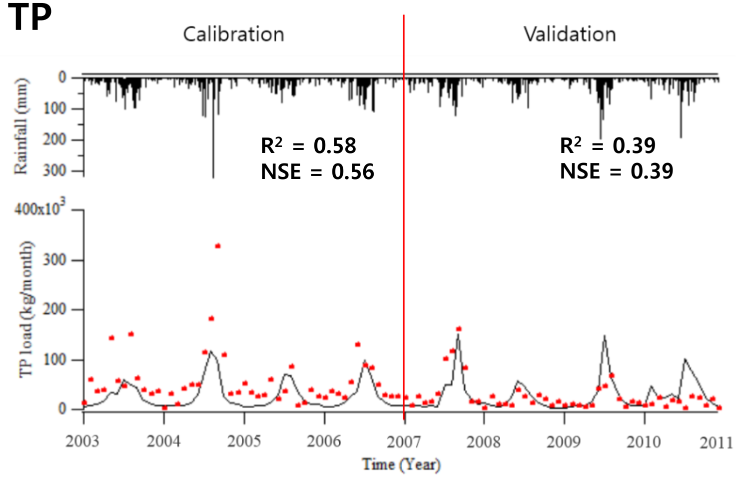
- **Flow**



- **Sediment**



- **TP**

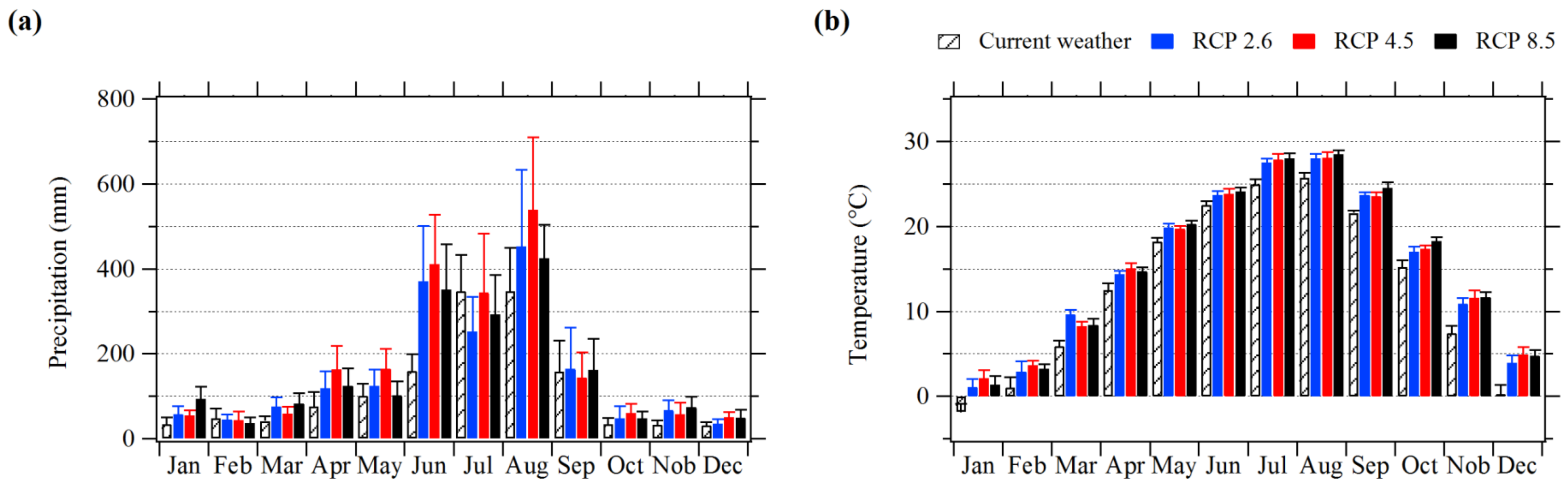


✓Typically values of R^2 and NSE greater than 0.5 are considered acceptable.

(ref. Daniel N. Moriasi, 2o6)

Results Variation of climate change

➢ Comparison of different weather inputs



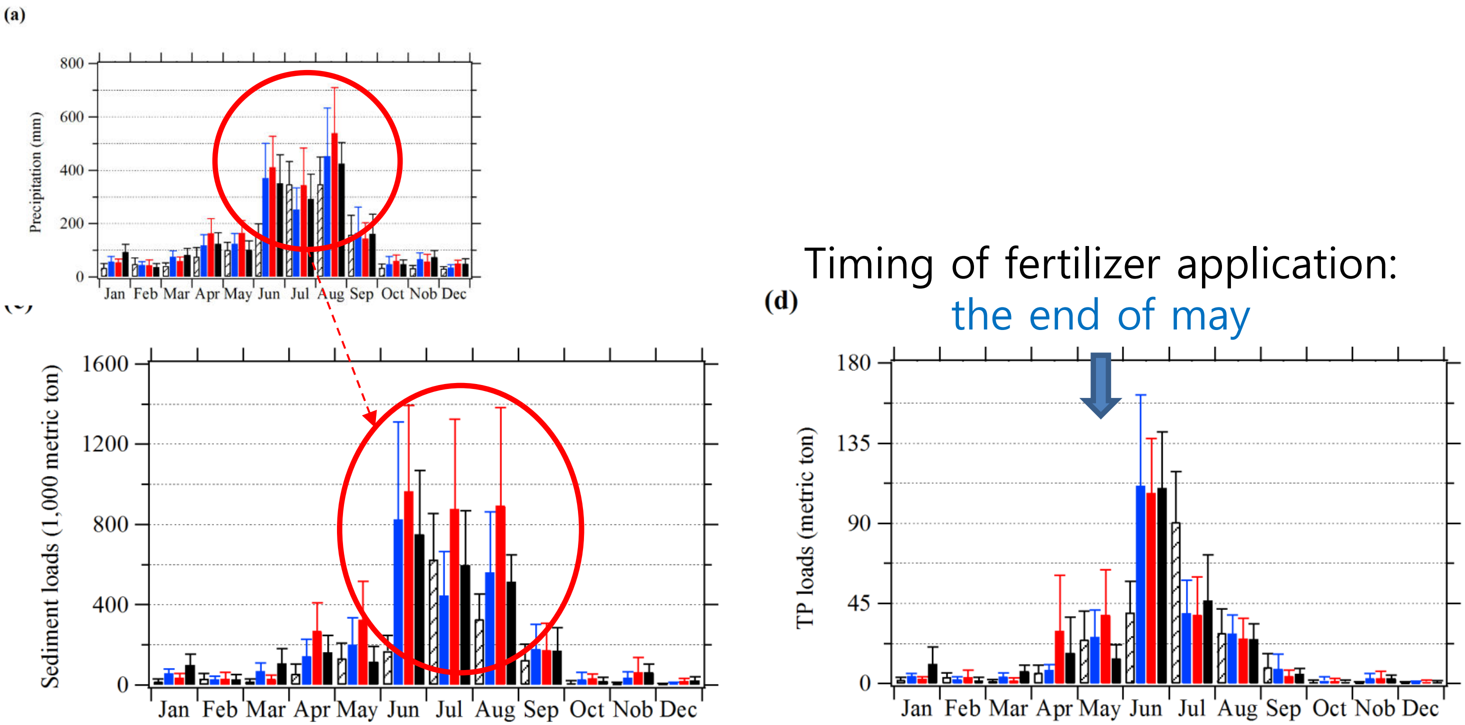
✓ Monthly precipitation of RCP were distinctly higher than current precipitation during Jun to Aug except for Jul.

✓ Especially, RCP 4.5 shows extreme change of precipitation than current precipitation.

✓ In case of monthly temperature, RCP were higher than current temperature values (RCP 8.5 > RCP 4.5 > RCP 2.6)

Results Variation of NPS loads

- Comparison of different weather inputs and their resulting outputs



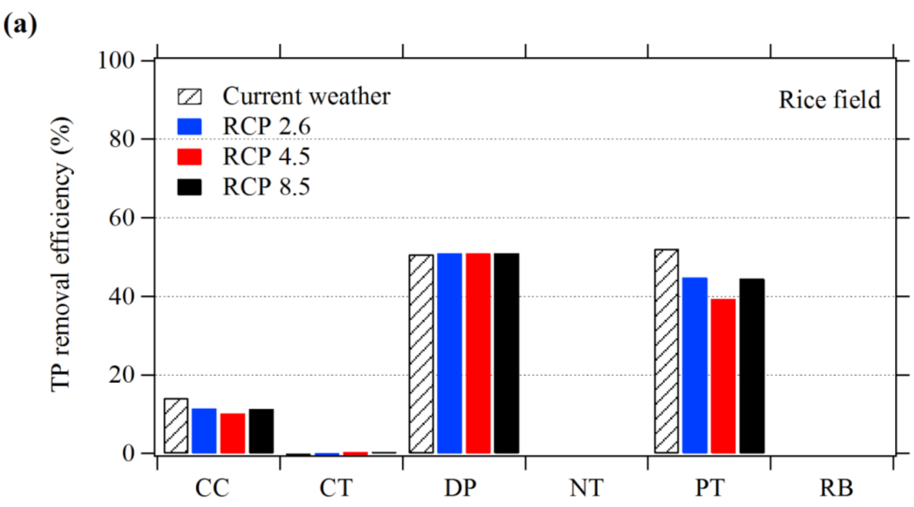
✓ Monthly sediment loads affected by increase in precipitation in summer season, and show similar monthly trend with precipitation intensity.

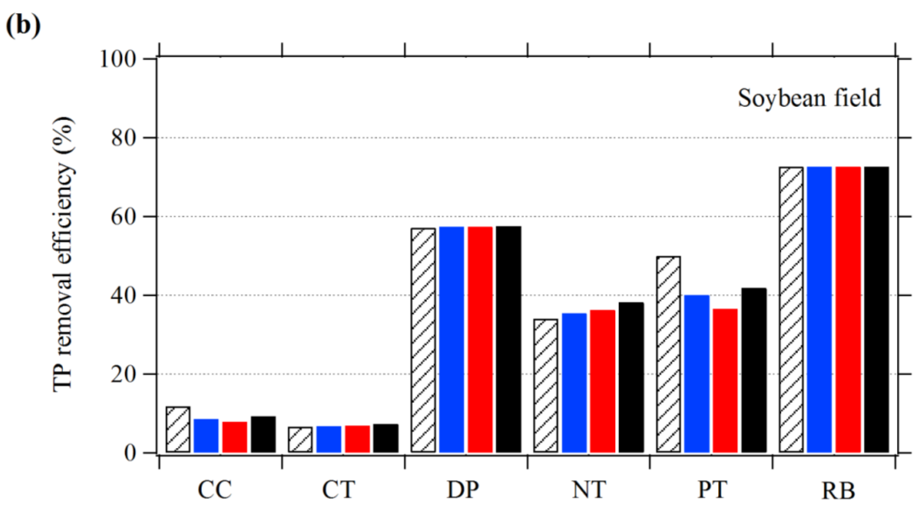
✓ However, TP loads appeared different patterns compared with monthly precipitation.

✓It seems to be related with timing of fertilizer application.

✓TP loads increased immediately after fertilizer application with increase in precipitation June.

➢ TP removal efficiency under different climate condition





✓ In case of rice field, DP shows constant removal efficiency regardless of climate, PT was changed under different climate scenarios.

✓ PT shows better efficiency than DP under current climate condition. However, DP shows better efficiency than PT under future climate condition.

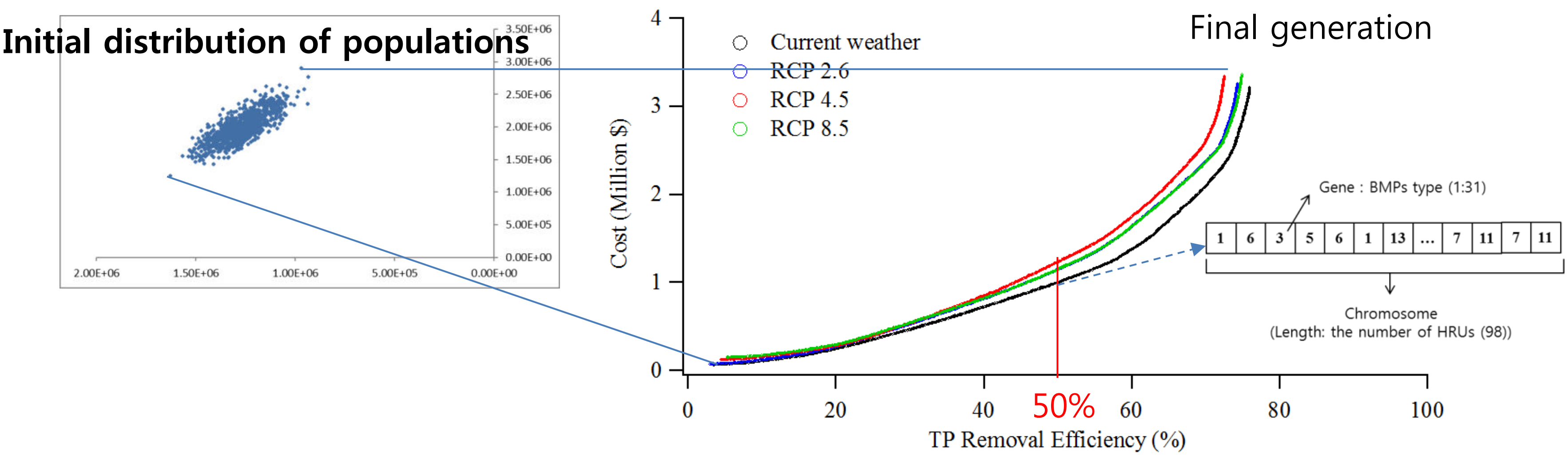
✓ In case of soybean field, RB shows remarkable removal efficiency compared with the other BMPs.

Results Genetic algorithms

➢ MODSS(NSGA-2)

✓ Generation number: 16,000

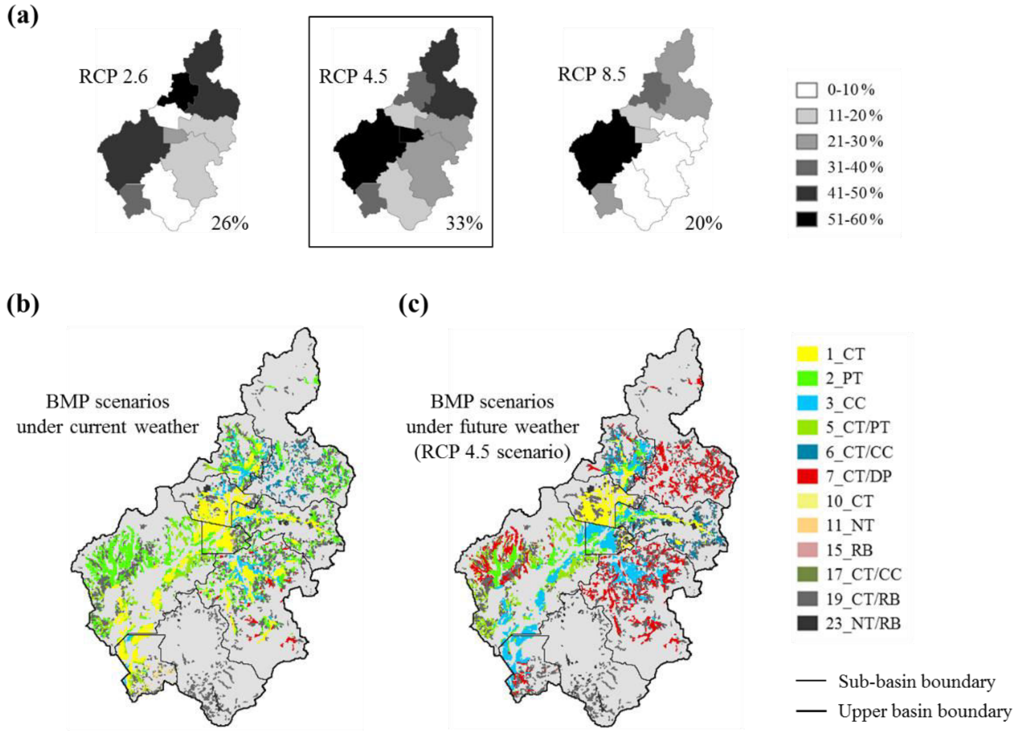
✓ Population size: 1,000

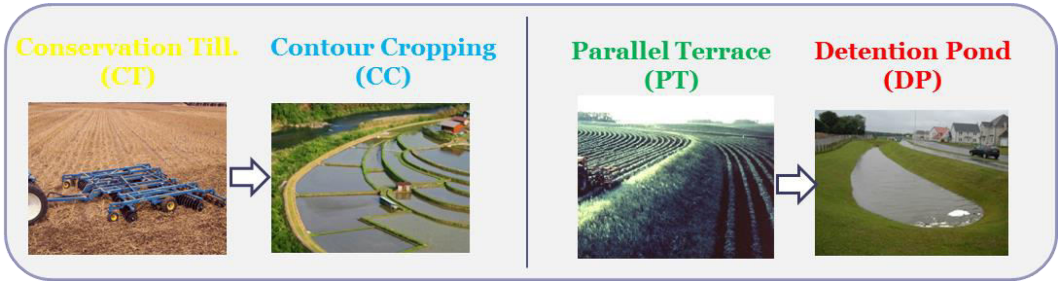


✓ MODSS result under RCP 4.5 shows the most different populations distribution compared with result under current climate.

✓ the criteria for choosing one population(BMPs allocation) is TP removal efficiency of 50%

➢ Optimal BMP strategies under climate condition





✓ Sub-basin scale: The amount change in the types of BMP assigned for individual sub-basins between current and any of these future weather scenarios

✓ HRU scale:

- Current climate: CT, PT
- Future climate: CC, DP

Conclusions

- The prediction of **flow discharge and sediment** from SWAT model was appeared **suitable goodness of fit**, however the **TP** prediction from SWAT model was appeared **not suitable goodness of fit** in study area.
- **In the rice area, contour cropping** was the BMP which could be optimized by the modeling approach.
- **In the soybean area**, **conservation tillage** and **riparian buffer** were the BMPs which could be optimized by the modeling approach.
- **The optimized BMPs** in many HRUs **are changed** with future climate change.
- This study can open new approach **to implement the BMPs by considering the future climate change** and **improve the water quality** of Yeongsan River

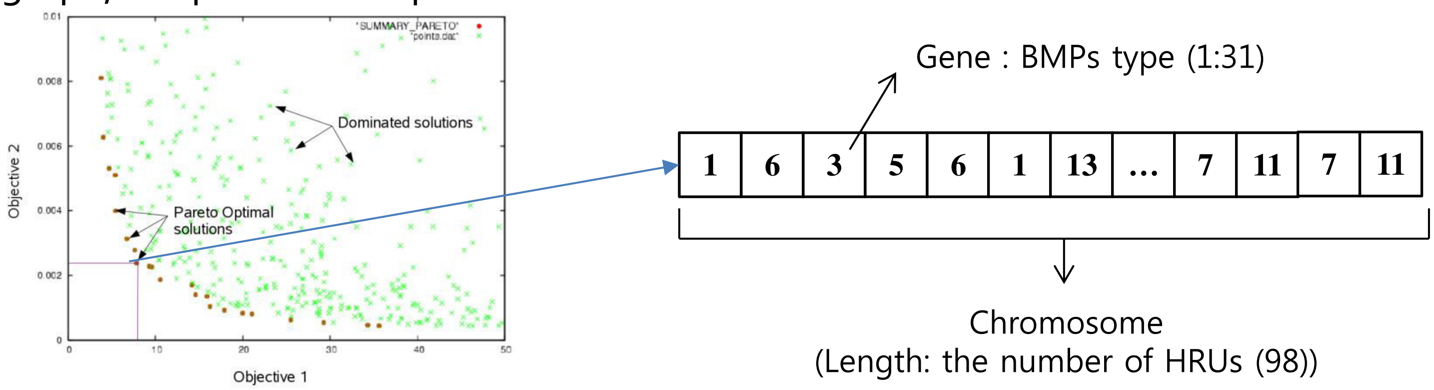
Thank you

Methodology MODSS

- **NSGA-2 (Non-dominated Sorting Genetic Algorithm-2)**

  ✓ Composition of chromosome

  In the graph, the points are represented as the chromosomes



  ✓ Objective function

  1) Minimizing TP loads

  2) Minimizing cost for implementing BMPs

  ✓ Input matrix

  1) TP loads according to BMP types of each HRUs

  2) needed cost according to BMP types of each HRUs

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Bias correction for precipitation

✓Local intensity scaling (LOCI) method

Step1

$$P_{contr*1}(d) = \begin{cases} 0, & if\ \ P_{contr}(d) < P_{th,contr} \\ P_{contr}(d), & otherwise \end{cases}$$

$$P_{scen*1}(d) = \begin{cases} 0, & if\ \ P_{scen}(d) < P_{th,contr} \\ P_{scen}(d), & otherwise \end{cases}$$

Step2

$$s = \frac{\mu_m(P_{obs}(d)|P_{obs}(d) > 0mm)}{\mu_m(P_{contr}(d)|P_{contr}(d) > P_{th,contr}) - P_{th,contr}}$$

Step3

$$P_{contr*}(d) = P_{contr*1}(d) * s$$

$$P_{scen*}(d) = P_{scen*1}(d) * s$$

P_{contr}(d): daily precipitation RCM during 1979-2005,
$P_{contr*I}$(d): bias corrected daily precipitation of RCM during 1979-2005,
$P_{th.contr}$: RCM-specific precipitation threshold,
P_{scen}(d): daily precipitation of RCM during 2040-2050,
P_{scen*I}(d): corrected daily precipitation of RCM during 2040-2050
P_{obs}(d): observed daily precipitation during 1979-2005
S: scaling factor
P_{contr*}(d): bias-corrected daily precipitation of RCM during 1979-2005
P_{scen*}(d): bias-corrected daily precipitation of RCM during 2040-2050

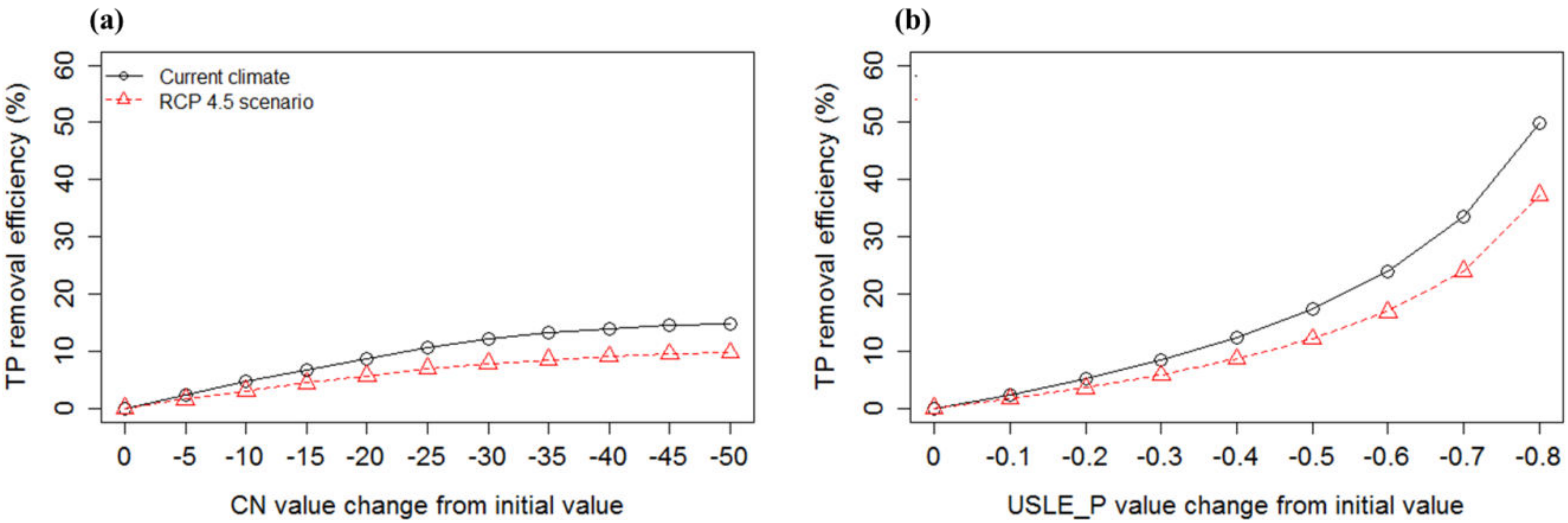
Bias correction for temperature

✓Linear scaling approach method

$$T_{RCM*} = T_{RCM} + (T_{mean.his} - T_{RCM.his})$$

$T_{mean.his}$: observed yearly mean temperature during 1979-2005
$T_{RCM.his}$: RCM yearly mean temperature during 1979-2005
T_{RCM}: RCM daily temperature during 2040-2050
T_{RCM*}: bias-corrected daily temperature of RCM during 2040-2050

➢ MODSS results (future climate)



✓ CN value and USLE_P value were adjusted for applying management practices in SWAT model.

✓ TP removal efficiency was better for the current climate than for the RCP 4.5 when CN and USLE_P values changed in the same degree.