Assessment of Climate Change Impact on Best Management Practices in the Yeongsan Watershed using the Multi-objective Decision Support System

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**Yeongsan River Environment Research Laboratory

Outline

Introduction

Introduction

Background

Agricultural practices

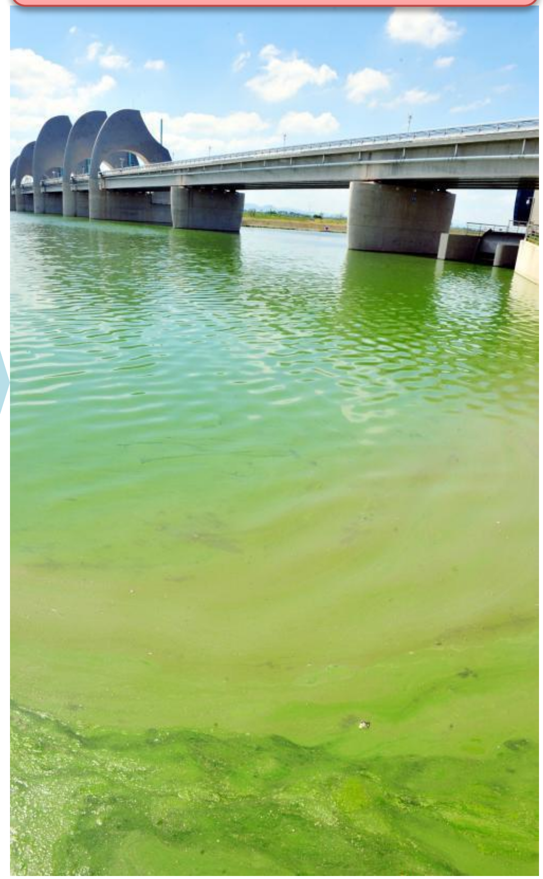
Tillage practices

Fertilizer scattering

Agricultural area in Yeongsan-river watershed : 40 %

NPS pollutants runoff

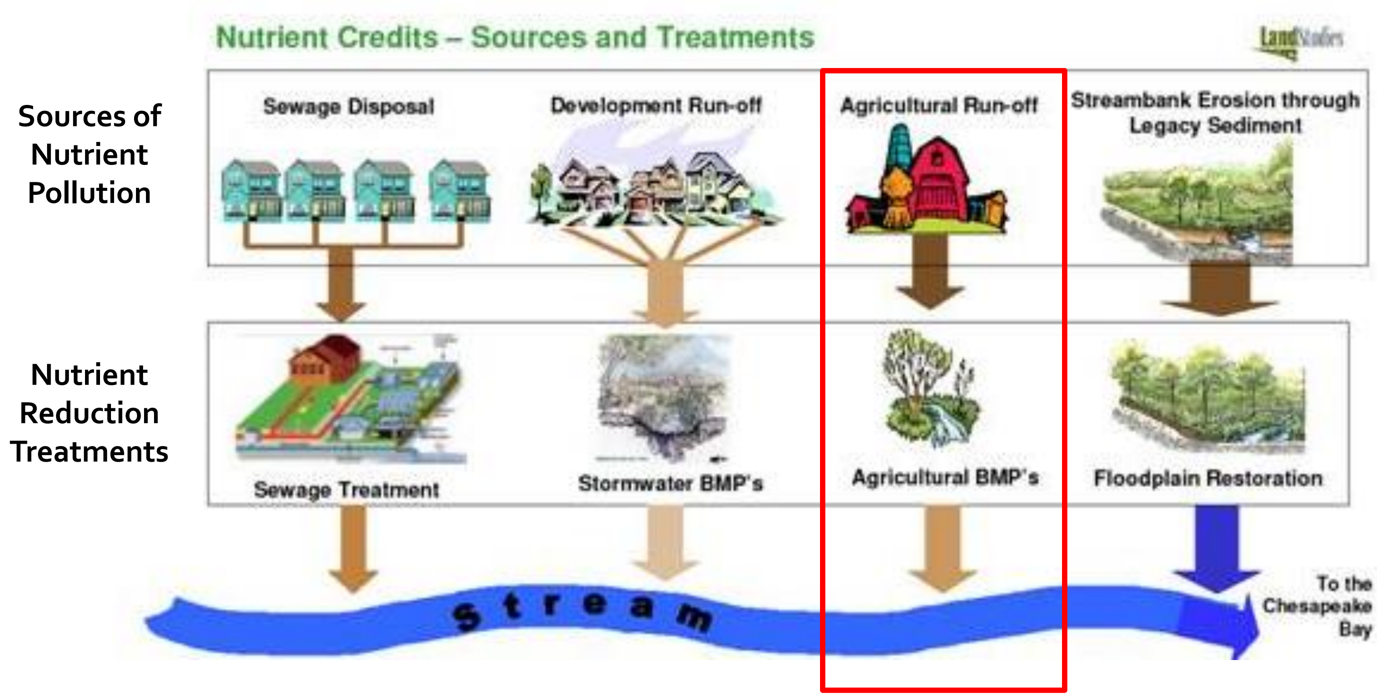
Green algae



How to reduce the NPS pollutants efficiently?

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

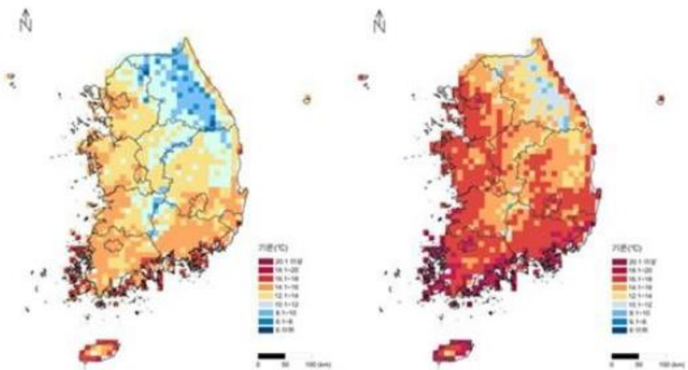
➢ **Solution : To suggest the best management practices (BMPs)**



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

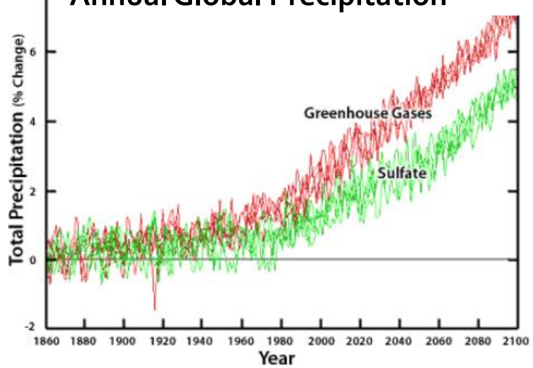
Climate Change

The present The future



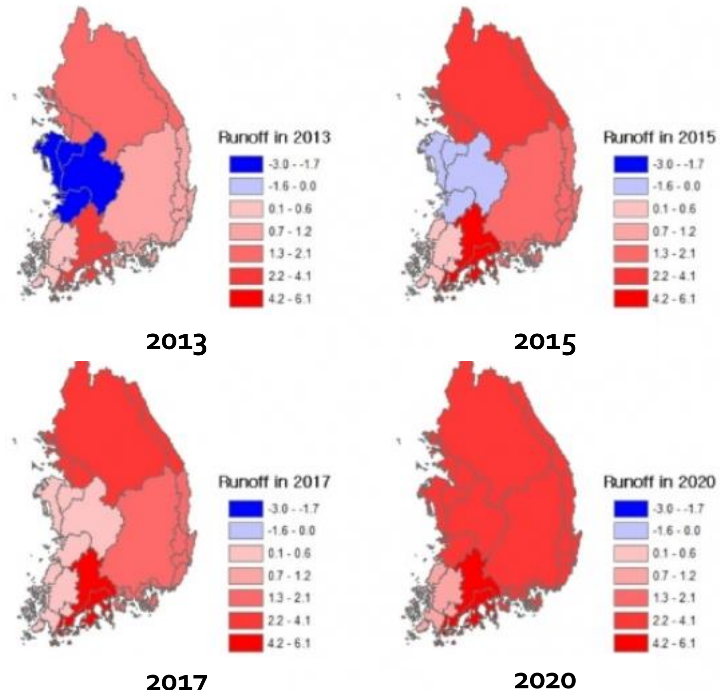
(ref. Jong-Suk Kim, 2011)

Annual Global Precipitation



(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

Introduction Background

BMPs

(Best Management Practices)

TP removal method

SWAT

(Soil & Water Assessment Tool)

Simulation tool

Solution

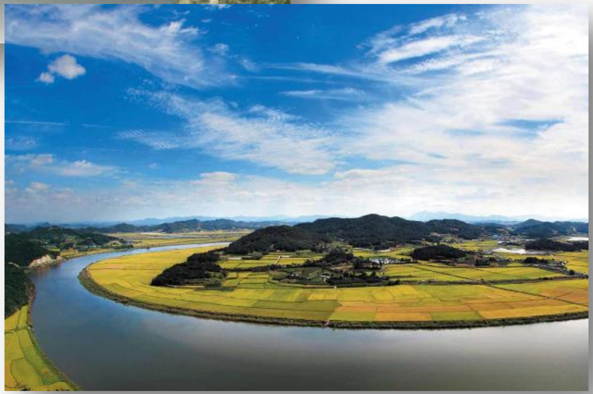
MODSS

(Multi-Objective Decision Support System)

BMPs optimizing tool

Climate change scenario

Applying future climate



Introduction Objective

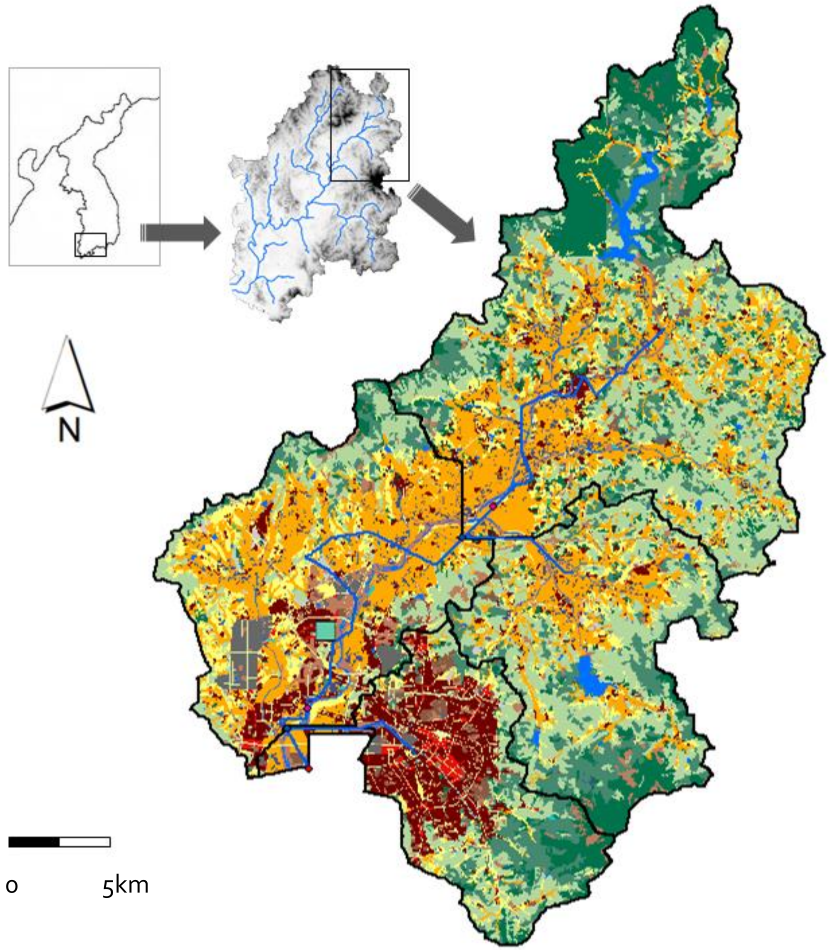
Objective To assess the change of optimized BMPs reflecting future climate at agricultural area.

- ✓ 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 apply the climate change scenario in the SWAT model

Methodology

Methodology

Site Description



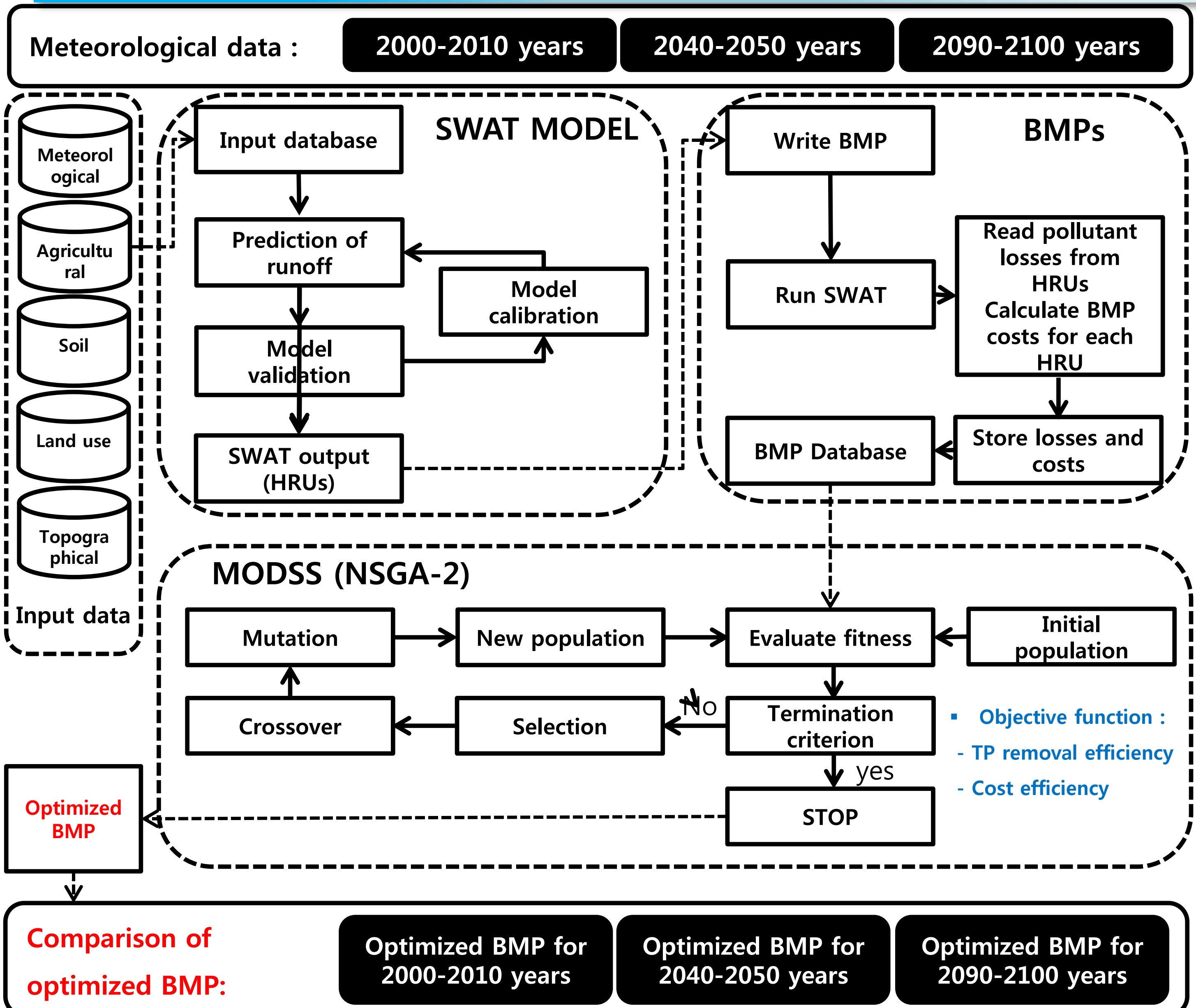
- Area [km²] : 724.37
- The number of sub-basins : **5**
- The number of HRU : **36**
- The number of Rice HRU : 6
- The number of Soybean HRU : 6

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

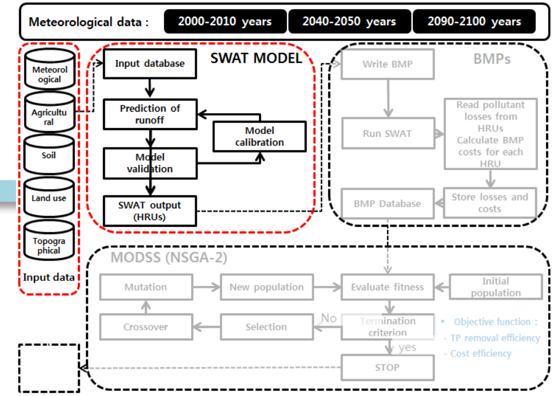
✓ HRU(Hydrologic Response Unit) are classified by land use, slope, and soil component

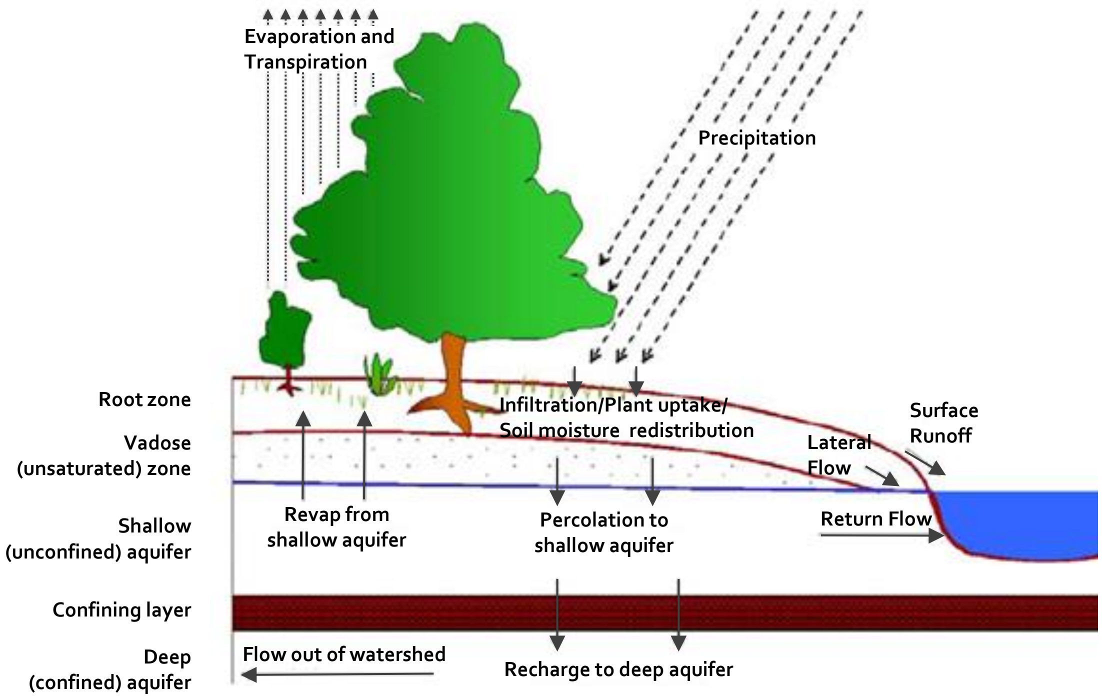
Methodology

Flow Chart



Methodology SWAT model

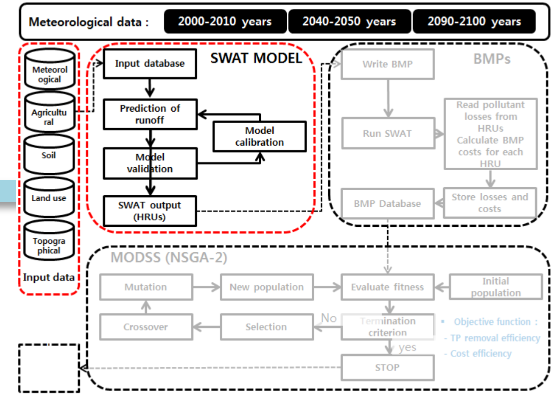




- ✓ SWAT is a basin-scale and continuous-time hydrologic model with GIS interface
- ✓ Water balance equation : $SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$

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

Methodology SWAT model



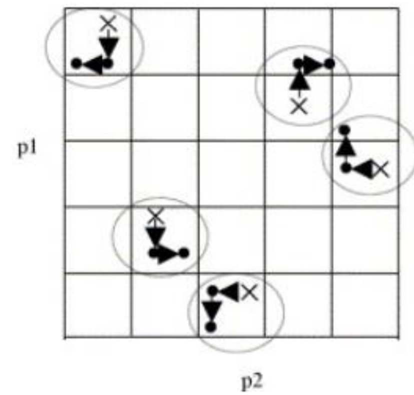
➢ Simulation Period : 11 years (2000 – 2010)

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.



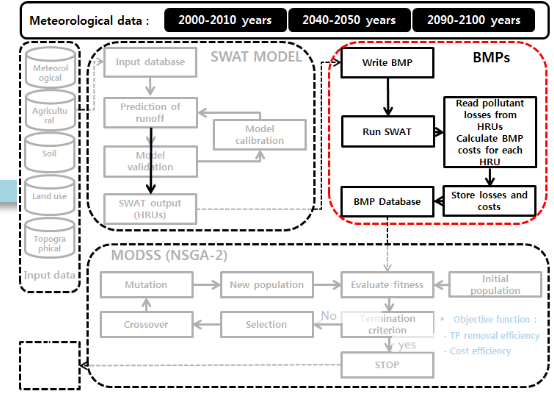
➢ Calibration/Validation

✓ 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

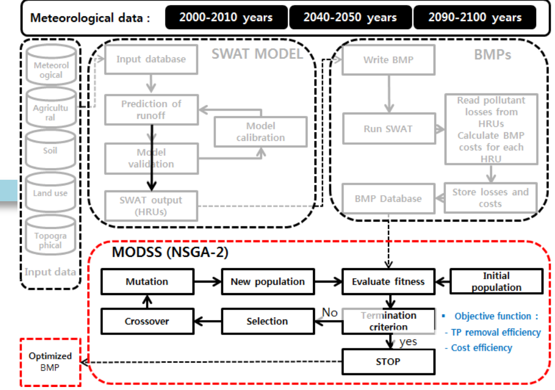
✓ Soybean area

	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

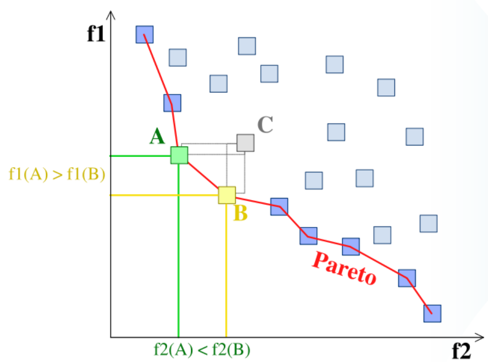
Methodology MODSS



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

  ✓ Composition of chromosome

  In the graph, the points are represented as the chromosomes



Gene : BMPs type (1:31)

1	6	3	5	6	1	13	…	7	11	7	11

Chromosome
(Length: the number of HRUs (12))

  ✓ Objective function

  1) Minimizing TP loads

  2) Minimizing cost for implementing BMPs

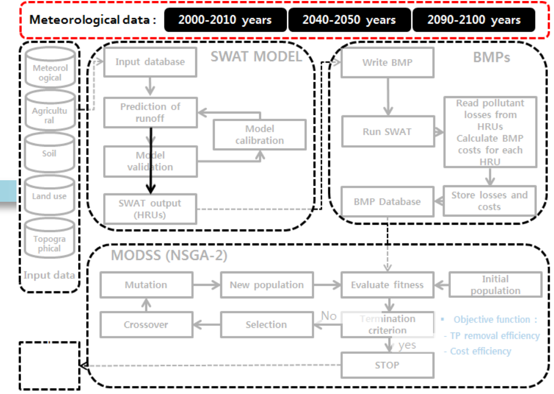
  ✓ Fitness function

  Chi-squared value aimed to find the combination of objective functions that would give the lowest chi-squared value

- $\chi^2 = \frac{(Y_2 - Y_1)}{Y_1}$ Y_1 : Implementation cost Y_2 : TP loads

Methodology

Climate change



➢ Scenario information

Climate change scenarios → RCP → Greenhouse gases scenarios → HadGEM2-AO → HadGEM3-RA → PRISM

Greenhouse gases scenarios:

- 2.6
- 4.5
- **6.0**
- 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 : IPCC fifth assessment report

✓ 6.0 : future world of stabilization without overshoot pathway to 6W/m²

(Source: Korea Meteorological Administration (KMA)")

➢ Scenario collection

✓Scenario duration : 2040-2050, 2090-2100

✓Scenario composition : daily precipitation, daily relative humidity, daily max/min temperature, daily wind speed

Results

Results SWAT Sensitivity Analysis

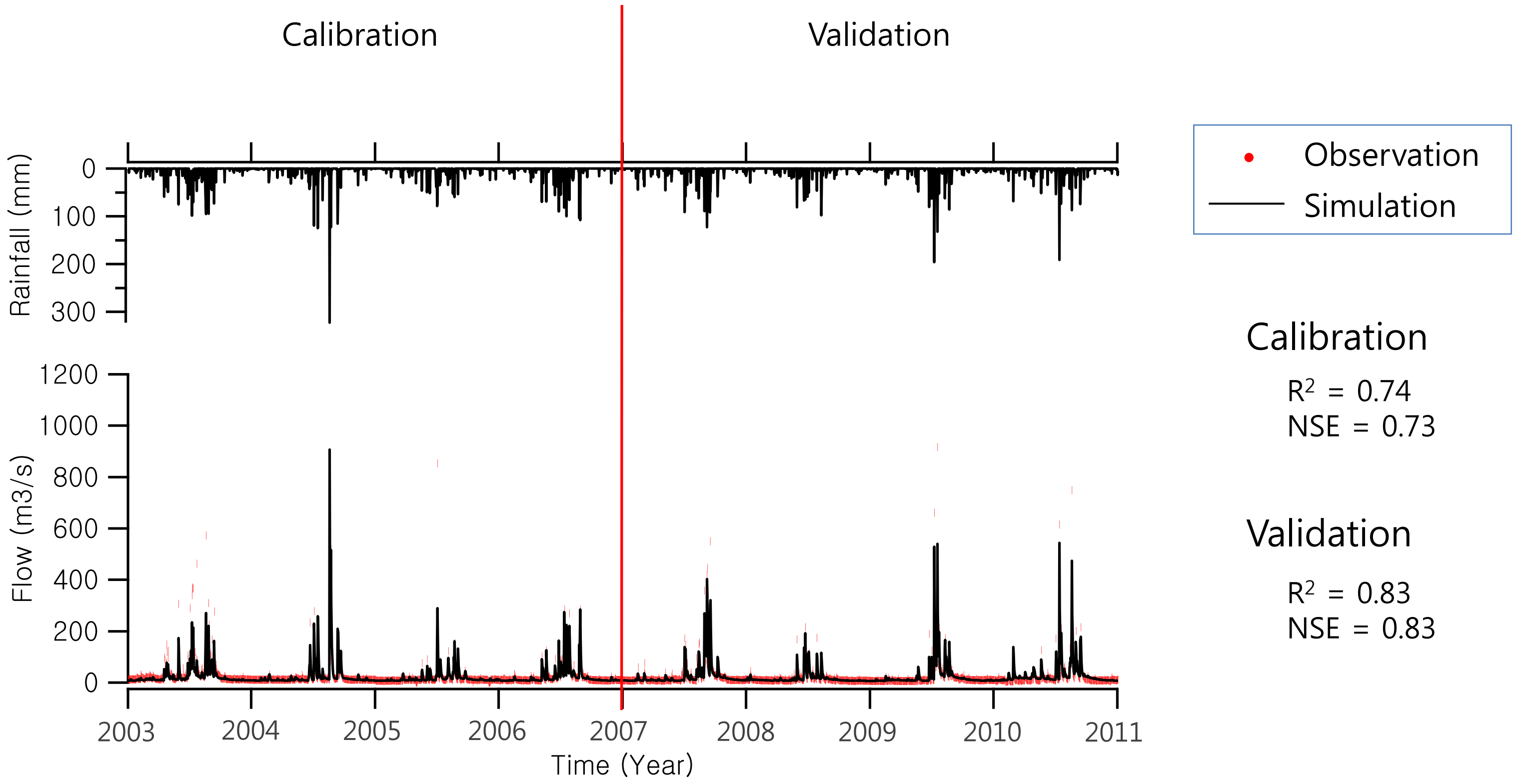
ESEL Environmental Systems Engineering Laboratory GIST

➢ Flow Discharge

Rank	Name	Definition	Bounds	Calibration value	Process
1	**Surlag**	Surface runoff lag coefficient	0-10	1.076	bsn
2	**Alpha_Bf**	Baseflow alpha factor (days)	0-1	1	gw
3	**Ch_N2**	Manning coefficient for channel	0-1	0.728	rte
4	**Ch_K2**	Effective hydraulic conductivity in main channel alluvium (mm/hr)	-0.01-150	77.894	rte
5	**Cn2**	SCS runoff curve number for moisture condition 2	-25-25	4.486	mgt
6	**Esco**	Soil evaporation compensation factor	0-1	0.203	bsn, hru
7	**Sol_K**	Soil conductivity (mm/hr)	-25-25	-24.837	Sol
8	**Sol_Awc**	Available water capacity of the soil layer (mm/mm soil)	-25-25	25	Sol
9	**Canmx**	Maximum canopy index	0-10	10	hru
10	**Sol_Z**	Soil depth	-25-25	-25	sol
11	**Blai**	Leaf area index for crop	0-1	0.759	crop
12	**Gwqmn**	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	-1000-1000	630.23	gw

✓The most sensitive parameter is Surlag which is a coefficient related with surface runoff volume.

➤ **Flow Discharge**



Calibration

R^2 = 0.74
NSE = 0.73

Validation

R^2 = 0.83
NSE = 0.83

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

(ref. Daniel N. Moriasi, 206)

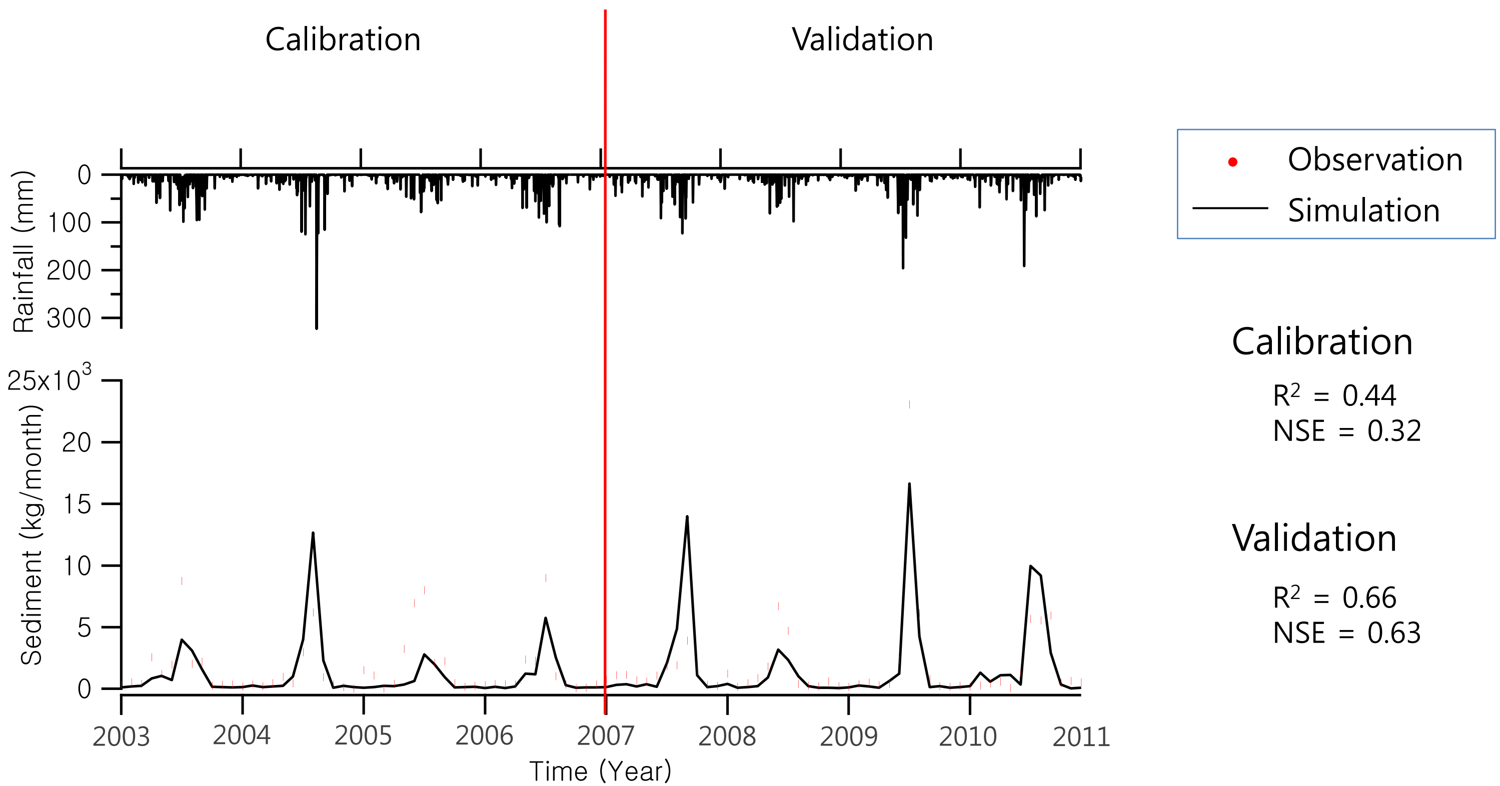
Sediment

Rank	Name	Definition	Bounds	Calibration Value	Preocess
1	**PRF**	Peak rate adjustment factor	0-2	0.290	rte
2	**SPEXP**	Exponent in sediment transport equation	1-1.5	1.295	rte
3	**SPCON**	Coefficient in sediment transport equation	0.0001-0.01	0.0005	bsn
4	**ADJ_PKR**	Peak rate adjustment factor	0.5-1.5	0.500	bsn
5	**USLE_P**	USLE support practice factor	0.1-1	1.000	bsn
6	CH_EROD	Channel erodibility factor (cm/hr/Pa)	-0.05-0.6	-	mgt
7	CH-COV	Channel cover factor	-0.001-1	-	bsn

✓ The most sensitive parameter is PRF which is adjustment factor of peak rate in channel.

Results SWAT Model Calibration/Validation

➤ Sediment



Calibration

R^2 = 0.44
NSE = 0.32

Validation

R^2 = 0.66
NSE = 0.63

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

(ref. Daniel N. Moriasi, 206)

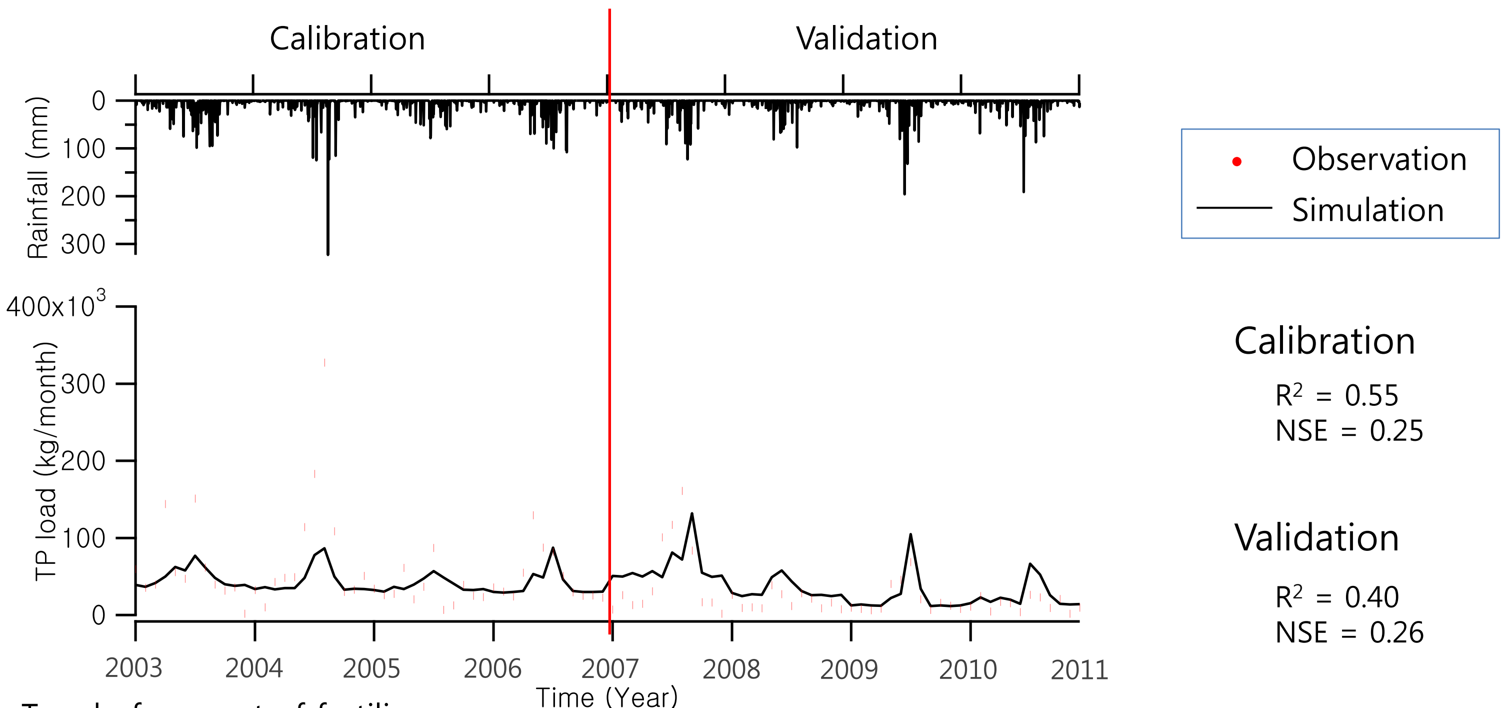
➢ Total Phosphorus

Rank	Name	Definition	Bounds	Calibration Value	Process
1	**RHCQ**	Local algal respiration rate at 20°C	0.05-0.500	0.05	wwq
2	**BIOMIX**	Biological mixing efficiency	0-1	0.001	mgt
3	**ERORGP**	Phosphorus enrichment ratio	0-5	0.02	Hru
4	**GWSOLP**	Concentration of soluble phosphorus in groundwater contribution to streamflow from subbasin (mg P/L)	0-1.000	0	gw
5	**AI2**	Fraction of algal biomass that is phosphorus	0.01-0.02	0.01	wwq
6	**PSP**	Phosphorus availability index	0.01-0.7	0.28	bsn
7	**BC4**	Local settling rate for organic phosphorus at 20°C	0.1-0.7	0.7	swq
8	MUMAX	Maximum specific algal growth rate	1-3	-	wwq
9	RS5	Local settling rate for organic phosphorus at 20°C	0.05-0.1	-	Swq
10	P_UPDIS	Phosphorus uptake distribution parameter	0-100	-	Bsn
11	CMN	Rate coefficient for mineralization of the humus active organic nutrients	0.0001-0.003	-	Bsn
12	PHOSKD	Phosphorus soil partitioning coefficient (m^3/Mg)	100-350	-	Bsn
13	PPERCO	Phosphorus percolation coefficient (10m^3/Mg)	10-17.5	-	Bsn
14	RS2	Sediment source rate for soluble phosphorus at 20°C	0.001-0.1	-	Swq

✓The most sensitive parameter is RHCQ which is related with local algal respiration rate

Results SWAT Modeling Calibration/Validation

➢ Total Phosphorus



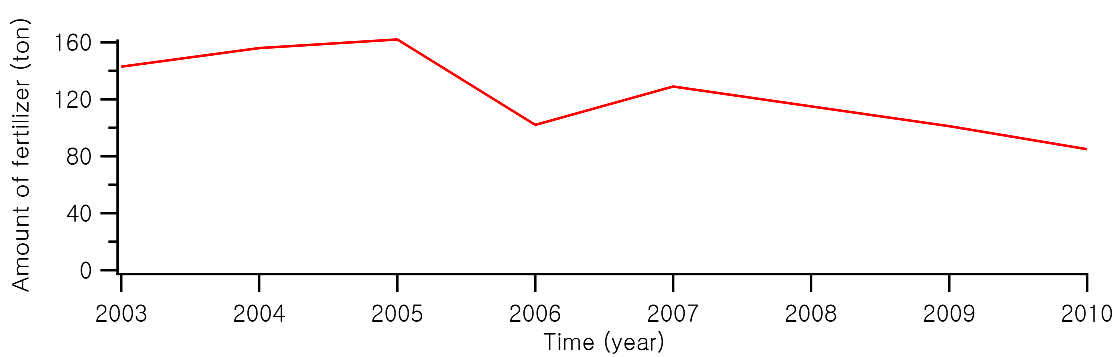
Calibration

R^2 = 0.55
NSE = 0.25

Validation

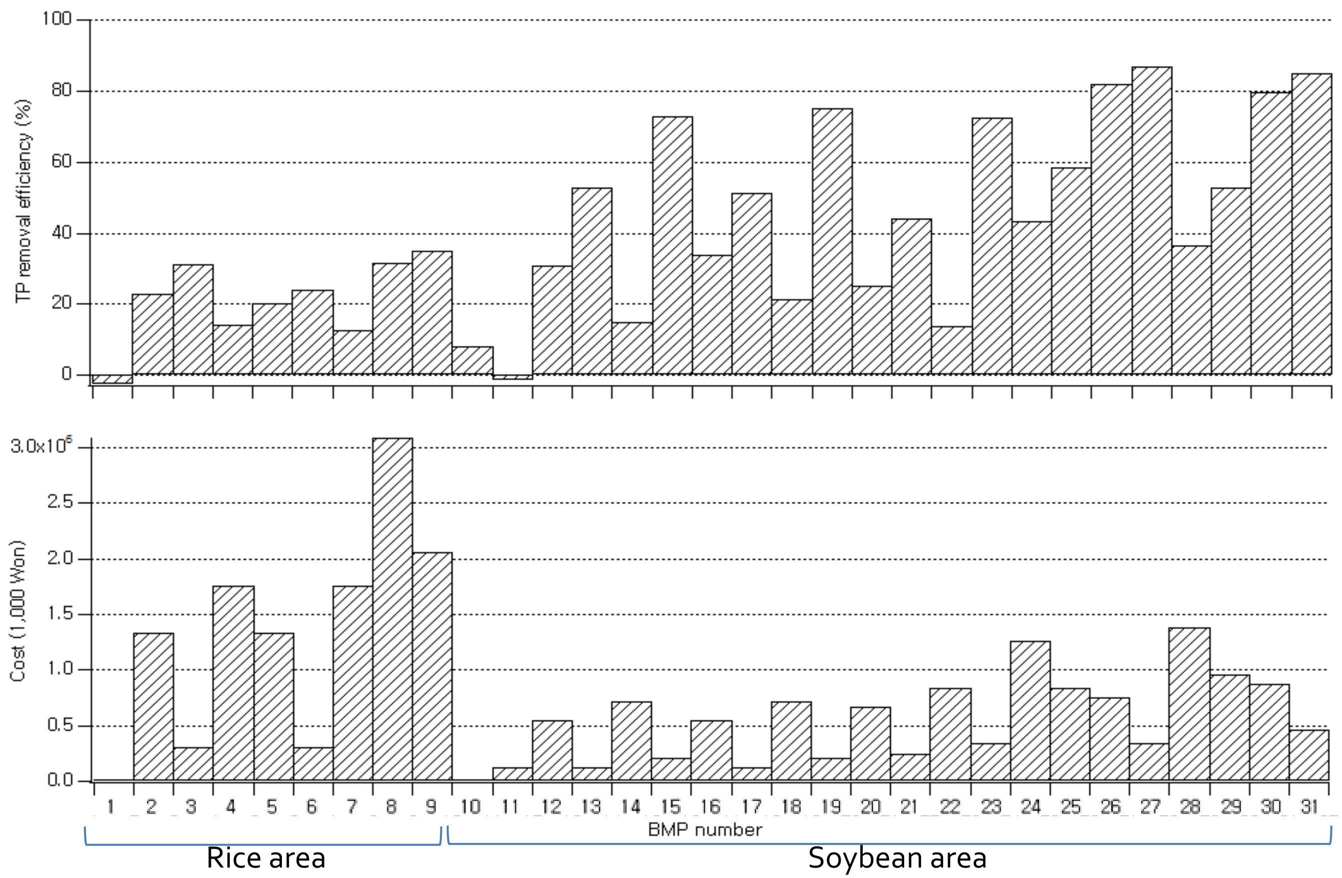
R^2 = 0.40
NSE = 0.26

- Trend of amount of fertilizer



✓ The amount of fertilizer was used in SWAT model as input data.

BMPs efficiency and cost

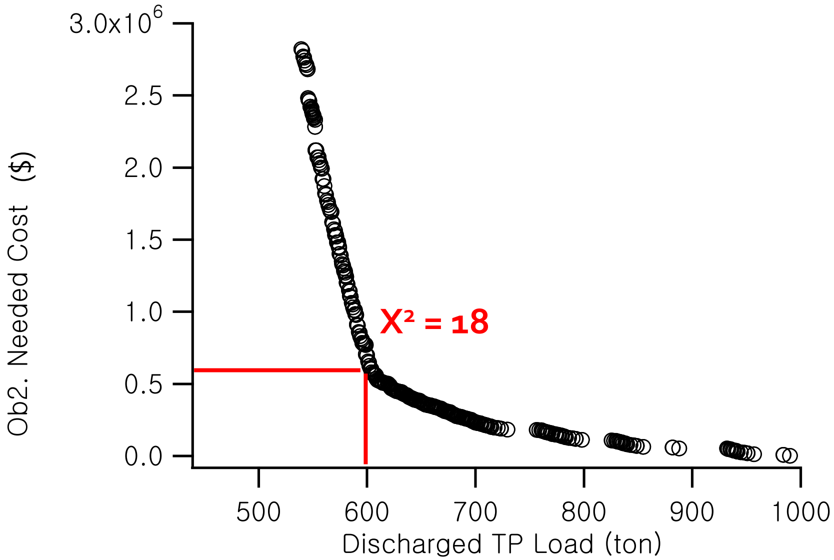


✓BMP types in rice area show relatively low removal efficiency than in soybean area

✓Conservation tillage in both agricultural area has negative removal efficiency

Results MODSS (2000-2010)

➢ **The most efficiency BMP**



HRU	Land	BMP
1	Rice	Contour Cropping
2	Rice	Contour Cropping
3	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
4	Rice	Contour Cropping
5	Soybean	Riparian Buffer
6	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
7	Soybean	Conservation Tillage, Riparian Buffer
8	Rice	Contour Cropping
9	Rice	Contour Cropping
10	Soybean	Conservation Tillage, Riparian Buffer
11	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
12	Rice	Terrace

- **Optimal TP removal rate : 40 %**
- **Optimal BMP cost : 6 hundred thousand $**

Results Variation of climate change

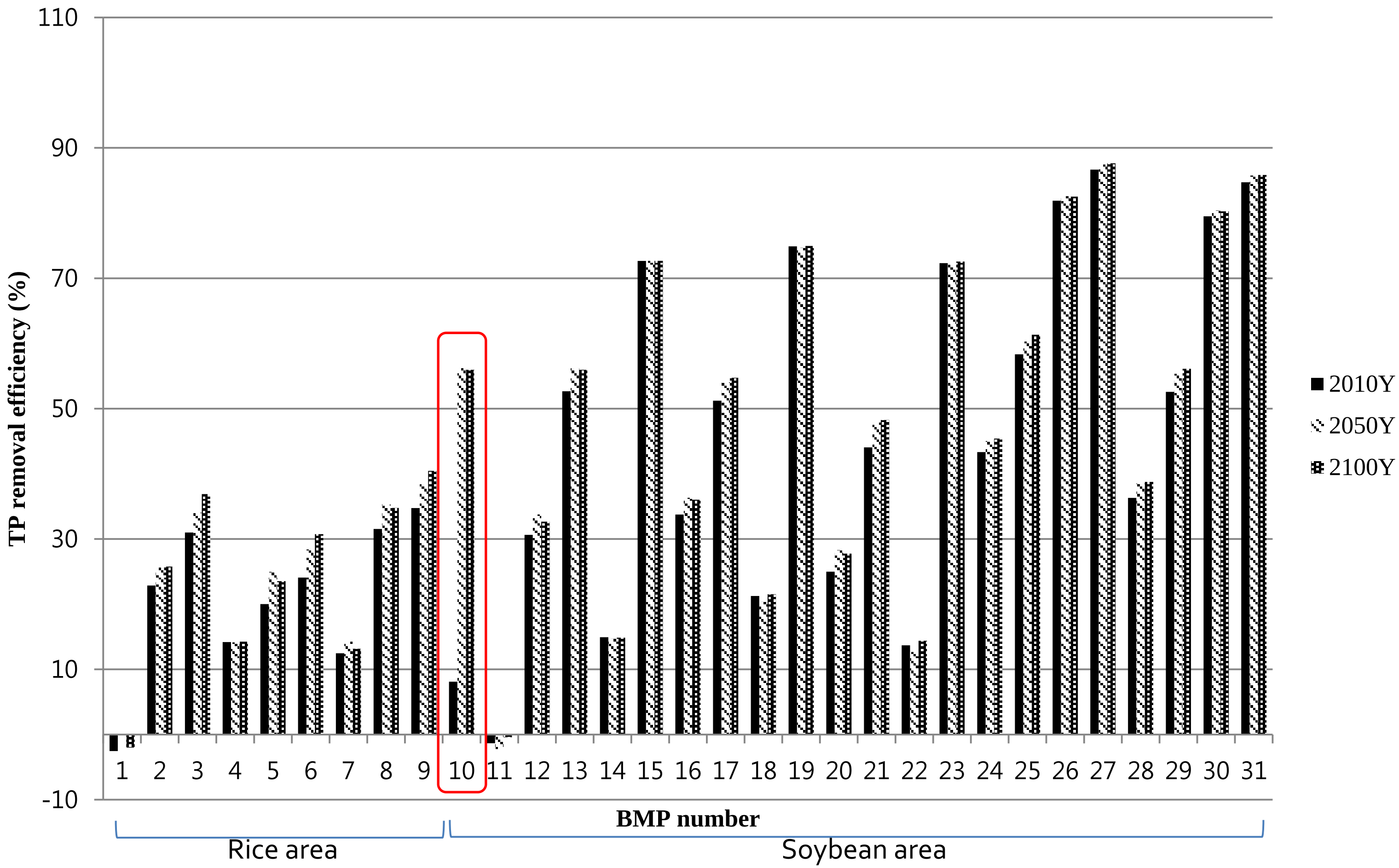
- The daily average data of climate

Parameters	2000-2010	2040-2050	2090-2100
Precipitation (mm)	4.06	**3.55**	3.96
Max tem (°C)	19.48	**18.01**	19.97
Min tem (°C)	9.98	**9.56**	11.55
Relative humidity (%)	66.62	75.08	74.72
Wind speed (m/s)	1.05	2.92	2.87

- SWAT model results with future climate change

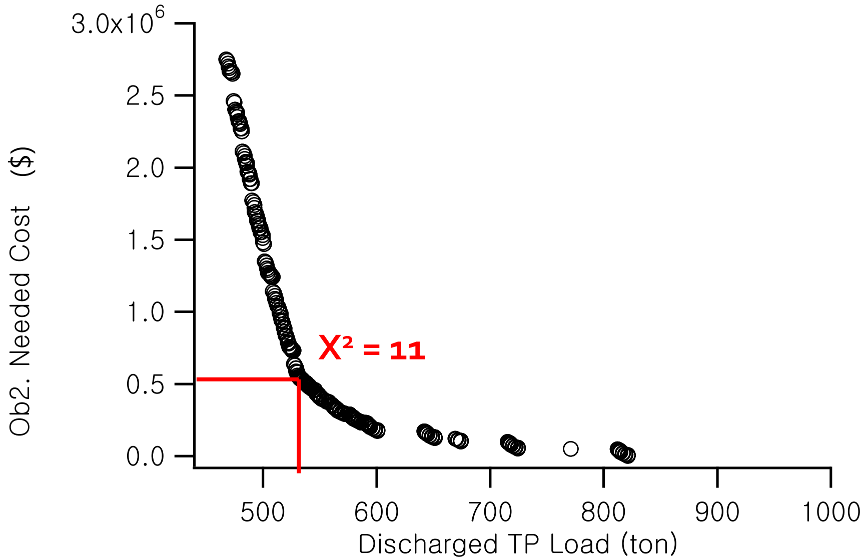
Parameters	2000-2010	2040-2050	2090-2100
Flow discharge (m^3/s)	25.30	**24.03**	24.61
Sediment load (ton/month)	1145.99	**922.26**	1032.80
TP load (kg/month)	39599.76	**36925.75**	38976.37

- BMPs efficiency with future climate



✓ Removal efficiency of conservation tillage in soybean area had differences between three durations.

➢ The most efficiency BMP (2040-2050)

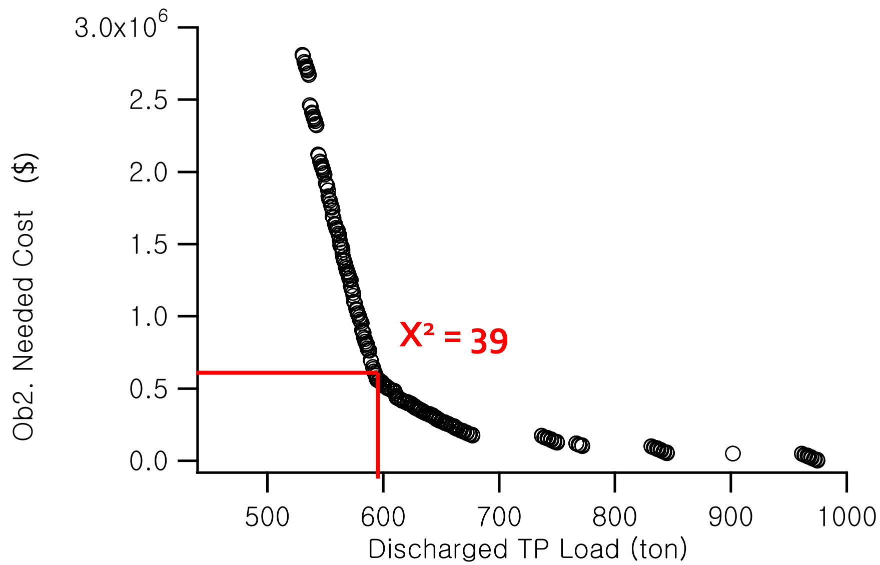


- **Optimal TP removal rate : 41%**
- **Optimal BMP cost : 5.3 hundred thousand $**

HRU	Land	BMP
1	Rice	Contour Cropping
2	Rice	Contour Cropping
3	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
4	Rice	Contour Cropping
5	Soybean	Conservation Tillage
6	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
7	Soybean	Conservation Tillage, Riparian Buffer
8	Rice	Contour Cropping
9	Rice	Contour Cropping
10	Soybean	Conservation Tillage, Riparian Buffer
11	Soybean	Conservation Tillage
12	Rice	Contour Cropping

Results MODSS with Climate change

➢ The most efficiency BMP (2090-2100)



- **Optimal TP removal rate : 44%**
- **Optimal BMP cost : 5.8 hundred thousand $**

HRU	Land	BMP
1	Rice	Contour Cropping
2	Rice	Contour Cropping
3	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
4	Rice	Contour Cropping
5	Soybean	Conservation Tillage
6	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
7	Soybean	Conservation Tillage, Riparian Buffer
8	Rice	Contour Cropping
9	Rice	Contour Cropping
10	Soybean	Conservation Tillage, Riparian Buffer
11	Soybean	Conservation Tillage, Contour Cropping, Riparian Buffer
12	Rice	Parallel Terrace

Results Variation of optimal BMP

➢ Variation of climate

Parameters	2000-2010	2040-2050	2090-2100
Precipitation (mm)	4.06	**3.55**	3.96
Max tem (ºC)	19.48	**18.01**	19.97
Min tem (ºC)	9.98	**9.56**	11.55

➢ Variation of runoff

Parameters	2000-2010	2040-2050	2090-2100
Flow discharge (m^3/s)	25.30	**24.03**	24.61
Sediment load (ton/month)	1145.99	**922.26**	1032.80
TP load (ton/month)	39599.76	**36925.75**	38976.37

➢ Variation of optimal BMP

Parameters	2000-2010	2040-2050	2090-2100
Optimal TP removal rate (%)	40	41	44
Optimal BMP cost (million Won)	600	531	588
Changed BMP (HRU)	-	**3**	**1**

Conclusions

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 some 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

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This research was supported by the Korea Ministry of Environment as "The Eco-innovation Project: Non-point source pollution control research group".

Results BMPs

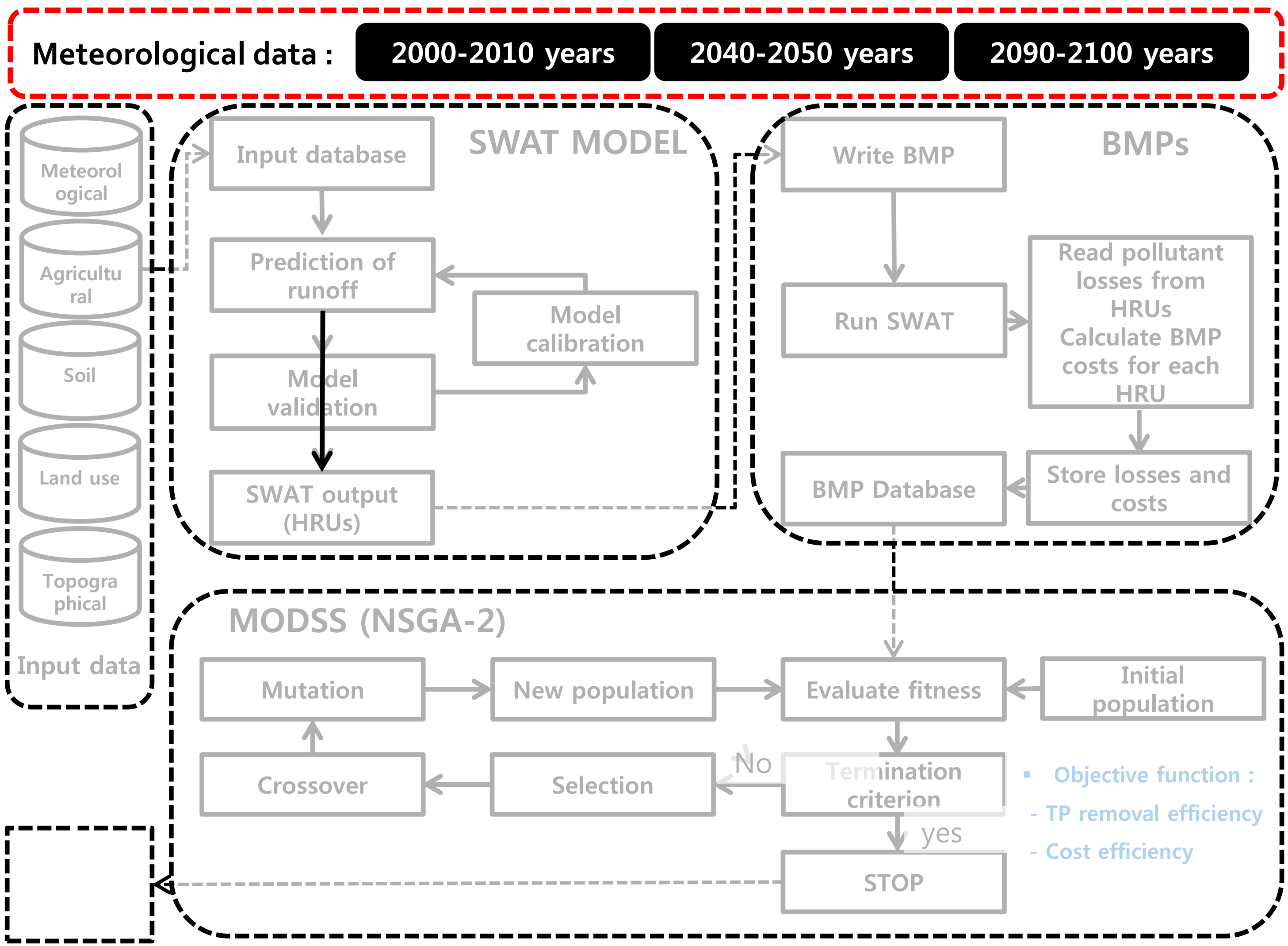
➢ Rice area

	BMP type	Removal efficiency
1	Conservation Tillage (CT)	-2.55
2	Parallel Terrace (PT)	22.86
3	contour Cropping (CC)	30.99
4	Detention Pond (DP)	14.18
5	CT/PT	20.01
6	CT/CC	24.08
7	CT/DP	12.47
8	CT/PT/DP	31.54
9	CT/CC/DP	34.74

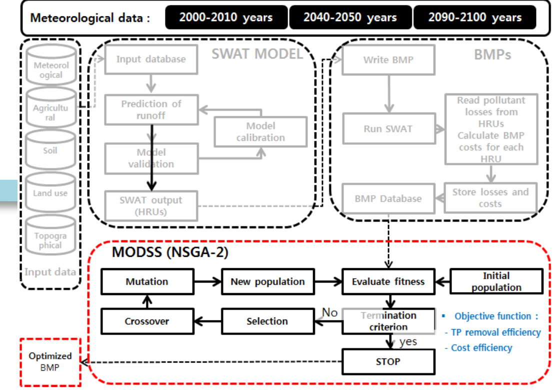
➢ Soybean area

	BMP type	Removal efficiency
10	Conservation Tillage (CT)	8.10
11	No Tillage (NT)	-1.34
12	Parallel Terrace (PT)	30.63
13	Contour Cropping (CC)	52.67
14	Detention Pond (DP)	14.93
15	Riparian Buffers (RB) 10m	72.67
16	CT/PT	33.74
17	CT/CC	51.21
18	CT/DP	21.26
19	CT/RB	74.88
20	NT/PT	24.98
21	NT/CC	44.05
22	NT/DP	13.69
23	NT/RB	72.31
24	CT/PT/DP	43.33
25	CT/CC/DP	58.33
26	CT/PT/RB	81.89
27	CT/CC/RB	86.66
28	NT/PT/DP	32.30
29	NT/CC/DP	52.58
30	NT/PT/RB	79.50
31	NT/CC/RB	84.71

Methodology Flow Chart



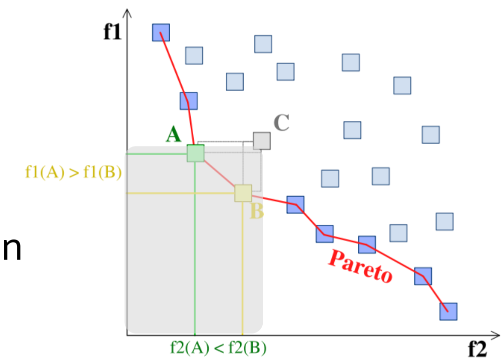
Methodology MODSS



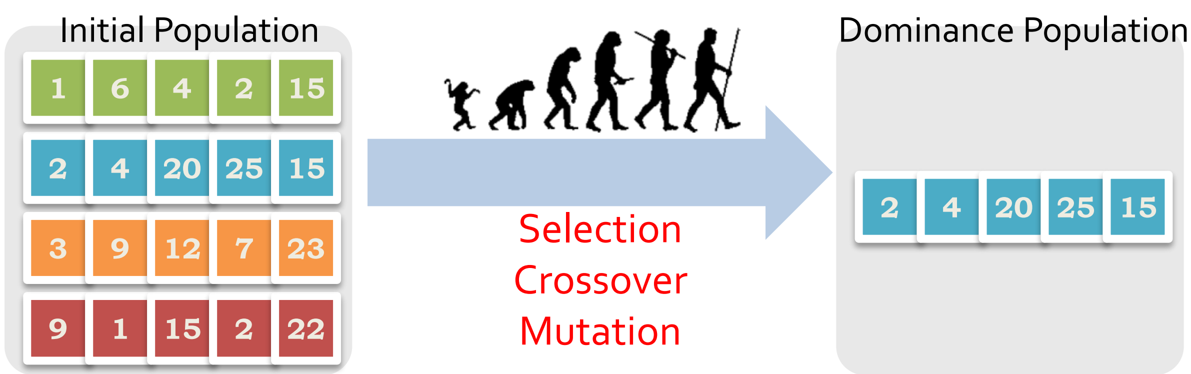
- **NSGA-2 (Non-dominated Sorting Genetic Algorithm-2)**

✓ Pareto-optimal front (Non-dominated sorting)

The point C is not on the Pareto Frontier because it is dominated by both point A and point B. **Point A and B are not strictly dominated by any other**, and hence do lie on the frontier.



✓ Principle of Genetic Algorithms



✓ Objective function

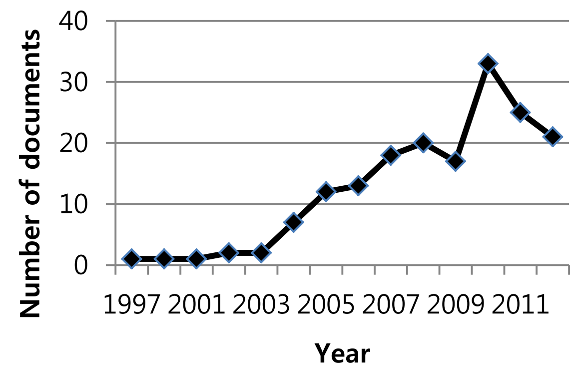
1) Minimizing TP loads

2) Minimizing cost for implementing BMPs

➢ History of BMPs with SWAT model

- Reference : Scopus

✓ **Total : 191**



Yildirim (1997)
- Evaluation of **BMPs using SWAT**

Gitau (2004)
- **Farm-level optimization** of BMPs for cost-effective pollution reduction

Bracmort (2004)
- Modeling the **long-term impacts** of BMPs

Gitau (2007)
- Analysis of BMP and **land use change effects** in agricultural watershed

Kaini (2009)
- Generating BMP designs in watershed scale with **multi-objective decision support system**

Woznicki (2012)
- Sensitivity analysis of BMPs **under climate change scenarios**

BMPs

: Assessment of BMPs using SWAT model