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
Introduction
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

Annual Global Precipitation

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

Runoff Change

2013

2015

2017

2020

BMPs can be changed

(ref. Jong-Suk Kim, 2011)

(ref. Hyun Suk Shin, 2012)

(ref. EPA)

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

**Solution**

- **BMPs** (Best Management Practices)
- **SWAT** (Soil & Water Assessment Tool)
- **MODSS** (Multi-Objective Decision Support System)
- Climate change scenario
- Applying future climate

**Background**

- TP removal method
- Simulation tool
- BMPs optimizing tool

**Climate change scenario**

Applying future climate
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 [km$^2$] : 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

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest-Evergreen</td>
<td>24.85</td>
</tr>
<tr>
<td>Rice</td>
<td>21.08</td>
</tr>
<tr>
<td>Forest-Mixed</td>
<td>12.34</td>
</tr>
<tr>
<td>Forest-Deciduous</td>
<td>10.94</td>
</tr>
<tr>
<td>Soybean</td>
<td>8.66</td>
</tr>
<tr>
<td>Residential-High Density</td>
<td>7.87</td>
</tr>
</tbody>
</table>

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

**Flow Chart**

**Meteorological data:**
- 2000-2010 years
- 2040-2050 years
- 2090-2100 years

**Input data**
- Meteorological
- Agricultural
- Soil
- Land use
- Topographical

**SWAT MODEL**
- Input database
- Prediction of runoff
- Model validation
- SWAT output (HRUs)

**BMPs**
- Write BMP
- Run SWAT
- Read pollutant losses from HRUs
- Calculate BMP costs for each HRU
- BMP Database
- Store losses and costs

**MODSS (NSGA-2)**
- Initial population
- Mutation
- Crossover
- Selection
- Evaluate fitness
- Termination criterion
  - Objective function:
    - TP removal efficiency
    - Cost efficiency
- New population
- New population
- New population
- New population
- New population
- New population
- New population
- New population
- New population

**Comparison of optimized BMP:**
- Optimized BMP for 2000-2010 years
- Optimized BMP for 2040-2050 years
- Optimized BMP for 2090-2100 years
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
- \( w_{seep} \): amount 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)

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2002</td>
<td>Spin Up</td>
</tr>
<tr>
<td>2003-2006</td>
<td>Calibration</td>
</tr>
<tr>
<td>2007-2010</td>
<td>Validation</td>
</tr>
</tbody>
</table>

➢ 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

<table>
<thead>
<tr>
<th>Rice area</th>
<th>Soybean area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMP type</strong></td>
<td><strong>Cost ($/ha)</strong></td>
</tr>
<tr>
<td>1 Conservation Tillage (CT)</td>
<td>0</td>
</tr>
<tr>
<td>2 Parallel Terrace (PT)</td>
<td>74.9</td>
</tr>
<tr>
<td>3 Contour Cropping (CC)</td>
<td>16.8</td>
</tr>
<tr>
<td>4 Detention Pond (DP)</td>
<td>99</td>
</tr>
<tr>
<td>5 CT/PT</td>
<td>74.9</td>
</tr>
<tr>
<td>6 CT/CC</td>
<td>16.8</td>
</tr>
<tr>
<td>7 CT/DP</td>
<td>99</td>
</tr>
<tr>
<td>8 CT/PT/DP</td>
<td>173.9</td>
</tr>
<tr>
<td>9 CT/CC/DP</td>
<td>115.8</td>
</tr>
</tbody>
</table>

**Simulated BMPs by SWAT**

<table>
<thead>
<tr>
<th>BMP</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Tillage (CT)</td>
<td>Till ID: 3</td>
<td>CN2-2</td>
</tr>
<tr>
<td>No Tillage (NT)</td>
<td>OV_N</td>
<td>0.30</td>
</tr>
<tr>
<td>Parallel Terrace (PT)</td>
<td>P-factor</td>
<td>0.1 if slope = 1 to 2%</td>
</tr>
<tr>
<td>Contour Cropping (CC)</td>
<td>P-factor</td>
<td>0.5 if slope = 1 to 2%</td>
</tr>
<tr>
<td>Detention Pond (DP)</td>
<td>pnd_k</td>
<td>0</td>
</tr>
<tr>
<td>pnd_fr</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>pnd_ESA</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Nutrient Management (NM)</td>
<td>Amount of fertilizer</td>
<td>-25%</td>
</tr>
<tr>
<td>Riparian Buffers (RB)</td>
<td>FILTERW</td>
<td>10</td>
</tr>
</tbody>
</table>
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

- 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

- RCP: IPCC fifth assessment report
- 6.0: future world of stabilization without overshoot pathway to 6W/m²

➢ Scenario collection

- Scenario duration: 2040-2050, 2090-2100
- Scenario composition: daily precipitation, daily relative humidity, daily max/min temperature, daily wind speed

(Source: Korea Meteorological Administration (KMA)"")
Results
## Results

### SWAT Sensitivity Analysis

#### Flow Discharge

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

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

SWAT Model Calibration/Validation

Flow Discharge

Calibration

Validation

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

(ref. Daniel N. Moriasi, 206)
### Sediment

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

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

SWAT Model Calibration/Validation

- Sediment

![Graph showing rainfall and sediment over time with calibration and validation phases]

- 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

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name</th>
<th>Definition</th>
<th>Bounds</th>
<th>Calibration Value</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RHCQ</td>
<td>Local algal respiration rate at 20°C</td>
<td>0.05-0.500</td>
<td>0.05</td>
<td>wwq</td>
</tr>
<tr>
<td>2</td>
<td>BIOMIX</td>
<td>Biological mixing efficiency</td>
<td>0-1</td>
<td>0.001</td>
<td>mgt</td>
</tr>
<tr>
<td>3</td>
<td>ERORGP</td>
<td>Phosphorus enrichment ratio</td>
<td>0-5</td>
<td>0.02</td>
<td>Hru</td>
</tr>
<tr>
<td>4</td>
<td>GWSOLP</td>
<td>Concentration of soluble phosphorus in groundwater contribution to streamflow from subbasin (mg P/L)</td>
<td>0-1.000</td>
<td>0</td>
<td>gw</td>
</tr>
<tr>
<td>5</td>
<td>AI2</td>
<td>Fraction of algal biomass that is phosphorus</td>
<td>0.01-0.02</td>
<td>0.01</td>
<td>wwq</td>
</tr>
<tr>
<td>6</td>
<td>PSP</td>
<td>Phosphorus availability index</td>
<td>0.01-0.7</td>
<td>0.28</td>
<td>bsn</td>
</tr>
<tr>
<td>7</td>
<td>BC4</td>
<td>Local settling rate for organic phosphorus at 20°C</td>
<td>0.1-0.7</td>
<td>0.7</td>
<td>swq</td>
</tr>
<tr>
<td>8</td>
<td>MUMAX</td>
<td>Maximum specific algal growth rate</td>
<td>1-3</td>
<td>-</td>
<td>wwq</td>
</tr>
<tr>
<td>9</td>
<td>RS5</td>
<td>Local settling rate for organic phosphorus at 20°C</td>
<td>0.05-0.1</td>
<td>-</td>
<td>Swq</td>
</tr>
<tr>
<td>10</td>
<td>P_UPDIS</td>
<td>Phosphorus uptake distribution parameter</td>
<td>0-100</td>
<td>-</td>
<td>Bsn</td>
</tr>
<tr>
<td>11</td>
<td>CMN</td>
<td>Rate coefficient for mineralization of the humus active organic nutrients</td>
<td>0.0001-0.003</td>
<td>-</td>
<td>Bsn</td>
</tr>
<tr>
<td>12</td>
<td>PHOSKD</td>
<td>Phosphorus soil partitioning coefficient (m³/Mg)</td>
<td>100-350</td>
<td>-</td>
<td>Bsn</td>
</tr>
<tr>
<td>13</td>
<td>PPERCO</td>
<td>Phosphorus percolation coefficient (10m³/Mg)</td>
<td>10-17.5</td>
<td>-</td>
<td>Bsn</td>
</tr>
<tr>
<td>14</td>
<td>RS2</td>
<td>Sediment source rate for soluble phosphorus at 20°C</td>
<td>0.001-0.1</td>
<td>-</td>
<td>Swq</td>
</tr>
</tbody>
</table>

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

SWAT Modeling Calibration/Validation

➢ Total Phosphorus

![Graph showing TP load and rainfall over time]

- **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

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

### Variation of climate change

#### The daily average data of climate

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

#### SWAT model results with future climate change

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2000-2010</th>
<th>2040-2050</th>
<th>2090-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow discharge (m³/s)</td>
<td>25.30</td>
<td>24.03</td>
<td>24.61</td>
</tr>
<tr>
<td>Sediment load (ton/month)</td>
<td>1145.99</td>
<td>922.26</td>
<td>1032.80</td>
</tr>
<tr>
<td>TP load (kg/month)</td>
<td>39599.76</td>
<td>36925.75</td>
<td>38976.37</td>
</tr>
</tbody>
</table>
BMPs efficiency with future climate

- Removal efficiency of conservation tillage in soybean area had differences between three durations.
Results MODSS with Climate change

The most efficiency BMP (2040-2050)

• Optimal TP removal rate: 41%

• Optimal BMP cost: 5.3 hundred thousand $

<table>
<thead>
<tr>
<th>HRU</th>
<th>Land</th>
<th>BMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rice</td>
<td>Contour Cropping</td>
</tr>
<tr>
<td>2</td>
<td>Rice</td>
<td>Contour Cropping</td>
</tr>
<tr>
<td>3</td>
<td>Soybean</td>
<td>Conservation Tillage, Contour Cropping, Riparian Buffer</td>
</tr>
<tr>
<td>4</td>
<td>Rice</td>
<td>Contour Cropping</td>
</tr>
<tr>
<td>5</td>
<td>Soybean</td>
<td>Conservation Tillage</td>
</tr>
<tr>
<td>6</td>
<td>Soybean</td>
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</tr>
<tr>
<td>12</td>
<td>Rice</td>
<td>Contour Cropping</td>
</tr>
</tbody>
</table>
The most efficiency BMP (2090-2100)

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

### Variation of optimal BMP

#### Variation of climate

<table>
<thead>
<tr>
<th>Parameters</th>
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<td>11.55</td>
</tr>
</tbody>
</table>

#### Variation of runoff

<table>
<thead>
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<td>39599.76</td>
<td><strong>36925.75</strong></td>
<td>38976.37</td>
</tr>
</tbody>
</table>

#### Variation of optimal BMP

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2000-2010</th>
<th>2040-2050</th>
<th>2090-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal TP removal rate (%)</td>
<td>40</td>
<td>41</td>
<td>44</td>
</tr>
<tr>
<td>Optimal BMP cost (million Won)</td>
<td>600</td>
<td>531</td>
<td>588</td>
</tr>
<tr>
<td>Changed BMP (HRU)</td>
<td>-</td>
<td><strong>3</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>
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

• djjeon@gist.ac.kr (Dong Jin Jeon)

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

#### BMPs

<table>
<thead>
<tr>
<th>BMP type</th>
<th>Removal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice area</td>
<td></td>
</tr>
<tr>
<td>1  Conservation Tillage (CT)</td>
<td>-2.55</td>
</tr>
<tr>
<td>2  Parallel Terrace (PT)</td>
<td>22.86</td>
</tr>
<tr>
<td>3  contour Cropping (CC)</td>
<td>30.99</td>
</tr>
<tr>
<td>4  Detention Pond (DP)</td>
<td>14.18</td>
</tr>
<tr>
<td>5  CT/PT</td>
<td>20.01</td>
</tr>
<tr>
<td>6  CT/CC</td>
<td>24.08</td>
</tr>
<tr>
<td>7  CT/DP</td>
<td>12.47</td>
</tr>
<tr>
<td>8  CT/PT/DP</td>
<td>31.54</td>
</tr>
<tr>
<td>9  CT/CC/DP</td>
<td>34.74</td>
</tr>
</tbody>
</table>

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

**Input data**
- Meteorological
- Agricultural
- Soil
- Land use
- Topographical

**SWAT MODEL**
- Input database
  - Prediction of runoff
    - Model validation
    - SWAT output (HRUs)
    - Model calibration

**BMPs**
- Write BMP
  - Run SWAT
    - BMP Database
    - Read pollutant losses from HRUs
    - Calculate BMP costs for each HRU
    - Store losses and costs

**MODSS (NSGA-2)**
- Initial population
- Evaluate fitness
  - Termination criterion
    - Objective function:
      - TP removal efficiency
      - Cost efficiency
    - New population
      - Mutation
      - Crossover
      - Selection
      - No
      - Yes
      - STOP

**Meteorological data:**
- 2000-2010 years
- 2040-2050 years
- 2090-2100 years

**Meteorological data:**
- Meteorological data:
  - 2000-2010 years
  - 2040-2050 years
  - 2090-2100 years
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
  - Initial Population
  - Dominance Population

- Objective function
  1) Minimizing TP loads
  2) Minimizing cost for implementing BMPs
History of BMPs with SWAT model

- **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**

**Introduction**

**Literature review**

- **Total**: 191 documents
- **Reference**: Scopus

**BMPs**: Assessment of BMPs using SWAT model