The Economics of Stormwater BMPs in Tehran, Iran

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Sakineh Tavakoli, Sarif University of Technology, Tehran
Masoud Tajrishy, Sarif University of Technology, Tehran

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Introduction

- Urban Development
- Increased Imperviousness
- Enhanced flow velocities & Stormwater runoff volume
- Water Quality Degradation
Stormwater Management

• Water quantity control (Flood control)
• Water quality control
• Nutrients and Suspended Solids
• Non-Point Source pollution control
• Complex decision making problem
• Best Management Practices
• Find minimum cost combination of BMPs regarding pollutant outflow limits
Study Area

- Maqsudbeig watershed in Elahiyeh the north of Tehran, Iran
- 350 ha drainage area
- Semi-arid climate
- Average annual precipitation of 250 mm
- Stream collects surface runoff and aesthetic objectives
- 3.3 km long
- No point source pollution
- Main source of pollution
  
  *Non-point source pollution resulting from stormwater runoff*
Study Area
Methodology

- BMP Selection
- BMP Characteristics
- Watershed Model (MUSIC)

Economic Model (Linear Programming)

- Optimization Analysis (GAMS)
- Sensitivity Analysis

Decision Making
BMP Selection

1. Site investigation
2. BMPs requirements

1 & 2  Three types of BMP

Typical sizes for BMPs

<table>
<thead>
<tr>
<th>BMP</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swale</td>
<td>100</td>
<td>3</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>1</td>
<td>150</td>
</tr>
<tr>
<td>Bioretention</td>
<td>10</td>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>Pond</td>
<td>15</td>
<td>4</td>
<td>60</td>
</tr>
</tbody>
</table>
Schematic of Swales
Schematic of Bioretention Systems
Schematic of Pond

4m  15m
Watershed Model

- MUSIC (Model for Urban Stormwater Conceptualization), CRCC, 2005
- Decision support system
- Predicting stormwater treatment measures
- Removal rates for TSS, TP and TN
# TSS Removal Rates for BMPs

<table>
<thead>
<tr>
<th>Combination</th>
<th>3 m width swale</th>
<th>1.5 m width swale</th>
<th>Bioretention Systems</th>
<th>Wet Pond</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42%</td>
<td>28%</td>
<td>24%</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>55%</td>
<td>34%</td>
<td>29%</td>
<td>12%</td>
</tr>
<tr>
<td>3</td>
<td>62%</td>
<td>35%</td>
<td>33%</td>
<td>12%</td>
</tr>
<tr>
<td>4</td>
<td>71%</td>
<td>38%</td>
<td>38%</td>
<td>16%</td>
</tr>
<tr>
<td>5</td>
<td>81%</td>
<td>42%</td>
<td>44%</td>
<td>17%</td>
</tr>
<tr>
<td>6</td>
<td>85%</td>
<td>42%</td>
<td>51%</td>
<td>27%</td>
</tr>
<tr>
<td>7</td>
<td>86%</td>
<td>45%</td>
<td>53%</td>
<td>29%</td>
</tr>
<tr>
<td>8</td>
<td>86%</td>
<td>47%</td>
<td>55%</td>
<td>30%</td>
</tr>
<tr>
<td>9</td>
<td>90%</td>
<td>51%</td>
<td>59%</td>
<td>32%</td>
</tr>
<tr>
<td>10</td>
<td>90%</td>
<td>51%</td>
<td>65%</td>
<td>32%</td>
</tr>
<tr>
<td>11</td>
<td>92%</td>
<td>57%</td>
<td>67%</td>
<td>41%</td>
</tr>
<tr>
<td>12</td>
<td>93%</td>
<td>64%</td>
<td>70%</td>
<td>48%</td>
</tr>
<tr>
<td>13</td>
<td>95%</td>
<td>77%</td>
<td>79%</td>
<td>67%</td>
</tr>
<tr>
<td>14</td>
<td>100%</td>
<td>100%</td>
<td>91%</td>
<td>83%</td>
</tr>
<tr>
<td>15</td>
<td>100%</td>
<td>100%</td>
<td>99%</td>
<td>100%</td>
</tr>
<tr>
<td>16</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Economic Model

• Cost effective method
• Minimum cost combinations of BMPs
• Environmental standard
• Two major issues in economic model
  ❑ Cost of stormwater BMPs
  ❑ Associated pollutant removal efficiencies
Economic Model Structure

- **Model Objective**

\[
TotalCost = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} C_{ijk} X_{ijk}
\]

- \(C_{ijk}\): Total cost of \(k\) number combination of BMP \(i\) installed in subcatchment \(j\)
- \(X_{ijk}\): The number of \(k\) number combination of BMP \(i\) installed in subcatchment \(j\), a binary variable
- \(i\): type of BMPs
- \(j\): indication of subcatchment
- \(k\): number of BMPs combination (contribute to form \(X_{ijk}\) )
Model Constraints

a. Pollutant Removal Efficiencies

\[ I_{TP} \left( \prod_{i=1}^{m} \prod_{j=1}^{n} \prod_{k=1}^{p} (1-a_{ik})x_{ik} \right) \leq I_{s,TP} \]

\[ I_{TN} \left( \prod_{i=1}^{m} \prod_{j=1}^{n} \prod_{k=1}^{p} (1-b_{ik})x_{ik} \right) \leq I_{s,TN} \]

\[ I_{TSS} \left( \prod_{i=1}^{m} \prod_{j=1}^{n} \prod_{k=1}^{p} (1-d_{ik})x_{ik} \right) \leq I_{s,TSS} \]

\( I_{TP} \) = initial concentration of total phosphorus, before implementation of stormwater BMPs

\( I_{s,TP} \) = standard concentration of total phosphorus that is expected to achieve after stormwater BMPs implementation

\( a_{ik} \) = total phosphorus removal rate of k number combination of ith BMP (%)
Model Constraints

b. Installation Area for a BMP

\[ \sum_{k=1}^{p} X_{ijk} S_{ik} \leq A_{ij} \quad \forall i, j \]

\( S_{ik} \) = area of \( k \) numbers of BMP \( i \)

\( A_{ij} \) = area available for BMP \( i \) in subcatchment \( j \)

(available land for each type of BMP was defined by site investigation)
Costs

- **Total Capital Cost**
  - Land cost
  - Construction cost

- **Design, Permitting and Contingencies Costs** (unexpected costs)
  - Percentage of construction cost

- **Operation and Maintenance Costs**
  - Post-Construction activities
  - Prevention odour, turbidity, trash and sediment
  - A fraction of construction cost
Total Present Costs

\[ P = A \times E \]

\[ E = \left[ \frac{1 + r}{1 + i} \right]^n \]

- **P** = present worth of annual O&M costs
- **A** = annual O&M costs; **r**: inflation rate (20%) 
- **i** = interest rate (12%)
- **n** = number of years (i.e. 20 year life period of BMPs)
# Total Present Costs of BMPs

<table>
<thead>
<tr>
<th>BMP</th>
<th>Design and construction costs (million Rial*)</th>
<th>Annual O &amp; M costs (Million Rial)</th>
<th>Longevity (year)</th>
<th>Total Present Cost (Million Rial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3m width swale</td>
<td>46.1</td>
<td>2.4</td>
<td>20</td>
<td>134.5</td>
</tr>
<tr>
<td>1.5m width swale</td>
<td>19.1</td>
<td>1</td>
<td>20</td>
<td>54.9</td>
</tr>
<tr>
<td>Bioretention Systems</td>
<td>36</td>
<td>2</td>
<td>20</td>
<td>110.8</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>29.2</td>
<td>1.2</td>
<td>20</td>
<td>74.2</td>
</tr>
</tbody>
</table>

*Iranian Rials (IRR), 1 USD = 13000 Rial
Results

- Ignoring Land Cost
- The least cost BMPs to construct and maintain Swale

<table>
<thead>
<tr>
<th>BMP</th>
<th>k</th>
<th>Number</th>
<th>Area (m²)</th>
<th>Removal Rate (%)</th>
<th>Cost (Million Rial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m width swale</td>
<td>1</td>
<td>1</td>
<td>300</td>
<td>TSS 42, TP 54, TN 32</td>
<td>134.5</td>
</tr>
<tr>
<td>1.5 m width swale</td>
<td>1</td>
<td>7</td>
<td>1050</td>
<td>TSS 28, TP 48, TN 30</td>
<td>494.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1</td>
<td>300</td>
<td>TSS 34, TP 54, TN 36</td>
<td></td>
</tr>
<tr>
<td>Bioretention Systems</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>TSS 0, TP 0, TN 0</td>
<td>0</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>TSS 0, TP 0, TN 0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>9</td>
<td>1650</td>
<td>-</td>
<td>628.6</td>
</tr>
</tbody>
</table>
### Discussion

- **Random Combinations**
- **Do they meet the standards?**

<table>
<thead>
<tr>
<th>Combination</th>
<th>Definition</th>
<th>Does the combination meet standards?</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>300m² of 3m width swale + 150m² of 1.5m width swale + 50m² of bioretention + 60m² of pond</td>
<td>No</td>
</tr>
<tr>
<td>b</td>
<td>1200m² of 1.5m width swale</td>
<td>No</td>
</tr>
<tr>
<td>c</td>
<td>900m² of 3m width swale + 150m² bioretention</td>
<td>No</td>
</tr>
<tr>
<td>d</td>
<td>600m² of 3m width swale + 300m² of 1.5m width swale + 100m² of bioretention + 120m² of pond</td>
<td>No</td>
</tr>
<tr>
<td>e</td>
<td>1200m² of 1.5m width swale + 150m² of bioretention</td>
<td>Yes</td>
</tr>
<tr>
<td>f</td>
<td>2400m² of 1.5m width swale</td>
<td>Yes</td>
</tr>
<tr>
<td>g</td>
<td>300m² of 3m width swale + 750m² of 1.5m width swale + 250m² of bioretention</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Cost Comparison for Different Combinations

- For Combinations that meet the standard
Summary and Conclusion

- A methodology was developed to find optimal solution for controlling NPS pollution caused by urbanization.
- General modelling approach involves a pollution simulation model and an optimization model.
- Effectiveness in reducing TSS, TP and TN concentration by each type of BMPs has been assessed by watershed model.
- Life cycle costs of swale, bioretention system and pond were calculated.
- Optimization procedure was used to find the optimum solution.
- Results show that, swales have been the least expensive BMPs to construct and maintain if appropriate land is available.
Ecological engineering is the design of human society with its natural environment for the benefit of both...