Stormwater Management in the Context of Sustainable Green Campuses: A Case Study on METU Campus, Turkey

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Smart and Sustainable Campuses Conference,
March 31, 2015
Introduction

• Middle East Technical University
• Stormwater Related Problems
• Goal of Study
• Methodology
• Preliminary Results
• Future Studies
Location of METU Campus, Ankara, Turkey

Istanbul
Ankara
Lake Eymir

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Stormwater Management in the Context of Sustainable Green Campuses: A Case Study on METU Campus

METU is a state university founded in 1956. After 1960’s under the leadership of Prof. Dr. Kemal Kurdaş, forestation and planting works accelerated.

- Located in Ankara
- Total 4500ha (Ankara Campus)
- 3043 ha of forest land
- Lake Eymir, 9km² surface area

Lake Eymir
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Middle East Technical University

- METU is one of the most remarkable universities in Turkey
  - METU accepts only the top 1% of approximately 1.5 million applicants taking the National University Entrance Examination
  - Times Higher Education 2014
    - 85th in World University Rankings
- Two Campus Locations
  - Ankara Campus
  - Northern Cyprus Campus
- METU has 26500 students
- There are over 40 Bachelor’s Science program within 5 faculties 5 graduate schools, 104 Master of Science and 66 Doctoral Programs
Stormwater Problems

- Current situation
  - In Ankara
  - In METU Campus
• Storm sewer length is approximately 10.5 km
• There are more than one outlets in storm sewer
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March 10, 2014

Photo: Gizem Gül Topal
Low Impact Development (LID)

- Runoff and diffuse pollution Control
  - Mimics pre-development hydrological conditions
- Rerofit systems
- Small scale ve distributed systems
- Easy to implement
- Rain garden, green roofs, Infiltration trenches, Rain Barrels and Cisterns, Pervious Pavements
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http://water.epa.gov/infrastructure/greeninfrastructure/gr_what.cfm

http://www.uri.edu/ce/healthylandscapes/rainbsources.html

http://columbus.gov/Templates/Detail.aspx?id=54218

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Goal of the Study

- Goal is to develop technical background for establishing a stormwater management plan
Methodology

Problems
- Floods
- Urban Diffuse pollution

Runoff Model
- SWMM Applications

LID Site Selection
- MCDM Applications

Preliminary Results:
Evaluation of LID Effectiveness
Stormwater Modeling

• Stormwater model is selected among commercially available hydrologic/stormwater models
  – MUSIC (Model for Urban Stormwater Improvement Conceptualization) – 2000s
  – MOUSE (Model for Urban Sewers), its engine is now used for MIKE URBAN (DHI Water.Environment.Health) - 1985
  – WBM (Water Balance Model), Vancouver, 2004
  – UVQ (Urban Volume Quality), CSIRO, 2000 etc.
• Models are evaluated according to their capabilities and EPA SWMM has chosen among all options
Why SWMM

- It is a commonly used model and it’s free.
- EPA Stormwater Management Model (SWMM) is a dynamic rainfall-runoff simulation model.
- Model uses subcatchment areas that receives precipitation and generates runoff and pollutant loads.
- Uses multiple time steps; It can be used to simulate single or long-term events.
- It can simulate unlimited size of drainage network.
- Introduces Low Impact Development (LID) practices.
- Open source code: It can be developed by other users.
Conceptual Model and Data Requirements of SWMM

Atmosphere
- Meteorologic Data

Land Surface
- Topographic
  - Land use Land Cover Information

Groundwater
- Infiltration equations
  - Soil characteristics
  - Hydraulic Routing

Transport
- Nodes
  - Channels
  - Outfalls

Outflow
Runoff
Meteorology Data

- Rainfall data is obtained from General Directorate of Meteorology
- Total daily rainfall data from 2007 to 2014 is used as input

Ranges between 0.1-44.2 mm (0.004-4.42 inches)
**Contours**

- Contours in CAD files obtained from METU-General Directorate of Construction
- Contours are used to create DEM and Hydrology Analysis
- Elevation in campus ranges from 850 to 1000m
Slope Map

• Majority of the slope 0-5
Watershed and Stream Network Definition

- Two watersheds exist in study area
- Areas of watersheds are approximately 220 and 370 ha
Land Use Data

- 11 land use types are defined
- 80% of total area is covered by forests and green land and 17.5% by buildings parking lots
- Rest of the land covered with other manmade structures

<table>
<thead>
<tr>
<th>Land Use</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt (Roads)</td>
<td>3.8</td>
</tr>
<tr>
<td>Alley</td>
<td>0.3</td>
</tr>
<tr>
<td>Buildings</td>
<td>15</td>
</tr>
<tr>
<td>Sidewalk</td>
<td>0.4</td>
</tr>
<tr>
<td>Parking Lots</td>
<td>2.5</td>
</tr>
<tr>
<td>Barren Land</td>
<td>6.5</td>
</tr>
<tr>
<td>Sports Courts</td>
<td>0.2</td>
</tr>
<tr>
<td>Green Spaces w/ trees</td>
<td>11.4</td>
</tr>
<tr>
<td>Grass Area</td>
<td>1.1</td>
</tr>
<tr>
<td>Walkways</td>
<td>0.4</td>
</tr>
<tr>
<td>Forest Land</td>
<td>58.4</td>
</tr>
</tbody>
</table>
Subcatchments

- There are 57 subcatchments
- Defined based on:
  - Flow direction, Stream Network, Manmade structures, Land Slope
- Area: 1.5-22.5 ha
- Average Slope: 2.42-14.5 %
Conceptual Model and Data Requirements of SWMM

- Atmosphere
  - Meteorologic Data

- Land Surface
  - Topographic
  - Land use Land Cover Information

- Groundwater
  - Infiltration equations
  - Soil characteristics
  - Hydraulic Routing

- Transport
  - Nodes
  - Channels
  - Outfalls

Outflow

Runoff

METU Problems
GOALS
Methodology
SWMM Applications
MCDM Applications
Future Studies
The weighted average curve numbers calculated using the ratio of land uses respective curve numbers with the equation given above:

\[ A = A_1 + A_2 + A_3 + A_4 + A_5 \]

\[ CN = \frac{1}{A} \left[ A_1 (CN_1) + A_2 (CN_2) + A_3 (CN_3) + A_4 (CN_4) + A_5 (CN_5) \right] \]
**Example Subcatchment Area**

- Subcatchment Name: S1
- Area: 17.88 ha
- Slope: 3.78%
- Imperviousness: 43.31%
- Number of land use in S1: 5
  - Asphalt, Buildings, Parking Lots, Barren Land and Grassland
- Curve Numbers: 77-99
- Rainfall data used: 2007-2014
- Total of 196 Junction nodes (manholes), 189 Conduit Links and 57 Subcatchments introduced into model.
SWMM Calibration

• Simulated runoff results will be compared with the onsite runoff measurements
  • Flow Data: Area/Velocity Sensor installation (Hach-Sigma 950)
  • Meteorological Data: Davis Instruments Vantage-Pro Meteorology Station
• Calibrated model will be used with the meteorological data for a period of 2007-2014 to test the effectiveness of the LID applications
Flow Data: Area/Velocity Sensor installation (Hach-Sigma 950)

Meteorological Data: Davis Instruments Vantage-Pro Plus Meteorology Station
Methodology

Problems
- Floods
- Urban Diffuse pollution

Runoff Model - SWMM Applications

LID Site Selection - MCDM Applications

Preliminary Results: Evaluation of LID Effectiveness
## Multicriteria Decision Making

- Site selection for LIDs done by MCDM
- What is Multicriteria Decision Analysis?
  - Making decisions with multiple criteria
  - Criteria that usually conflicts with each other

<table>
<thead>
<tr>
<th>METU</th>
<th>Problems</th>
<th>Goals</th>
<th>Methodology</th>
<th>SWMM Applications</th>
<th>MCDM Applications</th>
<th>Future Studies</th>
</tr>
</thead>
</table>
\[ \sum = \text{Weight} \times \text{Score} \]

Multicriteria Decision Making

Criteria Selection

Attribute score and Weight

Weighting method: Case 1

Weighting Method: Case 2

Weighting Method: Case 3

Evaluation of Results: Comparing Suitable Areas

Tool to select application sites for LIDs

15 Criteria Selected

Overall weight 5 categories

Land use
Depression Storage
Sewer and Stream Network
Land Slope

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## Criteria for Rain Garden

- Criteria used in rain garden site selection
- Other criteria chosen by expert opinion

<table>
<thead>
<tr>
<th>Rain Garden Design and Site Selection Criteria</th>
<th>Preferred Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from foundation of buildings</td>
<td>More than 3 meters</td>
</tr>
<tr>
<td>Distance from foundation of buildings</td>
<td>3-8 meters</td>
</tr>
<tr>
<td>Slope of the land</td>
<td>5-7%</td>
</tr>
<tr>
<td>Distance to trees</td>
<td>More than 3 meters</td>
</tr>
<tr>
<td>Distance from septic drians</td>
<td>More than 10-15 meters</td>
</tr>
</tbody>
</table>
Selection and Scoring Criteria

- Land Use and land Cover Types
- Depression Storage
- Stream Network
- Wastewater Sewer
- Contours (for slope calculation)

<table>
<thead>
<tr>
<th>Layers</th>
<th>Buffers (m)</th>
<th>Attribute Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>1,2,3,4</td>
<td>9,6,3,1</td>
</tr>
<tr>
<td>Sewer Network</td>
<td>1,15,30</td>
<td>1,3,9</td>
</tr>
</tbody>
</table>

(1→9: lower importance to higher importance)

Sewer line is passing through this side of the road
MCDM Case 1: GIS Based Tool for Site Selection
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Multicriteria Decision Making

Criteria Selection

 Attribute score and Weight

Weighting method: Case1

Weighting Method: Case2

Weighting Method: Case3

Evaluation of Results: Comparing Suitable Areas

Overall weight 5 categories

Tool to select application sites for LIDs

15 Criterias Selected

Weight x Score

Land use
Depression Storage
Sewer and Stream Network
Land Slope

METU

Problems

Goals

Methodology

SWMM Applications

MCDM Applications

Future Studies

\[ \sum = \text{Weight} \times \text{Score} \]
MCDM Case 1: GIS Based Tool for Site Selection

- A GIS based tool is developed
- Buffer limits are specified
- Buffer limits scored: Attribute Weights (Scoring: 1-9)
- Weighting is done (Weighting: 1-9 scale)

(1→9: lower importance to higher importance)

<table>
<thead>
<tr>
<th>Layers</th>
<th>Buffer Limits</th>
<th>Attribute Weights</th>
<th>Overall weighting between criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depression Storage</td>
<td>1,2</td>
<td>9,2</td>
<td>9</td>
</tr>
<tr>
<td>Contour Lines</td>
<td>0-5,5-7,7-12,12-90</td>
<td>1,9,5,1</td>
<td>9</td>
</tr>
<tr>
<td>Sewer Network</td>
<td>1,15,30</td>
<td>1,3,9</td>
<td>7</td>
</tr>
<tr>
<td>Stream Network</td>
<td>1,2</td>
<td>9,4</td>
<td>8</td>
</tr>
<tr>
<td>Asphalt (Roads)</td>
<td>1,2,3,4</td>
<td>9,6,3,1</td>
<td>8</td>
</tr>
<tr>
<td>Alley</td>
<td>1,2,3</td>
<td>9,5,1</td>
<td>2</td>
</tr>
<tr>
<td>Buildings</td>
<td>1,3,8,10</td>
<td>1,1,9,3</td>
<td>8</td>
</tr>
<tr>
<td>Sidewalk</td>
<td>1,2,3</td>
<td>9,5,1</td>
<td>3</td>
</tr>
<tr>
<td>Parking Lots</td>
<td>1,2,10</td>
<td>1,3,9</td>
<td>7</td>
</tr>
<tr>
<td>Barren Land</td>
<td>1,10</td>
<td>9,8</td>
<td>6</td>
</tr>
<tr>
<td>Sports Courts</td>
<td>1,2,10</td>
<td>1,3,9</td>
<td>6</td>
</tr>
<tr>
<td>Green Spaces w/trees</td>
<td>1,3</td>
<td>1,9</td>
<td>5</td>
</tr>
<tr>
<td>Grass Area</td>
<td>1,10</td>
<td>9,8</td>
<td>6</td>
</tr>
<tr>
<td>Walkways</td>
<td>1,2,3</td>
<td>9,5,1</td>
<td>3</td>
</tr>
<tr>
<td>Forest Land</td>
<td>1,3</td>
<td>9,1</td>
<td>5</td>
</tr>
</tbody>
</table>
MCDM Case 2: Equal Weight Scenario

- Buffer distances and scoring stays the same
- Overall weighting is different than Case 1
- Total of weights equal to 1.

<table>
<thead>
<tr>
<th>Layers</th>
<th>Buffer Limits</th>
<th>Attribute Weights</th>
<th>Overall weighting between criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depression Storage</td>
<td>1,2</td>
<td>9,2</td>
<td>0.0667</td>
</tr>
<tr>
<td>Contour Lines</td>
<td>0-5,5-7,7-12,12-90</td>
<td>1,9,5,1</td>
<td>0.0667</td>
</tr>
<tr>
<td>Sewer Network</td>
<td>1,15,30</td>
<td>1,3,9</td>
<td>0.0667</td>
</tr>
<tr>
<td>Stream Network</td>
<td>1,2</td>
<td>9,4</td>
<td>0.0667</td>
</tr>
<tr>
<td>Asphalt (Roads)</td>
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<td>9,6,3,1</td>
<td>0.0667</td>
</tr>
<tr>
<td>Alley</td>
<td>1,2,3</td>
<td>9,5,1</td>
<td>0.0667</td>
</tr>
<tr>
<td>Buildings</td>
<td>1,3,8,10</td>
<td>1,1,9,3</td>
<td>0.0667</td>
</tr>
<tr>
<td>Sidewalk</td>
<td>1,2,3</td>
<td>9,5,1</td>
<td>0.0667</td>
</tr>
<tr>
<td>Parking Lots</td>
<td>1,2,10</td>
<td>1,3,9</td>
<td>0.0667</td>
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<tr>
<td>Barren Land</td>
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<td>9,8</td>
<td>0.0667</td>
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<tr>
<td>Sports Courts</td>
<td>1,2,10</td>
<td>1,3,9</td>
<td>0.0667</td>
</tr>
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<td>Green Spaces w/ trees</td>
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<td>1,9</td>
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<td>0.0667</td>
</tr>
<tr>
<td>Forest Land</td>
<td>1,3</td>
<td>9,1</td>
<td>0.0667</td>
</tr>
<tr>
<td>TOTAL WEIGHT</td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
MCDM Case 3: Base Scenario

- **Criteria**
  - 3 different categories
  - The most important criteria determined and weighted accordingly to their importance

<table>
<thead>
<tr>
<th>Importance</th>
<th>Least Importance</th>
<th>Medium Importance</th>
<th>High Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓Grass Area</td>
<td>✓Building</td>
<td>✓Contour Lines</td>
<td></td>
</tr>
<tr>
<td>✓Alley</td>
<td>✓Asphalt</td>
<td>✓Stream Network</td>
<td></td>
</tr>
<tr>
<td>✓Barren Land</td>
<td>✓Forest Land</td>
<td>✓Depression Storage</td>
<td></td>
</tr>
<tr>
<td>✓Sidewalks</td>
<td>✓Green spaces w/ trees</td>
<td>✓Sewer Network</td>
<td></td>
</tr>
<tr>
<td>✓Walkways</td>
<td>✓Sports Courts</td>
<td>✓Parking Lots</td>
<td></td>
</tr>
</tbody>
</table>

**Weight for each layer**

<table>
<thead>
<tr>
<th>Weight for each layer</th>
<th>0.04</th>
<th>0.05</th>
<th>0.125</th>
</tr>
</thead>
</table>

**Overall weight**

| Overall weight | 0.2 | 0.3 | 0.5 |
Suitable Areas According to Site Selection Methods

Multicriteria Decision Analysis
Suitability Results

Suitability Results of Equally Weighted Layers

Suitability Result of Base Condition

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Suitable Areas According to Site Selection Methods

Case 1

Multicriteria Decision Analysis
Suitability Results

Case 2

Equally Weighted Analysis

Case 3

Multicriteria Decision
<VALUE>

Base Condition Analysis
<VALUE>

METU
Problems
Goals
Methodology
SWMM Applications
MCDM Applications
Future Studies

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Sensitivity

- The most important four criteria used
  - Different weight factors used (weight perturbation)
- Paired comparisons are done for Case 3
- Contours (Land Slope) is the most sensitive criteria
Methodology

Problems

Swmm Applications

MCDM Applications

Preliminary Results: Evaluation of LID Effectiveness
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# LID Application Summary: Preliminary Results

- LID located according to site selection analysis

## Base Scanario Summary

<table>
<thead>
<tr>
<th>Subcatchment</th>
<th>Junction</th>
<th>Conduit</th>
<th>Peak Runoff (m³/s)</th>
<th>Total Runoff (10⁶ ltr)</th>
<th>% Change</th>
<th>% Change</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcatchment 25</td>
<td>Junction 119</td>
<td>Conduit 127</td>
<td>2.67</td>
<td>718.99</td>
<td>2.67</td>
<td>718.94</td>
<td>0.0069</td>
</tr>
<tr>
<td>Subcatchment 22</td>
<td>Junction 141</td>
<td>Conduit 149</td>
<td>7.33</td>
<td>1864.77</td>
<td>7.33</td>
<td>1864.70</td>
<td>0.0375</td>
</tr>
<tr>
<td>Subcatchment 20</td>
<td>Junction 115</td>
<td>Conduit 123</td>
<td>3.36</td>
<td>889.35</td>
<td>3.36</td>
<td>889.26</td>
<td>0.01</td>
</tr>
<tr>
<td>Subcatchment 10</td>
<td>Junction 102</td>
<td>Conduit 110</td>
<td>9.68</td>
<td>2592.19</td>
<td>9.68</td>
<td>2591.93</td>
<td>0.01</td>
</tr>
</tbody>
</table>

---

**SWMM Applications**

**MCDM Applications**

**Future Studies**
Future Studies

- Placement of sensors for Onsite and Online Monitoring of:
  - Meteorologic Data
  - Runoff Generation Data
- Calibration of model
- Evaluation of Effectiveness of LID Applications under different conditions
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