Storm Water Modeling and its Utility for Predicting Impacts on Santa Monica Bay

Michael K. Stenstrom
Professor
Civil and Environmental Engineering Department, UCLA

October 9, 2002
Available Data

- Land Use: 1993 SCAG
- Drainage: Catchment and Basin Coverages from Los Angeles Public Works, DEM
- Rainfall: Los Angeles Airport Gage
- Monitoring Data: 43,015 Data Points of 47 Monitoring Locations
- Pollutant Concentrations: Local monitoring data, NURP, Calibrations
Land Use Pattern in SMB Watershed (6498)

Santa Monica Bay
## Land Use Characteristics

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Impervious Surface Area [%]</th>
<th>Runoff Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Family</td>
<td>42</td>
<td>0.39</td>
</tr>
<tr>
<td>Multi-Family</td>
<td>68</td>
<td>0.58</td>
</tr>
<tr>
<td>Commercial</td>
<td>92</td>
<td>0.74</td>
</tr>
<tr>
<td>Public</td>
<td>80</td>
<td>0.66</td>
</tr>
<tr>
<td>Light Industrial</td>
<td>91</td>
<td>0.74</td>
</tr>
<tr>
<td>Other Urban</td>
<td>80</td>
<td>0.66</td>
</tr>
<tr>
<td>Open</td>
<td>0</td>
<td>0.10</td>
</tr>
<tr>
<td>Unknown</td>
<td>65</td>
<td>0.56</td>
</tr>
</tbody>
</table>
Rainfall Catchment Coverage (500)
Sampling Location

Basin Coverage (28)
Model Schematic

Rainfall

Land Use

Water Quality

GIS

Runoff Model

Spatial Coverage

Model Results
Rainfall vs Runoff

\[ \text{ASV} = \text{R} \times \text{A} \times \text{C} \times \text{ASRF} \]

\[ \text{AASV} = \text{ASV} \times \text{NSTORM} \]

where:

- \( \text{ASV} \) = Average storm runoff volume
- \( \text{ASRF} \) = Average storm rainfall
- \( \text{AASV} \) = Annual average storm runoff volume
Spatial Union Operation of GIS

\[ C_i = \sum_{k=1}^{8} \sum_{n=1}^{N} AASV_{n,k,i} \times ME_{n,k,i} \times G \]

\[ B_j = \sum_{i=1}^{M} C_i \]

where

- AASV = Average Annual Storm Volume [m³/yr]
- ME = Event Mean Concentration [mg/L]
- G = Conversion Factor (m³*mg/L to kg) [10⁻³]
- Ci = Estimated Annual Pollutant Loading of catchment i [kg/yr]
- Bj = Estimated Annual Pollutant Loading of sub-basin j [kg/yr]
- N = Total number of land use polygons with land use type k within catchment i.
- M = Total number of catchment polygons within sub-basin j.
- k = Land use type.
- n = Land use polygon n within the catchment i.
Water Quality

\[ ME = SM \sqrt{1 + CV^2} \]

\[ APLi = AASV*ME_i \]

Where:
- \( SM \) = Site Median EMC [mg/L]
- \( ME \) = Event Mean Concentration [mg/L]
- \( CV \) = Coefficient Variation
- \( APL \) = Annual Pollutant Loadings [kg/year]
- \( i \) = Pollutant i
Spatial Union Operation Using GIS and Nonpoint Source Modeling

Land Use Polygons

Overlay
Catchment Polygons

\[ C_i = \sum_{k=1}^{8} \sum_{n=1}^{N} AASV_{n,k,i} \times ME_{n,k,i} \times G \]
Basin Polygons
Model Calibration Using Ballona Creek

Total Area: 217 km² (84 mi²)
Number of Storm Drains: 255
Number of Catch Basins/Manholes: 6600
Total Length of Storm Drains: 282.2 km (175.4 miles)
Land Use of Ballona Watershed

- Single-Family: 45%
- Multi-Family: 20%
- Commercial: 13%
- Public: 4%
- Light Industrial: 4%
- Other Urban: 2%
- Open: 12%

- Single-Family
- Multi-Family
- Commercial
- Public
- Light Industrial
- Other Urban
- Open
Total Mass Loadings $= M_{t1}$

$= \int C(t) \, Q(t) \, dt$

$= \sum_k C_k \left( \sum_i Q_i \Delta t \right)$
Mass Pollutant Loadings

Tons/Event

1/15/96
1/30/96
2/18/96
3/3/96
1/15/96
1/30/96
2/18/96
3/3/96
Error Analysis

Error (%) = (Loadings_{calibration} - Loadings_{sample}) / Loadings_{calibration}
What can you do with this?

• Rank pollutants, find out pollutant origins.
• Compare nonpoint and point sources
• Simulate BMPs and growth
Annual Pollutant Loadings

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>TSS</th>
<th>BOD5</th>
<th>COD</th>
<th>TOTP</th>
<th>SOLP</th>
<th>TKN</th>
<th>NO3</th>
<th>TOTCU</th>
<th>TOTPB</th>
<th>TOTZN</th>
<th>O&amp;G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kgs per Subbasin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Log[Kgs]</td>
<td>0</td>
<td>0.001</td>
<td>0.01</td>
<td>0.1</td>
<td>1</td>
<td>10</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Copyright 2000   Michael K. Stenstrom
Drainage Basin Ranking by TSS Loadings

- Ranking = 1
- Ranking = 2
- Ranking = 3
- Ranking = 4
- Ranking = 5
- Ranking = 6

Basin Boundary

1=highest mass loading
Two Hypothetical BMPs

*or* What if?

**Case One**
- 50% reduction in fertilizer for single and multiple family land uses
- 50% reduction in oil & grease for commercial and industrial land uses

*Assumption: 50% reduction in ME*

**Case Two**
- Land use transformation (20% Open)
Case One: Annual NO23 and O&G Loadings (MT/Yr)

<table>
<thead>
<tr>
<th></th>
<th>SMB</th>
<th></th>
<th></th>
<th>Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO23</td>
<td>182</td>
<td>133</td>
<td></td>
<td>26</td>
</tr>
<tr>
<td>O&amp;G</td>
<td>1,336</td>
<td>1,103</td>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>
## Increase(%) of Annual Loading in Subbasin 12
### Landuse Transformation (20% Open)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>S. Family</th>
<th>M. Family</th>
<th>C. &amp; LI.</th>
<th>Public</th>
<th>O. Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>18</td>
<td>20</td>
<td>23</td>
<td>19</td>
<td>25</td>
</tr>
<tr>
<td>BOD5</td>
<td>78</td>
<td>86</td>
<td>124</td>
<td>109</td>
<td>117</td>
</tr>
<tr>
<td>COD</td>
<td>41</td>
<td>60</td>
<td>53</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>TP</td>
<td>43</td>
<td>50</td>
<td>43</td>
<td>36</td>
<td>57</td>
</tr>
<tr>
<td>SP</td>
<td>50</td>
<td>25</td>
<td>75</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>TKN</td>
<td>50</td>
<td>40</td>
<td>43</td>
<td>37</td>
<td>46</td>
</tr>
<tr>
<td>NO23</td>
<td>-94</td>
<td>-91</td>
<td>-91</td>
<td>-91</td>
<td>-91</td>
</tr>
<tr>
<td>Cu</td>
<td>300</td>
<td>450</td>
<td>350</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>Pb</td>
<td>140</td>
<td>180</td>
<td>320</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>Zn</td>
<td>370</td>
<td>30</td>
<td>410</td>
<td>380</td>
<td>350</td>
</tr>
<tr>
<td>O&amp;G</td>
<td>5</td>
<td>201</td>
<td>263</td>
<td>232</td>
<td>232</td>
</tr>
</tbody>
</table>
Increase of Annual Pollutant Loadings (%)
# Model Prediction vs. Hyperion Wastewater Treatment Plan

(30% secondary, MT/Yr)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model</th>
<th>HTP</th>
<th>T. Load</th>
<th>%NPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>37,000</td>
<td>30,000</td>
<td>67,000</td>
<td>55</td>
</tr>
<tr>
<td>BOD</td>
<td>1,500</td>
<td>60,000</td>
<td>61,500</td>
<td>3</td>
</tr>
<tr>
<td>TP</td>
<td>80</td>
<td>1,500</td>
<td>1,580</td>
<td>5</td>
</tr>
<tr>
<td>NO2+NO3</td>
<td>180</td>
<td>250</td>
<td>430</td>
<td>42</td>
</tr>
<tr>
<td>Cu</td>
<td>10</td>
<td>30</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>Pb</td>
<td>37</td>
<td>22</td>
<td>59</td>
<td>63</td>
</tr>
<tr>
<td>Zn</td>
<td>54</td>
<td>90</td>
<td>144</td>
<td>38</td>
</tr>
<tr>
<td>O&amp;G</td>
<td>1,200</td>
<td>7,800</td>
<td>9,000</td>
<td>13</td>
</tr>
</tbody>
</table>
Outline

Santa Monica Bay
  Facts and Data Sources
  Statistics
  Land Use
  Data Sources

Spreadsheet Model
  Parameters
  Calibration
  Predictions

SWMM Model
  Network
  Calibration

Some Simple Solutions
  Sorbents
  Simple Screens
  Boardovers

Current Research
  Knowledge Based Tools
  Molecular Markers

Final Remarks
Second Generation Model

Preprocessor

GIS

Input data

Urban Runoff Model

Spatial Coverage Land Use data Drainage data

Rainfall and Flow Rate

Model Results

GIS

Output Results

Input data

Model Results
Modeling Approach

● Preprocessor (GIS/Scripting Language)
  Convert GIS Spatial Coverage and Attribute data to ASCII Input data set

● Urban Runoff Model (SWMM)
  Use the ASCII Input data set

● Model Calibration
  Rainfall and Stream Flow from the Outlet gage station

● Postprocessor (GIS/Scripting Language)
  Convert Model Results to Graphical Displays within GIS
Outline

Santa Monica Bay
Facts and Data Sources
Statistics
Land Use
Data Sources

Spreadsheet Model
Parameters
Calibration
Predictions

SWMM Model
Network
Calibration

Some Simple Solutions
Sorbents
Simple Screens
Boardovers

Current Research
Knowledge Based Tools
Molecular Markers

Final Remarks
Some New Ideas for BMPs

- Boardover and Flat Screens
- Catch Basin Inserts
- Special Screens
- Bioinfiltration
Lab Scale Setup
## Lab Scale Results

<table>
<thead>
<tr>
<th>Sorbent Type</th>
<th>Oil and Grease Type</th>
<th>Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated Carbon</td>
<td>Emulsified</td>
<td>11</td>
</tr>
<tr>
<td>Aluminum Silicate (e.g., Perlite, Xsorb, straw, compost, OARS)</td>
<td>Emulsified</td>
<td>0-3</td>
</tr>
<tr>
<td>OARS Polymer</td>
<td>Free</td>
<td>88, 91</td>
</tr>
<tr>
<td>Aluminum Silicate (e.g., Perlite, Xsorb)</td>
<td>Free</td>
<td>88, 91, 94, 89</td>
</tr>
<tr>
<td>Compost</td>
<td>Free</td>
<td>28, 49</td>
</tr>
<tr>
<td>Polypropylene (type 1 &amp; 2)</td>
<td>Free</td>
<td>86, 92, 78, 85</td>
</tr>
</tbody>
</table>
General Insert Sketch

Street Surface

Catch Basin Insert

Normal Flow

High Flow

Outlet

Side Walk
Simulator
Simulator
AbTech New
United - Influent Conc

Sorbent = 12 oz fabric; Flow = 75 GPM

Removal efficiency (%)

Time (min)

INF = 8.13 mg/L
INF = 17.62 mg/L
INF = 30.5 mg/L
Flow = 75 GPM

- 12 oz bag (INF = 8.13 mg/L)
- 8 oz bag (INF = 8.12 mg/L)
- Double bag liner (INF = 11 mg/L)
United - Influent Flow Rate

Sorbent = 12 oz fabric; Influent = 23 mg/L

Removal efficiency (%) vs Time (min)

- 190 GPM
- 125 GPM
- 75 GPM
- 15 GPM
United - Consecutive Tests

Sorbent = 12 oz fabric
Flow = 75 GPM
Influent = 24.71 +/- 3.53 mg/L
AbTech new filter box
Flow = 35 GPM

- INF = 19.02 mg/L
- INF = 14 mg/L
- INF = 10.91 mg/L

Removal efficiency (%) vs. Time (min)
AbTech Results - New vs Used

Flow rate = 15 GPM/box

- Used (INF = 8.40 mg/L)
- Used (INF = 24.72 mg/L)
- New (INF = 14.14 mg/L)

Removal efficiency (%) vs Time (min)
AbTech Results - used box

![Graph showing removal efficiency over time for two flow rates: 15 GPM (INF = 8.4 mg/L) and 35 GPM (INF = 10.7 mg/L). The graph indicates a decrease in removal efficiency with time.]
AbTech Results - PAHs

Nominal influent concentration = 50 ppb

AbTech new filter box (with bottom blocked); Flow = 35 GPM

Removal efficiency (%)
## Table CB-2.
Estimated Number of Catch Basin Associated with the Corresponding Land Uses in the Santa Monica Bay Watershed

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Area (acres)</th>
<th>Estimated Number of Catch Basins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single family</td>
<td>64,500</td>
<td>6,694</td>
</tr>
<tr>
<td>Multi-family</td>
<td>19,942</td>
<td>4,114</td>
</tr>
<tr>
<td>Commercial</td>
<td>12,113</td>
<td>3,586</td>
</tr>
<tr>
<td>Light Industrial</td>
<td>5,486</td>
<td>1,008</td>
</tr>
<tr>
<td>Totals of above Land Uses</td>
<td>102,041</td>
<td>15,401</td>
</tr>
</tbody>
</table>
Catchbasin Design Factors

- Catchbasins in Southern California are typically sized on opening length, not on volume.
- Opening length is a function of slopes and drainage area as it affects gutter velocity and side channel spillway design.
- High calculated gutter velocity lead to long below ground chambers (up to 28 feet).
- Chamber volume is then a function of standard depth and width applied to the calculated length.
- Sometimes depth is extended to allow easier connection to pipe system.
- Therefore, below ground chambers volumes are often very over designed and excess volume should be available for retrofits.
# Catchbasin Retrofit Potential for Trash and Debris Removal

## Table 5-5 Analysis of Potential Trash/Debris Retofits of Catchbasins

<table>
<thead>
<tr>
<th>Land Use/Trash Loading Percentages:</th>
<th>Single Family</th>
<th>Multi-Family</th>
<th>Commercial</th>
<th>Public</th>
<th>Light Industrial</th>
<th>Other Urban</th>
<th>Open</th>
<th>Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Use as a Percent of Total</td>
<td>24.4%</td>
<td>7.5%</td>
<td>4.6%</td>
<td>2.4%</td>
<td>2.1%</td>
<td>2.7%</td>
<td>56.5%</td>
<td>0.01%</td>
<td>100%</td>
</tr>
<tr>
<td>Estimated Trash Production*</td>
<td>46.1%</td>
<td>14.2%</td>
<td>26.1%</td>
<td>4.5%</td>
<td>4.0%</td>
<td>5.1%</td>
<td>0.0%</td>
<td>0.02%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
## Potential Catchbasin Retrofit Potential for Trash and Debris Removal

<table>
<thead>
<tr>
<th>Catch Basins Retrofit (%)</th>
<th>Trash Removal Reduction from Commercial Areas (%)</th>
<th>Trash Reduction (% of total)</th>
<th>Number of Retrofits</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>80</td>
<td>72%</td>
<td>3227</td>
</tr>
<tr>
<td>50</td>
<td>80</td>
<td>40%</td>
<td>1793</td>
</tr>
</tbody>
</table>
Screens
Screen 1 inch wire mesh
Accumulation - Wire Screen
Accumulation - Control (Open)
Accumulation - Control (open)
Clogging in Wet Weather
Hanging Wire Basket
Removal
UPS
UPS Installation
UPS
Bioinfiltration
Outline

Santa Monica Bay
Facts and Data Sources
Statistics
Land Use
Data Sources

Spreadsheet Model
Parameters
Calibration
Predictions

SWMM Model
Network
Calibration

Some Simple Solutions
Sorbents
Simple Screens
Boardovers

Current Research
Knowledge Based Tools
Molecular Markers

Final Remarks
On Going Research

• Knowledge Based Tools to Develop Model Data
• Better Calibrations and Techniques
• Molecular Markers for Different Types of Land Use
• Nutrients
<table>
<thead>
<tr>
<th>Satellite</th>
<th>Launch Date</th>
<th>Decommission Date</th>
<th>Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 1</td>
<td>July 23/72</td>
<td>Jan. 6/78</td>
<td>MSS-RBV</td>
</tr>
<tr>
<td>Landsat 2</td>
<td>Jan. 23/95</td>
<td>Feb. 25/82</td>
<td>MSS-RBV</td>
</tr>
<tr>
<td>Landsat 3</td>
<td>Mar. 5/78</td>
<td>Mar. 31/83</td>
<td>MSS-RVB</td>
</tr>
<tr>
<td>Landsat 4</td>
<td>July 16/82</td>
<td>Aug. /93</td>
<td>MSS-TM</td>
</tr>
<tr>
<td>Landsat 5</td>
<td>Mar. 1/84</td>
<td></td>
<td>MSS-TM</td>
</tr>
<tr>
<td>Landsat 6</td>
<td>Oct. 5/93</td>
<td></td>
<td>ETM</td>
</tr>
<tr>
<td>Landsat 7</td>
<td></td>
<td></td>
<td>ETM-M</td>
</tr>
</tbody>
</table>
Molecular Markers

What is a molecular marker?
A compound found consistently in specific wastes.

What is the role of the molecular marker?
Provides information on the source of pollutants.
Concept of Marker Approach

Runoff Samples

Organic Analysis

Information

Identify the source of pollutants
Determine the concentration of the markers

Application

Estimate the mass loading of wastes
Relative levels of runoff volume are related to land use.

Relative levels of pollution are closely related to land use.
Objectives

- Select molecular markers.
- Determine the distribution of the molecular markers.
- Estimate the marker mass loading
Literature Review

- Criteria for ideal markers
- Selected Molecular markers
Criteria for Ideal Markers

- **Source Specificity** - fewer sources
- **Conservative Behavior** - highly resistant
- **Magnitude** - large concentration
- **Analysis** - easy to analyze, little cost
### Summary of selected Markers

<table>
<thead>
<tr>
<th>Sources</th>
<th>Markers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicular emissions</td>
<td>$17\alpha$(H)$21\beta$(H)-hopane</td>
</tr>
<tr>
<td>Tire dust</td>
<td>Benzothiazole(BT) and $24$MoBT</td>
</tr>
<tr>
<td>Detergent</td>
<td>Linearalkylbenzenes(LABs)</td>
</tr>
<tr>
<td>Animal feces</td>
<td>Coprostanol and Cholesterol</td>
</tr>
<tr>
<td>Pesticides</td>
<td>Atrazine, Simazine and Diazinon</td>
</tr>
</tbody>
</table>
17α(H)21β(H)-Hopane

- Structure and sources
  - Lubricant oil
  - Vehicular emission

**17α(H)21β(H)-hopane**

- Marker of vehicular emissions in atmosphere
  Rogge et al., 1993
- Marker of the lubricating oil contamination
  Bieger, 1996
Molecular Markers

• Measure presence or absence of markers for various land uses
• Use regressions to predict water quality as a function of land use
• Develop fuzzy reasoning to infer land use and contributors from marker distribution
Outline

Santa Monica Bay
- Facts and Data Sources
- Statistics
- Land Use
- Data Sources

Spreadsheet Model
- Parameters
- Calibration
- Predictions

SWMM Model
- Network
- Calibration

Some Simple Solutions
- Sorbents
- Simple Screens
- Boardovers

Current Research
- Knowledge Based Tools
- Molecular Markers

Final Remarks
Some thoughts

• For developed areas in the United States, stormwater (urban runoff) the next frontier for water pollution control.
• GIS in combination with empirical runoff models are useful for predicting stormwater emissions
• GIS/SWMM can be used for extremely complex networks, such as the Ballona Creek sub-basin
• Some very simple solutions exist, and have yet to be exploited
• Some advanced tools need to be developed to help understand this very complex issue
Acknowledgements

Sources of Support:

1. UCLA
2. Santa Monica Restoration Project
3. US EPA Watershed Project
4. Catch Basin City Consortium

Partners in Research:

Prof. Mel Suffet, Dr. Sim-Lin Lau, Eric Strecker
• Michael K. Stenstrom

• Email: stenstro@seas.ucla.edu

• URL: www.seas.ucla.edu/stenstro

~ End ~
Acknowledgement to the Santa May Bay Restoration Project for their continuing support, and my research group!

Stenstro @ seas.ucla.edu
www.seas.ucla.edu/stenstro

Mike Ma
Andy Lee
Sabbir Khan