SWMM LID Module Validation Study

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Presentation Overview

- Urban Stormwater Impacts and Controls
- What is SWMM?
- SWMM LIDs
- PEST
- Multi-Storm, Multi Objective Validation
- Conclusions

Urban Stormwater Impacts

Flooding Impacts:

- Disruption of traffic
- Flooding of underpasses
- Damage to homes and properties
- Costly interruptions of urban activities

Urban Stormwater Impacts

Water Quality Impacts:

- Urban stormwater is listed as the “primary” source of impairment for 13% of all rivers, 18% of all lakes, and 32% of all estuaries.
- In 2010, stormwater caused more than 8,700 beach closing and advisory days; sewage spills and overflows caused more than 1,800 of those.
- Insecticides often occur at higher concentrations in urban streams than in agricultural streams.
- Total phosphorus concentrations in urban streams exceed EPA’s goal for nuisance plant growth in 70% of streams.
- Fecal coliform bacteria commonly exceed recommended standards for water recreation

Urban Stormwater Impacts

Hydrologic, Geomorphic, and Biological Impacts:

- Increased stormwater volume and velocity causes flooding, erosion, and sewer overflows.
- Increased erosion leads to increased channel width and reduced bank stability.
- Reduced groundwater recharge impacts water supplies.
- Impaired habitat and water quality impact fisheries and shellfish harvesting.

Approaches to Managing Stormwater

The Conveyance Approach –
Rapidly remove stormwater from impervious surfaces to receiving streams by way of engineered drainage systems (e.g. culverts, storm drains, and channelized streams).

"Water is a problem. Its the enemy. Get it away from here. NOW!"

The Infiltration Approach –
Retain stormwater as close as possible to its originating source(s), infiltrating as much as possible into the soil by using best management practices and strategies.

"Water is a precious resource, keep it here, clean it, save it for later -we need it, and our local our ecosystems need it too!"

End-of-Pipe Stormwater BMPs

Ponds

Wetlands

Sand Filters

High Rate Treatment

Source Control BMPs (GI, LID, SUDS)

Disconnection

Infiltration Basin

Rain Garden

Cistern

Infiltration Trench

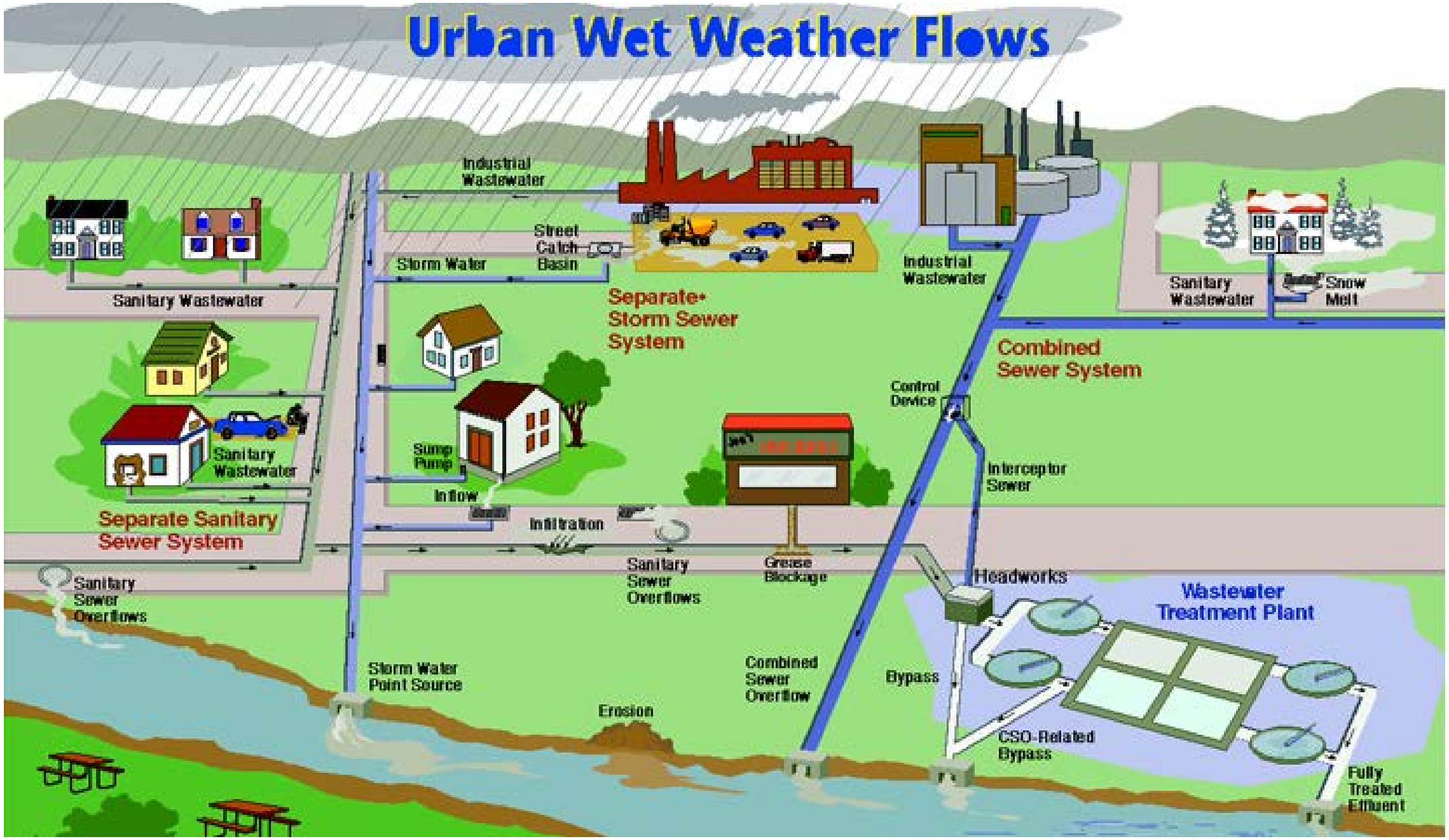
Green Roof

Permeable Pavement

Vegetative Swale

Street Planter

What is SWMM



SWMM is a public domain, distributed, dynamic hydrologic - hydraulic - water quality model used for continuous simulation of runoff quantity and quality from primarily urban areas.

SWMM's LID Application

- SWMM 5 recently updated to model Low Impact Developments (LIDs)
- Seven green infrastructure modules available:
  - Permeable pavements
  - Rain gardens
  - Green roofs
  - Street planters
  - Rain barrels
  - Infiltration trenches
  - Vegetative swales

Why Validate?

- Validate: determine accuracy with which SWMM models LIDs
- No formal validation completed on LID application previously
- Planners and engineers relying on SWMM to make costly decisions
- Want to identify potential areas of improvement for next update

Validation Subject Material

- Data collected by Cadmus (contractor) from previous LID studies
- Nine individual LID studies used in validation
  - 1 Permeable pavement
  - 1 Rain gardens
  - 1 Bio-retention
  - 3 Green roofs
  - 1 Infiltration trench
  - 2 Vegetative swales

SWMM Models

- SWMM Model created for each LID
- LID represented by single subcatchment
- Inflow input methods:
  - If measured - data time series directly inputted
  - If not measured - drainage area modeled
- Rainfall inputted with rain gauge
- Outflow generated by running simulation

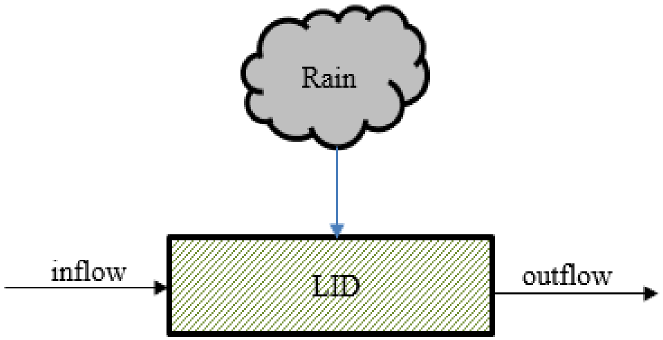


Figure: Typical Model Configuration

Parameter Optimization: PEST Calibration

- PEST: nonlinear parameter estimation tool
- Used to calibrate SWMM model by estimating unmeasured parameters
  - Uses the Gauss-Marquardt-Levenberg method
    - also known as the damped least-squares (DLS) method

$$S(\boldsymbol{\beta}) = \sum_{i=1}^{m} [y_i - f(x_i,\ \boldsymbol{\beta})]^2$$

Eq. 1

- given a set of m empirical datum pairs of independent and dependent variables, (x_i, y_i), optimize the parameters β of the model curve $f(x, \boldsymbol{\beta})$ so that the sum of the squares of the deviations becomes minimal.

Parameter Optimization: PEST Cont.

- PEST executes SWMM continuously, altering specified parameters each time
- After each SWMM run, PEST compares simulated output to measured output
- Optimization accomplished when weighted sum of least squares is minimized
- Used iterative approach
    - Started with differing sets of parameters
    - Want to attain global optimum rather than local optimum.

Validation Process

- Multiple storm events chosen for each LID
- SWMM calibrated to each storm
- Parameters from calibration trial used in validation trials
- Event with highest performance among all events chosen as calibration event

Validation Process Cont.

- Given measured inflow, compare how well SWMM matched observed outflow
- Nash-Sutcliffe Efficiency Coefficient used to measure goodness of fit

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q_o}\right)^2}$$

Eq. 2

  - Q_o is the mean of observed discharges, and Q_m is modeled discharge. Q_o^t is observed discharge at time t
- Value can range from −∞ to 1.
- The closer the model efficiency is to 1, the more accurate the model is.

Calibration/Validation Table

Table: Example of Calibration/Validation Procedure

Calibration Storm	Event 1	Event 2	Event 3	Event 4	AVG
Event 1	Calibration	Validation 1	Validation 2	Validation 3	
Event 2	Validation 1	Calibration	Validation 2	Validation 3	
Event 3	Validation 1	Validation 2	Calibration	Validation 3	
Event 4	Validation 1	Validation 2	Validation 3	Calibration	

Validation Example: EOC Green Roof

- Emergency Operations Center (EOC), Seattle, Washington
- 7,480 square foot green roof
- Only intercepts precipitation that falls upon it; no additional runoff received
- Two inches granular stone drainage
- Four Inches growing media
- Outflow routed to roof drain

Figure - Photograph of the EOC Seattle Green Roof

SWMM Input File Parameters

Table: SWMM 5 Input Parameters

Type	Value	Range (if estimated)	Data Source
Subcatchment			
Total Area (ac)	0.172		LID Study
Percent Slope	4.1		LID Study
Percent Impervious	100		LID Study
Green Roof Usage			
Area (ft^2)	7480		LID Study
Width (ft.)	100.8	30-110	Estimated
Initial Saturation (%)	2.82	0.01-25	Estimated
Surface Layer			
Berm Height (in)	0.10	0.10-1.0	Estimated
Veg. Volume Fraction	0.05	0.01-0.5	Estimated
Surface Roughness	0.41	0.01-0.70	Estimated
Surface Slope (%)	4.17	1.0-5.0	Estimated
Soil Layer			
Thickness (in)	4.00		LID Study
Porosity (v. fraction)	0.70	0.34-0.70	Estimated
Field Capacity (v. fraction)	0.33	0.30-0.33	Estimated
Wilting Point (v. fraction)	0.22	0.09-0.29	Estimated
Conductivity (in/hr)	3.00	0.60-45.0	Estimated
Conductivity Slope	0.50	0.01-20.0	Estimated
Suction Head (in)	4.00	3.0-8.0	Estimated
Drainage Mat Layer			
Drain Mat Thickness (in)	2.00		LID Study
Drain Mat Void Ratio	0.50	0.20-0.50	Estimated
Drain Mat Roughness	6.99	0.01-10.0	Estimated

EOC Calibration Table

Table: Calibration Method

Calibration Storm	5/5/2009	12/11/2010	4/12/2009	10/9/2010	AVG
5/5/2009	0.977	0.825	0.775	0.901	0.870
12/11/2010	0.582	0.890	0.729	0.893	0.773
4/12/2009	0.970	0.853	0.988	0.939	0.937
10/9/2010	0.969	0.856	0.967	0.941	0.933

Example of Validation Results: EOC Green Roof

Emergency Operations Center (EOC), Seattle, Washington

- Average N-S: 0.937
- Most sensitive parameters: soil wilting point, soil field capacity, drainage mat void ratio, soil porosity
- Rating of performance: Excellent

Table 6: Calibration and Validation Results Summary EOC Green Roof

Run	Storm ID	Storm Date	Total Inflow (in)	Total Observed Outflow (in)	Total Simulated Outflow (in)	N-S Value *	R^2 Value	% Change Outflow Volume	Initial Deficit
Calibration	137	4/12/2009	0.750	0.367	0.370	0.988	0.99	0.82	2.82
Validation 1	140	12/11/2010	3.586	2.53	3.21	0.853	0.97	26.9	2.82
Validation 2	138	5/5/2009	0.862	0.667	0.720	0.970	0.97	7.95	11.6
Validation 3	139	10/9/2010	1.625	1.09	1.20	0.939	0.94	10.1	2.82

EOC Green Roof Parameter Sensitivity

Table 4: Parameter Sensitivity

Parameter		Estimated Value	Sensitivity	Rank
LID Usage	Width (ft.)	100.8	0.000003	7
	Initial Saturation	2.82	0.000068	5
Soil	Porosity	0.70	0.000318	4
	Field Capacity	0.33	0.017666	2
	Wilting Point	0.22	0.023487	1
Drainage Mat	Void Ratio	0.50	0.000423	3
	Roughness	6.99	0.000050	6

Example Result Plots

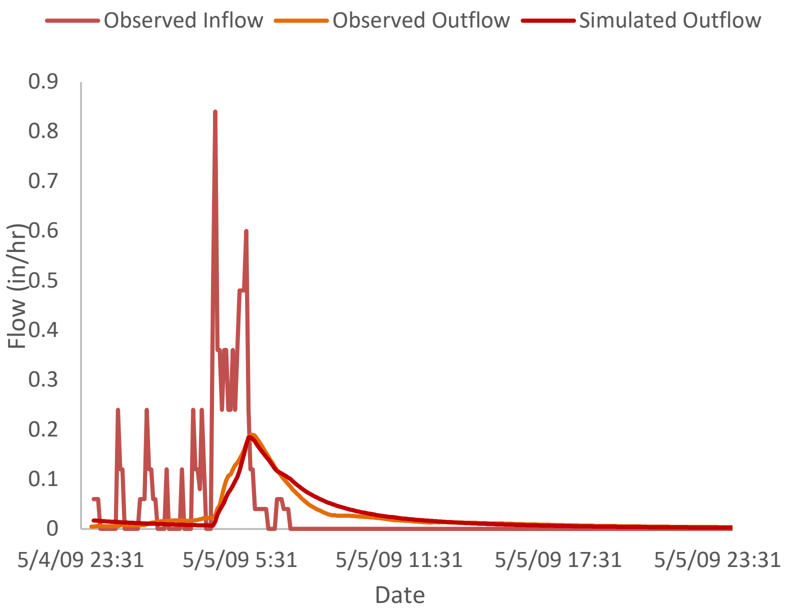


Figure: Validation 2 Hydrograph

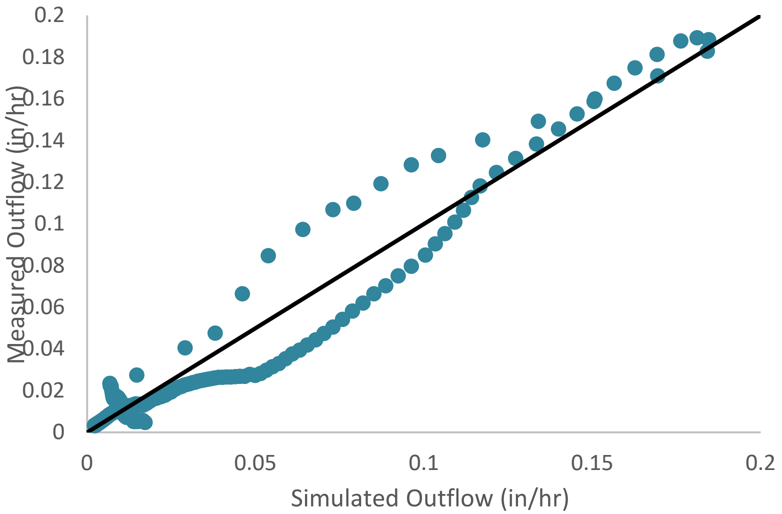


Figure: Validation 2 Correlation Plot

Changes to SWMM During Validation

- Uniform report step for outflow time series
  - Outflow always reported in the same time step for entire simulation
  - Allowed time stamps to match when comparing measured and simulated datasets
- Lateral exfiltration in infiltration trench
  - Simulated using underdrain
- Surface ponding added as initial condition for bio-retention units
  - Initial saturation more than 100% simulated ponding
- Underdrain offset height limitations removed
  - Offset height no longer restricted to storage layer height
- Underdrain upturn and saturated soil layer added
  - Saturated zone can rise into soil layer

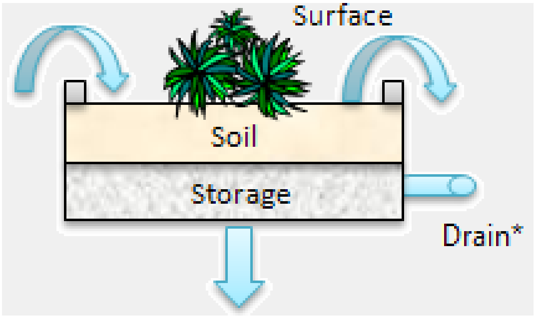


Figure: Schematic of Bio-Retention Unit

Recommendations for Future Updates

- Incorporate multi-event parameter estimation tool
  - Utilizing PEST drastically improved calibration abilities and outcome
- Allow for swale side slopes to differ
  - In validation, side slopes averaged to input single value
- Model directional flow of water through LID
  - Inflow automatically distributed equally throughout LID
  - Small segments in series approach

Recommendations for Future Updates Cont.

- Incorporate lateral exfiltration
  - For deep retention units, sidewall exfiltration significant
  - Currently, only vertical exfiltration used
- Address surface outflow for rain gardens
  - Discrepancy in surface outflow attenuation
  - Eliminate oscillations experienced in simulated outflow

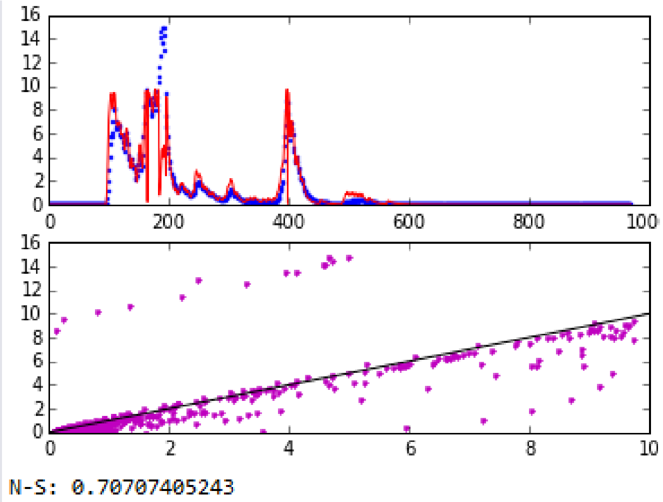


Figure: Example of Outflow Oscillations

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Thank You