Post-audit Verification of the Model SWMM for Low Impact Development

Basic Information

Title:	Post-audit Verification of the Model SWMM for Low Impact Development
Project Number:	2011CT231B
Start Date:	3/1/2011
End Date:	5/31/2013
Funding Source:	104B
Congressional District:	2
Research Category:	Water Quality
Focus Category:	Hydrology, Models, Non Point Pollution
Descriptors:	None
Principal Investigators:	Michael Dietz, John Campbell Clausen

Publications

1. Rosa, D. 2012. Modeling the Effectiveness of Low Impact Development Using SWMM. Connecticut Conference on Natural Resources, 3/12/12, University of Connecticut.
2. Rosa, D. 2013. Post-audit Verification of the Model SWMM for Low Impact Development College of Agriculture and Natural Resources Graduate Research Forum, 4/6/13. University of Connecticut.
3. Rosa, D. 2012. Modeling the Effectiveness of Low Impact Development Using SWMM. Connecticut Conference on Natural Resources, 3/12/12, University of Connecticut.
4. Rosa, D. 2013. Post-audit Verification of the Model SWMM for Low Impact Development College of Agriculture and Natural Resources Graduate Research Forum, 4/6/13. University of Connecticut.

Post-audit Verification of the Model SWMM for Low Impact Development

ANNUAL REPORT

May 24, 2013

Michael Dietz, UConn CLEAR
John Clausen, UConn NRE
David Rosa, UConn NRE

Table of Contents

List of Figures

List of Tables

Introduction/Research Objective

The impact of traditional development on local waters is well known; increases in stormwater runoff volume, rate, and pollutant export have documented effects on receiving waters. Typical stormwater design only protects channel integrity by mitigating for increased flow rates; the volume and quality of stormwater are not typically considered.

Implementation of Low Impact Development (LID) techniques (Prince George's County, 1999) has increased steadily since the 1990s. The overall goal of LID is to have post-development hydrologic function mimic that of pre-development, thereby minimizing impacts to downstream channels and aquatic life. This is accomplished through proper site planning, preservation of existing vegetation, and directing runoff from impervious areas to pervious areas where possible. Individual practices used to accomplish these items include bioretention, grassed swales, water harvesting, green roofs, and pervious pavements. Numerous states and local municipalities have included LID in stormwater manuals (e.g. CT DEP, 2005; MA DEP 2008; RI DEM & CRMC 2010), although LID use is only recommended, not required, in most cases.

Since its inception, LID design was aimed at capturing and treating smaller, more frequent storms. For larger storms, some runoff would infiltrate close to its source, but the majority would bypass distributed LID features, and would need to be routed out of the area. Provisions for management of this size event need to be demonstrated to meet flood control requirements designed to protect public safety, however engineering design often has not given credit for the runoff reduction benefit provided by LID. Much research has been performed on individual LID practices, but little effort has been put into integrating the hydrologic and water quality benefits of LID techniques into engineering design models.

The main objective of this project was to determine how a residential watershed with LID features responds to larger, less-frequent precipitation events. Specific objectives were the following:

a. Calibrate and validate a distributed, continuous model simulation using the Storm Water Management Model (SWMM) for the Jordan Cove LID and traditional watersheds, using existing precipitation, discharge, and pollutant (nitrogen and phosphorus) export data.

b. Compare the runoff volume and peak flow rate response of LID and traditional watersheds for hypothetical 10, 25, 50 and 100-year (24 hr) precipitation events using a calibrated SWMM model.

Materials/Procedures/Progress

Study Site

The Jordan Cove Urban Watershed Project is located in Waterford, CT (Figure 1). The project consisted of a traditionally built subdivision and a low impact development subdivision. A control watershed was also monitored to statistically evaluate the effects of the two types of construction methods using a paired watershed design (Clausen & Spooner, 1993). Monitoring methods for the project have been described previously (Clausen, 2008). Land cover, surface infiltration rates, precipitation, continuous flow measurements, and pollutant export data are available for the pre-construction, construction, and post-construction phases of the traditional and LID watersheds. Only the results from the fully built-out (post-construction period) were used in this study.

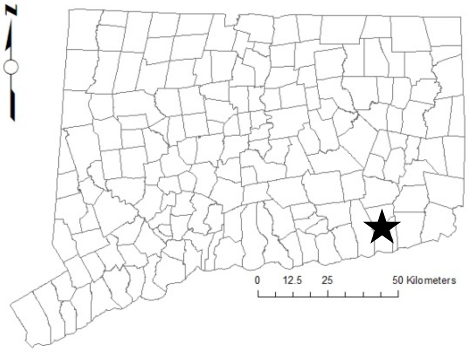

Figure 1. Location of Jordan Cove study site in State of Connecticut.

SWMM Model

A georeferenced aerial image of the watersheds was imported into SWMM (version 5.0.022) to allow for subcatchment digitization and automatic calculation of watershed areas (Figures 2,3). The LID watershed was modeled using a distributed parameter approach that resulted in the digitization of 105 subcatchments representing roofs, lawns, driveways, sidewalks, and individual LID controls. Field verification of impervious surfaces, drainage paths, and currently installed LID features was performed in both watersheds. LID controls included 11 rain gardens, 1 bioretention area in the cul-de-sac, 2 grassed swales, 1 permeable paver road, 2 permeable paver driveways, 2 crushed stone driveways, and a rain barrel. Subcatchments ranged in size from 0.3 m^2 to 20,396.2 m^2.

Initial input parameter values were estimated through a combination of field data, literature sources, and model defaults (Table 1). Field visits, as-built drawings, and manufacturer specifications were used to calculate slopes, pervious pavement parameters, and the percent of impervious area routed over pervious. Green-Ampt infiltration parameters were based on Natural Resource Conservation Service (NRCS) hydraulic conductivity values for Udorthents-urban land and soil suction and initial soil moisture deficit values for sandy loam (USDA-NRCS, 2012; Rawls *et al*., 1983; Maidment, 1993).

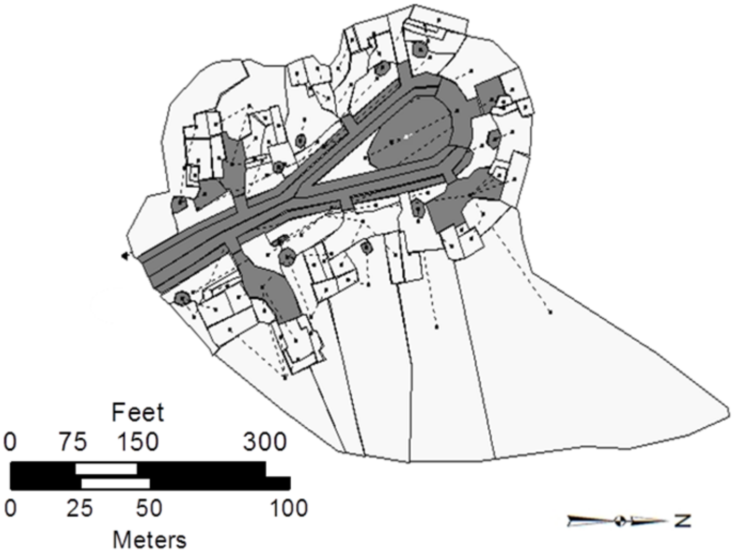

Figure 2. SWMM representation of the Jordan Cove LID watershed.

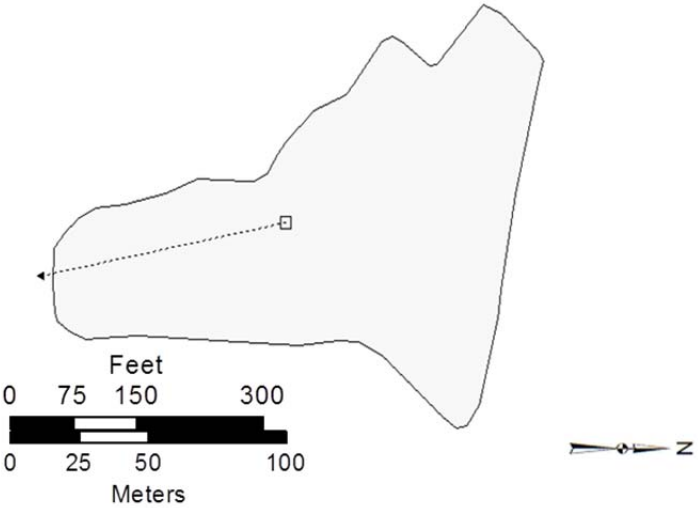

Figure 3. SWMM representation of the Jordan Cove Traditional watershed.

Sensitivity analysis was performed in order to identify which parameters would be most effective in minimizing differences between observed and predicted results. Parameters were adjusted over a range of ± 50% of their original value while keeping all other parameters unchanged and the corresponding difference in runoff volume and peak flow was calculated. Relative sensitivity was computed according to the method outlined in James and Burges (1982).

Calibration and Validation

The time period of August 12, 2004 to June 30, 2005 was used to conduct a manual calibration. Total rainfall for this period was approximately 111 cm. Sensitive parameters were systematically adjusted one at a time until differences between the simulated and observed values were minimized. A separate 46 week period from August 14, 2003 to July 08, 2004, which had approximately 91 cm of total rainfall was used for validation. Validation simulations used calibrated parameter values without further adjustment. Runoff was not simulated when there was a lack of observed data as a result of equipment malfunction or during periods of snowmelt. Agreement between predicted and observed data was assessed using coefficients of determination (R^2) and Nash Sutcliff Efficiency (NSE) coefficients (Nash and Sutcliffe, 1970).

Table 1. SWMM parameters and initial values for uncalibrated simulation of the LID and traditional Jordan Cove Watersheds.

Parameter (units)	Initial Value	Data Source
Subcatchments		
Area (ha)	0.0008 - 2.0396	Automatically calculated
Width (m)	0.9 - 1,247.0	Calculated (Rossman, 2010)
% Slope	0.5 - 30%	As-built drawings
% Imperv	0 - 100%	Bedan and Clausen, 2009
N-Imperv	0.01	Rossman, 2010
N-Perv	0.24	Rossman, 2010
Dstore-Imperv (in/mm)	0.07	Rossman, 2010
Dstore-Perv (in/mm)	0.15	Rossman, 2010
% Zero-Imperv	25%	Rossman, 2010
Percent routed	34%	Field observations
Suction head (mm)	110.1	Rawls, W.J. *et al.*, 1983
Conductivity (mm/hr)	25.1	USDA, NRCS, 2012
Initial deficit (a fraction)	0.246	Maidment, 1993
Snow melt		
Snow vs rain (degrees C)	1.1°	default
ATI Weight (fraction)	0.5	default
Negative Melt Ration (fraction)	0.06	default
Porous pavement - surface		
Storage Depth (mm)	1.52	Rossman, 2010
Manning's n	0.03	James and von Langsdorff, 2003
Surface Slope (percent)	1 - 20	As-built drawings
Porous pavement - pavement		
Thickness (mm)	79.37	Manufacturer specifications
Void ratio (Void/Solid)	0.75	Maidment, 1993
Impervious Surface Fraction	0.878	Manufacturer specifications
Permeability (mm/hr)	22.8 - 88.9	Clausen, 2008
Clogging factor	0.0	default
Porous pavement - storage		
Height (mm)	0 - 304.8	As-built drawings
Void Ratio (voids/solids)	0.75	default
Conductivity (mm/hr)	254	default
Bioretention cell - surface		
Storage Depth (mm)	15.2	As-built drawings
Bioretention cell - soil		
Thickness (mm)	609.6	As-built drawings
porosity (volume fraction)	0.45	Maidment, 1993
Bioretention cell - soil		
Field capacity (volume fraction)	0.1	Dunne and Leopold, 1978
Wilting point (volume fraction)	0.05	Dunne and Leopold, 1978
Conductivity (mm/hr)	25.1	USDA, NRCS, 2012
Conductivity Slope	10	default
Suction Head (mm)	110.1	Rawls, W.J. *et al.*, 1983
Bioretention cell - storage		
Conductivity (mm/hr)	25.1	USDA, NRCS, 2012
Vegetative Swale - surface		
Storage Depth (mm)	30.5	As-built drawings
Manning's n	0.24	Rossman, 2010

Rare Events

In order to simulate watershed response to rare rainfall events, synthetic 10, 25, 50, and 100-year 24 h storms were developed from Miller *et al*. (2002). A Type-III Soil Conservation Service (SCS) rainfall distribution was used to disaggregate total precipitation amounts over the 24 h period at 15 min intervals (Akan and Houghtalen, 2003).

Results/Significance

Uncalibrated discharge volumes and peak flows showed poor agreement with observed values in the LID watershed, but good agreement with observed values in the traditional watershed (Table 2). Sensitive parameters were identified and adjusted to optimize agreement between modeled and observed weekly discharge values (Table 3). Detail on sensitive parameters and calibration can be found in Rosa (2013).

Table 2. Observed and predicted runoff for the LID and traditional watersheds for uncalibrated simulation.

	LID			Traditional		
	Observed	Predicted	% Difference	Observed	Predicted	% Difference
Weekly Volume (m^3)	1,076	188	82.5%	3,647	3,021	17.2%
Average Peak Flow (m^3/s)	0.0048	0.0007	86.0%	0.0127	0.0113	11.0%

Table 3. Initial and final values of parameters adjusted during calibration.

Parameter	Initial Values for both watersheds	LID calibrated	Traditional calibrated
Ksat (mm/hr)	25.15	3.05	4.57
Suction head (mm)	109.98	101.60	228.60
Initial soil moisture deficit	0.25	0.40	0.40
N-Imperv	0.011	0.011	0.015
N-Perv	0.24	0.15	0.15
Manning's n for swale†	0.24	0.15	-
Dstore-Perv	3.81	2.54	5.08
Dstore-Imperv (mm)	1.78	1.27	2.54
Width‡	1,638	-	600
Washoff Coefficients			
Nitrogen	5.00	3.00	2.00
Phosphorus	5.00	0.03	0.01

†Applies only to LID watershed

‡Applies only to traditional watershed

Runoff Volume and Peak Flow

The model simulated weekly runoff volume and peak flow well for both the calibration and validation periods, with high R^2 values (>0.8) for all regressions (Figure 4). A hydrograph of weekly modeled runoff volume (LID watershed) showed good agreement during the calibration period (Figure 5). High NSE values were also found for the calibration period (Table 4). NSE values >0.5 have been suggested as an indication of good model prediction (Santhi, *et al.*, 2001). Observed and predicted values of total volumes and average peak flows for both the calibration and validation periods also showed good agreement (Table 5). These findings suggest that the calibrated model is performing well in predicting runoff volumes and peak flows from the two study watersheds.

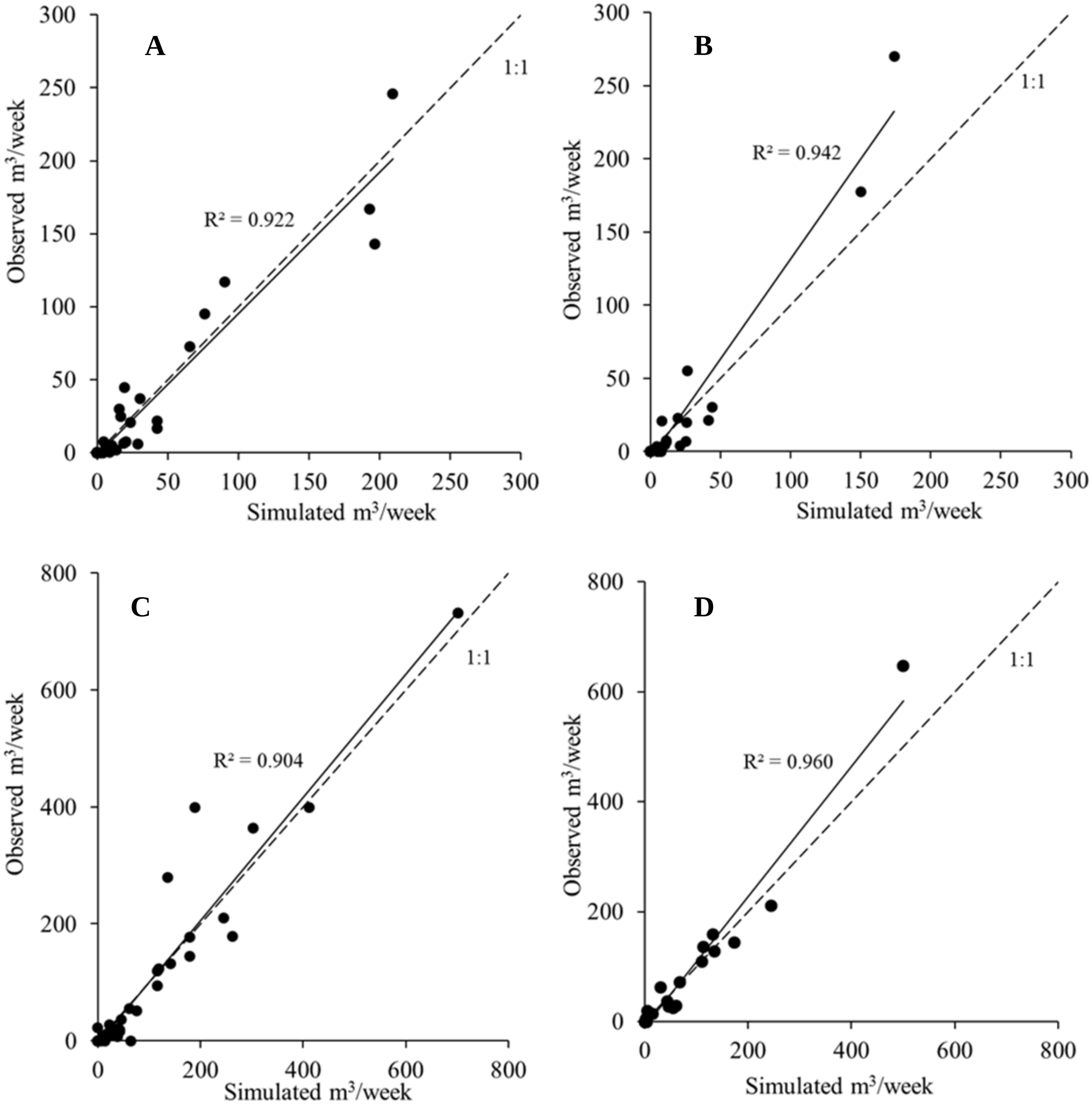

Figure 4. Weekly runoff volume for the LID and traditional Jordan Cove watersheds. A: LID Runoff volume calibration; B: LID runoff volume validation; C: Traditional runoff volume calibration; D: Traditional runoff volume validation.

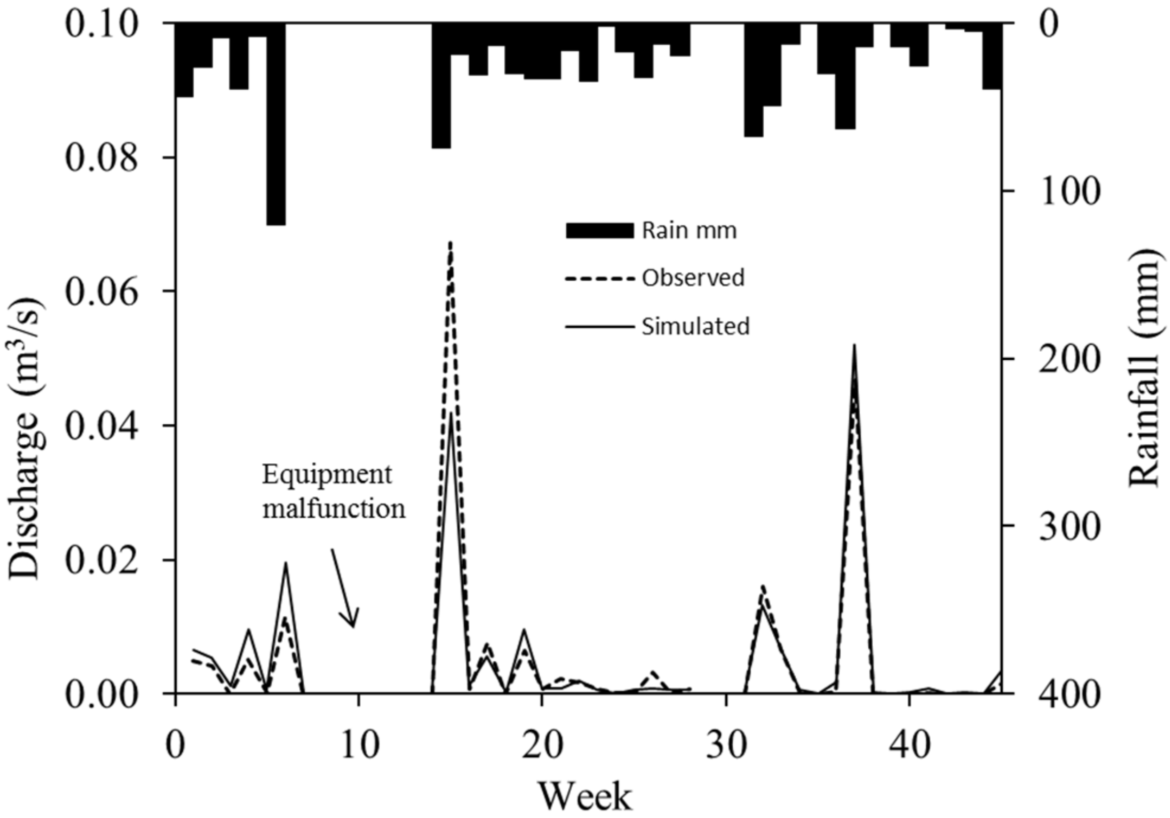

Figure 5. Weekly discharge and precipitation for the LID watershed calibration period (Aug. 2004-Jun. 2005).

Table 4. Nash-Sutcliffe Efficiency (NSE) coefficients for runoff volume and peak flow for Jordan Cove LID and traditional watersheds.

	LID		Traditional	
	Runoff Volume	Peak Flow	Runoff Volume	Peak Flow
Calibration	0.918	0.876	0.901	0.684
Validation	0.875	0.741	0.936	0.885

Table 5. Observed and predicted runoff for the LID and traditional watersheds.

	LID			Traditional		
	Observed	Predicted	% Difference	Observed	Predicted	% Difference
Calibration						
Total Volume (m^3)	1,076	1,162	8.0%	3,647	3,615	0.9%
Average Peak Flow (m^3/s)	0.0048	0.0047	2.1%	0.0127	0.0112	11.8%
Validation						
Total Volume (m^3)	664	625	5.9%	1,839	1,757	4.5%
Average Peak Flow (m^3/s)	0.0017	0.0015	11.8%	0.0116	0.0103	11.2%

Nutrient Export

In general, prediction of TN and TP export by the model was not as accurate as flow predictions; only TN export from the LID watershed had reasonable performance with NSE coefficient > 0.5. The model overestimated export of TN and TP from the LID watershed by 21% and 13%, respectively. For the traditional watershed, the model underestimated TN by 20%, and overestimated TP by 9%. The cause of the poor prediction of nutrient export is not known, but is likely due to homeowner activities such as lawn fertilization that were not accounted for in the model. Fluxes of nitrogen and phosphorus from homeowner activities could cause variability in the model that would not be accounted for by model algorithms.

Rare Events

The calibrated model was used to simulate runoff for the 10, 25, 50, and 100-year 24 hour rainfall events for the traditional and LID watersheds. A hydrograph of the 100-year 24 hour storm appears to show little difference in runoff per unit area from the two watersheds (Figure 6). The peak runoff rate from the LID watershed (34.5 $m^3/s/km^2$) was slightly lower than the rate from the traditional watershed (36.0 $m^3/s/km^2$). However, a steeper receding limb for the LID watershed resulted in less runoff compared to the traditional watershed. Although this difference appears to be slight, the LID watershed had consistently lower runoff coefficients (event runoff :

event rainfall) than the traditional watershed for all events modeled (Table 6). The percent difference decreased with increasing storm size, but was still substantial (22% less runoff from the LID watershed compared to the traditional) for the 100-year event. This is especially significant considering that in the predevelopment condition, the LID watershed had a higher runoff coefficient than the traditional watershed (Dietz and Clausen, 2007). It is not known what the predevelopment hydrologic response was to these large events, so pre- vs. post-development analyses cannot be performed. However, it is evident that there is some benefit of LID to reduce runoff from large events, despite common thinking that it only helps with small events.

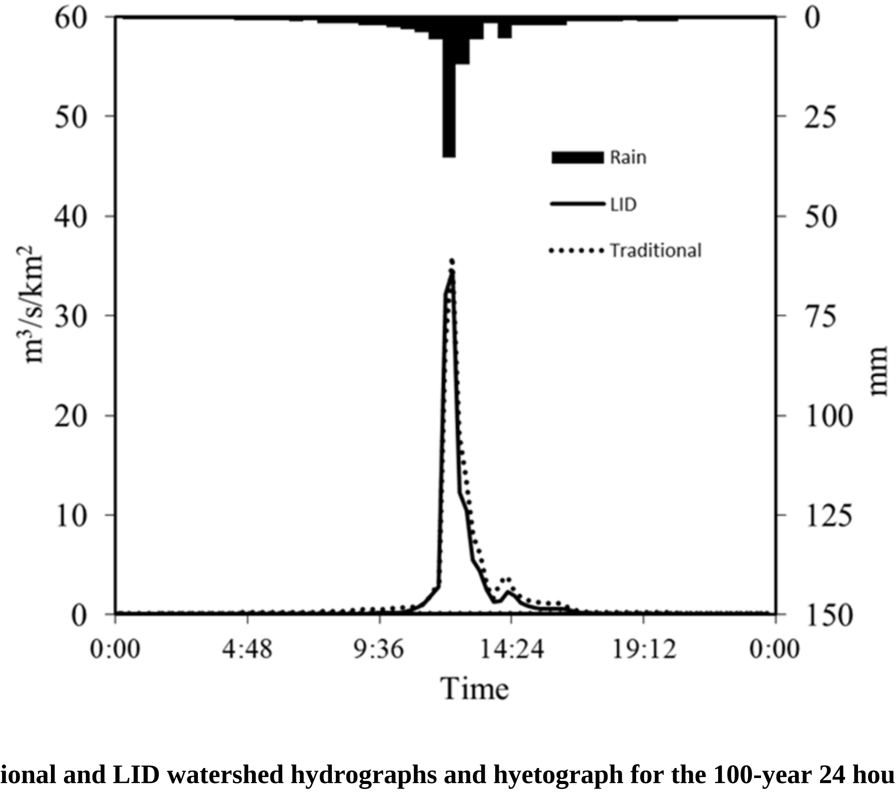

Figure 6. Traditional and LID watershed hydrographs and hyetograph for the 100-year 24 hour event.

Table 6. Rare event rainfall, runoff depth, and runoff coefficients for the Jordan Cove LID and traditional watersheds.

Recurrence interval (year)	Rainfall (mm)	LID Watershed		Traditional Watershed		Percent difference
		Runoff depth (mm)	Runoff coefficient	Runoff depth (mm)	Runoff coefficient	
10	132	44	0.34	60	0.46	26
25	163	62	0.38	82	0.51	25
50	198	84	0.42	110	0.55	24
100	234	107	0.46	138	0.59	22

Conclusions

The calibrated SWMM models for the LID and traditional Jordan Cove watersheds showed excellent predictive capabilities for runoff volume and rate according to standard metrics of accuracy. However, less accuracy was found for nitrogen and phosphorus loading estimates from the model as compared to observed values.

Simulation of the 10, 25, 50, and 100-year 24 hour events results in consistently lower runoff coefficients for the LID watershed compared to the traditional watershed, indicating that LID practices likely have stormflow control benefits even during large storms.

Literature Cited

Akan, A.O., R.J. Houghtalen. 2003. Urban hydrology, hydraulics, and stormwater quality: Engineering applications and computer modeling. John Wiley and sons, Hoboken, NJ, ISBN: 978-0-471-43158-9.

Baffaut, C. and J. Delleur, 1989. Expert system for calibrating SWMM. *Journal of Water Resources Planning and Management*, 115(3), 278-298, doi: 10.1061/(ASCE)0733-9496(1989)115:3(278).

Bedan, E. S. and J. C. Clausen. 2009. Stormwater runoff quality and quantity from traditional and low impact development watersheds. *Journal of the American Water Resources Association* (JAWRA) 45(4), 998-1008.

Clausen, J.C. 2008. Final Report Jordan Cove watershed project section 319 National Monitoring Program Project. Department of Natural Resources Management and Engineering, College of Agriculture and Natural Resources, University of Connecticut. Storrs, CT.

Clausen, J.C. and Spooner, J. 1993. Paired watershed study design. United States Environmental Protection Agency, EPA 841-F-93-009.

CT DEP. 2005. Connecticut Stormwater Quality Manual. Connecticut Department of Environmental Protection, 79 Elm St., Hartford, CT.

Dietz, M.E., and Clausen, J.C. 2007. Stormwater Runoff and Export Changes with Development in a Traditional and Low Impact Subdivision. *Journal of Environmental Management*, Vol. 87(4): 560-566.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Company. New York, NY.

James, L. D. and S. J. Burges, 1982. Selection, calibration, and testing of hydrologic models. Chapter 11 in: Hydrologic Modeling of Small Watersheds, C.T. Haan (Editor). American Society of Agricultural Engineers, St. Joseph, Michigan, 437-472.

Maidment, D.R., 1993. Handbook of Hydrology. McGraw-Hill, New York, New York, ISBN-13: 978-0070397323.

MA DEP. 2008. *Massachusetts Stormwater Handbook. Chapter 1: Overview of Massachusetts Stormwater Standards.* Massachusetts Department of Environmental Protection.

Miller, D. R., G. S. Warner, F. L. Ogden, A. T. DeGaetano. 2002. *Precipitation in Connecticut*. University of Connecticut College of Agriculture and Natural Resources. Connecticut Institute of Water Resources, Storrs, CT.

Nash, J. E. and J. V. Sutcliffe, 1970. River flow forecasting through conceptual models part I — A discussion of principles. *Journal of Hydrology*, 10(3), 282-290, doi: 10.1016/0022-1694(70)90255-6.

Prince George's County. 1999. Low-impact development design strategies: An integrated design approach. Prince George's County, MD Department of Environmental Resources.

Rawls, W.J., D. L. Brakensiek, N. Miller. 1983. Green-Ampt infiltration parameters from soils data. *Journal of Hydraulic Engineering*, 109, 62-70, doi: 10.1061/(ASCE)0733-9429(1983)109:1(62).

RI DEM & CRMC. 2010. *Rhode Island Stormwater Design and Installation standards Manual.* Rhode Island Department of Environmental Management and Coastal Resources Management Council.

Rosa, D. 2013. Post-audit verification of the model SWMM for Low Impact Development. M.S. Thesis, University of Connecticut Department of Natural Resources and the Environment.

Rossman, L. A., 2010. Storm Water Management Model user's manual version 5.0. United States Environmental Protection Agency, Water Supply and Water Resources Division, National Risk Management Research Laboratory. Cincinnati, OH.

Santhi, C., J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan, and L. M. Hauck, 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. *Journal of the American Water Resources Association* (JAWRA), 37(5), 1169-1188, doi: 10.1111/j.1752-1688.2001.tb03630.x.

Soil Conservation Service, 1986. *Urban hydrology for small watersheds*. U.S. Department of Agriculture Technical Release No. 55 (revised), 210-VI-TR-55.

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS), 2012. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed 10/2/2012.