Modeling of Stormwater Low Impact Development in Urbanized Areas

Modélisation des solutions durables de gestion des eaux pluviales dans les zones urbanisées

Li, James and Joksimovic, Darko

Department of Civil Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario, Canada M5B 2K3 (jyli@ryerson; darkoj@ryerson.ca)

RÉSUMÉ

La planification des solutions durables de gestion des eaux pluviales (LID) dans les zones urbanisées nécessite des méthodes de modélisation adéquates pour leurs simulations de performance. Cet abrégé élargi décrit les approches de modélisation de trois études de cas du LID qui englobent trois échelles de planification (villes, subdivisions et sites isolés). De nombreuses municipalités du Canada favorisent la planification du LID sur une base urbaine, ce qui peut nécessiter la modélisation de centaines ou de milliers de lots de LID. Afin de modéliser un grand nombre de lots de LID sur toute la ville de Barrie, on a utilisé une approche de modélisation semi-distribuée (basée sur des fonctions d'unité hydrologique des sites avec et sans LID) pour déterminer la réduction annuelle du volume de ruissellement sur toute la ville. Beaucoup de subdivisions urbaines incorporent le LID dans leurs conceptions urbaines de drainage. Pour simuler les performances du LID d'une subdivision dans la région du grand Toronto, une approche de modélisation distribuée a été utilisée pour simuler la réduction annuelle du volume de ruissellement.

ABSTRACT

Planning of stormwater low impact development (LID) practices in urbanized areas requires proper modelling approaches for their performance simulations. This extended abstract outlines the modelling approaches of three LID case studies which encompass three planning scales (cities, subdivisions, and single sites). Many municipalities in Canada favor LID planning on a citywide basis which may require the modelling of hundreds or thousands of LID lots. In order to model large number of LID lots over the whole City of Barrie, a semi-distributed modeling approach (based on hydrologic unit response functions of sites with and without LID) was used to determine the annual runoff volume reduction over the whole city. Many urban subdivisions incorporate LID in their urban drainage designs. To simulate the LID performances of a subdivision in the Greater Toronto area, a distributed modeling approach was used to simulate the annual runoff volume reduction. The last case study of a small urban street illustrates a fine scale distributed hydrologic approach without calibration can be to simulate annual runoff volume reduction. These case studies indicate that the spatial scales of LID planning may govern LID performance modeling.

KEYWORDS

Hydrologic Simulations, Low Impact Development, Modeling Approaches, Stormwater Management

1 STORMWATER LOW IMPACT DEVELOPMENT

Distributed stormwater management practices (i.e. Low Impact Development and Green Infrastructure) are becoming popular in recent years across the world. These practices are designed to restore the post-development hydrologic balance to that before urbanization and also provide resilience to future variable precipitation due to climatic change. Low Impact Development (LID) practices tend to imitate natural systems and thus reduce runoff volumes by increasing infiltration into the ground. Green infrastructure (GI) has similar effects, but includes only certain LID techniques implemented on different elements of municipal infrastructure (e.g. rain gardens, permeable pavements, bioretention facilities, and green rooftops.

This extended abstract summaries three LID studies which encompass three planning scales (cities, subdivisions, and single sites). The purpose of this extended abstract is to illustrate different modelling approaches LID and GI.

2 MASTER PLANNING OF LID FOR THE CITY OF BARRIE

City of Barrie, a medium size (99 km^2) municipality of 200,000 in Central Ontario, is part of the Lake Simcoe watersheds. In order to protect the Lake Simcoe from eutrophication, the city actively looks for solutions to reduce runoff as well as phosphorus loading to the lake. A master LID plan was developed by authors which involved three steps: (1) screening of suitable lots for various LIDs; (2) modeling of runoff and pollutant loading reduction with LID; and (3) cost-effective analysis of different LIDs. The objective of this study was to determine the overall effectiveness of LIDs in the whole city. Traditional lump or sub-catchment approach to model lot scale LIDs cannot permit detailed modelling of LID on a lot level basis. A semi-distributed modeling approach of annual runoff volume reduction of LIDs is described below.

2.1 Hydrologic Response Units

Five lot-based LIDs were considered in the master planning of LIDs: (1) bioretention cells (BR); (2) soakaway pits (SP); (3) green roofs (GR); (4) permeable pavement (PP); and (5) rainwater harvesting (RH). After the suitable lots of various LIDs have been identified, hydrologic response units (HRU) of runoff volume and pollutant loading reduction were developed. The concept of HRUs is based on the premise that drainage areas which contain similar runoff generating mechanisms are identified to facilitate evaluating the response of large drainage areas composed of hydrologically homogeneous units in a more efficient manner. HRUs are developed separately for each LID practices using the City's long-term rainfall and the lot characteristics of controlled and uncontrolled areas. The hydrological responses computed at the lot scale can be extrapolated to yield the response of an entire neighbourhood/watershed with reasonable accuracy by adding the responses of individual units. This allows the modelling and evaluation of each individual LID practice implemented over the suitable urban lot area of the whole city to be conducted on a local scale. Details can be found in Eric *et al.* (2013).

Histograms for lots which are amenable to each LID practice were used to select representative lots for detailed modelling the lot-based LIDs using the US EPA SWMM LID software. The x-axis were divided into three (3) regions based on the percentage value (0 % to 33 %, 34 % to 66 %, and 67 % to 100 %) of criteria such as (building area + parking area)/lot area or imperviousness area, depending on the LID being modelled. One lot was selected from each of the three (3) regions for detailed hydrological modelling of LID. The US EPA SWMM LID software was used to model the representative lots for the scenarios of both with and without LID implementation. Performance runoff reduction curves and associated equations were then developed based on the data derived from the hydrological modelling procedure. For example, the performance curve of the SP in the uncontrolled area in the City is illustrated in Fig. 1. These performance curve were used to aggregate runoff reduction of LIDs at feasible lots (Eric *et al.* 2013). Additional investigations (e.g. randomly selected lots, cluster lot analysis) of more than 3 representative LID lots can be found in Eric *et al.* (2015).

HRU is a semi-distributed approach where lot-level LID performance simulation is based on detailed lot-level models and extrapolation of lot-level performance over large planning area (e.g. the whole city) is based on linear assumptions. Although no hydrologic routing is performed, HRU is better than typical lumped pr sub-catchment approaches for large drainage areas where homogeneous subcatchment hydrologic parameters are adjusted to simulate LID performance for each subcatchment.

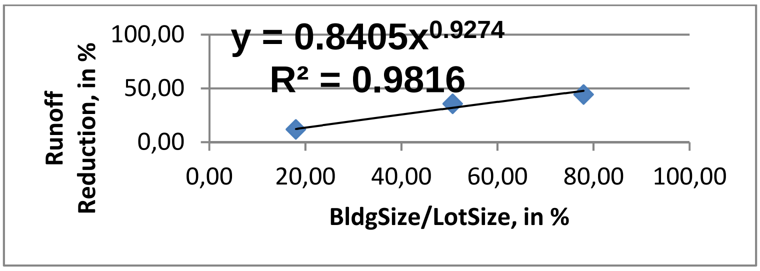


Figure 1 Percent reduction in runoff versus building size/lot size for SP.

3 A MULTI-USE SUBDIVISION

A private development site of 28.3 hectares (70 acres) in the City of London, Ontario, Canada has incorporated LID in its drainage plan. This multi-use community will comprise 20,000 living units (hig-rise, medium-rise, and town homes), and 40,000 m^2 of retail/commercial space. After screening analysis of various LIDs, the recommended LIDs are: green roofs for commercial buildings, rain water harvesting for single family houses, permeable pavements for parking lots and driveways, and infiltration trench/bioretention cell/vegetative swales for road sides (Fig. 2). This objective of this study was to determine the runoff volume reduction of various LIDs on a development site.

A homogeneous sub-catchment approach was used to model the runoff volume with and without LIDs. Routing of runoff was done along the drainage system using US EPA SWMM model. Annual water balance in terms of runoff, infiltration, and evapotranspiration was simulated for 18 individual or combined LID scenarios (Fig. 3). This modeling approach is typically used for subdivision level LID design. While this modelling approach is appropriate for development site LID design, the homogeneous sub-catchments still lump catchment parameters.

Figure 2 Sub-catchments modified with LIDs and locations of swales.

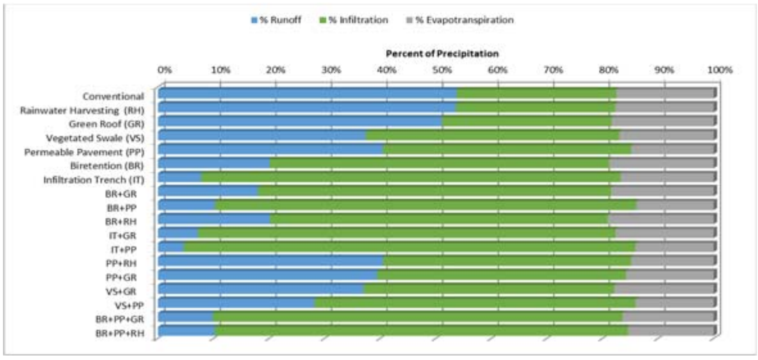


Figure 3 Water balance of different combinations of LID alternatives.

4 A SMALL RESIDENTIAL STREET

A 1.64 hectare residential site within the Lakeview District neighbourhood in the City of Mississauga, Ontario, Canada was selected for the investigation of retrofit LIDs. Field monitored rainfall and runoff events were conducted during January to December 2011.

4.1 Grid, Homogeneous One Catchment, and Homogenous Subcatchment Approaches

The model investigation was conducted to compare three uncalibrated hydrologic models (grids, homogeneous one catchment, and homogeneous subcatchments) with field monitored rainfall and runoff events (Ahmed 2013). A 10 m x 10 m grid model was developed to discretize the drainage area into small homogeneous grid cells. Using remote sensing techniques and a local digital elevation model, the routing between cells was modeled using the US EPA SWMM's deterministic eight node option. Two other models (homogeneous one catchment and homogeneous subcatchments) were also developed. Fig. 4 shows the aerial photograph of the site, and the grid and homogeneous subcatchment models. The hydrologic parameters of the three models were selected consistently based on typical values without any calibration with the measured data.

It can be seen from Fig. 5 that the grid model compares favorably with the measured runoff volume. The homogeneous one catchment model is the worst among the three models. These results further indicate that uncalibrated grid model may be appropriate for this small site. Although this is only one case study, the findings certainly encourage further investigations to test this approach.

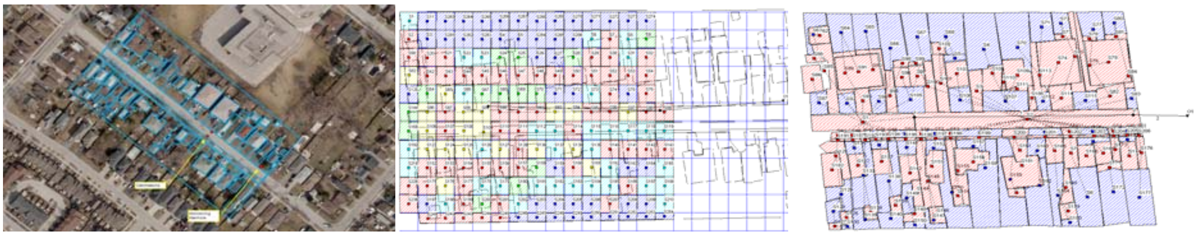
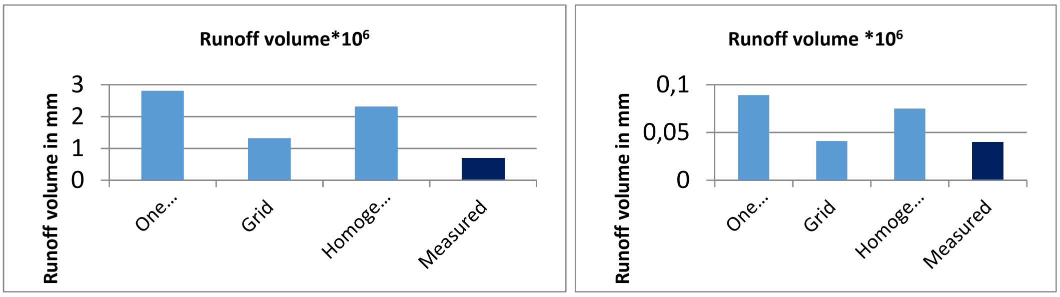


Figure 3 A 1.64 ha site and the two modeling approaches (grids and homogeneous subcatchments).



(a) Six months continuous simulation

(b) Runoff event volume on 30-9-2011

Figure 4 Comparison among the measured and modelled runoff volume.

5 CONCLUSIONS

These three case studies demonstrate that different scales of LID planning will require different modeling approaches. Conclusions drawn from these case studies are:

1. For high level master LID planning for cities, the semi-distributed approach of HRU offers a detailed lot level LID runoff performance analysis and an efficient aggregation of runoff control performance over a large planning area (e.g. city). Simulation of thousands of LID site is possible but the compilation of hydrologic parameters for these thousand LID site is time-consuming. Traditional lumped sub-catchment approach may not produce noticeable change in overall runoff reduction because small changes in small impervious area may not change the overall runoff volume of large drainage areas. HRU offers a balance approach where detailed hydrologic modelling can be performed on lot level and aggregation of model results can be done on spreadsheets using these HRUs.
2. The homogeneous subcatchment approach is used by many modelers for subdivision level LID planning. Given no field data for calibration, this approach does offer routing opportunities for LIDs.
3. LID planning of small sites may be modeled by uncalibrated grid models as illustrated in the case study. Although this finding may not be generalized for other small sites, this case study offer some some positive motivation to use the uncalibrated grid approach.

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