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DEVELOPMENT OF A STORMWATER LOW IMPACT DEVELOPMENT PLANNING TOOL FOR THE PROVINCE OF ONTARIO, CANADA

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Stormwater low impact development practices (LID) are lot-level measures which reduce runoff from lots and roads. Although there are many LID planning tools available (ranging from watershed, city, and site levels), it is not easy to find one that is appropriate for development of a LID site plan in Ontario. In particular, the Province of Ontario's LID performance requirements are based on long-term average annual runoff and pollutant loading reduction. After a review of 16 LID planning tools in North America, it was found that 70% of these tools are site or city level and outputs from these tools include runoff and nutrient loading reduction and cost. However, most tools use average reduction efficiencies based on short-term field measurements or computer simulations to represent average LID performances. As a result, a new LID planning tool which addresses physical constraints, full lifecycle cost, and long-term average annual performance was developed for Ontario, Canada using local precipitation and hydrologic and development properties. The first step is to screen 7 types of (bioretention cells, downspout disconnection, dry wells, green roofs, porous pavement, rainfall harvesting devices, soakaway pits) based on physical constraints and lot characteristics. After the appropriate LID has been identified for a development site, alternatives of LID combinations will be formulated. Using full lifecycle cost (construction, operation, and maintenance costs) and average annual runoff and pollutant loading reduction efficiency (using the US EPA SWMM LID module over 20 years of hourly precipitation for different regions of Ontario), the best LID alternative will be selected based on the achievement of the government performance requirement and the cost-effectiveness considerations.

Introduction

Rapid population growth has become a major driving force of urbanization, which inevitably affects landscape, watershed, and surface and ground water. Urbanization changes runoff quality and affects water quality in receiving water bodies, and generates significant environmental impacts on receiving waters, and their habitats. A low impact development (LID) urban drainage uses effective and attractive micro-scale techniques to control stormwater runoff, minimize pollution, and protect developing watersheds; it is employed to address many of the new challenges as well as providing promising outcomes in storm water management. [1]. After a review of 16 LID planning tools in North America, it was found that most tools use average reduction efficiencies based on short-term field measurements or computer simulations to represent average LID performances. An ideal planning tool with appropriate features should allow users to apply regional watershed criteria and local physical constraints to LID selection. As a result of the deficiencies discussed above, there is an acute need to devise an innovative

lot-based LID planning tool for engineers and decision-makers. By comparing the performance and cost-efficiency of different LID combinations, users could determine whether or not the LID plan is likely to meet the provincial standards and the most cost-effective combination.

Review of Sixteen Available LID Planning Models

Models can be used to facilitate design and policy decision-making by predicting the outcomes of different design and management approaches and alternatives. A range of models is available to analyze the costs and environmental outcomes associated with LID implementation. In order to identify the features of an ideal planning tool, 16 available planning models were reviewed. Table 1 indicates the models. Among these models, more than 70% of them are at site or city scale. Models at the stage can allow users to link a site's land cover and stormwater controls to the volume of stormwater discharged by the site and the pollutant loads exported by those discharges. Site designers can use these results to meet mandatory or voluntary performance standards. For planning a new subdivision, site-scale tool can give more appropriate and compatible results. However, most of the site-scale planning tools normalize designate LID to the entire proposed area, so the outputs, especially the cost, vary significantly depending on the land use and percentage of impervious area. In addition, most tools are suitable for modeling drainage characteristics before LID planning and are more useful during the last stages of decision-making. Only a few tools can provide detailed runoff analysis at the early stage of planning.

Other than just technical criteria, economics is also a driving factor in prioritizing management strategies. As cost associated with LID implementation is identified as a significant barrier among traditional stakeholders of stormwater, it is critical that the financial impacts and benefits connected to LID application be investigated [5]. About one third of the models can calculate the total cost. However, most tools with cost estimation function are based on either complex models, or simple spreadsheets without runoff analysis. In addition, among these sixteen models, only two models are specially designed for Ontario, and one of model outputs do not include cost calculation. It means none of reviewed tools except one can calculate the capital cost, and operation and maintenance cost based on Ontario market prices.

SWMM Modeling and Reference Data Table Preparation

Site suitability for selecting a particular LID strategy is the key to successful performance. It is impossible to include all LID simulations in one planning tool. Seven common LIDs are incorporated into the new planning tool: green roof, porous pavement, dry well, bioretention cell, soakaway pits, rainwater harvesting, and downspout disconnection. The seven LID practices could be combined in various ways to yield seventeen reasonable combinations.

According to Ontario Ministry of Environment, the Province of Ontario was divided into four regions: Central, North, East, and West. Toronto, North Bay, Ottawa, and Windsor were picked as the representative municipalities for each region. In order to obtain lot width, lot area, and imperviousness, a single-family housing survey of Ontario was conducted. A total of 58, 21, 34 and 14 new subdivisions were reviewed in the Greater Toronto Area (GTA), Windsor, Ottawa, and North Bay respectively. The average lot area and imperviousness are used for SWMM simulation. In order to achieve a more accurate result, 20-year continuous hourly rainfall from 1984 to 2003 was used to simulate the long-term average performance of

LID. Any years with more than 30 days missing records were excluded in the further performance modeling. Each typical lot was modeled either with or without LID or LID combinations. A total runoff table, total suspended solids load table, and total phosphorus load table were generated for each region with and without LID.

A total cost table of each region was created to determine the cost-efficiency of implementing LID practices. The cost function was adopted from Low Impact Development Practices Life Cycle Costing Tool published by Toronto and Region Conservation Authority (TRCA) and University of Toronto in 2013. The construction cost includes all material, delivery, labor, equipment, and hauling and disposal costs [10]. Because LIDs were assumed to be constructed as part of a new development, mobilization and demonization costs were not included. Establishing maintenance and rehabilitation costs are calculated using the same approach. One difference is the mobilization cost was included because equipment would not already be on site. Also, the design costs are not included because the original LID design is assumed to be used to inform this work [10]. Life cycle cost is calculated based on an evaluation period of 50 years. At the end of 50 years, the LID is considered to have no salvage value, and no extra value is attributed to the additional lifespan expected for the LID beyond the 50 year mark.

Tool Development

After developed the reference data tables, the next stage of this study was to develop the tool structure linked to the data tables. The new planning tool consists of seven worksheets, one summary table and seventeen reference tables. By several clicks and a few data inputs, the tool can link all the parameters to the database and generated outputs automatically. An 80% reduction of TSS loading [8] was used as the pollutant control standard. If all alternative designs meet the standard, a final decision could be made based on the best cost-efficiency alternative.

The first step of LID planning is to screen alternate LID practices to eliminate any unsuitable practices. All the physical constraints, shown in Table 1, were extracted from the Low Impact Development Stormwater Management Manual by CVC and TRCA [1] and the study by Li et al. [6]. The first two tables (Table A and Table B) of the planning tool were developed based on physical and lot constraints. Users can use the check boxes of constraints to match the site characteristics. If a particular LID practice is not suitable for the design lot; the LID will be given a score of zero. For LID which may partially violate the site constraints, he designer can check a comment table to determine whether the LID practice may be applied resulting in a score of 0.5. All other feasible LID would be given a score of 1. A comment table is provided for users to review the suitability criteria.

Table 1. Physical Constraints Imposed on Lots for Each Lot-based LID

Lot- Based LID	Site Criteria
Bioretention Cell	Soil over 2.2m deep to water or bedrock Slopes between 2% and 5% Off trees and roads Beyond Buildings and their buffers Not located within 2 year time-of-travel well head protection areas Not treat pollution hot spot runoff Drainage area : Bioretention Cell range from 5:1 to 15:1
Downspout Disconnection	Slopes between 2% and 5% Off trees and roads Beyond Buildings and their buffers
Dry Well	Slopes below 15% Beyond Buildings and their buffers Off trees and roads Drainage area : Dry Well range from 5:1 to 15:1
Green Roofs	On buildings larger than 500m ² in area
Porous Pavement	Soil over 2.2m deep to water or bedrock Slopes between 2% and 5% Off trees and roads On driveways, parking lots, and sideways Not located within 2 year time-of-travel well head protection areas Not treat pollution hot spot runoff Drainage area : Porous Pavement greater than 1.5:1
Rainwater Harvesting	Soil over 2.2m deep to water or bedrock Off trees and roads Beyond Buildings and their buffers
Soakaway Pit	Slopes below 15% Beyond Buildings and their buffers Off trees and roads Drainage area : Soakaway Pit range from 5:1 to 15:1

The third table (Table C) is used to identify all feasible LID practices for the site. It summarizes the scores by multiplying the scores from Table A and B. Features that end up with a final score of one are fully compatible with the designed site. Features with a final score of 0.5 or 0.25 are potentially compatible with either or both site characteristics and lot planning characteristics. The fourth table (Table D) is used to select appropriate LID or LID combinations for the site based on the overall score from Table C. Users can choose up to three alternative scenarios to compare their performance.

In order to compare different LID combination scenarios from Table D, there are three Table E's to evaluate different LID combinations. Users can choose the study region from a drop-down list first, and then the lot width can be selected from another drop-down list. The

only number required for the whole tool is the total number of lots because the database is based on single lot simulation. Using these Table E's, the user can decide the best LID combinations based on total cost and cost-effectiveness (e.g. \$/m³ annual runoff controlled or \$/kg of annual pollutant loading controlled).

Case Study: Bayview Wellington Centre in the Town of Aurora, Ontario

In order to illustrate the application of the new planning tool, the Bayview Wellington Center in the Town of Aurora, Ontario, was examined as a case study. The objective of the case study was to determine performance, adaptability and stability of the new tool, and demonstrate the convenience of using the new tool at the planning level.

The Bayview Wellington Center is within the Aurora East Industrial Area. In 2008, the town of Aurora released Bayview Wellington Center Secondary Plan Official Plan Amendment #6 [9] to promote a multi-use urban centre providing a range of housing, shopping, and employment and recreation opportunities. The physical constraints of the study area could be concluded as:

1. Climate is vulnerable to cold and snowy winters
2. Soil infiltration is smaller than 15mm/hr (Soil infiltration rate of loam is 3.4mm/hr)
3. Drainage area is larger than 0.8ha
4. Drainage area/treated area is smaller than 5

Since soil type, rainfall, imperviousness and single lot area are defaulted in the database, only data on the type of lot and total number of each type are needed to be collected.

After gathering the site characteristics, the new planning tool was applied to the study area. It should be emphasized that only a single-family residential housing area was simulated in this case study. The total runoff and total pollutant loading cannot represent the whole subdivision because the residential area comprises about 60% of the total area. There is a shopping mall with large parking lot in this area. Roads, sidewalks, and open space were also not included in previous studies. The summary table (Figure 1) illustrates that only one combination (RH+PP) met the MOE standard of 80 percent TSS loading reduction. Scenario 2 could be selected as the best combination.

Comparison Summary Table			
	Scenario 1	Scenario 2	Scenario 3
Total Runoff (m ³)	52300.45	52300.45	52300.45
Total Runoff Reduction (m ³)	30361.92	34264.64	38028.75
Total Runoff Reduction (%)	58%	66%	73%
Total TSS (kg)	13887.34	13887.34	13887.34
Total TSS Reduction (kg)	10752.92	11834.06	9669.30
Total TSS Reduction (%)	77%	85%	70%
Total TP (kg)	21.93	21.93	21.93
Total TP Reduction (kg)	17.09	18.77	15.95
Total TP Reduction (%)	78%	86%	73%
Total Cost (Canadian Dollar)	7010685.00	8587368.00	2635083.00
Cost Efficiency (\$/m ³)	230.90	250.62	69.29
Meet MOE Standard	No	Yes	No

Figure 1. Comparison Summary Table

Two available LID planning tools (i.e. New York State Green Infrastructure Worksheets and Phosphorus Budget Tool for the Lake Simcoe Watershed) were also applied to the case study area using the same settings. Compared to New York State Green Infrastructure Worksheets, the difference of total runoff was about 13%, which was considered within a reasonable range. However, the difference between runoff reductions after LID implementation varies significantly from 30% to 40%. The difference between runoff reductions was caused by different removal efficiency assumptions. New York State Green Infrastructure Worksheets assumed that Porous Pavement and Rainwater Harvesting achieve 100% runoff compared with the associated 80% and 50% for the new planning tool. The new planning tool gave an estimated TP loading of 20.93 kg/yr compared to 27.72kg/yr obtained from Phosphorus Budget Tool for the Lake Simcoe Watershed. The difference was due to the phosphorus export coefficients used in Phosphorus Budget Tool for the Lake Simcoe Watershed. When deriving these coefficients, groundwater, tile drainage and stream bank erosion was also taken into consideration. The new tool does not have any of this information.

Conclusions

As the urban areas grow, environmental problems grow exponentially. More flooding, higher level of contaminants in receiving water, serious erosion, and reduction in groundwater recharge has been observed. Despite the benefits of LID implementation, absence of an effective LID planning tool has been identified. According to literature review, an ideal LID planning tool should be workable, timely, defensible, and adaptable. The new planning tool described in this paper was based on several assumptions including soil, typical single-family lot size, rainfall, evapotranspiration rate, and LID sizing. A housing survey was conducted to identify a typical lot of each region. A case study of Bayview and Wellington Centre in the Town of Aurora, Ontario, demonstrated the usefulness and effectiveness of the new planning tool. A comparison of the LID planning results using different planning tools shows that the new LID planning tool could offer a feasible LID plan for single-family housing in Ontario.

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