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Cost Efficiency of Low Impact Development (LID) Stormwater Management Practices

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Abstract

Stormwater management has focused increasingly on Low Impact Development (LID) techniques in recent years. Although their effectiveness has been demonstrated in a number of cases, methodologies for the selection of most appropriate solutions for individual sites are still evolving. The cost efficiency of implementing a wide range of LID techniques in a proposed land development in the City of London, Ontario, Canada was investigated using continuous hydrologic simulation and a recently developed LID costing tool. The results indicate that infiltration trench and infiltration trench in combination with green roof were the most cost efficient solutions for runoff reduction.

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Keywords: Low impact development; land development; cost efficiency.

1. Introduction

Stormwater management in many parts of the world has evolved to place a much greater emphasis on Low Impact Development (LID) techniques, to supplement or even replace the conventional measures such as stormwater management ponds. LIDs attempt to restore natural or pre-development hydrologic budget of a site and capture the pollutants through infiltration, filtration, evaporation and detention of runoff. Such approaches are increasingly being required by municipalities and government agencies tasked with the protection of receiving waters. In addition, numerous guidance documents for planning, design, implementation and maintenance of LIDs exist. A variety of LID evaluation tools have been developed ranging from easy to use, sizing and costing spreadsheets [1,2,3] and

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simple screening models [4] to physically-based simulation models such as the US Environmental Protection Agency Stormwater Management Model (USEPA SWMM) [5].

Although the effectiveness of LIDs has been demonstrated in a number of cases, barriers still exist to their broader implementation in new land developments including the potentially increased cost of their implementation and maintenance. In the Canadian province of Ontario, the lead on LID guidance, evaluation tools and demonstration projects has been taken by Conservation Authorities, two of which provided a guidance document [6] that outlines ten different practices ranging from roof downspout disconnection to perforated pipe systems. In addition, a detailed costing tool has recently been provided [7], allowing the designers to conduct a life-cycle costing of different LID practices and evaluate their cost efficiency. The objective of the project discussed in this paper was to utilize the guidance and costing tools, and conduct an evaluation of cost efficiency of several practices and their combinations in controlling the runoff from a mixed-use development site in southern Ontario. The project involved identification of LID opportunities within the planned site, development of baseline and LID hydrologic models and evaluation of long-term performance and cost in order to identify the most cost efficient options.

2. Methodology

2.1. Study area

The study area is located in the City of London, Ontario. The site is a 30 ha greenfield site surrounded by existing and future primarily residential development. At the present time, small patches of trees are situated along the site boundaries and most of the site is used for agricultural purposes. The site is being planned as a sustainable, mixed use, pedestrian oriented community integrating medium and high density residential, commercial, office and open space uses as shown in Fig. 1. A unique feature of the site is that it is located in proximity to a creek that is one of the last remaining cold water fisheries in the area, requiring the stormwater management solutions that ensured that the western portion of the developed site provides infiltration sufficient to preserve the base flows in the creek, while the eastern portion would drain to an existing stormwater management pond. The previously identified preferred solution, which covers a drainage area that extends beyond the boundaries of the site that is the subject of this investigation, consists of a series of detention and infiltration facilities including the infiltration channels shown along the western site boundary in Fig. 1.

Fig. 1. Conceptual layout of the study area.

2.2. Data collection and preparation

In addition to the proposed layout, a number of other data was collected and prepared to conduct the evaluation of long-term performance of alternative stormwater management solutions. The hourly rainfall record covering years 1960 to 2002 was obtained from an Environment Canada monitoring location at the London International Airport. The rainfall record analysis using a minimum intervention time of 24 hours showed an average of 58 events per year, ranging from 1 to 170 hours in duration and 0.20 to 150 mm in depth. Evaporation data and soil information was collected from the available reports [8,9]. The area soils are sandy, making the site a good candidate for infiltration LID practices.

Seven types of land use classes, such as house roofs, patios, green area, driveways, courtyards, parking spaces and roads were identified within the study area. The next step was to create separate GIS layers for each landuse class. Separate GIS shape files were created for each homogeneous land use type. The preparation of the subcatchment layers involved digitizing the polygons from the projected concept plan. Digitizing in GIS is the process of 'tracing' in a geographically correct way from the photogrammetric data. Each polygon of all the layers was modelled as a separate subcatchment with a view to build up a detailed drainage model. GIS layers were also created to represent the LIDs, such as, vegetative swales, infiltration trenches and bioretention cells. Green roofs and permeable pavements were modelled using the layers created to represent roofs and parking lots and driveways respectively. Layers of sewer network, junctions and homogeneous subcatchments for the seven land use types are shown in the Fig. 2.

Fig. 2. Data layers for each homogeneous land use type and sewer network.

2.3. Models development

In this research work, PCSWMM [10] was used for long-term continuous hydrologic simulation of the study area. PCSWMM is a spatial decision support system for EPA SWMM used for stormwater management, wastewater and watershed modelling. All the GIS data layers representing the subcatchments, outfall, conduits and junctions were imported to the PCSWMM interface to develop the model structure. The rainfall data were assigned to a single rain gauge. Since this study deals with homogeneous subcatchments, internal routing of runoff between pervious and impervious areas is ignored. The choice of developing a detailed, distributed model that represents each homogeneous area as a single subcatchment was based on a previous study that demonstrated the ability of such approach to accurately capture the recorded runoff from a typical residential street with little to no calibration [12].

Runoff from any subcatchment was therefore assumed to flow directly to the outlet and the percent of runoff routed between pervious and impervious subareas is assumed to be 0%. Exchange of groundwater with the drainage system was not modelled. Vertical movement of water infiltrating from the subcatchments and snow pack factors were also neglected.

Simulation was carried out by applying six types of LIDs: green roof, permeable pavement, infiltration trench, bioretention cell, vegetative swale and rain water harvesting, as well as 11 combinations of them. The studied combinations are listed below:

- Vegetative Swale + Porous Pavement (VS+PP)
- Vegetative Swale + Green roof (VS+GR)
- Porous Pavement + Green Roof (PP+GR)
- Porous Pavement + Rain Water Harvesting (PP+RH)
- Infiltration Trench + Porous Pavement (IT+PP)
- Infiltration Trench + Green Roof (IT+GR)
- Bioretention Cell + Green Roof (BR+GR)
- Bioretention Cell+ Rain Water Harvesting (BR+RH)
- Bioretention Cell + Porous Pavement (BR+PP)
- Bioretention Cell + Porous Pavement + Green Roof (BR+PP+GR)
- Bioretention Cell + Porous Pavement + Rain Water Harvesting (BR+PP+RH)

Green roofs were assumed to be implemented only on the roofs of commercial buildings since owners of single-family houses might not be interested to maintain or install green roofs and the roof slope might be a prohibiting factor. Rainwater harvesting was modelled only for single-family housings. Permeable pavements were implemented only on the parking lots and on the driveways. Infiltration trenches, bioretention cells and vegetative swales were modelled along the sides of the roads.

3. Results and discussion

3.1. Runoff reduction

The generated subcatchments, junctions and sewer network layers were implemented on the PCSWMM platform to perform hydrologic simulation. Water balance was studied from the simulation output. The water balance for the pre-development conditions, and for developed site without any LID and with LIDs are summarized in Fig. 3. The simulation results for the pre-development site conditions showed that no runoff was generated over the simulated period, because the soils in the study area are sandy. For the developed site before any LID implementation the infiltration is greatly reduced, resulting in slightly more than a half of rainfall ending up as surface runoff thereby significantly reducing the infiltrated volume required for the maintenance of the nearby stream

Fig. 3 shows that the LIDs and LID combinations contribute in restoring the hydrology of the existing site by increasing the infiltration and decreasing runoff, although none of the investigated options was capable of fully restoring the pre-development infiltration. The rainwater harvesting and green roof show relatively small runoff reduction since these LIDs were considered only for single-family housings and commercial buildings, respectively, which represent a smaller portion of the overall drainage area. For this particular site, which is dominated by paved surfaces such as roads and parking areas, the measures that were more effective included those that allowed greater infiltration of runoff from these areas. Whilst the model results indicate a decrease of runoff to approximately 40% of rainfall volume for permeable pavement implementation, significant runoff from paved surfaces still exists. Measures implemented along the right-of-way to allow prolonged infiltration of runoff from paved surfaces, including the vegetated swale, bioretention and infiltration trenches were the most effective in controlling the overall surface runoff from the site down to less than 10% of rainfall volume. As expected, implementing a combination of LID measures in treatment trains was more effective in controlling surface runoff compared to single LID implementation. The combination of infiltration trench and permeable pavement was shown to reduce the runoff volume more than any other LID combination.

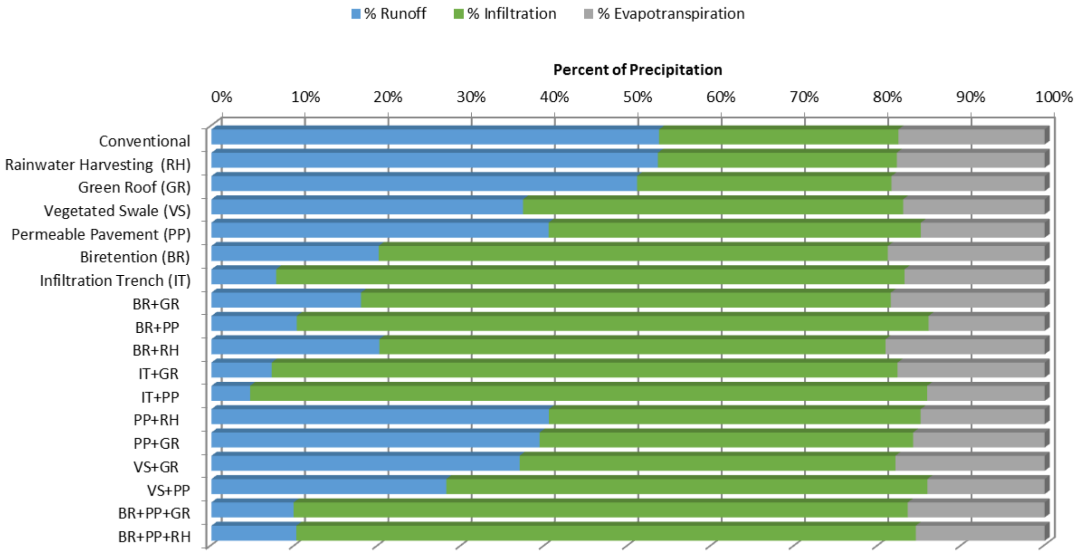

Fig. 3. Water Balance for different LID combinations.

3.2. Costs

The LID costs are calculated using the costing tool [7], and based on the area of the LIDs and the area that contributes flow to each LID. The focus of the study was on determining the capital costs, although the tool is capable of calculating the life-cycle costs, as the intention was to ultimately compare the LID options to the preferred alternative that involved the capital-intensive construction of centralized detention and infiltration facilities. The calculated capital cost of the LIDs for the proposed site is given in Table 1.

Table 1. Capital costs of implementation of individual LIDs.

LID measure	Capital cost ($)
Bioretention cell	2,024,786
Permeable pavement	4,308,214
Infiltration trench	1,497,319
Vegetated swale	523,985
Green roof (on commercial buildings)	1,620,802
Rainwater harvesting (in single family housing)	16,706

3.3. Cost efficiency

The cost efficiency of LIDs and their combinations investigate in this study is first reported in terms of the cost per $m^3$of runoff reduction, as shown in Fig. 4. The rainwater harvesting option had the lowest cost overall, as the capital cost incurred is simply the provision of a rain barrel to each single family household in the study area. Similarly, the unit cost of any LID combination involving rainwater harvesting is not significantly affected by its inclusion due to low cost and performance. It is noted that the assumption made here is that the stored roof runoff would be used only for irrigation of the immediate green areas, without the need for any treatment, as the primary concern in this particular development was the maximization of infiltrated volumes. The costing tool was used to also evaluate the costs of utilizing the rainwater for indoor water uses, requiring treatment systems and indoor piping, and the cost were significantly higher.

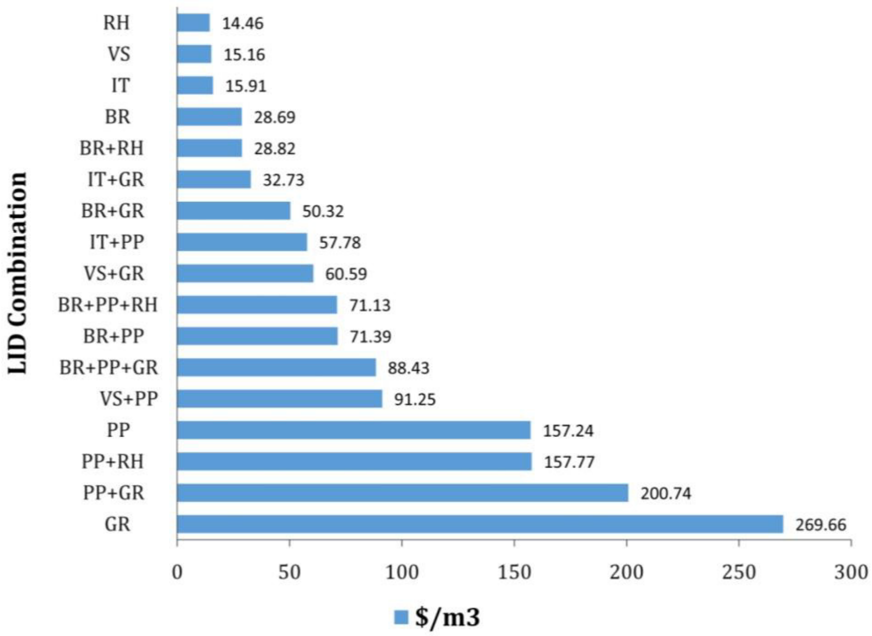

Fig. 4. Comparison of cost per unit volume of runoff reduction using different LIDs.

Although the calculated capital cost of infiltration trenches was nearly three times that of the vegetated swales, their runoff control performance was higher in proportion to this cost. As a result, the unit cost of these two technologies was almost the same. Although the unit costs are also comparable to that calculated for rainwater harvesting, these two technologies have much higher runoff volume reduction. The bioretention option for treating runoff from paved surfaces had a predictably higher unit cost, due to its performance that was between the other right-of-way techniques and more complex and expensive design.

From the investigation of implementing single LID techniques, the highest unit cost were determined for permeable pavement and green roof. With the capital cost of constructing the permeable pavement over the large portion of the proposed development far exceeding the cost of any other LID technique, their relatively good runoff control performance was not sufficient to produce a unit cost comparable to other infiltration techniques. On the other hand, the green roofs high capital cost and small gains in runoff control made them the most expensive option in terms of unit costs. It is noted that combining these two techniques with other LIDs that infiltrate the runoff from paved surfaces resulted in the significant reduction of unit costs. For example, the unit cost of permeable pavement combined with infiltration trenches, which showed the highest overall reduction in runoff volume, is approximately one third of that calculated in the case of using permeable pavement as a single LID.

To provide a greater insight into the cost efficiency of different options for the studied site relative to their runoff control performance, capital costs of each LID and LID combinations can be plotted against their runoff reduction performance, as shown in Fig. 5. The figure clearly illustrates that the highest performance at the lowest cost are the green roof and vegetated swales, although the runoff reduction achieved by each of these techniques is quite limited. If the desired runoff control is in the 30% range, other LID options such as the options involving permeable pavement with or without rainwater harvesting and green roofs can be easily dismissed. Similarly, if a limit is placed on the capital investment in LIDs, conclusions regarding the superiority in cost efficiency of different LIDs and their combinations can be easily reached. The chart shown in Fig. 5 therefore provides a useful summary of cost efficiency of different LID options for a particular site that can effectively guide the decision making process.

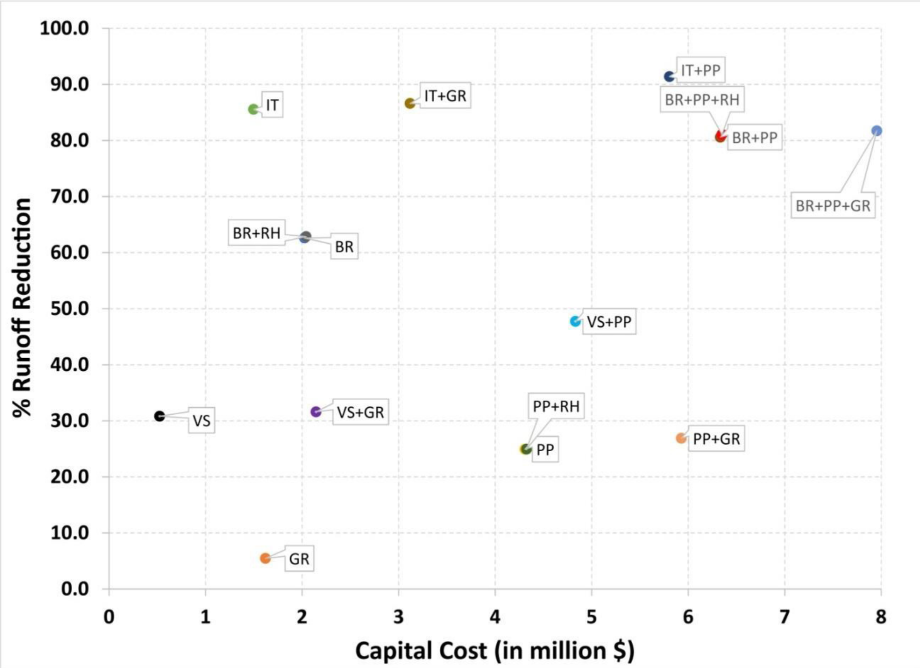

Fig. 5. Capital cost vs percentage runoff reduction by LID combinations.

4. Conclusions

The study presented above involved the development of detailed drainage models that were used to evaluate the average long-term performance of a wide range of LID stormwater management practices. The focus of the study was on determining the changes in the hydrologic budget resulting from LID implementation, commensurate with the goal to increase the infiltration from the developed site for maintaining the base flows in the nearby sensitive stream. The results indicated a markedly better performance of LID techniques that manage the runoff from roads and parking areas through maximizing its infiltration, either directly by making the pavements permeable, or by diverting the flows to right-of-way conveyance and infiltration facilities. Combining the model results with application of a tool to calculate the capital costs of each LID technique allowed for their cost efficiency evaluation to be conducted. While the overall costs as well as the unit costs of removal of a single m^3 of runoff were both valuable, the chart plotting the percent runoff reduction versus the capital cost was the most useful in evaluating the cost efficiency of individual LID techniques and their combinations.

It is noted that the results achieved in this study are very much case specific, and depend very much on the site characteristics including the distribution of different land use and hydrologic properties. Nevertheless, the methodology involving a comprehensive evaluation of different LID combinations, including their cost and average long-term performance is recommended, as a way of ensuring that the most cost efficient options are ultimately selected for detailed design and implementation. The limitations of this study that should be addressed in the future include: considering the operation and maintenance costs in the evaluation, although the two could be borne by different entities, accounting for other documented benefits of LIDs such as their pollution control and ecological functions and conducting the performance analyses utilizing projected precipitation and temperature under climate change scenarios rather than historic information.

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