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Importance of hydrologic simulation for lids and BMPs design using hec-hms: a case demonstration

Abstract

Best management practices (BMPs) and the Low impact development (LIDs) is water management tools used to mitigate hydrological impact resulting from unpremeditated urbanization. For the proper functioning of the LID and BMP features the volume of the runoff generated, peak runoff rate before and after the installation, need to be accessed. Modeling by comparing different developmental scenarios helps to characterize the impact of BMPs and LIDs practices on the surface runoff. Therefore, this paper describes a modeling approach to predict the performance of these BMPs and LIDs in an existing hydrological model. This type of modeling approach is important to understand the long-term operation of the watershed post-development plan. A single rainfall event in May 2013 has been modeled and the characteristics graphs such as outflow, precipitation, runoff, infiltration have been analyzed. Run-off volume after retrofitting infiltration trench has decreased by 351m^3 at the outlet with an increase of 39 L/s in peak discharge. Time series study of reservoirs depicts low performance of infiltration trench at latter phase of rainfall event. This leads with a rational that infiltration trench cannot result favorable for longer rainfall events unless underlying soil has superior geo-technical properties with low level water table. Results manifest the benefits of using hydrologic modeling software to understand the watershed hydrology.

Keywords: hec, hms, hydrographs, infiltration trench, low impact development, stormwater management

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Introduction

Management of the fresh water has been an irony issue with the ever-increasing population in urban areas. Declining resources and unbalanced utilization of the available resources have adversely affected socioeconomic prospects of the societies around the world. Mentioned that especially, developing countries around the world are facing these problems due to lack of understanding of the dynamics of the basin water and the assessment of basin water for development use.[1] Precipitation is identified as the major source of the fresh water; however, the water washes on the surface (semi impervious or impervious surfaces) is termed as runoff. Runoff water disturbs the basin hydrology which significantly reduces the groundwater recharge which can lower the groundwater table, increase run-off peak, run-off volume.[2] This makes the ecosystem prone to natural calamities. Urbanization increases the impervious lands.[3] Therefore, storm water management is a crucial problem in today's world. Rathnayake[4] and Rathnayake and Tanyimboh[5,6] have extensively shown the importance of control of urban storm water. Urbanization incorporating pervious surfaces is one solution; however, many developing countries are yet to practice the state of the art technologies. Therefore, with ongoing urbanization, the hydrological and hydraulic problems due to storm water are going to be practiced in developing countries. Low-impact development (LID) tools have been developed and applied to mitigate the hydrological effects of urbanization.[7] Hydrological modeling is one of the approaches to assess the effectiveness of LID tools before their implementation and today a range of suitable models are available which are either based on physical or mathematical models.[8] Both independent models and models incorporated into the watershed-scale models like the Bay Area Hydrology Model (BAHM), HEC-HMS, EPA Sustain, EPA Stormwater Management Model (SWMM), Hydro CAD, and Soil and Water Assessment Tool (SWAT) have been applied in different areas.[9] The selection of the model depends on the basin and the objective of the hydrological prediction in the basin.[1] HEC-HMS uses a set of mathematical models to simulate the precipitation runoff-routing. The capabilities of HEC-HMS lie on simulation of watershed runoff and stream flows, determination of flood flows, evaluation of land use and topographic changes and computation of damage frequency curves. A detailed description of the theoretical aspects of the hydrological model is given in the technical reference manual.[10] However, there are some traditional empirical evaluation approaches which are capable of rainfall-runoff modeling; however, they have limited applicability to evaluate the LIDs / BMPs performance as compared with the technologically advanced software models. The major obstruction in using the empirical equations is that current hydrological performance evaluation indicators such as curve number (CN), runoff volume, and peak runoff reduction, and time to peak runoff becomes challenging if we are to deal with large watershed area. Moreover, it becomes impossible when long-term rainfall data are applied over a watershed to model the runoff.[9–11] Sri Lanka Institute of Information Technology (SLIIT) is a higher education institute in an urbanized area in the closer proximity to the capital of Sri Lanka. SLIIT has an area of 25 acres and out of those 13 acres are used for the university activities. However, among them seven acres of land is impervious due to existing buildings, roads, parking areas and playing courts. Khaniya et al.[2] have shown the present issues in the University due to unplanned storm water runoff (Figure 1).

Figure 1 Water pooling in front of Faculty of Engineering due to a small rainfall.[2]

Methodology

Figure 2 gives the flow chart of our work presented in this research paper. This presented a detailed flow over the methodology which we have used.

Study site: The study site is located at the premises of Sri Lanka Institute of Information Technology (SLIIT), Malabe campus, Sri Lanka. The pre-development of the site has not been carried out to mitigate the storm water effects due to which students are facing the problem of temporary pooling of water and flooding situation during rainfall. Therefore, this research paper targets to present the hydrological modeling of the university premises for a sustainable solution for the unplanned storm water management. The previous research carried with the same or indirect prospect of management of storm water at the same site help to know the pre-development site functions such as identification of the soil profile, soil properties' values such as infiltration rate, permeability, and moisture content at different soil depths. The results had satisfied the design guidelines provided by the Prince George's County LID design manual.[12] Based on the results, recommendations have been made to set up infiltration trench and retention pond at different identified locations. Hydrological modeling of the basin area before and after the recommended installations has been done separately and their results have been analyzed. Contour map of the basin area was drawn to visualize the natural water flow around the area which followed with eye observation of the site during the rainfall events together with the observation of the 1:10,000 topographic maps obtained from the survey department, Colombo. The basin area was divided into different sub basins based on the water flow around the basin area. Figures 3 show the contour map and the divided sub basins.

Hydrological modeling: HEC-HMS 4.1 was used in this study to simulate the hydrological performances of BMPs and LID practices. Event simulation of a rainfall event that occurred in May 6-7 2013 at Colombo was conducted. The highest rainfall was recorded by the Data Division, Department of Meteorology, and Colombo since last 5 years (01-Jan-2011-19-Jan-2016) was selected. Event simulation in HEC-HMS uses a time window that begins just before a storm and ends several days after the storm stops; however, continuous simulation starts and may cover several months or possibly many years. Khaniya et al.[2] and Dietz[7] have supported the need of continuous simulation for studying the performance of the LID components. For this research, focus has been given to the event simulation as the amount of runoff generated at the end of every storm event and the peak flow during the event will be a major concern as the proposed LID design feature should accommodate the runoff after every rainfall event. Khaniya et al.[2] suggested installment of an Infiltration trench along with a Bio-retention pond at the site to mitigate the effects of storm water. However, for the modeling purpose Bio-retention pond has not been included. It is considered that the Bio-retention pond can be set-up at the outlet and it is assumed that the water infiltrates down through the detention basin with the velocity as of the native soil infiltration rate. An intuitive idea can be generated to moderate the detention basin area by evaluating the run-off volume collected at the outlet. HEC-HMS 4.1 consists of basin models, meteorological models, and control specifications which can be considered the major components needed for a simulation run. Additional components useful are time series gauges, paired data functions, grid data sets. Data collection is a very important part of the hydrologic modeling. Since the site area was un-gauged with no observed data, there were no data available for the calibration of the model. Data collection is supposed to be one of the most challenging tasks in storm water management.[1] Khaniya et al.[2] have obtained several data using field observations. Table 1 provides the data of the sub-basins including its catchment area, slope, impervious percentage, curve number (CN). Curve number selection was based on the type of soil, its infiltration rate, land use pattern and location of water table around the site. The United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) classification was used to classify hydrologic soil groups (HSGs).[13] The site having CN 62 and 65 was considered to have type 'A' HSG whereas other sites were considered to have type 'C' HSG. HEC-HMS 4.1 uses deterministic techniques to compute the results. In this technique, different parameters is given as input then, HEC-HMS automatically processes and gives the output. The output completely relies upon the input given by the user. Table 2 provides the parameter values inputted to the model. Actual modeling started with the creation of basin model consisting of sub-basins, reaches, reservoirs, junctions, diversions and sink elements. The elements were connected as shown in Figures 4. Figure 4(A) shows the basin model of pre-development phase whereas Figure 4(B) represents post-development phase. The sub-basins were connected downstream to each other by reach element only if there was stream flow of runoff from one sub-basin to other. Loss method and transform method at the sub-basin was selected as SCS Curve Number and SCS Unit Hydrograph. The curve number method is a convenient and widely for hydrologic modeling to calculate storm runoff volume. Though this method has faced criticism in recent years, it is equally used all over the world by most of people.[14] As the evapotranspiration and base flow in the hydrological model was not accounted, the CN method was found to suit the hydrological model. The routing method along the reach element was used as Muskingum.

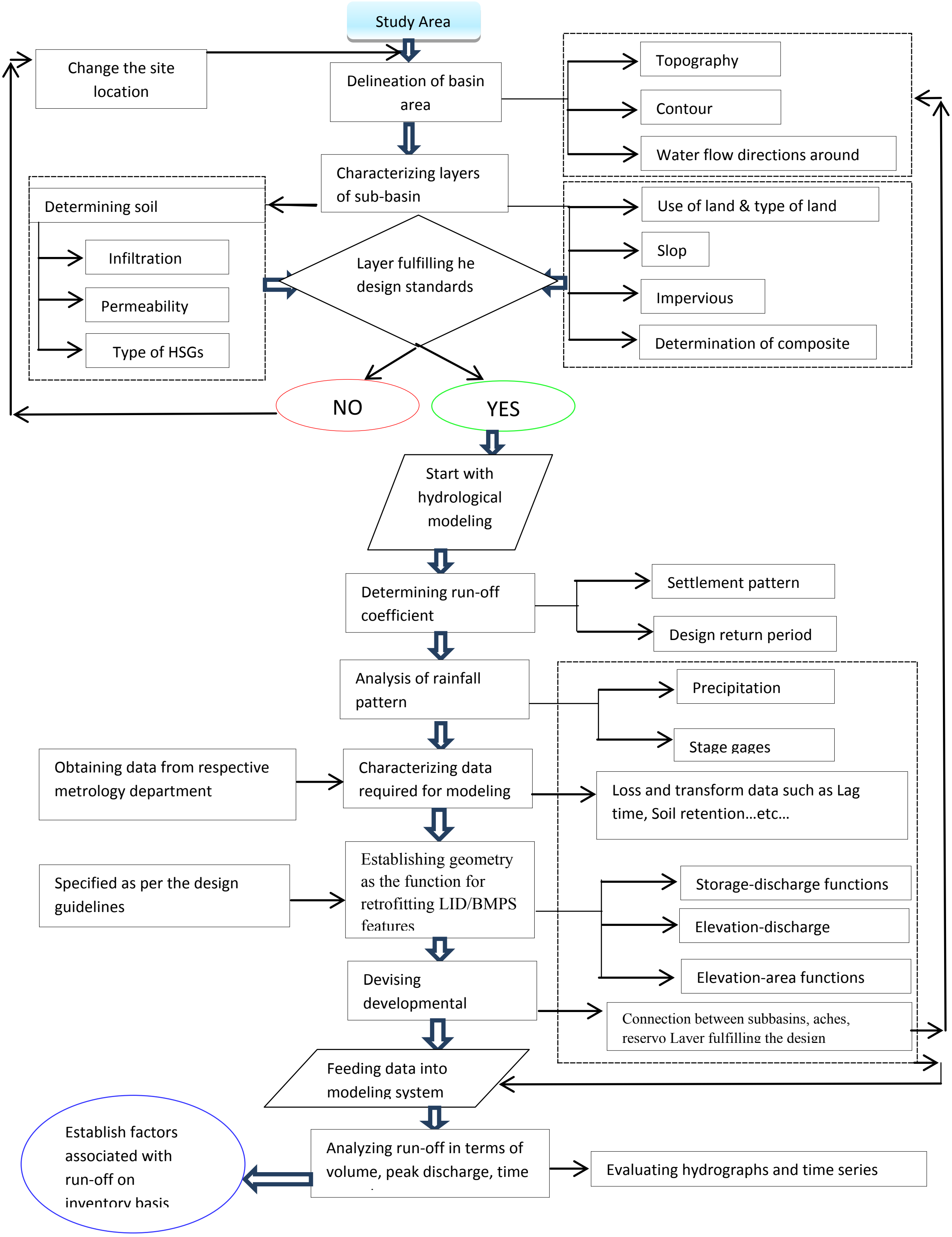

Figure 2 Flow chart of methodology.

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Figure 3(A) Basin area divided into smaller basin area sub basins and identified LID installation.

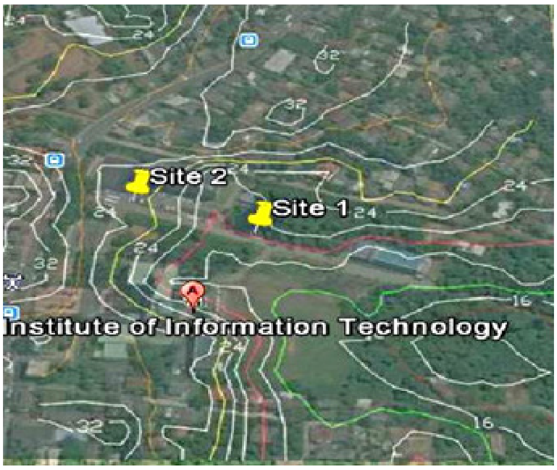

Figure 3(B) Contour map around the locations.

Figure 3 Depiction of basin area.

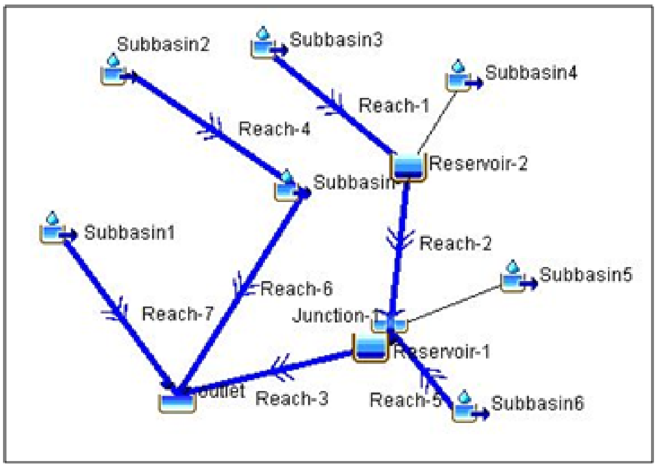

Figure 4(A) Pre-development phase.

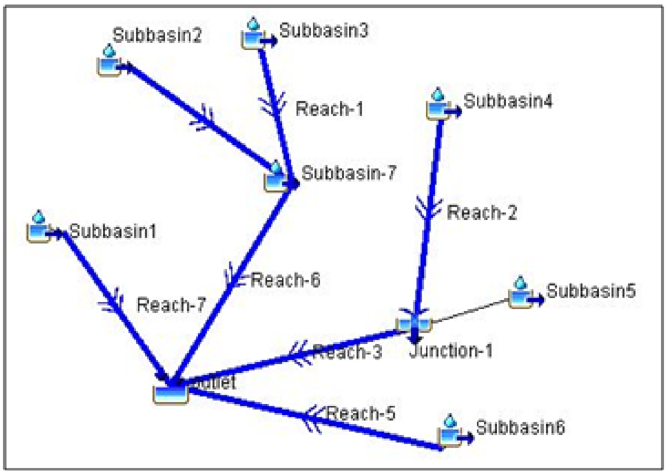

Figure 4(B) Post-development phase.

Figure 4 Developed hydrologic model.

Table 1 Characteristics of sub-basins

Sub-basins	Area (m^2)	Impervious percentage (%)	Slope (%)	Curve number (CN)
1	5,799	86	6.34	94
2	8,761	81	5.83	93
3	4,271	25	8.51	65
4	8,107	82	6.23	93
5	6,082	82	6.18	93
6	3,777	84	5.73	88
7	4,392	40	5.15	62

Table 2 Input loss and transform parameters to HEC-HMS 4.1

Sub-basins	Loss parameters				Routing Parameters		
	lag time/(tl Min)	Initial abstraction (ia, inches)	Soil retention (S, Inches)	Hydraulic (L, m)	Reach	Muskingum (K, hr)	Muskingum (X)
1	4.02	0.128	0.64	266	1	0.112	0.35
2	4.56	0.151	0.755	279	2	0.13	0.45

Citation: Khaniya B, Wanniarachchi S, Rathnayake U. Importance of hydrologic simulation for lids and BMPs design using hec-hms: a case demonstration. *Int J Hydro.* 2017;1(5):138–146. DOI: 10.15406/ijh.2017.01.00027

Table Continued....

Sub-basins	Loss parameters				Routing Parameters		
	lag time/(tl Min)	Initial abstraction (ia, inches)	Soil retention (S, Inches)	Hydraulic (L, m)	Reach	Muskingum (K, hr)	Muskingum (X)
4	6.3	0.151	0.755	233	4	0.105	0.3
5	4.8	0.151	0.755	165	5	0.08	0.5
6	5.4	0.273	1.365	140	6	0.09	0.3
7	11.94	1.226	6.13	133	7	0.199	0.45

Results and discussion

The Pre-development or the existing scenario is compared with the hypothetical Post-developed scenario with LID feature retrofitted. Total run-off volume collected at the outlet for the pre-development phase was 4404m^3 whereas the peak discharge was 379 L/s. Table 3 gives the results for the sub-basins under pre-development phase. The volume of the run-off and the peak discharge are the maximum at the points where the reach elements meet, i.e. reach element 3 and 6 carry larger volume of run-off as compared to other. Similarly, the volume of run-off generated is the maximum at the sub-basins where the weighted curve number (CN) is high. It can be clearly observed that sub-basins 1 and 4 have high run-off volume and peak discharge compared to sub-basin 3 and 7 which has low curve numbers. The land covers and the modifications of the land for various anthropogenic purposes have a strong influence over the run-off generation and the peak discharge. The post-development scenario additionally consists of two reservoirs at the junctions where the peak discharge and the run-off volume at the pre-development scenario are high. The placement of these reservoirs aimed to control the storm water volume at its source while obeying the principles of the LID design. Routing directions for the Reach1 and Reach5 were changed by connecting them to Reservoir2 and Reservoir1, respectively. The areas for the Reservoirs1 and 2 were calculated as 96m^2 and 125m^2 with the depths of 1.5m and 3m respectively from the ground surface. As both of the reservoirs are made to function as the Infiltration trenches with perforations, the geometry for them was calculated. Reservoir1 consists of 18 perforations at a depth of 0.3m with each of diameter of 1m measured from the ground surface. Similarly, Reservoir2 has 18 perforations at a depth of 0.3 m with each of diameter 2 m measured from the ground surface. The reservoir 1 and reservoir 2 had water table at a location of 1.7 m and 3.3 m respectively from the existing ground surface. The elevation-area and the elevation discharge for each of the reservoir were calculated separately including the discharges through the outlets. Table 4 presents the results of the analysis for the sub-basins under the post-development phase. Similar type of generalization as for the pre-developed stage can be made to understand the chemistry of the volume of run-off generated at each sub-basin. The decrease in the volume of the run-off can be considered due to the addition of the reservoir element. The volume of the run-off generated exceeded the reservoirs storage capacity which caused a significant increase in the volume of the run-off and a slight increase in the peak discharge at the outlet. Figures 5 show the hydrographs for the post-development phase at Reservoir1 and Reservoir2. Table 5 & Table 6 shows the Global summary table which includes characteristic parameters such as inflow, outflow, storage and elevation for Reservoir1 and Reservoir2, respectively. It can be clearly observed that the outflow from the reservoir is dependent on the inflow. Inflow to the Reservoir is directly proportional to the intensity of rainfall. As there is inflow to the reservoir, run-off water elevation on the reservoir increases. If the volume of the run-off water collected at the reservoir is more than reservoir volume capacity then water overflows. The hydrographs shown in Figure 5 elaborates this conception. Stormwater management using infiltration trenches and monitoring the run-off volume and peak discharge using HEC-HMS were the basic objectives of this research. The post-development analysis of the basin area should decrease certain volume of run-off and peak discharge as it was equipped with the LID feature, infiltration trench. However, in contrast, peak discharge got increased as compared to pre-development phase by 39 L/s along with a 371m^3 decrease in run-off volume after the application of the LID feature in the watershed. Discharges through the perforations were considered even if the run-off water height at the reservoir was low. This implies there were discharges from the reservoir even at the very initial stage of rainfall-runoff process. To be more precise, discharges were there before the run-off through the infiltration trench could overflow. As there was an increase in the inflow to the reservoir, the volume of outflow and the peak discharge rate got increased. The outflows from both reservoirs got decreased as compared to the inflow at the initial stage of the rainfall. Reservoirs which were functioning as the infiltration trench stored the run-off and released them to the ground through the perforations. This feature is a splendid feature of infiltration trench which makes this superior for storm water management. Due to the increased inflow volume of water to the reservoir, the reservoir gets filled with the run-off water and it attains a constant height for some time period. At this stage, reservoir cannot accommodate any run-off so; the excess run-off overflows from the trench relatively with high velocity due to increased rainfall intensity. This phenomenon caused an increase in the peak discharge for Reservoir 2. After certain time, the run-off water elevation of reservoir gets decreased due to reduced inflow and due to the underground flow of run-off through the perforations. This entire phenomenon's can be observed from Table 5 & Table 6 by correlating it with the rainfall data. This lineage testifies the infiltration trench's performance in experimental basis. It is visibly clear that the objective of the storm water management is not capitally achieved as run-off was not restrained as it was aimed with no control of peak discharge. This endangers the idea to use infiltration trench as a micro-management design solution for the site area. Generally, shorter rainfall events are preferred in modeling of the LID elements; however, longer rainfall event was used which might have altered the results. This elaborates the concept that infiltration trenches cannot perform well for long rainfall events. This develops the need to use combined LID features at a particular watershed. The conventional storm water management techniques can prove to be the best in these stages. Most of the micro-management concepts available in LIDs can control storm water for small rainfall events, but it is necessary to

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affix conventional water management techniques while considering long rainfall events. Initial design consideration to include the detention basin along with the infiltration trench to manage the run-off at the watershed is very beneficial from hydrologic point of view. Hydrological modeling can be an important tool to rationalize the selection of the best LID design required for a particular watershed. The run-off volume and the peak discharge can be analyzed and the effective design can be chosen based on the function of the design concept chose. Focusing on the characteristics parameter such as run-off volume and peak discharge only can be considered a traditional practice to evaluate the hydrological performance. There are other parameters such as run-off coefficient; time to peak that can be used as the parameter to evaluate performance.[9] However, selecting the evaluation parameters should be based on inventory basis. The parameters indicating certain characteristics can be listed and dissolved one into another to obtain the results. It is best suited to establish the parameters based on the research aim and based on the landscape area on which hydrologic modeling is preferred. The results of the hydrological modeling can further be used to develop the site environment in an effective manner as the flow data through each and every element of the watershed will be known. HEC-HMS provides a user friendly interface for modeling LID and BMP tools. However, certain assumption has had to be made based on site characteristics to idealize the run-off flow as per practical condition. HEC-HMS has not been used frequently around the world for event modeling of LID and BMP elements. Presented methodology is best suited for modeling LIDs and BMPs in urban areas where effects of concretization has caused significant increase in run-off quantity. Since management of urban sewer network has become challenging with increasing volume of storm water run-off, this modeling approach can be used to manage the run-off by source control mechanism which is being popular these days. The presented methodology can be implemented at any site to perform hydrologic modeling to assess the suitability of installing LID and BMP tools at any other site. The methodology offers unique blend of tralatitious concepts along with intricate modern concepts to wangle the negative effects of storm water to our environment nonetheless, the structured methodology presented might have to be altered if other available software models are used for modeling run-off. Furthermore, no explanations have been given for other loss and transform options available in HEC-HMS except SCS CN and SCS unit hydrograph method. HEC-HMS features the capability to access the water quality assessment and sediment transport assessment of run-off water but the proposed methodology does not incorporate water quality and sediment transport assurance procedures. Thus, methodology fails to integrate future problems such as clogging that might take place in future on infiltration trench. These are included in future work and have not been enclosed here due to lack of time and funding to carry out the research work. Comparing rainfall events to choose different available LID features only cannot fulfill the intention of storm water management. The vivid picture of the actual process of loss and transform can be obtained from the modeling of the run-off water. Developing countries like Sri Lanka are using the LID features extensively; this shows an enormous interest of the country people towards sustainability issues. At the same time, it should be made aware of the hydrologic modeling for the proper functioning of the features before it is applied in a certain area.

Table 3 Global summary table for the pre-development phase

Hydrologic element	Drainage area (m^2)	Peak discharge (L/s)	Volume (m^3)
Sub-basin1	5799	61	747
Sub-basin2	8761	92	1118
Sub-basin3	4271	31	315
Sub-basin4	8107	85	1035
Sub-basin5	6082	64	777
Sub-basin6	3777	39	477
Sub-basin7	4392	13	161
Reach1	4271	31	310
Reach2	8107	87	1030
Reach3	14189	153	1802
Reach4	8761	75	935
Reach5	3777	40	475
Reach6	17424	122	1384
Reach7	5799	63	744
Junction1	14189	151	1808
Outlet	41189	379	4404

Table 4 Global summary table for the post-development phase

Hydrologic element	Drainage area (m^2)	Peak discharge (L/s)	Volume (m^3)
Sub-basin1	5799	61	747
Sub-basin2	8761	92	1118
Sub-basin3	4271	31	315
Sub-basin4	8107	85	1035
Sub-basin5	6082	64	777
Sub-basin6	3777	39	477
Sub-basin7	4392	13	161
Reach1	4271	30	307
Reach2	12378	144	975
Reach3	22237	226	2090
Reach4	8761	94	1114
Reach5	3777	40	475
Reach6	13153	103	1219
Reach7	5799	62	744
Junction1	22237	248	2228
Reservoir1	22237	217	2093
Reservoir2	12378	155	991
Outlet	41189	418	4053

Table 5 Global Summary table for Reservoir1

Time	Inflow (m^3/s)	Storage 1000 (m^3)	Elevation (m)	Outflow (m^3/s)
8:00	0	0	0	0
9:00	0	0	0	0
10:00	0	0	0	0
11:00	0	0	0	0
12:00	0.002	0.003	0.032	0.001
13:00	0.002	0.006	0.066	0.001
14:00	0.002	0.008	0.079	0.002
15:00	0.004	0.012	0.121	0.002
16:00	0.003	0.015	0.158	0.002
17:00	0.002	0.014	0.15	0.002
18:00	0.003	0.014	0.149	0.002
19:00	0.02	0.047	0.485	0.002
20:00	0.054	0.134	1.401	0.023
21:00	0.143	0.135	1.405	0.174
22:00	0.248	0.135	1.406	0.217
23:00	0.117	0.135	1.404	0.149
0:00	0.039	0.134	1.4	0.008

Table 6 Global Summary table for Reservoir2

Time	Inflow (m^3/s)	Storage 1000 (m^3)	Elevation (m)	Outflow (m^3/s)
8:00	0	0	0	0
9:00	0	0	0	0
10:00	0	0	0	0
11:00	0	0	0	0
12:00	0.002	0.003	0.028	0
13:00	0.001	0.008	0.065	0
14:00	0.002	0.011	0.091	0.001
15:00	0.003	0.018	0.141	0.001
16:00	0.002	0.024	0.193	0.001
17:00	0.001	0.027	0.213	0.001
18:00	0.002	0.03	0.237	0.001
19:00	0.018	0.063	0.506	0.001
20:00	0.052	0.186	1.49	0.001
21:00	0.099	0.35	2.802	0.059
22:00	0.115	0.351	2.806	0.155
23:00	0.067	0.35	2.801	0.028
0:00	0.018	0.35	2.802	0.058

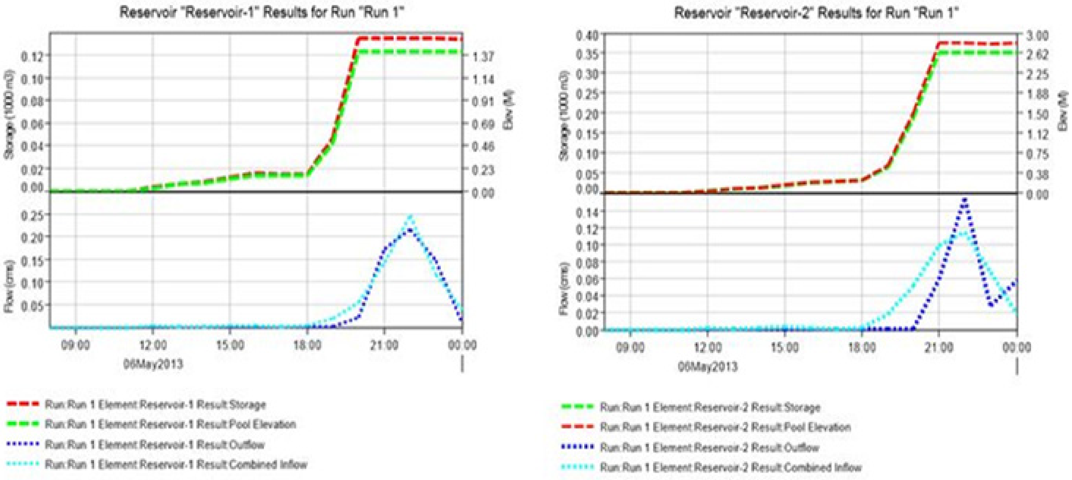

Figure 5 Hydrographs for post-development phase for reservior1 & reservior2.

Recommendations

Instrumentation should be included in the design of the infiltration trench to record the flow data. This can validate the hydrologic analysis results by comparing with the flow data. Instrumentation in the design of the infiltration trench along with other LID feature is must if the site area is not gauged where calibration of the data cannot be done. A data acquisition system can be created using data logger system that can be connected to pressure transducers, flumes to get the flow data. Validation work has not being done due to lack of funding and is included in future work. This research work can also be implemented in multi-objective optimization algorithms platform to bring up any optimal solutions in controlling storm water in SLIIT premises. Readily available genetic algorithm based optimization modules can be linked to hydraulic and hydrological models to come up with optimal solutions. Usage of optimization techniques and their benefits in storm water management is highly appreciated in the literature.[15–18] As a potential Non-dominated Sorting Algorithm (NSGA II) and storm water Management Model (SWMM) are proposed.

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Conclusion

Using HEC-HMS 4.1, an attempt was made to characterize the hydrological performance of the infiltration trench and the bio-retention pond in SLIIT, Malabe campus, Sri Lanka. The following conclusions can be derived from the analysis.

a. HEC-HMS 4.1 can be used to study hydrological performances BMPs and LID practices. Event simulation can be done in HEC-HMS 4.1 to model installments of the infiltration trench along with a bio-retention pond instead of continuous simulation.

b. Performance of the infiltration trenches can be evaluated by studying and comparing the pre - development and post-development scenario results such as hydrographs and time series data. Functioning completely relies on the geo-technical properties of the underlying soil.

c. Infiltration trench cannot perform very well for long rainfall events and for areas where the underlying soil has very less permeability rate. So, long duration rainfall should not be used while designing the LID and BMP structures.

d. Hydrological modeling must be done to check the best suitable LID feature for a particular watershed by altering the different scales of rainfall events.

e. Hydrologic evaluation parameters should be determined based on the characteristics of the site area on inventory basis.

f. Hydrological modeling before the installments of the LID components minimizes the hazard of waste of time, money and energy. This type of absolute thinking in water engineering progresses the development of water sector in meteoric rate.

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None.

Conflict of interest

Authors declare there is no conflict of interest in publishing the article.

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