Managing Storm Water Runoff of a Housing Scheme Employing Low Impact Development Techniques

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Abstract-Development practices have directly impacted natural hydrological cycle and resulting in storm water flooding scenario as it is happening in southern Lahore. Low Impact Development Techniques (LIDs) such as Bioretention Cells, Rain Gardens, Rain Barrels, Porous Pavements, Infiltration Trenches and Green Roofs etc are the mitigation measures to compensate such disturbance in hydrological cycle. This research broadly encompasses utilization and significance of LIDs in efficient control of storm water runoff and reducing flooding problems in one of the rapidly developing area of Lahore. Land use and rainfall data of study area was collected and analyzed for preparation of IDF curves in order to analyze and predict rainfall distribution pattern in the study area. After that EPA's Storm Water Management Model SWMM 5.1 was used to carry out storm water management studies by designing a storm water drainage network of the study area and for assessing significance of LIDs. Model results exhibited that there is about 54.68% reduction in quantity of storm water runoff along with 51.29% increase in soil infiltration rate. Similarly, LIDs (chiefly rain barrels) provided water storage of about 1.455 acres feet. This depicted that LIDs are not only fruitful in efficient management of storm water runoff but also contribute towards groundwater recharge and water conservation.

Keywords-Storm Water Management, Low Impact Development Techniques (LIDs), SWMM 5.1, Storm Water Management Modeling, Flooding and Ponding, New Lahore City Housing Scheme, Lahore.

I. INTRODUCTION

With the passage of time in all over the world including Pakistan, the development practices are increasing day by day thus subsequently increasing the impervious areas. Similarly, in Lahore and especially in southern region, the pace of development works/urbanization is extraordinary and about 250 private housing schemes have been approved by Lahore Development Authority (LDA) on agricultural lands up till now and the figure is still increasing. As a result broad scale urban areas flooding have been occurring in the said area during the last many decades and situation is also cumbersome in many other urban areas of Pakistan. Storm water management authorities (such as Water and Sanitation Agency, WASA) are facing severe problems and are going into crisis situation. The main reason behind such enlarged and recurrent flooding is urbanization and increased pervious surfaces such as rooftops, driveways, walkways, paved streets and parking areas are the components in modern urbanization which contribute in larger quantities of storm water flow. Similarly unplanned development in Lahore is also resulting in severe flooding in different areas of city, possessing the greater rate of growth and maximum land cost. Due to limited space and financial issues, the capacities of the existing drainage system (e.g. storm sewers and drains) cannot be restored. On the other hand, no appreciable effort has been made to assess the impacts of new development on the existing drainage network and hence it further complicates the situation.

Therefore, in order to cope with the said difficulties and especially for the topographic, geographical conditions that Lahore region have, proper storm water management techniques are required such as LIDs. Keeping in view the aforesaid key factors, this study has been planned with an aim to:

a. Evaluate the significance of different LID (Low Impact Development) techniques in better control and management of storm water runoff.
b. Propose most appropriate storm water management system for avoiding the chances of flooding.

II. BACKGROUND

Over the years, many research works have been done for storm water management using Storm water management model and employing LIDs some of the important are:

SWMM was used for simulating runoff and nutrient export from a LID water shed located at Long

Island, Connecticut, USA and it was found that LID practices have storm water flow control benefits even for larger return periods storms [i].

LID techniques were used for four sites at Florida, USA and it was observed that LID design reduced the need for conveyance infrastructure and found to be a cost effective approach in development sector [ii].

A study was conducted on a development site of Fort Collins, Colorado, USA using EPA SWMM in order to investigate the significance of Low Impact Development (LID) Techniques in managing urban storm water runoff and restoring pre-development site hydrology. Four LID techniques such as grassed swales, Rain gardens, infiltration trenches, permeable pavements were used for managing storm water runoff and it was found that LIDs are beneficial in managing urban storm water runoff and restoring pre-development hydrology [iii].

Hydrological modeling of the little Crum creek watershed, Pennsylvania was carried out with SWMM. The purpose of the study was to analyze quantity and some characteristics of the quality of the water in Crum Creek Watershed for periods of rainfall between summers, 2008 to spring; 2009.The authors observed that SWMM Model can be used to find the changes occurred in stream flow as a result of change in land use. They also found that SWMM most accurately models runoff in upper part of water shed and can be used for steam rehabilitation by targeting sites with high peak flows runoff volumes or TSS concentrations [iv].

Hydrologic evaluation of Low Impact Development techniques was carried out using a continuous spatially distributed model such as SWMM 5.1 on a 4.3 acres water shed at village near Virginia Tech Campus, USA. It was concluded that LIDs if managed properly offers substantial benefits towards reducing runoff volume and pollutant loads. LID practices such as bioretention cell, dry swales, green roofs can reduce runoff volumes, peak flows, pollutant loads even further what obtainable [v].

Hence, several studies have been carried out in recent past in various different countries regarding the management of runoff quantity or quality using Storm Water Management Model with or without application of LIDs, however in fact no study has yet been conducted in Pakistan regarding significance of various Low Impact Development Techniques (LIDs) such as Rain gardens, Bioretention cells, Infiltration trenches, Permeable pavements, Rain barrels, Green roofs etc in managing storm water runoff by using latest version of Storm water management model 5.1 with LID editor.

III. MODEL DESCRIPTION

Storm Water Management Model (SWMM 5.1) developed by EPA of USA in 1971 has taken a important position among various hydrological models for dynamic rainfall runoff modeling of single occasion or long term continuous simulation of runoff quantity and quality from principally urban areas. SWMM 5.1 consists of two portions i.e. runoff portion and routing portion. Runoff component works on collection of storm water runoff from various subcatchments as a result of precipitation whereas, routing component of SWMM 5.1 transports it through system of conduits, channels, storage/treatment devices, pumps and regulators. SWMM 5.1 has also LID control editor for Low impact development studies of any area. SWMM 5.1 accounts for various hydrological processes such as time varying rainfall, evaporation, snow accumulation and melting, rainfall interception, depression storage "dp", infiltration of rainfall, percolation of infiltrated water into ground. Interflow between ground water and drainage system, non linear reservoir modeling etc. Surface runoff occurs when depth "d" of water in reservoir exceeds depression storage "dp"[vi]. Conceptual view of runoff used by SWMM 5.1 can be depicted in Fig.1.

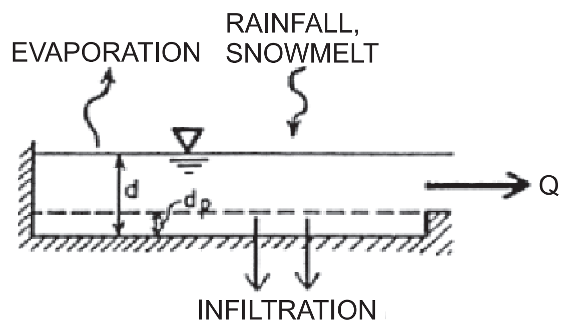

Fig.1.Conceptual view of surface runoff used by SWMM 5.1[vi]

IV. STUDY AREA

The study has been conducted on New Lahore city Housing scheme which was approved by LDA in the year 2012 as per LDA building byelaws. New Lahore City (NLC) Housing Scheme is located on the eastern bank of Lahore branch canal between Bahria Town and Sunder Road. Fig.2 shows location of the scheme.

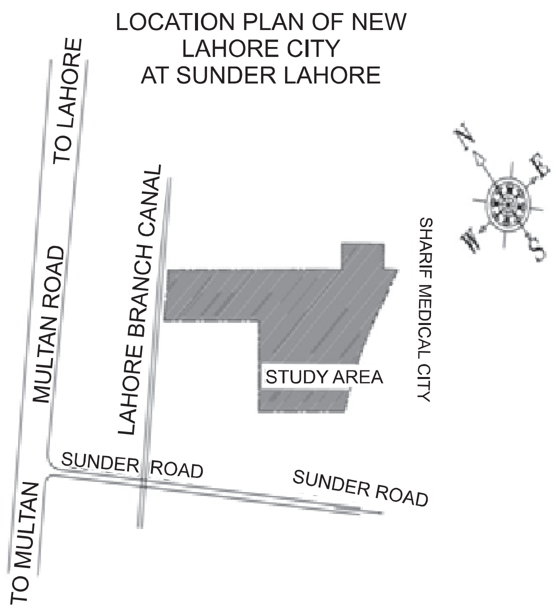

Fig.2. Location plan of the study area

The topography of New Lahore city housing scheme from mean sea level (MSL) does not vary much with reduce levels ranging from 682.043ft to 677.343ft at extreme ends. The area where this housing scheme is located is semi arid in nature with mean annual rainfall ranging from 20 inches to 25 inches. The housing scheme consists of less pervious area and located in one of the densely urbanized area of Lahore that's why it faces ponding issues during monsoon seasons. Table I gives description about the land use conditions of the housing scheme.

TABLE I
LAND USE DESCRIPTION OF NEW LAHORE CITY HOUSING SCHEME (NLC)

S.N	Land Use	Area (kanal)	Percentage Distribution
1	Residential	113.26	40.16
2	Roads	99.10	35.14
4	Parks	27.34	9.69
5	Public buildings LDA	3.66	1.30
6	Public buildings sponsor	13.58	4.82
7	Commercial and Parking	17.35	6.15
8	Grave yard	7.04	2.50
9	Solid waste Management	0.70	0.25
	Total	282.03	100

V. Low Impact Development Techniques

Low Impact Development (LID) techniques are the most comprehensive techniques used for the efficient management of storm water runoff. They were first prepared in 1999 by Prince George county Maryland, Dept of Environmental Resources.LID approach combines a hydrological functional site design with an aim to restore pre-development site hydrological conditions along with pollution prevention measures by reducing land development impacts on hydrology and water quality [vii].

Some of the well known LID techniques that have been used in the research work are:

- Bioretention Cells
- Rain Gardens
- Infiltration Trenches
- Permeable Pavements
- Rain Barrels
- Green Roofs

VI. Data Collection

The collection of metrological data of study area such as rainfall record and pan evaporation data was the first step towards carrying out research work. As there was no rain gauging station at the study area hence rainfall record of past years for study area was collected from Pakistan Metrological Department (PMD), Pilot Balloon Observatory (PBO) station Jail road, Lahore which was nearest rain gauging station to the study area. Three hourly rainfall records up to 12 hrs along with 24 hourly rainfall records (1953-2015) of PBO Station Jail road, Lahore were collected (Table II). The data also contained some missing rainfall records from 1971-1973.Similarly in past, PBO station had the facility of autographic rainfall recorder for rainfall record of shorter durations which is not being practiced now a day. Hence rainfall record of shorter durations (15, 30, 60 and 120) minutes along with 3hrs rainfall duration data for about 20 years was also collected from PBO station Jail road from 1940-1987 as shown in Table III. However, rainfall record for many years was missing in between 1940-1987. This shorter duration data is helpful in preparation of IDF curves even for shorter durations of rainfall against desired return periods. It's unfortunate to say that recording practice of smaller durations of rainfall via autographic rainfall recorder is not now being carried out by PMD since last many years. Hence, through interpolation and trend line analysis between 3hrs and shorter durations of 15, 30, 60, 120 minutes rainfall, filling up of rainfall record for years 1953-2015 was carried out. By doing this practice, rainfall data for shorter (15, 30, 60 and 120minutes) as well as longer durations (3, 6, 9, 12, 24 hours) from 1953-2015 was available. As the longer durations rainfall data i.e. of 3, 6, 9, 12 and 24 hrs rainfall was not available from 1940-1952, hence rainfall record from 1953-2015 could only be used for frequency analysis and preparation of IDF curves of study area. Mean monthly evaporation values of study areas shown in Table IV as well as reduce levels of study area were also collected. The infiltration values of study area were decided on the basis of NRCS Runoff Curve number method depending on percentage of pervious and impervious area, soil type and land use conditions of each subcatchment [viii]. As per soil strata of study area Group-C soils were selected for deciding infiltration values. Composite curve numbers calculated on the basis of land use, and pervious and impervious conditions of each and every subcatchment were determined as per requirement of the model to be feed in infiltration editor of SWMM.

A. Frequency Analysis Of Rainfall

After collection of all the rainfall record from 1953-2015 and pan evaporation data, the next step was the frequency analysis of rainfall data i.e. determination of return periods for different durations of rainfall ranging from 15 minutes to 24 hrs rainfall data (1953-2015). In order to do the same, Weibull (1939) method was used. Frequency analysis is helpful in finding probability of occurrence of past and future events of rainfall.

According to that:

$$T_r = \frac{N+1}{M} \quad (1)$$

Where, Tr = return periods of rainfall.
N = total no of years
M = rank of different durations of storms when arranged in descending orders.

After calculations of return periods for different durations of rainfall using Weibull (1939), graphs were plotted to develop relationship between return periods and different durations of rainfall such as (15, 30, 60, 120) minutes and (3, 6, 9, 12 and 24) hours. Similarly, trend lines were drawn to select best fitted trend line on the basis of R-Square values. By using trend line equations, it became possible to calculate rainfall magnitudes and intensities against 2, 5, 10, 25 and 50 years return periods as shown in Table V. By utilizing data of Table V, Intensity Duration Frequency (IDF) curves of the study area were prepared from 1953-2015 as depicted in Fig. 3.

TABLE II
COLLECTED RAINFALL DATA (1953-2015)

Year	Rainfall Data (1953-2015) (inches)				
	3Hrs	6Hrs	9Hrs	12Hrs	24Hrs
1953	5.24	5.36	5.36	5.36	5.36
1954	8.06	8.06	8.06	8.07	8.99
1955	2.71	3.41	4.55	4.57	4.58
1956	2.59	2.61	2.61	3.17	3.19
1957	1.43	1.83	2.37	2.97	3.68
1958	4.19	4.39	4.39	6.16	8.08
1959	4.18	4.26	4.39	4.42	4.94
1960	1.76	1.76	1.76	1.76	1.76
1961	1.71	1.71	2.09	2.17	2.18
1962	3.03	3.24	3.25	3.47	3.47
1963	1.15	1.16	1.41	1.41	2.60
1964	2.79	3.0	3.96	4.52	7.88
1965	1.56	1.73	1.73	1.73	1.73
1966	0.58	1.06	1.23	1.53	1.95
1967	1.12	1.12	1.88	1.94	2.03
1968	2.83	2.88	2.88	2.88	2.88
1969	4.61	4.65	4.87	4.87	4.87
1970	1.43	1.74	1.74	1.94	1.97
1974	1.43	1.48	1.66	1.66	1.66
1975	1.67	2.01	2.75	2.75	2.75
1976	5.83	6.73	7.29	7.62	8.32
1977	2.38	2.75	2.97	3.11	3.39
1978	3.35	3.75	3.75	3.75	3.75
1979	1.51	1.92	2.23	2.23	2.23
1980	2.92	4.7	6.55	8.08	8.17
1981	2.81	4.42	4.95	4.95	4.95
1982	1.53	1.88	1.88	2.31	2.67
1983	3.34	3.54	3.54	3.54	3.70
1984	1.59	1.59	1.65	1.71	2.40
1985	1.44	2.99	2.99	2.99	4.63
1986	1.51	2.36	2.36	2.36	2.58
1987	2.34	2.34	2.34	2.34	2.34

1988	1.40	2.20	2.20	2.23	3.04
1989	0.94	1.24	1.52	1.52	1.52
1990	2.43	2.60	2.60	2.60	3.28
1991	2.10	2.42	2.62	2.74	2.99
1992	1.93	2.23	2.41	2.52	2.75
1993	1.53	1.76	1.91	1.99	2.18
1994	1.37	1.58	1.71	1.79	1.95
1995	2.13	2.46	2.66	2.78	3.03
1996	3.28	4.62	5.8	6.92	7.48
1997	1.70	2.52	3.29	4.03	5.96
1998	2.33	2.33	2.33	2.33	2.33
1999	3.30	3.45	3.48	3.48	3.48
2000	2.18	3.32	4.1	4.34	4.34
2001	2.96	3.44	3.44	3.44	3.44
2002	1.10	1.17	1.17	1.17	1.17
2003	1.75	3.32	3.32	3.32	3.32
2004	2.29	2.29	2.29	2.29	2.29
2005	5.09	5.40	5.40	5.40	5.40
2006	3.26	3.60	3.86	4.09	4.52
2007	0.80	1.35	1.60	1.71	1.94
2008	1.98	2.43	2.69	2.85	3.18
2009	0.80	1.35	1.60	1.71	1.94
2010	3.53	3.85	4.11	4.35	4.80
2011	2.18	2.62	2.87	3.05	3.39
2012	3.08	3.44	3.70	3.91	4.33
2013	5.41	5.58	5.83	6.16	6.77
2014	4.88	5.09	5.35	5.65	6.22
2015	2.11	2.55	2.80	2.97	3.31

TABLE III
SHORTER DURATION RAINFALL DATA (1940-1987)
WITH MISSING RAINFALL RECORDING YEARS

Year	Rainfall Data for Shorter Durations (in)				
	0-15 Mins	0-30 Mins	0-60 Mins	0-120 Mins	3Hrs
1940	0.90	1.66	2.06	2.06	2.21
1942	0.35	0.67	1.00	1.41	2.18
1949	0.23	0.28	0.33	0.42	0.53
1950	0.21	0.41	0.71	0.99	1.69
1956	0.43	0.80	1.43	2.23	2.59
1957	0.30	0.38	0.38	0.62	1.43
1959	1.12	1.86	2.24	2.60	2.71
1960	0.51	0.91	1.25	1.47	1.76
1965	0.48	0.51	0.51	0.88	1.56
1966	0.27	0.42	0.44	0.49	0.58
1970	0.31	0.56	0.87	1.29	1.43
1974	0.41	0.80	1.36	1.41	1.43
1978	1.31	2.61	2.99	3.16	3.35
1980	0.80	1.19	1.90	2.57	2.92
1981	0.52	0.95	1.16	1.81	2.81
1982	0.60	0.98	1.41	1.57	1.57
1983	0.80	1.55	2.45	3.04	3.34
1984	0.40	0.75	0.76	1.43	1.59
1985	0.40	0.80	1.19	1.35	1.44
1987	0.40	0.72	1.03	1.03	2.34

TABLE IV
PAN EVAPORATION DATA FOR STUDY AREA

S. No	Months	Mean Monthly Pan Evaporation Rates (in)
1	January	1.40
2	February	1.72
3	March	3.13
4	April June	4.34
5	May	5.54
6	June	6.10
7	July	5.12
8	August	4.49
9	September	3.95
10	October	2.67
11	November	2.17
12	December	1.43

TABLE V
RAINFALL MAGNITUDES AND INTENSITIES FOR DEVELOPMENT OF IDF CURVES OF THE STUDY AREA

Rainfall Duration (minutes &hrs)	*Trend line Equations	Return Periods (years)	Rainfall (in)	Rainfall Intensity(in/hr)
15 Minutes (0.25Hrs)	R_m=0.262+0.440ln(T_r) R^2 = 0.986	2	0.567	2.268
		5	0.970	3.881
		10	1.275	5.101
		25	1.678	6.713
		50	1.983	7.933
30 Minutes (0.5Hrs)	R_m=0.390+0.875ln(T_r) R^2 = 0.985	2	0.997	1.993
		5	1.798	3.597
		10	2.405	4.810
		25	3.207	6.413
		50	3.813	7.626
60 Minutes (1 Hr)	R_m=0.535+1.182ln(T_r) R^2 = 0.985	2	1.354	1.354
		5	2.437	2.437
		10	3.257	3.257
		25	4.340	4.340
		50	5.159	5.159
120 Minutes (2 Hrs)	R_m=0.746+1.388ln(T_r) R^2 = 0.985	2	1.708	0.854
		5	2.980	1.490
		10	3.942	1.971
		25	5.214	2.607
		50	6.176	3.088
3 Hours	R_m=1.018+1.574ln(T_r) R^2 = 0.984	2	2.109	0.703
		5	3.551	1.184
		10	4.642	1.547
		25	6.085	2.028
		50	7.176	2.392
6 Hours	R_m=1.394+1.602ln(T_r) R^2 = 0.983	2	2.504	0.417
		5	3.972	0.662
		10	5.083	0.847
		25	6.551	1.092
		50	7.661	1.277
9 Hours	R_m=1.521+1.748ln(R_p) R^2 = 0.989	2	2.733	0.304
		5	4.334	0.482
		10	5.546	0.616
		25	7.148	0.794
		50	8.359	0.929
12 Hours	R_m=1.518+1.966ln(T_r) R^2 = 0.995	2	2.881	0.240
		5	4.682	0.390
		10	6.045	0.504
		25	7.846	0.636
		50	9.209	0.767
24 Hours	R_m=1.638+2.232ln(T_r) R^2 = 0.983	2	3.185	0.133
		5	5.230	0.218
		10	6.777	0.282
		25	8.823	0.368
		50	10.370	0.432

***Note:** In trend line equations, Rm= rainfall magnitude (inches) and Tr = return periods of different storms (years).

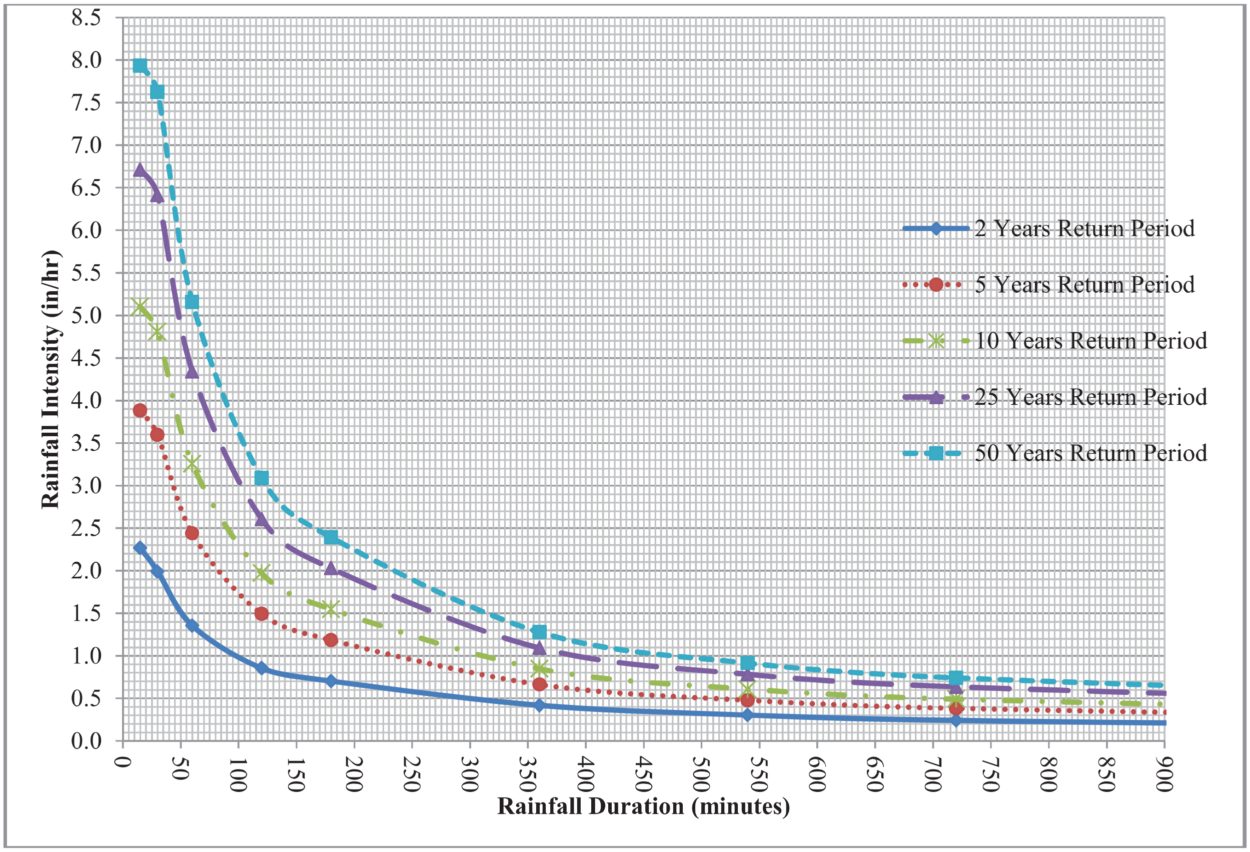

Fig. 3. Intensity Duration Frequency (IDF) curves for study area (1953-2015)

B. Selection Of Rainfall Pattern

In order to decide rainfall data to be used in rain gage property of Storm Water Management Model (SWMM 5.1), rainfall pattern for about six years was determined on the basis of Table V. However, final selection of rainfall duration for storm water management modeling in SWMM 5.1 was decided on the basis of time of concentration as calculated through rational method. Six hours rainfall pattern that was determined on the basis of Table V against different return periods is summarized in Table VI below:

TABLE VI
SIX HOURS RAINFALL PATTERN FOR DIFFERENT DURATIONS OF RAINFALL

2 Years		5 Years		10 Years		25 Years		50 Years	
Time (hr)	**Rainfall (in)**	**Time (hr)**	**Rainfall (in)**	**Time (hr)**	**Rainfall (in)**	**Time (hr)**	**Rainfall (in)**	**Time (hr)**	**Rainfall (in)**
1	1.354	1	2.437	1	3.257	1	4.340	1	5.159
2	0.354	2	0.543	2	0.685	2	0.874	2	1.017
3	0.401	3	0.571	3	0.700	3	0.871	3	1.000
4	0.099	4	0.060	4	0.029	4	0.010	4	0.041
5	0.122	5	0.200	5	0.251	5	0.319	5	0.370
6	0.418	6	0.161	6	0.161	6	0.157	6	0.150

C. Storm Water Management Modeling

After collection of all the required metrological data and rainfall analysis, the next step was the setting up of EPA's Storm Water Management model (SWMM 5.1) and its calibration. For setting up of SWMM 5.1model, whole study area was divided into small subcatchments and then storm water drainage conduits “C”, nodes ”J”, rain gauge “Rain gauge” and outfall station ”Out” were marked in the model view of whole scheme. Fig. 4 represents model view of whole study area as divided into 14 subcatchments along with storm water conduits, junction points, outfall station and rain gauge.

For designing the storm drainage network using SWMM 5.1 model, the various input parameters for the subcatchments, conduits, junctions/nodes and rain gage property of SWMM 5.1 were calculated. Similarly infiltration parameters of the subcatchments were also decided on the basis of NRCS runoff curve number method and Group C soils were selected. Rain gage parameters such as rainfall magnitude was decided on the basis of rainfall duration/time of concentration as calculated from rational method against five years return periods. Storm drainage networks are usually designed on the basis of 2-5 years return period because the cost of infrastructure significantly increases by designing on larger return periods; hence five years return period was selected as design period in modeling.

E. SWMM 5.1 Modeling After Employing LIDs

Finally, model was run by using different LID techniques such as bioretention cells, rain gardens, infiltration trenches, green roofs, permeable pavements, and rain barrels. Different LID techniques were utilized for evaluating and studying their significance in better control and management of storm water runoff. In order to do this design properties of different LID techniques were determined. Similarly, software was run up to the stage until it depicted no flooding or ponding/surcharging at any node or conduit in the study area. Conduits were tried to perfectly design so that neither of them may surcharge during whole span of storm event as it was done earlier before employing LIDs.

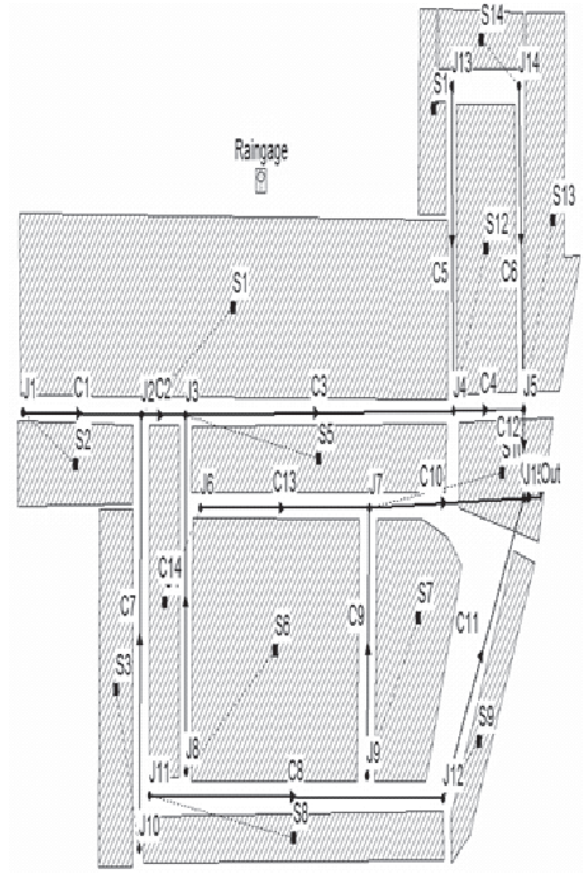

Fig.4. Model view of the study area

VII. RESULTS AND DISCUSSIONS

A. SWMM 5.1 Calibration And Modeling Before Employing LIDs

When the storm water management model was operated using same rainfall duration of 60 minutes with magnitude 2.437 inches against five years return periods and under similar catchment conditions as that used for rational method, the model ran successfully. Table VIII shows comparison between the peak discharges from the rational method and SWMM 5.1 model and percentage difference between them.

TABLE VIII
PERCENTAGE DIFFERENCE BETWEEN RATIONAL METHOD AND SWMM 5.1 RESULTS

Rational Method Peak Discharge (cfs)	**SWMM 5.1 Peak Discharge (cfs)**	**% Difference**
72.08	72.48	0.55

Table VIII shows that output of rational method and SWMM 5.1 are same with negligible percentage difference of only 0.55%. Hence, it means that SWMM 5.1 produced realistic results similar to that of rational method. After model calibration, sizes of storm conduits were determined through SWMM 5.1 modeling at no flooding and ponding conditions in order to have perfectly designed and efficient storm water management system. Fig. 5 shows model results of the study area with different sizes of conduits (in feet) obtained before employing LIDs using SWMM 5.1 modeling at no flooding and surcharging conditions.

B. SWMM 5.1 Modeling After Employing LIDs:

Finally, the model was run after employing LIDs as mentioned. Hence, various important input parameters regarding subcatchment imperviousness, conduit and nodal properties of the model were readjusted with decrease in conduit diameters. The sizes of diameters were decreased i.e. smaller were required because of the fact that LID techniques due to their detention, infiltration properties reduced quantity of runoff that was previously entering into the conduits. The SWMM 5.1 model was operated up to the stage until no flooding or surcharging remained at junctions or conduits. After using LIDs, the sizes of storm conduits required for whole study area were reduced as the total volume of inflow/storm water runoff which the outfall station was receiving got reduced up to 1.132 million gallons than the previous one of 1.751 million gallons before application of LIDs. Fig. 6 shows SWMM 5.1 modeling results and reduction in conduit diameters (in feet) after employing LIDs at no flooding and ponding conditions.

Similarly discharge at outfall disposal station was reduced to 58.32 cusec than the previous one of 72.48 cusec after employing LIDs. Fig. 7and 8 shows flow hydrographs for two scenarios before and after employing LIDs at outfall station by SWMM 5.1. Infiltration capacity of study area after employing LIDs was enhanced up to 0.997 acres feet from previous one of 0.659 acres feet without LIDs. From the analysis it was observed that LIDs (especially rain barrels) provided storage of about 1.455 acres feet.

VIII. CONCLUSIONS

Low Impact Development Techniques play vital role in efficient and better control of storm water runoff as after employing LIDs, total runoff volume gets reduced up to 1.132 Million gallons than the previous one of 1.751 Million gallons before application of LIDs i.e. about 54.68% reduction in quantity of runoff as a result design sizes of conduits gets reduced .

LIDs not only contribute in recharging groundwater aquifer but also helpful in restoring pre-development site ecology and natural hydrological cycle due to their detention and infiltration properties. Infiltration capacity of study area after employing LIDs has been enhanced to 0.997 acres feet from previous one of 0.659 acres feet without LIDs i.e. 51.29% increase in aquifer recharging rate.

LIDs not only reduce quantity of storm water runoff but also improve quality of runoff thus making operation and maintenance of infrastructure easier as with reduction in quantity of runoff by about 54.68% volume, pollutants loads accompanying with it will also automatically get minimal. Similarly, some LID techniques such as bioretention cells, rain gardens, green roofs and infiltration trenches with vegetation surface covers and alternate courses of sand or gravel have the ability to detain/treat and drain off surplus water to the storm conduits thereby reducing pollutants loads on conduits.

LID techniques especially rain barrels can also help in storing/conservation of rain water for future household purposes such as car washing, gardening and floor washing etc. From the analysis it is observed that LIDs have provided storage of about 1.455 acres feet.

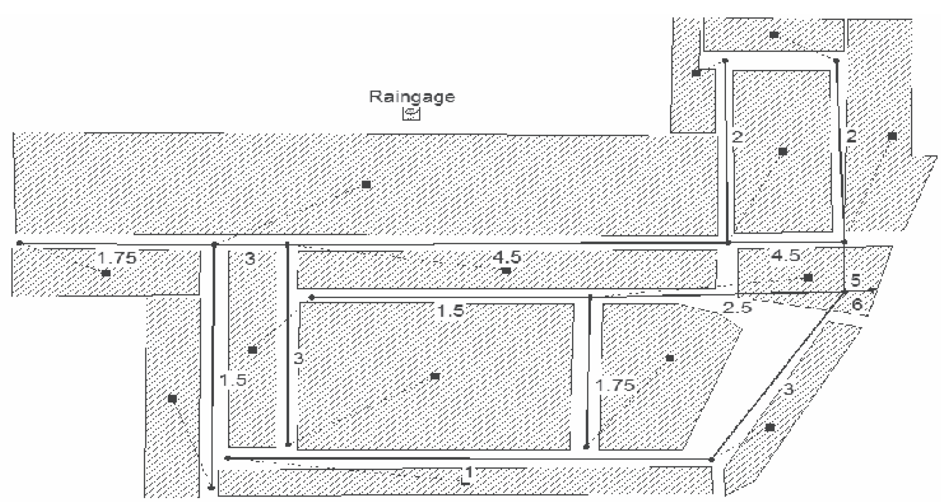

Fig. 3. Intensity Duration Frequency (IDF) curves for study area (1953-2015)Fig.5.Model view of the study area before employing LIDs at no flooding conditions (SWMM 5.1 results)

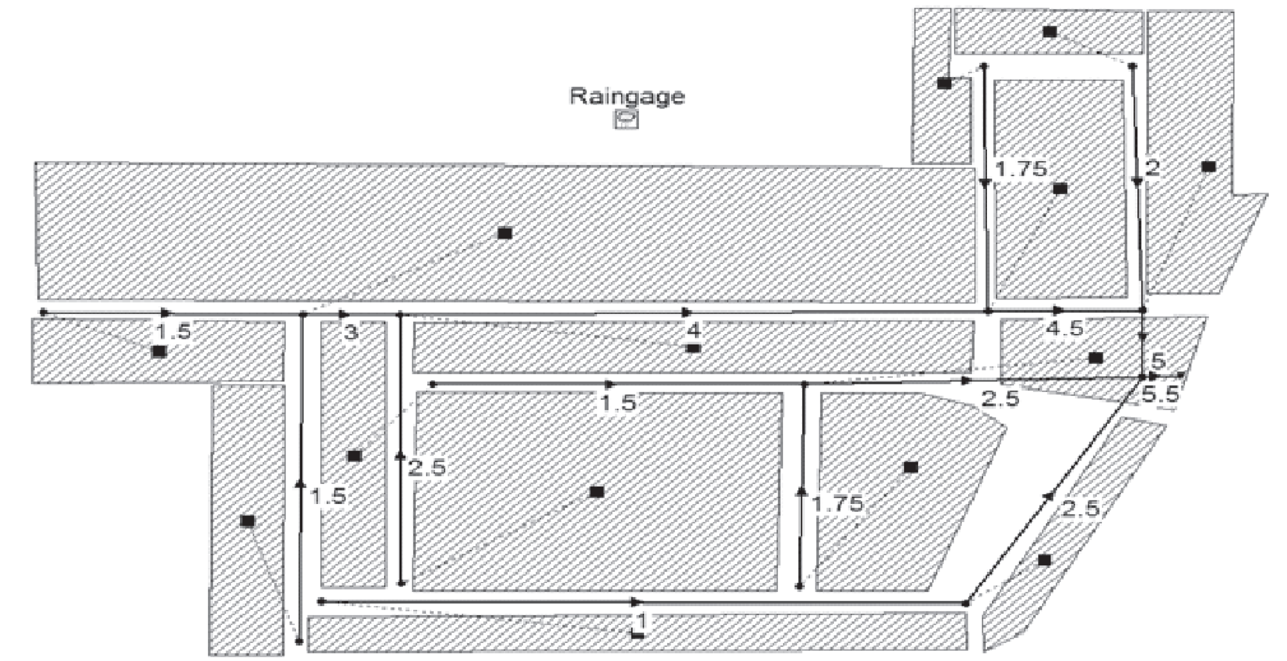

Fig.6.Model view of the study area after employing LIDs at no flooding conditions (SWMM 5.1 results)

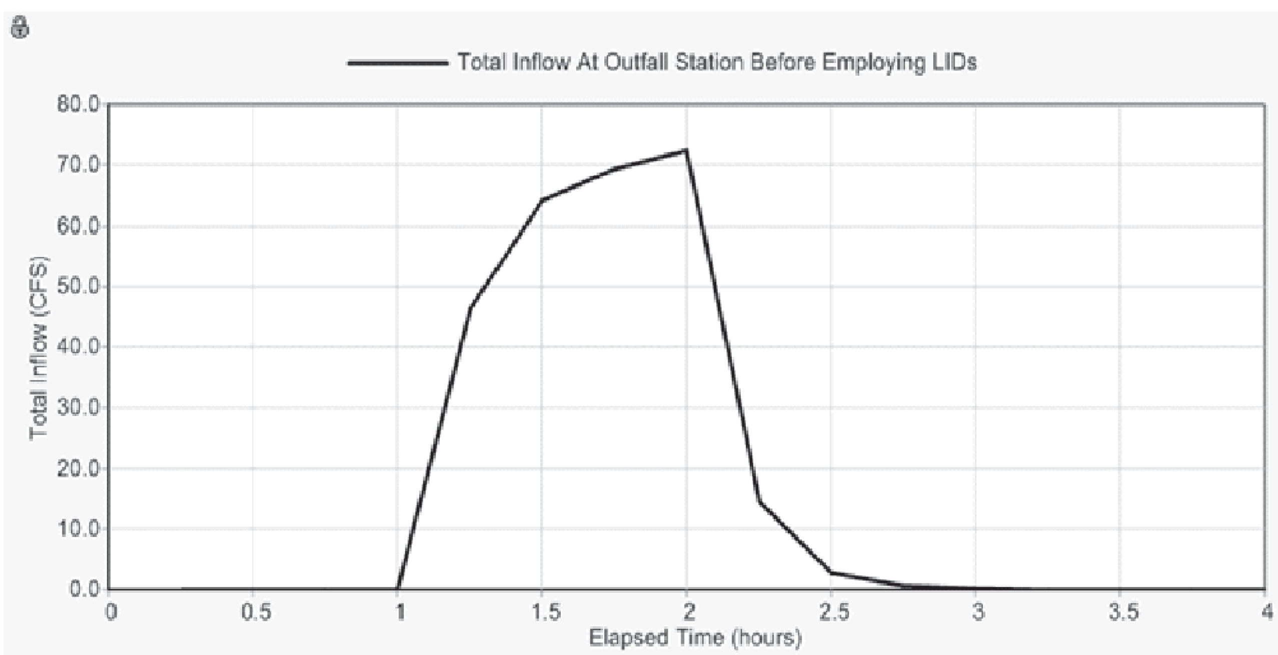

Fig. 7.Total discharge (72.48 cusec) at outfall station before employing LIDs (SWMM 5.1 results)

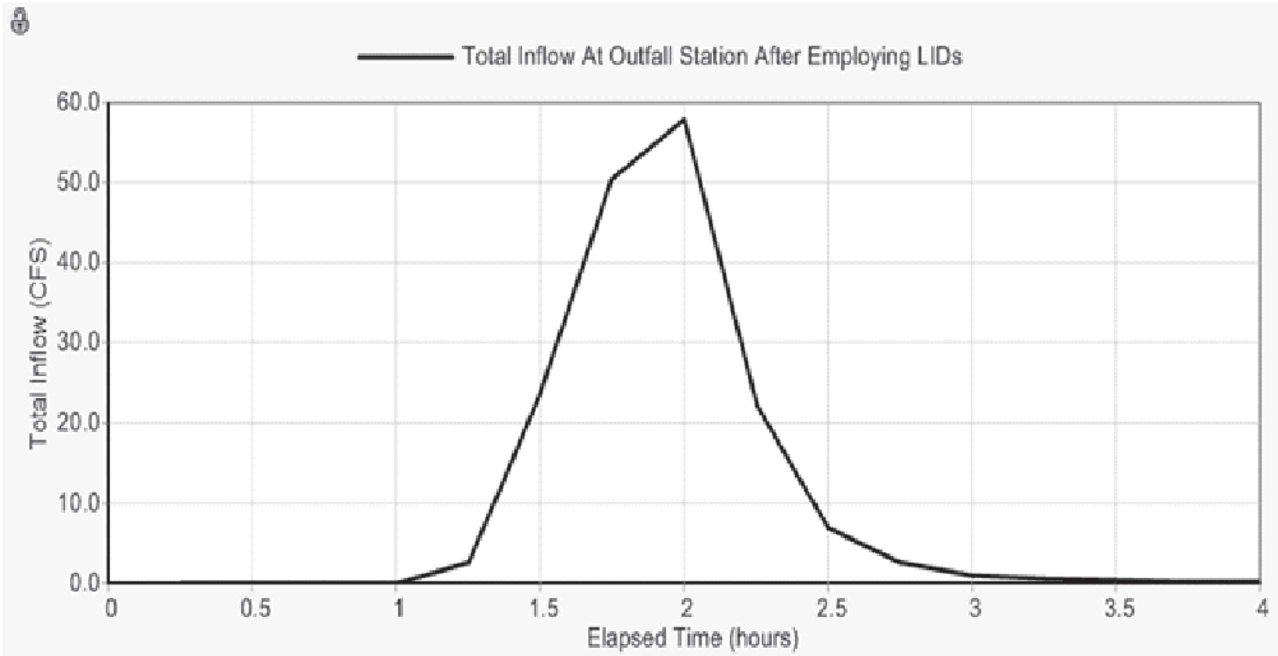

Fig. 8. Total discharge (58.32 cusec) at outfall station after employing LIDs (SWMM 5.1 results)

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