MODELLING TO MANAGE URBANSTORM WATER RUNOFF OF MNIT CAMPUS

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Abstract—In recent times, hydrological effect study of urban development has started gaining attention. Urban streams shows drastic change to their natural flow regime, main reason being the augmented rate and volume of runoff. Traditional storm water management concentrate in controlling peak rate by utilizing detention and retention basin, while concentrating less on increased volume of urban runoff. The MNIT campus located at Jaipur, Rajasthan is suffering from urban runoff problem from considerable time. After rain day, the majority of rain water fails to percolate into the soil and is converted to urban runoff. In this investigation paper study, modeling of the site is done using Storm Water Management Model (v.5.0) to analyze the urban runoff generated by various subcatchments present within the building. After knowing subcatchment that is producing highest runoff, an attempt was made to hydrologically restore the site. This was done by using Low Impact Development. Low Impact Development also known as LID's a land planning with aim to restrict the runoff close to its source as much as possible. The Low Impact Developments utilizes the natural processes like infiltration to decrease the volume and rate of runoff and also enhancing water quality. Various types of LID's were installed to find the most suitable. The amounts of LID's were increased till water balance and peak flow rate were met, done via simulation. The modeled LID BMP's include grass swale, Infiltration trenches, rain garden, and permeable pavements. However, no cost estimation was done of the installed LID design to explore the financial practicality. The result showed that the site can be recovered hydrologically, however since no cost study was carried out; they may or may not prove to be cost effective. In the study it was also found that the installed drainage systems are not properly maintained and hence suitable suggestions were made to restore and improve the drainage system.

Index Terms—LID's, MNIT campus, Strom water management model (v 5.0), Urban-storm water runoff

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I. INTRODUCTION

With time urbanization is taking place at very fast pace. The area earlier covered by forest and natural vegetation is being occupied by urban development like houses, industries, road, driveways, sidewalks, and streets prevent etc. Urban terrain is non porous and unlike natural soil lack capability of filtration. This has result in decline in the infiltration characteristics in the soil. The area which were prone to deep infiltration and shallow infiltration, after construction has turned into shallow or almost nil infiltration. Urban storm water is nothing but the rainfall that fall over urban areas and fail to percolate in the ground and changes into runoff .The study of urban storm water is very important as with the increase in urbanization more and more rain water is being converted to runoff. As rain water is being converted into urban storm water, with it, it picks up debris, chemical, dirt and other pollutant and flow into sewer system or a nearby water source like lake, river, coastal water and wet lands. This polluted water lead to very harmful effect on aquatic and non-aquatic animal.

Importance of Study of Urban Runoff

As explained above urban runoff is the extra runoff resulting due to failing of rainwater to percolate into the earth surface. With it, it takes water contaminating pollutant like industrial discharge, dumps and waste, suspended sediments which finally mix with nearby water sources and hence contaminate it. Suspended sediments is primary pollutant in urban runoff, it contain oil, greases, road salt, pesticides, metals, viruses and bacteria.

Earlier urban runoff was insignificant and was not considered as contamination contributor to drinking water, but within the last few decades with increase in urban runoff, regulatory controls and safe disposal method and practice has to be instituted. The hazard to human health by urban runoff is not only due to scoured surface materials, but also from sewer systems. In most conditions storm water are considered with sanitary sewer system. This joint sewer system may overflow, due to which sewage contamination of water ways may take place.

Hydrology of Catchment Suffering From Urban Runoff

Hydrology of the site is completely changed by the effect of urban storm water. The reason being that the runoff is increased and percolation of water is considerably decreased. If hydrograph of an area suffering from urban storm water is drawn and a comparison between hydrograph is made than the result will be clearly visible. On comparison it's found that the base flow of site suffering from urban storm water is decreased. Also, in the hydrograph of site suffering from the storm water runoff the peak flow is increased abruptly with a steep as compare to the site which is not suffered by the urban storm water. On comparison of hydrograph of same site, but before and after urbanization it's also found that post urbanization, time of concentration is decreased, flow velocity is increased, peak volume has increased, in fact, on comparison a huge difference in peak flow is clearly visible. This is due to decrease in percolation and increase in runoff called urban runoff.

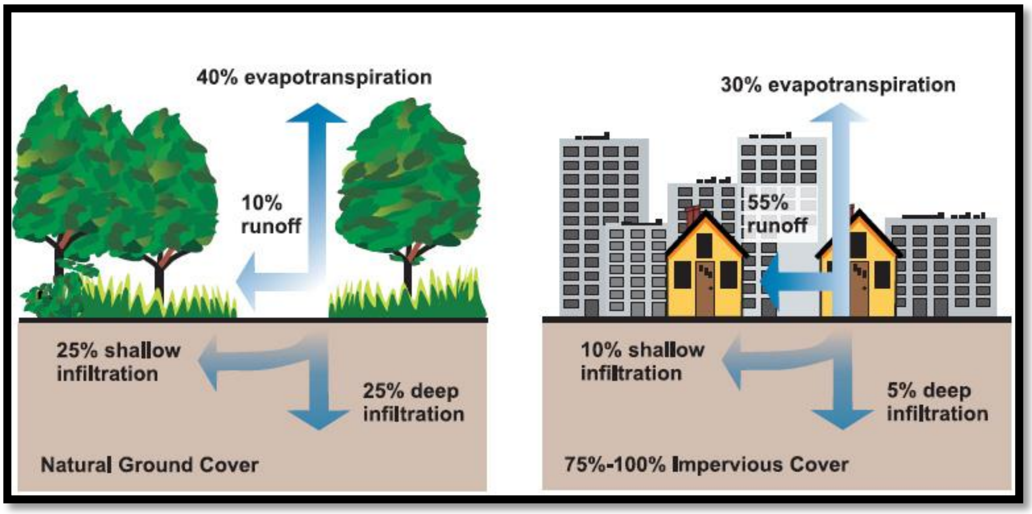

Figure 1 Effect of Urbanization on infiltration (SOURCE:INTERNET)

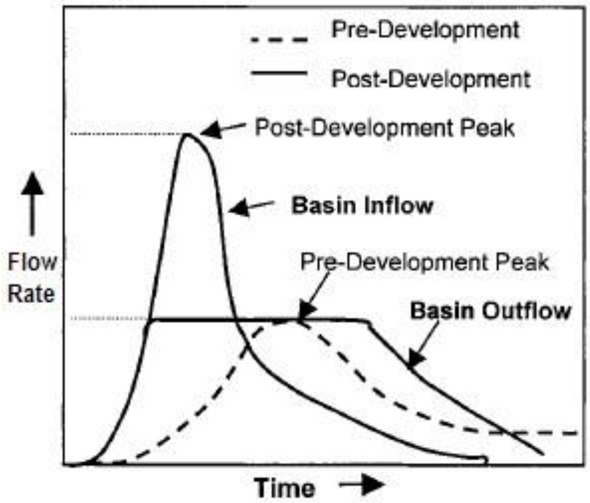

Figure 2 Peak Shaving Effect on a Hydrograph

The above figure shows hydrograph of a catchment before and after the development of a site. From the graph it's clear that how the peak flow rate of the catchment increase abruptly after the development of the catchment, the reason for this abrupt change is that before development, the runoff water was allowed to infiltrate into the soil, but after the construction, the surface become less permeable and hence the rainfall water instead of infiltrating into the soil get converted into runoff resulting in increase in peak.

II. STROM WATER MANAGEMENT MODEL (V 5.0)

This section includes various features and limitation that are adopted for urban runoff management.

Quality Control Feature

The software has various features designed specifically for urban runoff modeling, and modeling of Best Management Practices. The feature can be divided into two categories: Quality control and Quantity control. The quantity control features are as follows

Infiltration

Best management practices uses two primary methods for quantity control, these methods are infiltration and overland flow control. Infiltration is generally obtained on site by appropriate runoff in storage area and then allowing it to infiltrate at designed rate. These impoundments are given the form of infiltration basin or trench. To model basin, open conduits with strong nodes and trenches are used in SWMM5. However there is limitation in SWMM5 that only in subcatchments infiltration occurs, not in conduits or nodes.

Modeling of infiltration using subcatchment is also feasible as SWMM5 permits flow from one runoff of a subcatchment to flow directly into another subcatchment. The subcatchment which is receiving the runoff can be made to reflect basin or trench dimension. Depression storage parameter can be used to for retaining the desired infiltration volume for the subcatchment. The required infiltration can be obtained by modifying or manipulating the standard infiltration parameters by using Horton method, SCS curve method or Green Amt method. This is the most reliable way to fully simulate the characteristics of infiltration; but, it is very hard to make a subcatchment that exactly shows the behavior of detention basin. This method can only be applied for runoff that are flowing directly from nearby catchment as once the flow has entered a conduit it can't go back into a subcatchment.

Overland Flow

Overland flow is principal model consideration because it influences the extent (magnitude) of peak, peak time, and total runoff volume. One procedure to restrict overland flow is by detaching the impervious area from the drainage network. By doing so, the runoff, which would have entered the pipe quickly without any major reduction or delay, will now be delayed and will partially be infiltrated. This can be done in SWMM5 by using Subarea Routing feature. By using this feature runoff can be routed either from pervious area or impervious area by selecting the option as per interest. By allowing impervious runoff to pervious area before flowing into pipe lead to notable peak and reduction in volume from an unchanged section. If not mentioned, SWMM5 uses default option which is Outlet option, in this option, the runoff from pervious and impervious are is drained into sewers. The result obtained by taking outlet option will give very small difference from the Impervious option reason being that the outflow hydrograph is controlled by runoff from impervious areas.

Quantity Control Features

As compared to runoff quantity control, Quality control is more difficult. In SWMM5 there are several features available for quality control modeling. Though these features are very useful and very important use for effective modeling, yet in practice have certain limitations. SWMM5 have following quality control features:

- Pollution Definition
- Land Use
- Pollutant Treatment
- Quality Routing Continuity

Short Circuiting

For treatment facility, short circuiting comes out to be another limitation in SWMM5. There is no or a little treatment for passing overflow runoff. When modeling , the BMP's are modeled as storage node, which is treated as continuously mixed reactor in SWMM5, hence any pollutant which is entering the node is assumed to be mixed with water completely and immediately, which result in treatment of water at some level before it exit the node, hence by passing short-circuiting and flowing without being treated.

III. LOW IMPACT DEVELOPMENT

The following method is based on assumption that infiltration rate from a permeable pavement surface is not a limited factor; instead it's more than sufficient to accept rainfall plus runoff.

Steps

1. Input permeable pavement surface area after drawing catchment. Auto length setting should be chosen "on" and subcatchment should not overlap other subcatchment.
2. Set percentage impervious equal to zero.
3. Input pervious depression storage equal to base depth multiplied with porosity of base.
4. Input Pervious manning "n" equal to surface material of permeable pavement. This must be greater than manning "n" value of pavement.
5. Input subcatchment minimum and maximum infiltration value equal to subsurface soil saturated hydraulic conductivity.
6. Input permeable pavement surface area after drawing catchment. Auto length setting should be chosen "on" and subcatchment should not overlap other subcatchment.
7. Set percentage impervious equal to zero.
8. Input pervious depression storage equal to base depth multiplied with porosity of base.
9. Input Pervious manning "n" equal to surface material of permeable pavement. This must be greater than manning "n" value of pavement.
10. Input subcatchment minimum and maximum infiltration value equal to subsurface soil saturated hydraulic conductivity.

Infiltration Trenches

These are excavated trench which are backfilled with aggregate and stone. These are effective reservoir providing extra infiltration to the runoff. They can be placed anywhere, where runoff can be directed to, however they are preferred at the base of grass swale because grass swale provide pretreatment by sieving out sediment, and also grass swale are basically designed to convey water. If needed infiltration trenches can also be under drained. Pollutant contained in runoff can be removed by filtration, adsorption etc.

Figure 3 Infiltration Trenches Managing Runoff from a Roadway

Method to Create Infiltration Trenches in Storm Water Management Model

The steps mentioned here and in other segments are adopted from storm water management model manual. For detailed explanation, it's advised to refer to SWMM 5.0 manual. Subcatchment is used for modeling of infiltration trenches. It's assumed that full infiltration of water which was captured by infiltration trenches is permitted by the soil.

Step by step method to create infiltration trench in storm water management model is given below:

1. After making subcatchment, input data related to infiltration trench.

2. Percentage imperviousness is set zero.
3. Input pervious depression storage is equivalent to effective depth.
4. Input pervious Manning "n" equal to surface material of trench.
5. Input minimum and maximum infiltration data of subcatchment equal to subsurface soil's saturated hydraulic conductivity.

Rain Gardens

These are also called bio-retention. In rain garden, a low lying area is excavated and then backfilled with porous material combined with organics and then it's covered by munch and natural vegetation. One of the most important advantage of rain garden is that these can be placed at any place where run off is directed for example, streets, lawns, parking lots etc. in term of treating storm water these are very effective, and the treatment is done trough filtration and infiltration by porous soil mixture. Another advantage of rain garden is that suspended pollutants are readily absorbed by biological method and by filter media.

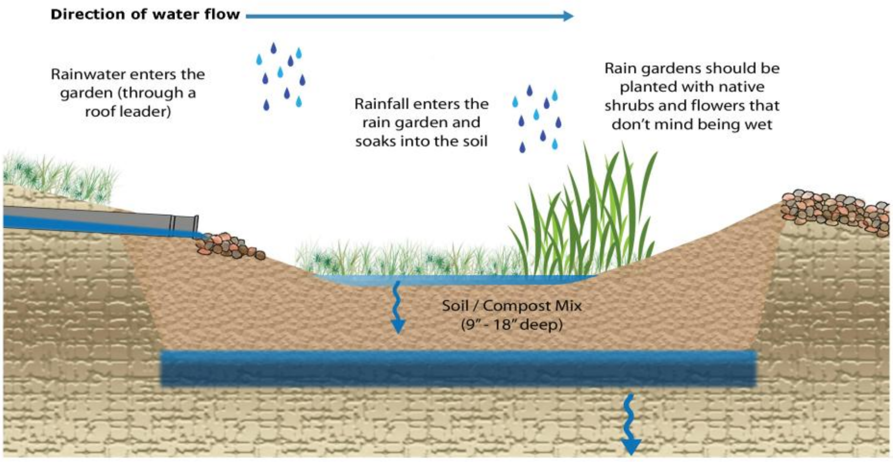

Figure 4 Working of Rain Garden

Method to draw Rain Garden in storm water management model 5

1. Keep sub catchment's subarea routing equal to pervious.
2. Estimate storage volume of rain garden.
3. Now multiply obtained storage volume with number of rain garden per subcatchment.
4. Now this volume is added to pervious area under depth of pervious depression storage.

IV. Model Development

Study Site

Malaviya National Institute of Technology, Jaipur (MNIT), is an engineering college located in Jaipur, Rajasthan, India. It was established in 1963. The campus is cover over 312 acres. It contain academic blocks, hostels, school, dispensary, staff residence, guest houses, canteen, banks, playing fields, gymnasium, post office, staff clubs and community centre. The campus is divided into four major sectors, that is, Academic buildings which include departments, administrative block and library, student hostels, central facilities including guest house and sports facilities and staff colony.

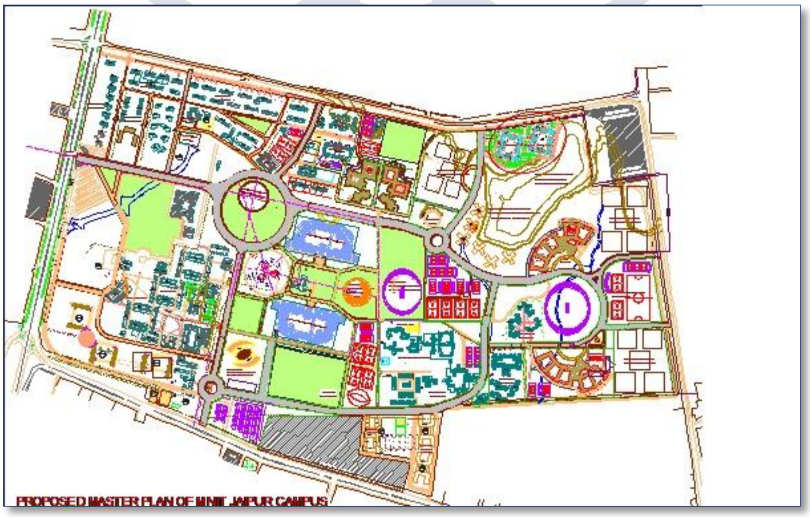

Figure 5 Study Site

Soil Report

According to report published by Central Ground Water Board Ministry of Water Resources Government of India named "Ground Water scenario: Jaipur district" Jaipur district is enriched with following type of soil: Loamy sand to sandy loams, sandy clay loam, sandy clay, Windblown sand and River sand. To be more specific soil report by Department of Agriculture and Cooperation was referred which specified that 59.2 % of land area is covered by medium brown loamy soil succeed by deep brown loamy soil (12.3%), hence for modeling purpose soil distribution was assumed to be uniform throughout the campus with loamy soil. infiltration rate for this type of soil is .22 inches/hour (source : http://qcode.us), hence a factor of safety of 2 is applied and a design rate of .44 inches/ hour was used.

Evaporation Data

Evaporation play very significant role for estimating overall budget. It is instrument to decrease the depression storage of impervious areas between rainfall events. To get evaporation data for the study area, hydrology and water resource information system of India (www.nih.ernet.in) was referred where an average evaporation rate was provided on an average basis, for an exact value of monthly value evapotranspiration data; Indian water portal sites (www.Indiaportal.Org) was referred and was used, and are given as following:

Table 1 Evaporation Data for Jaipur city

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	4.84	5.57	6.82	7.75	8.42	7.9	6.66	5.8	6.31	6.87	5.94	5.08
1984	4.89	5.41	6.88	8.04	8.79	8.3	6.61	5.8	6.27	6.96	5.91	4.94
1985	4.84	5.91	6.89	8.13	8.76	8.14	6.54	5.64	6.35	6.78	5.95	5.11
1986	4.97	5.66	6.81	8.08	8.68	8.26	6.61	5.7	6.33	6.97	6.12	5.04
1987	5.04	5.81	6.89	8.16	8.39	8.13	6.4	5.87	6.45	6.96	6.32	5.06
1988	4.91	5.84	6.79	8.12	8.87	8.27	6.42	5.55	6.14	6.96	6.04	5.17
1989	4.81	5.5	6.85	8.09	8.6	8.11	6.65	5.74	6.33	6.89	6.05	5
1990	5.02	5.66	6.69	8.04	8.57	8.13	6.57	5.68	6.31	6.8	6.01	5.06
1991	4.89	5.71	6.93	8.07	8.68	8.23	6.66	5.78	6.33	6.93	5.99	5.09
1992	4.96	5.63	6.81	8.08	8.62	8.3	6.65	5.78	6.28	6.88	5.99	5.18
1993	4.94	5.8	6.8	8.05	8.79	8.26	6.49	5.8	6.32	6.94	6.11	5.12
1994	5.02	5.67	7	8.05	8.71	8.35	6.54	5.73	6.27	6.88	6.03	5.17
1995	4.85	5.7	6.77	8.03	8.67	8.34	6.67	5.71	6.29	6.9	6.06	5.08
1996	5.09	5.69	6.93	8.3	8.72	8.11	6.56	5.66	6.21	6.88	6.1	5.18
1997	4.93	5.71	6.71	8.06	8.63	8.17	6.68	5.94	6.39	6.73	5.87	4.72
1998	4.92	5.76	6.84	8.05	8.81	8.38	6.58	5.76	6.28	6.81	6.08	5.16
1999	4.85	5.64	7.05	8.34	8.71	8.34	6.49	6.03	6.19	6.89	6.2	5.28
2000	5.03	5.63	6.84	8.1	8.87	8.18	6.38	5.89	6.44	6.88	5.99	5.45
2001	4.96	5.71	6.92	8.08	8.74	8.07	6.29	5.91	6.54	6.88	6	5.12
2002	4.96	5.62	6.91	8.09	8.69	8.35	6.7	5.78	6.39	6.95	5.89	4.97

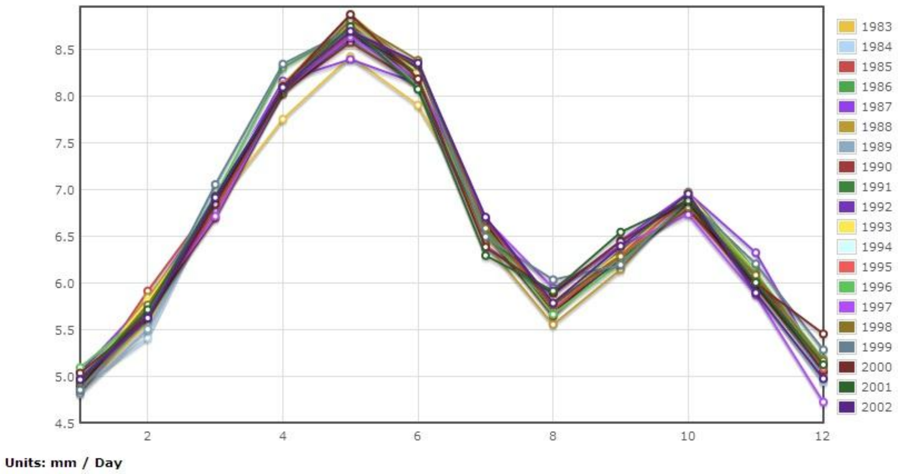

Figure 6 Monthly Variation of Evaporation from 1983-2002

Hydrological Overview of Site

Runoff is generated when rainfall and run on is larger than infiltration capability of ground. There can be two explanations for this condition:

a) Infiltration capacity of soil is less than the rainfall plus run-on produced.

b) Soil storage has been worn out.

At an average Jaipur city is face 35 days of rainy days, as per 2012 rainfall data highest daily rainfall for 2012 was 300mm. During this rainy season runoff produced at the study site is very high, on surveying and studying site, following reasons are suggested for this runoff generation:

a) Presence of poor drainage facility: it was found out during study that the drainage facilities available at the site were not managed properly. There runoff water was not disposed in a well-planned manner and there was no fix outfall decided for the campus.

Figure 7 Lack of Proper Drainage Facility at Site

b) Improper maintenance of drainage facilities: it was also found out that the drainage facilities that were provided were not properly maintained. These were filled with garbage, debris, and disposed other pollutant, which hinders infiltration and disposal of water.

Figure 8 Lack of Maintenance of Drainage System

V. Model Design

This section gives details about how MNIT site plan was modified and modeled in thesis study. It was aimed that there is least deviation from the genuine layout, with exception of accumulation of more LID feature. All data like slope, layout, imperviousness, area, drainage network, all remained same.

Models

Different models were created in order to estimate the LID effect on hydrological regime. These were as follows:

a) Model without LID
b) Permeable pavement
c) Infiltration trenches

Model without LID

This model was inclined on MNIT plan, without any LID elements. All roads, pipes and gutter were used without any modification, and all impervious area was openly connected. This model was the basic model and was used for comparison purpose with the model with LIDs, and results were compared in the upcoming section.

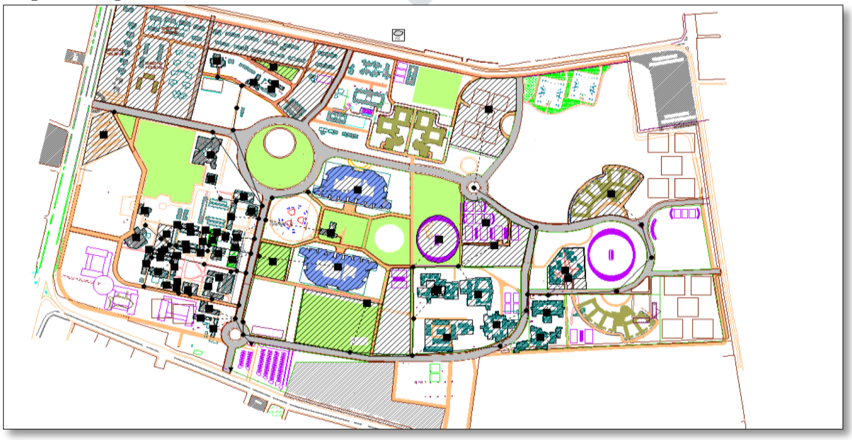

Figure 9 Model without LID

Permeable Pavement Model

In this model, subcatchments were converted into permeable pavements using full infiltration method; with this some of the road where outfall was high was converted into permeable pavements.

Infiltration Trenches

In this model, infiltration trenches were provided throughout the subcatchments. The infiltration trenches were without under drains and vegetation volume fraction was taken as 0.2 indicating that high vegetation.

VI. Result and Discussion

In this section give results and output of the modeling done and also discusses the SWMM modeling outcome of the scenarios explained above

Traditional Model Result

The detailed report generated via modeling is attached at the end of the paper. However comparison between different structures is mentioned below:

Runoff Produced

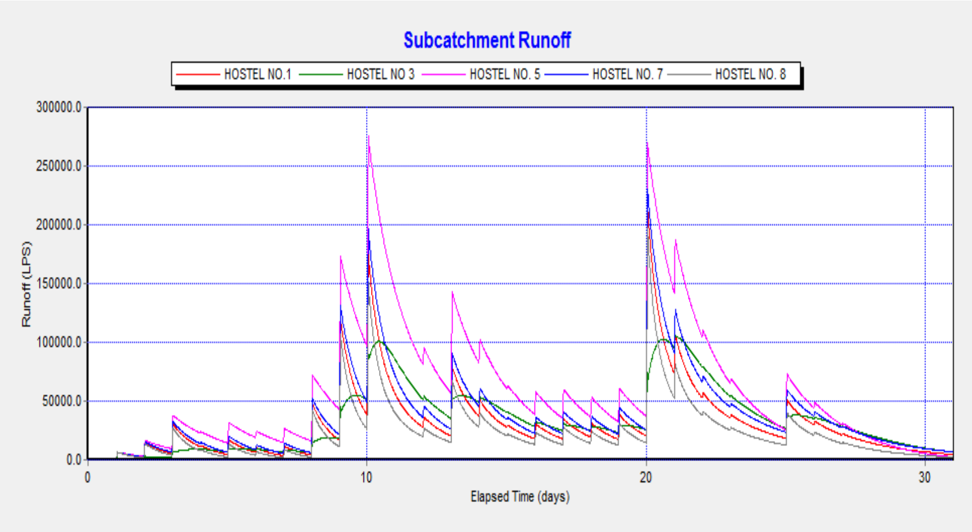

Figure 10 Runoff Genrated By Different Hostels

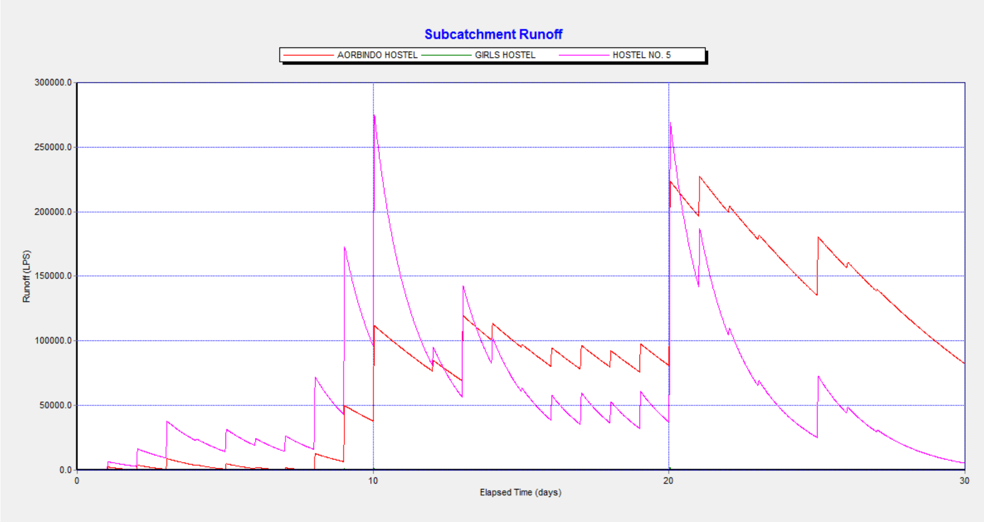

Figure 11 Runoff Generated by Different Hostels

On comparing runoff generated by different hostel present on study site it was found that runoff produced at hostel number 5 is greatest. The reason for this may be that the conduits of this hostel take runoff produced by hostel number 4, runoff coming from 6 and 8. On comparing runoff generated by different academic structures, it was evaluated that sports complex and mechanical department structure produce large runoffs. The result can be seen in figure 12.

Likewise on comparing runoff produced residential structure present in the campus, the results showed that residential building too were among highest producing runoff catchments. The results can be seen in figure 13. However, it's interesting to note that the faculty housing having green area produce less runoff then the faculty housing having small or no

Green area. A comparison is also made between other minor structures like estate section, dispensary, lab and workshop present in the campus and result are shown in figure 14.

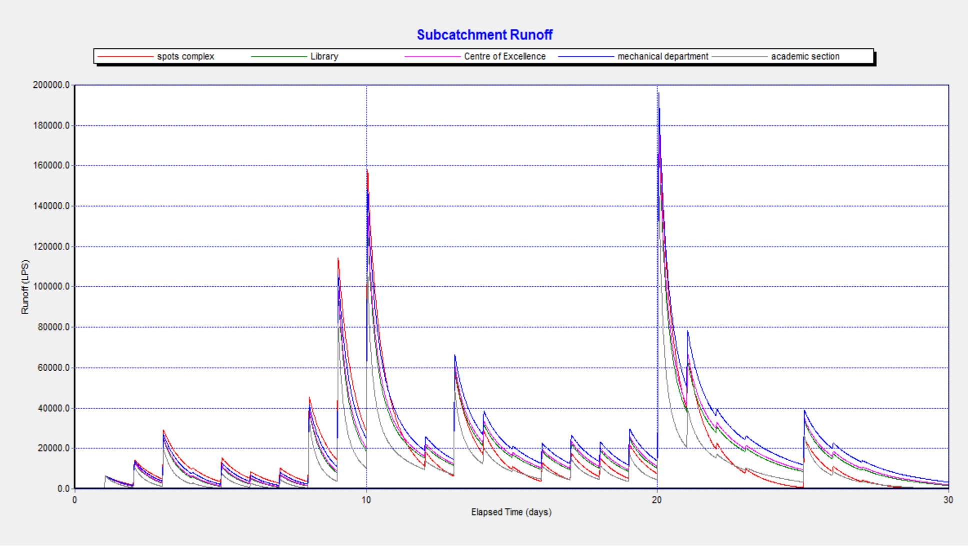

Figure 12 Runoff Comparison between Academic Structures

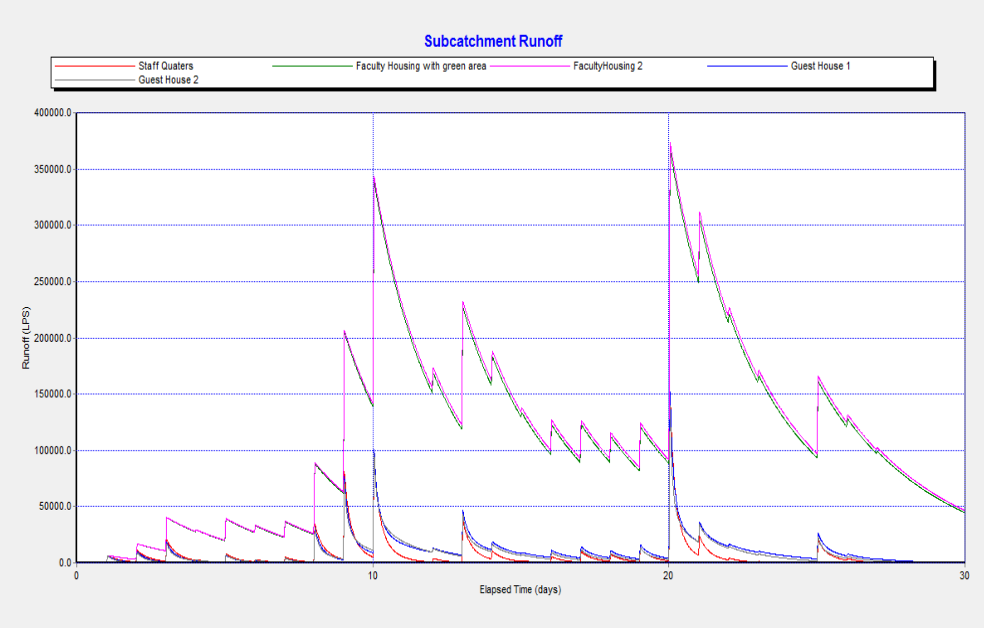

Figure 13 Runofff Comparision Between Housing Present In Campus

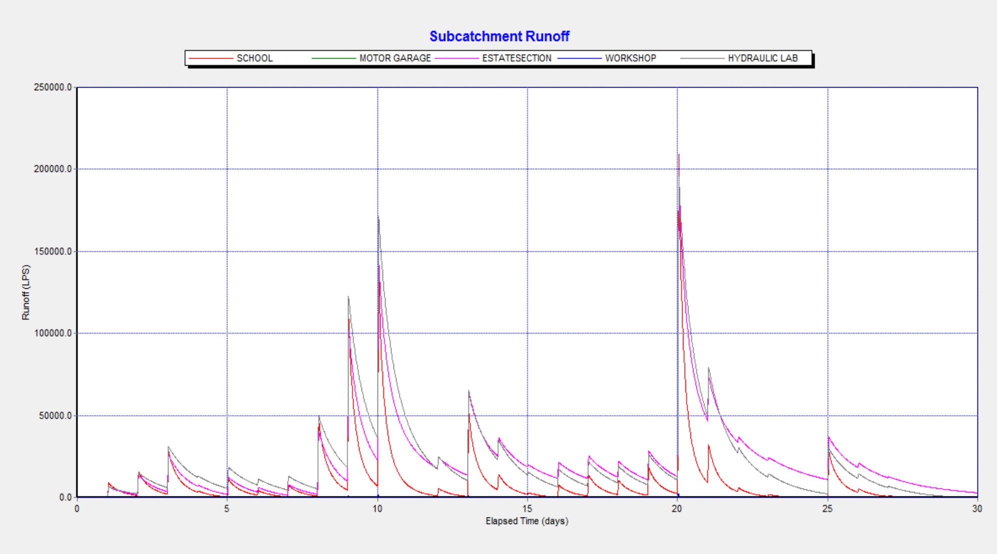

Figure 14 Runofff Comparision Between Other Structures

Flooding of Nodes and Conduits

Simulation result showed that every node was flooded, that is, water overflows the node except nodes94, 102, 125, 126, 133, 134, 136 and 143. These are the node present near hostel number 8, and the sub node present at academic wing.
Same was the case with conduits; each conduit was flooded with a rate of 29.3 liters per second.

Model Having Porous Pavements without under drains

The major subcatchments producing highest runoff were installed with porous pavements having following characteristics:

- SURFACE PROPERTIES:
  - STORAGE DEPTH = 6mm
  - VEGETATION VOLUME FRACTION = 0.2
  - SURFACE ROUGHNESS =0.1
  - SLOPE = 1%
- PAVEMENT PROPERTIES :
  - THICKNESS = 6 mm
  - VOID RATIO =0.15
  - PERMEABILITY = 100 mm/Hr
- STORAGE PROPERTIES :
  - HEIGHT = 6 mm
  - VOID RATIO = 0.75
  - CONDUCTIVTY = 10 mm/Hr

In first simulation 50 % of the sub catchment area was covered with porous pavements full report is attached at the end of the report, however few important result are mentioned below:
The pavement was most effective for parking places where runoff was reduced to zero.

Below is figure showing precipitation versus runoff characteristics before the installing pervious pavements:

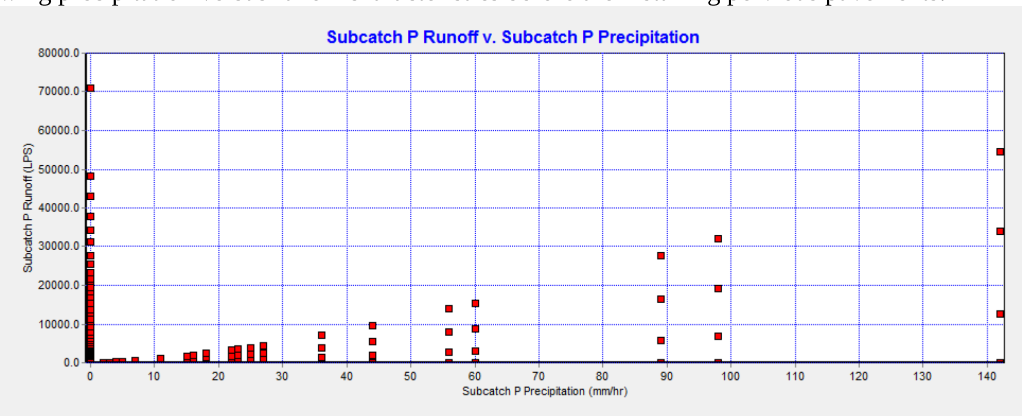

Figure 15 Runoff V/S Precipitation of Parking Area

And below is figure showing variation after installation of porous pavements:

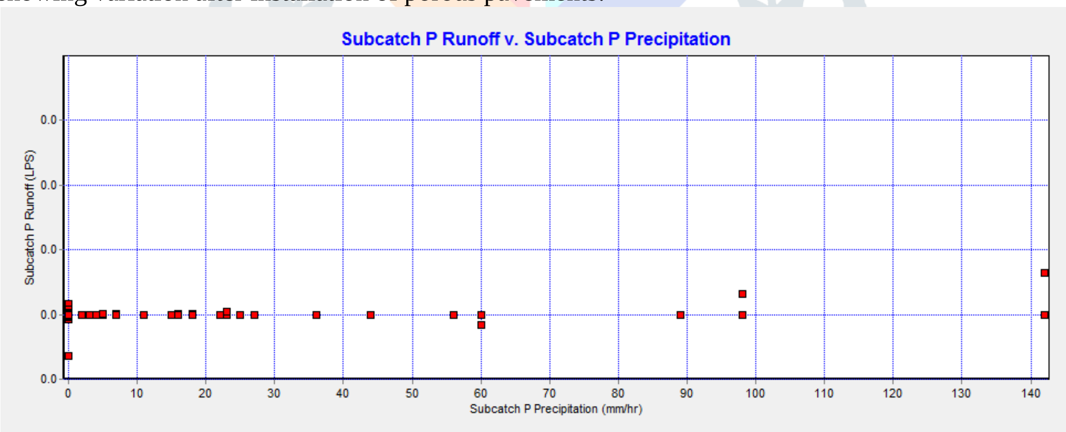

Figure 16 Parking Area after Installation of Pervious Pavements

For large areas producing large runoff the results were also satisfactory for example, figure below is between precipitation v/s runoff before and after installation of pervious pavements in faculty housing area.

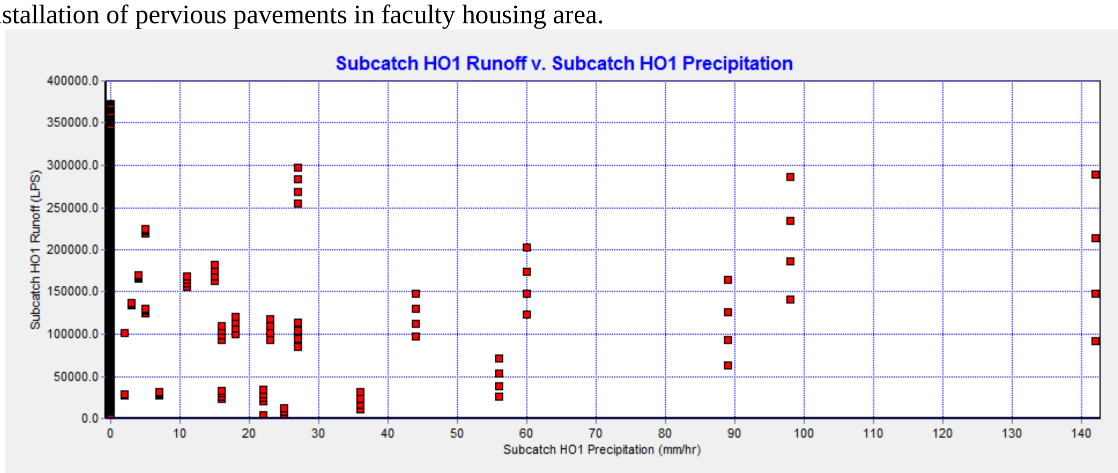

Figure 17 Before Installation of Pervious Pavements

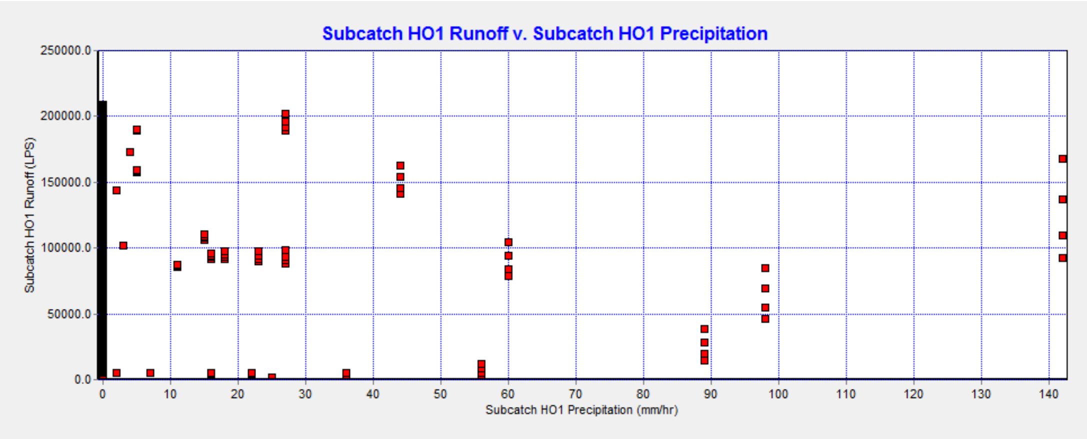

Figure 18 After Installation of Pervious Pavements

However, for few areas which were producing high runoff, installation of previous pavements lead to greater runoff.

Models with Infiltration Trenches

In this case modeling was done by installing infiltration trenches throughout the catchments.
The infiltration trenches were designed as follows:
Surface properties:

- Storage depth = 8mm
- Vegetation volume = 0
- Surface roughness = 0.1
- Slope =2 %

Storage properties:

- Height = 12mm
- Void ratio = 0.8
- Conductivity = 12

Under drain

- Drain coefficient = 10
- Drain exponent = 0.5

VII. CONCLUSION

The result obtained clearly show that there is high rate of runoff generated throughout the site. This urban runoff can be controlled by using various Best Management Practices. It was also proved by simulation by using best management practices the peak flow rate can be controlled, which in normal conditions adequate to meet storm water requirements. It was seen by modeling that when the subcatchments were installed with infiltration trenches and pervious pavements, the runoff was reduced to great extent, however, it should be mentioned here that LID is complex to model, care must be taken while designing and planning LID systems and before installing LIDs there cost perspective must be taken into account. Though installation of LIDs is efficient but during the study it's found installing only BMP's is not enough for managing the urban runoff for the site. Simulation also showed that there is large overflow occurrence situation persists in drains. The basic reason for this situation is mismanagement and poor design of structure. The water flow distribution throughout the drains was uneven. Simulation result showed that continuous conduits number 95 and 90 were surcharging whereas conduit 94 which was succeeding the conduits series was not flooding. This means that conduit number 95 and 90 were receiving surplus amount of water but this water was not able to transfer to conduit number 94, there are multiple reason for this phenomena. the important reasons are a) the conduit are provided with minimum elevation, because of which the water is not able to flow under the efficiently under gravity effect, b) The conduit are filled with pollutant sources, there are grasses, plants and variety of garbage present in almost all conduits present in campus which hinders the flow of water. Simulation showed that all conduit were provided with minimum elevation, which need to be taken care of as without appropriate elevation, runoff water does not able to flow efficiently. It was also seen from simulation that almost all conduits present in study site were suffering from surcharge and flooding problem. The simulation also showed that the speed with which urban runoff water was moving through nodes and conduits was very slow, which resulted in poor disposal of urban runoff water, this was due to the fact that the conduits were provided with minimum elevation.

As a conclusion of this study, further exploration is required for following:

1. Study on cost effectiveness of LID's like infiltration trenches, pervious pavements, and how this cost can be reduced.
2. Supervising rate of percolation of water through permeable pavements in new and existing pavements.
3. Further study of economics of LID's
4. Effective clogging prone areas present in study site and how they can be eliminated.
5. Better designing of nodes and conduits throughout the study site.
6. Use of multiple LID's for getting more efficient as well as economical results.

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