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Applicability of SWMM for semi Urban Catchment Flood modeling using extreme Rainfall Events

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Abstract: Urban floods are different type of flooding event as compared to normally occurring riverine floods which is very often seen along the river banks during heavy rainfall in monsoons. Continuous human interventions in natural vegetative land for rapid Urbanization activities has given rise to Urban Flooding. So, there is a need for capacity analysis of existing storm networks and identification of overflow locations is the need of the study. Hence, in the present study an attempt has been made to simulate Urban Flood scenario for a semi Urban catchment using Storm Water Management Model (SWMM). The whole area is divided into 20 sub catchments and the data acquired from 2017 rainfall events is used for modelling. The study area is represented in SWMM by the help of Master Plan AutoCAD maps having drain lines and Reduced Levels (R.L.s) information. From this detailed elevation information of various nodes and length of pipe lines has been estimated to make the schematic view of the study area in SWMM. The focus of the present study is to model runoff conditions using Dynamic wave method of flood routing and Green-Ampt Infiltration model in SWMM. The results showed that SWMM has capability to model and interpret flows at various channel sections and nodes for mitigating floods. Due to unavailability of gauged flow data the model Parameters needs calibration for more reliable results. Model has effectively given catchment responses for peak flow and volume of runoff which is considered as one of the essential components of Urban drainage planning to mitigate the risk of flood.

Index Terms: Reduced Levels, Green-Ampt Infiltration model, Modeling, SWMM, Urban Flood.

I. INTRODUCTION

Flood is a natural phenomenon which has certain positive consequences but when it occurs in an urban area then it may results into great devastation to people. Due to high intensity rainfall events in Urban areas prevention of flooding is very difficult due to lack of adequate drainage systems [1]. Across the Globe Urban planners are encountering enormous challenges due to increment in Urban flooding situations [2]. Due to Urbanization vegetative areas are being converted into roads, buildings, side walk, parking lot etc. [3]. Due to Urbanization imperviousness of the watersheds is a crucial parameter to manage [4]. Due to excess runoff from imperviousness surface there is negative ecological effects which increases flood risk [5]. In India some major metropolitan cities like Bengaluru, Chennai, Hyderabad, Kolkata etc. has encountered numerous number of Urban flood situation in last few decades. Generally due to inadequate capacity of drainage systems and in congestion of sewer systems it has contributed large scale flooding events. During this type of events regional transport facilities is also disturbed due to failure in Traffic systems thus, causing great inconvenience to people. Due to high intensity rainfall events which are unpredictable in naturally occurring in urban catchments is becoming a major challenge these days due to inadequate proper drainage systems and climate change factors [6]. Thus, an Integrated Urban watershed management is very much required to mitigate the population from ill effects of Urban Floods. Rainfall-runoff relationship of the catchment is mostly altered by Urbanization. Due to unplanned Urbanization and reckless deforestation there is more availability of barren and impermeable land surfaces which alters the natural flow route. There are various types of open source available software tools like Hydrologic Engineering Centers-River Analysis System (HEC-RAS), Hydrologic Engineering Centers-Hydrologic Modeling System (HEC-HMS), Storm Water Management Model (SWMM), MIKE URBAN, MIKE FLOOD etc. which can efficiently model Urban Flood Scenarios in a catchment. SWMM can be used for design of drainage systems and to simulate dynamics of single events or for modeling on a continuous basis [7]. Generally, storm drainage infrastructures comprised mostly of manholes, pipes, gullies and pumping stations, which are mainly designed based on historical rainfall data. [8] Concluded that due to rapid urbanization infiltration reduces and surface runoff increases which consequences peak flood and also volume increases despite of low intensity rainfall. This catastrophic event may be life threatening as well as it can cause widespread damage to public as well as private property like infrastructure, highways and various lifeline services. It can further have many implications on National as well as state or regional level economy to a large extent. For Hydrologic designs computation of rainfall extremes is important for both structural as well as non-structural flood protection measures [9].

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SWMM is the open source software tool which is available most widely for research activities and solving real problems of Urban Floods in an urbanized catchment [10]. From this we can easily incorporate modeling capabilities for both hydraulic and hydrologic conditions which is its major advantage over other available tools. Moreover, after doing authentic calibration and validation of SWMM it will be more convenient to use it by incorporating rainfall and drainage characteristics of the area for prediction future flood events. [11] Developed an open source sub catchment generator program for SWMM to automate various stages in the model construction process. The system was tested by applying it to two small urban catchments with different fractions of impervious surfaces in Helsinki, Finland, using mostly openly available data. Automatically generated and manually constructed SWMM models produced discharge results that differed only slightly from each other. [12] Simulated scenarios with different layouts using SWMM, to enquire various layouts in controlled manner having different rainfall conditions. Storm water monitoring and analyzing tasks are expensive and time consuming, therefore, storm water quantity and quality models are needed [13]. Since, flood analysis due to land use pattern is a great concern ([14]). Hence, from the above research studies, it is observed that there is a need to model drainage networks in Urban and Semi Urban areas for Urban Flood Management. So, in the present study an attempt has been made to model KLEF campus by using SWMM (Storm Water Management Model) to check the likelihood of its vulnerability to urban flooding. Storm Water Management Model (SWMM) was used as the hydrologic model due to its capability to model Urban flood conditions for urban catchments ([15]). It is developed by Environment Protection Agency, USA [16] is a dynamic rainfall runoff simulation model which calculates runoff from urban areas [17]. SWMM can be used for design of drainage system and to simulate dynamic of single events or for modeling on a continuous basis [18]. Generally, runoff is diverted with the help of storage/Treatment devices, pipes, channels, Pumps and outlets. It is a full dynamic wave simulation model used for single event or long-term events [19]. According to (FDEP), As rainwater falls on the pervious surface in Florida, on an average 50% will evaporate, 30% will runoff and will enter a nearby surface water, and 20% will infiltrate into the ground [20]. This catastrophic events may be life threatening as well as it can cause widespread damage to public as well as private property like infrastructure, highways and various lifeline services. It can further have many implications on national as well as state or regional level economy to large extent. For Hydrologic designs computation of rainfall extremes it is important for both structural as well as nonstructural flood protection measures [21]. Flood modeling is mainly designed to explore all the characteristics and the nature of flood in the urban area with respect to the impacts of heavy rainfall on the runoff of the urban sub-catchments and the various socio-economic aspects of flood [22]. Several researchers tried to better the performance the EPA tool kit but considerable effects are not identified in SWMM [23].

II. MATERIALS AND METHODS

A. Study area Description

The loacation map of the study area has been shown in Fig. 1 which lies between 16°26'40" and 16°26'26" North Latitude and 80°37'12" and 80°37'24" East Longitude. It is in Vaddeswaram Village of Guntur district, Andhra Pradesh (India). The study area is receiving more than 900 mm of Annual Rainfall mostly from June to October. Temperature here rangining from 23.7 °C to 33.38 °C, with average temperature of 28.53 °C (Source: Climate-Data.org).

Since, a large portion of campus land is being pre- occupied by natural vegetation which includes trees, bushes, shrubs etc. so it is capable of infiltrating the precipitation occurring in the campus. But with the passage of time in near future there is more chances of infrastructure development in campus which will convert the major portion of campus land into impervious surface.

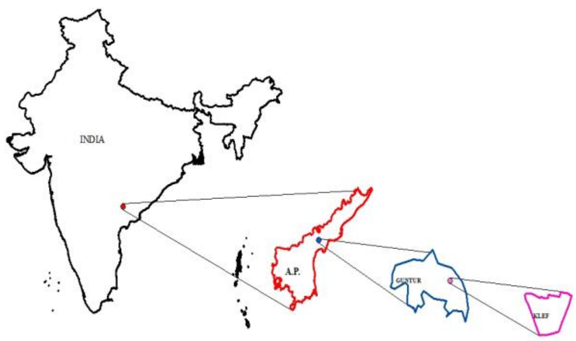

Figure 1: Location map of Study area

B. Data requirements

To set the basic framework of subcatchments in SWMM various sets of data is identified which is given in Table 1. This information is essential in physical representation of the study area in SWMM with various characteristics. Various other data which includes AutoCAD maps of the study area with proper drainage system (sewer lines, open channels etc.) is considered. Further information about the Invert level of sewer pipe lines (dia- 6 inch, 8 inch & 12 inch) which carry water to Sewage Treatment Plant at the outlet and rainfall data of 1 hr interval is being collected from one meteorological observatory of Vijayawada with the coordination of Atmospheric Science Division, KLEF.

Table I: Subcatchment characteristics and area

Subcatchments	Area (Acre)	Width (feet)	N - Imp	N - Perv	Average Slope (%)	Imperviousness (%)
Boys_Hostels1	0.511	290.01	0.01	0.1	2.5	94
Boys_Hostels2	0.782	99.04	0.01	0.1	3.5	87
Girls_Hostels	1.356	262.46	0.01	0.1	3.5	93
Bank/Post_Office	0.559	227.03	0.01	0.1	3.0	92
2Wheeler_Parking	0.528	328.08	0.01	0.1	3.5	84
FED_Block	0.679	154.33	0.01	0.1	3.5	91
C_Block	1.107	310.82	0.01	0.1	2.5	94
Mechanical_Block	0.6	291.99	0.01	0.1	3.5	93
Library	0.607	160.76	0.01	0.1	3.0	94
Electrical_Block	0.498	167.32	0.01	0.1	2.5	92
Indoor_Stadium	0.547	182.64	0.01	0.1	2.5	93
Research_Blocks	1.112	246.71	0.01	0.1	3.5	94
New_Block	0.782	146.02	0.01	0.1	3	94
Tennis_Court	0.511	141.05	0.01	0.1	1.5	95
Badminton_Court	0.512	148.21	0.01	0.1	2	92
Volley_Ball	1.35	217.82	0.01	0.1	2	75
Greenery	1.104	157.13	0.01	0.1	3.5	70
Bus_Terminal	0.769	175.08	0.01	0.1	4	75
RMC_Plant	1.65	126.21	0.01	0.1	3.5	75
Main_Ground	4.972	314.90	0.01	0.1	4	70

C. Building the model :

The entire study area is divided into 20 sub catchments in which storm networks are shown by nodes, junctions, conduits and outfall. Rainfall events of 2017 are considered to model with the help of Rainfall runoff block in SWMM. Horton method is used for Infiltration analysis while Dynamic wave method is used for flow routing assessment of the catchment. With the help of AutoCAD imagery of the study area Storm network map has been extracted which is loaded in SWMM through load image option. The layout of Storm network map is discretized in SWMM to make schematic of the study area. Various data of Junction like invert elevation and maximum depth are considered as input parameters while for conduits its dimension, depth, shape, roughness etc. is considered as input parameters. The Model building process in SWMM involves series of operations in various number of datasets which is being represented by flow chart in Fig 2. Firstly, in SWMM all the buildings are drawn and various nodes are made which represents drainage through each individual sub catchments and these nodes are further linked via conduits to further represent the drainage system. Thus, schematic representation of the study area is being well mentioned in SWMM with all components to model Urban Flood. The output of the model is being represented by Time Series, Profile and Scatter Plots.

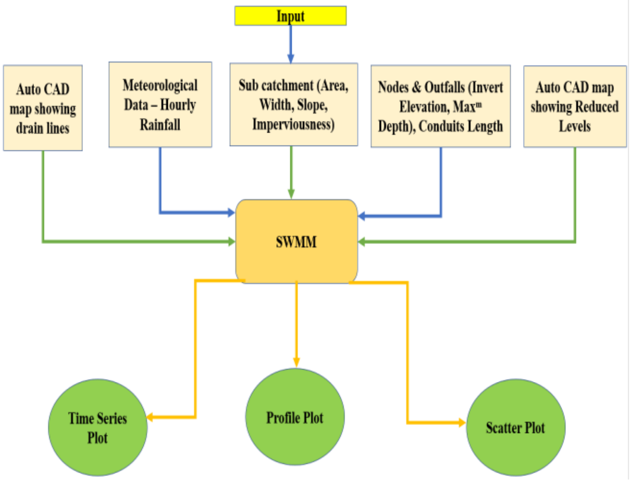

Figure 2: SWMM working Flow Chart

The study area is being represented in SWMM as shown in Fig 3. It consists of a Rain Gauge station, 18 number of sub catchments which are connected by 15 Nodes, 13 Conduits and an Outlet. The Runoff generated from each sub catchments is contributing to various nodes which are connected together through conduits networks.

Figure 3: Sub-catchment discretization in SWMM

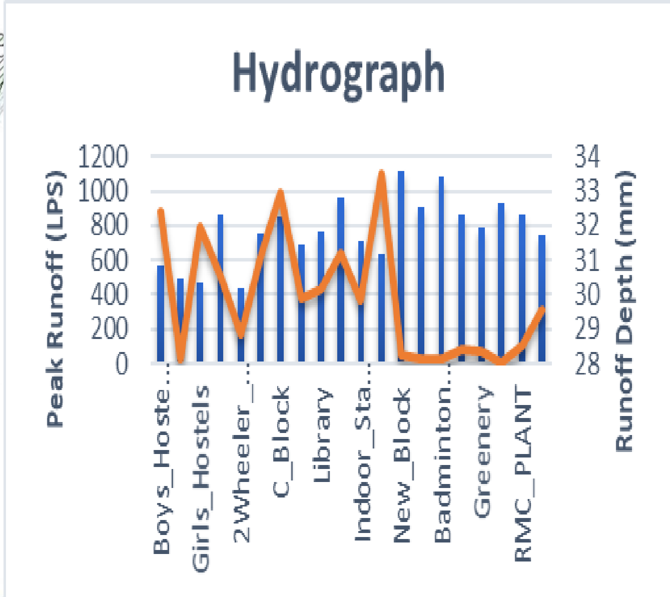

Fig 5: Sub catchments runoff for Sept 3, 2017 rainfall event

III. RESULTS AND DISCUSSION

It has been observed that SWMM has been reasonably generated the runoff for three extreme rainfall events. The study so far undertaken have attempted to determine the max runoff of each sub catchment. The runoff generated from major sub catchments of the study area for Rainfall events of Aug 29, 2017; Sept 3, 2017 and June 6, 2017 is shown in Fig. 4, 5 & 6 respectively. These Hydrographs guides us in understanding the Rainfall Runoff relationship of the sub catchments with respect to various rainfall events. It is being observed that peak of runoff and time to peak is highest observed for the rainfall event having more rainfall intensity.

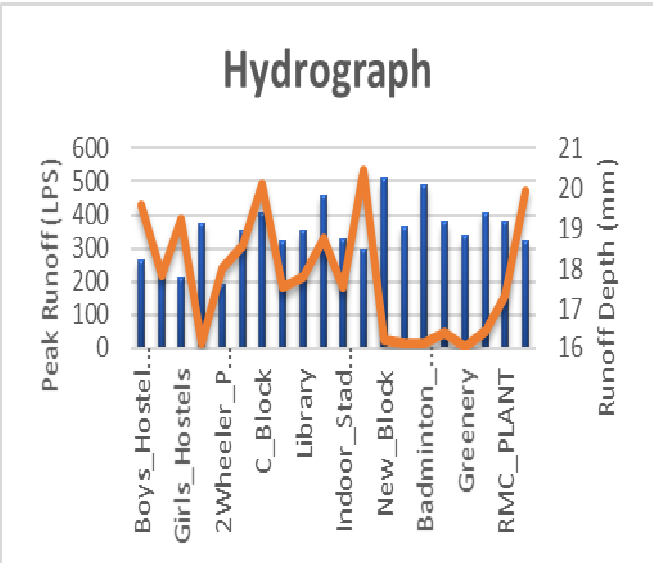

Fig 4: Sub catchments runoff for Aug 29, 2017 rainfall event

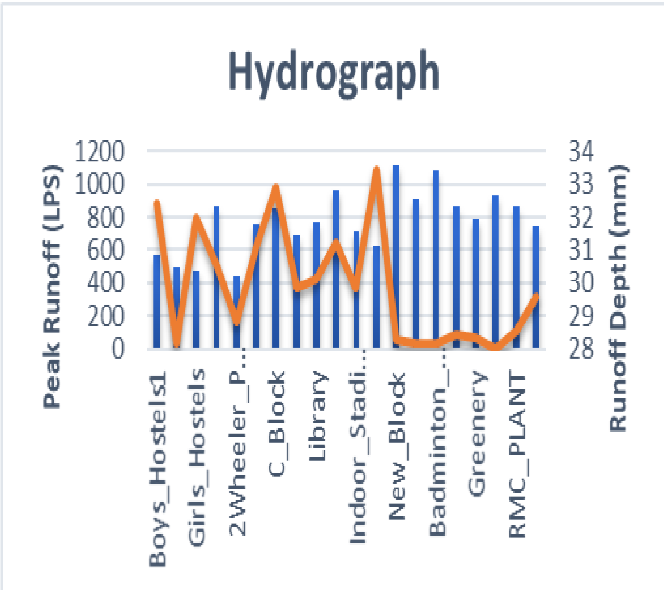

Fig 6: Sub catchments runoff for June 6, 2017 rainfall event

It is a technique which analyzes the information by graphical representation for understanding relative behavior of all variables in an information set. Profile plots give another helpful graphical outline of the information which is one of the effective data analysis techniques. Profile plot for water elevation from Node J1 to Node J14 is given in Fig. 7. From the Profile Plot it is observed that the elevation of the conduit is increased from RL 324 m to RL 326 m with the increase of the distances from sub catchments to the outlet as the elevation of the sub catchments is higher than the conduits mean water level.

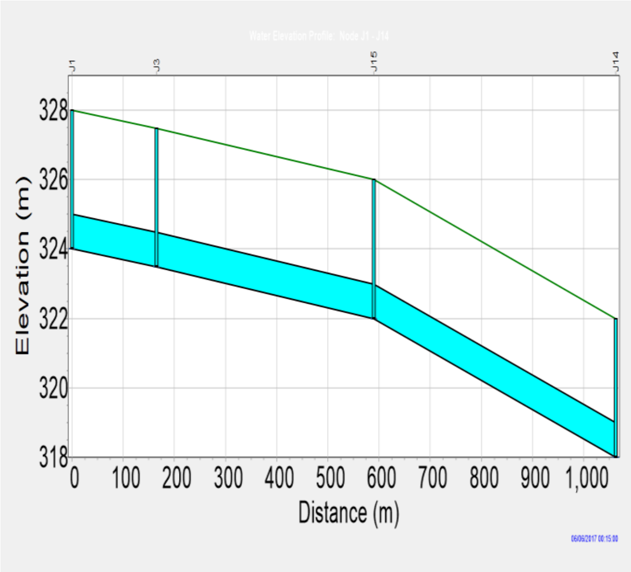

Fig 7: Profile Plot for Water Elevation between J1 to J14 Node

Node depths at various sections is shown in Table 2 which helps in understanding average depth of flow, maximum depth and maximum Hydraulic gradient line which the sum of Piezometric head and Datum head of water surface profiles is. This all relevant information guides us in determining adequate reduced levels of nodes to maintain suitable slope for proper flow in various conduit networks.

Link flows at various sections is shown in Table 3 which involves maximum flow, duration of maximum flow, maximum flow velocity, full flow and depths respectively. For designing and laying out various conduit networks these information is mostly desirable. It also helps in keeping adequate size and cross sections of conduits to easily cater the flow requirements during Urban flood conditions.

Table II: Node depth at various sections

Node	Average depth (m)	Maximum depth (m)	Maximum H.G.L. (m)
J1	0.13	0.66	324.66
J2	0.34	4	327.81
J3	0.4	4	327.81
J4	0.1	0.52	325.02
J6	0.12	0.6	324.58
J7	0.12	0.59	324.5
J8	0.13	0.66	324.42
J9	0.38	4	326.01
J10	0.1	1	322.01
J11	0.15	0.7	320.7
J12	0.02	0.08	321.08
J14	3.33	4	322
J15	0.19	1	323.01
J17	0.29	4	326.01
J22	0.16	0.96	319.96
J23	0.02	0.09	324.09
J24	0.02	0.09	323.19
J25	0.02	0.13	320.19
J26	0.07	0.35	320.35
J27	0.01	0.08	325.08
J28	0.08	0.41	319.41
Outlet	0.02	0.18	314.18

Table III: Link flow at various sections

Link	Maximum flow (LPS)	Hour of maximum flow	Maximum Velocity (m/sec)	Full flow	Full Depth
C1	924.23	2.43	1.35	1.08	1
C2	1331.53	3.01	2.46	0.77	0.66
C5	669.32	3.02	1.46	0.66	0.59
C6	1986.6	2.29	2.83	1.08	1
C7	2316.51	2.3	4.13	0.81	0.68
C8	1368.54	3.02	2.56	0.78	0.66
C9	1977.77	2.32	2.79	1.08	1
C10	1972.67	3.01	4.47	0.58	0.55
C15	2291.77	3.06	10.2	0.23	0.33
C16	2262.49	3.01	3.25	1.08	0.94
C17	65.18	2.32	2.08	0.01	0.08
C18	2100.44	2.19	3.65	0.83	0.69
C19	4928.57	3.02	2	0	0
C20	577.31	3.02	1.47	0.54	0.52
C21	44.52	3.02	1.22	0.02	0.09

C22	111.95	3.02	2	0.04	0.13
C23	18.69	3.02	0.82	0.01	0.08
C24	44.39	3.02	1.32	0.02	0.09
C25	551.37	3.01	2.31	0.26	0.35
C26	637.43	3.02	2.17	0.35	0.41

IV. CONCLUSIONS

The case study done in present research work has proved that SWMM is well suited for modeling and management Urban flood conditions. It is a suitable tool for modeling Urban Flood and considered very user friendly due to its result interpretation techniques in the form of Scatter plots, Time series and water profiles at various cross sections. It has facility to add backdrop imagery of the area which helps in laying out schematic view for sub-catchment discretization. Various input parameters like imperviousness and perviousness of an area along with roughness coefficients can adhere dynamism capability in Urban area. For considering flood mitigation scenarios SWMM has capacity to show case flows at various nodes, conduits and channel cross sections. Even in case of ungauged catchment and unavailability of high resolution imagery of ground features an effective modelling task can be accompanied with proper site survey. However, the SWMM Parameters need calibration for more reliable results. It is felt that the coupling of the GIS and SWMM create a useful and time saver tool to model large catchments. SWMM applicability provides peak flow runoff and volume of runoff which is considered as salient criteria for Urban drainage planning. Flow in the channels is dependent on the conduit slope and dimensions and roughness are the key factors.

REFERENCES

1. Ranger N, Hallegatte S, Bhattacharya S, Bachu M, Priya S, Dhore K, Rafique F, Mathur P, Naville N, Henriet F, Herweijer C, Pohit S, Corfee-Morlot J (2011) A preliminary assessment of the potential impact of climate change on flood risk in Mumbai. Clim Change. doi:10.1007/s10584-010-9979-2.
2. Goonetilleke A, Thomas E, Ginnc S, Gilbert D (2005) Understanding the role of land use in urban stormwater quality management. J Environ Manag 74:31–42.
3. S. Wang, H. Qiang, H. Ai, Z. Wang, Q. Zhang, Pollutant concentrations and pollution loads in storm water runoff from different land uses in Chongqing, J. Environ. Sci., 25 (2013) 502–510.
4. Lee, J.G. and Heaney, J.P., Estimation of Urban Imperviousness and its Impacts on Storm Water Sys- tems, J. Water Resour. Planning Management, 2003, vol. 129, no, 5, pp. 419–426.
5. Thurston, H.W., Goddard, H.C., Szlag, D., and Lem- berg, B., Controlling storm-water runoff with tradable allowances for impervious surfaces, J. Water Resour. Planning Management, 2003, vol. 129, no. 5, pp. 409– 418.
6. S. Wang, H. Qiang, H. Ai, Z. Wang, Q. Zhang, Pollutant concentrations and pollution loads in storm water runoff from different land uses in Chongqing, J. Environ. Sci., 25 (2013) 502–510.
7. J.Y. Wu, J.R. Thompson, R.K Kolka, K.J. Franz, T.W. Stewart, Using the Storm Water Management Model to predict urban headwater stream hydrological response to climate and land cover change, Hydrol. Earth Syst. Sci., 17 (2013) 4743–4758.
8. El Alfy, M. 2016, Assessing the impact of arid area urbanization on flash floods using GIS, remote sensing, and HEC-HMS rainfall–runoff modeling. Hydrol. Res. in press, DOI: 10.2166/nh.2016.133.
9. Rupa, C., Saha, U., Mujumdar, P.P., Model and parameter uncertainty in IDF relationships under climate change, Advances in Water Resources (2015), doi: hhtp//dx.doi.org/10.1016/j.advwatres.2015.02.011.
10. Kim, H., Jung, M., Mallari, K. J. B., Pak, G., Kim, S., Kim, S., Kim, L. & Yoon, J. 2015 Assessment of porous pavement effectiveness on runoff reduction under climate change scenarios. Desal. Water Treat. 53 (11), 3142–3147.
11. Lassi Warsta, Tero J. Niemi, Maija Taka, Gerald Krebs, Kersti Haahti, Harri Koivusalo & Teemu Kokkonen (2017): Development and application of an automated subcatchment generator for SWMM using open data, Urban Water Journal, DOI:10.1080/1573062X.2017.1325496.
12. Xing, W., Li, P., Cao, S.B., Gan., L.L., Liu, F.L. and Zuo, Z.," Layout effects and optimization of runoff storage and filtration facilities based on SWMM simulation in a demonstration area", Elsevier, 2016.
13. Ma. Christina A. Paule-Mercado, Chang-Hee Lee, 2016. Calibration of the SWMM for a mixed land use and land cover catchment in Yongin, South Korea. *Desalination and Water Treatment* doi: 10.5004/dwt.2017.11441.
14. Camorani, G., Castellarin, A., and Brath, A. (2005). "Effects of land-use changes on the hydrologic response of reclamation systems." Phys. Chem. Earth, Parts A/B/C, 30(8–10), 561–574.
15. Spry, R., and Zhang, S. (2006). "Modelling of drainage systems and overland flow paths at catchment's scales." Proc., Urban Drainage Modelling and Water Sensitive Urban Design, Monash Univ., Melbourne, Australia.
16. Rossman, L.A. (2005). Storm water management model- user's manual version 5.0, EPA-United States, <http//www.epa.gov/ednnrmrl/models/swmm5/manual.pdf>.
17. Huber, W. C., and Dickinson, R. E. (1988). Storm water management model, user's manual, version 4.0, EPA-600/3-88-001a. U.S. Environmental Protection Agency, Athens, GA.
18. Delleur, J.W., "The Evolution of Urban Hydrology: Past, Present, and Future," Journal of hydraulic engineering, vol. 129, Issue 8, 2003, pp.563-573.
19. M. L. Waikar and Undegaonkar Namita U, "Urban Flood Modeling by using EPA SWMM 5," SRTM University's Research Journal of Science, Vol. 1, 2015.
20. Florida Smart (2006). "Florida Climate- Seasons in Florida," Retrieved February 10, 2010. Florida Smart Web guide. www.floridasmart.com/sciencenature/weather/seasons.htm
21. Shashank Vanakudar, Raja Shekhar S. Laddimath, "Sustainable Development of Storm Water Management using SWMM for Bhagyanagar, Belagavi," International Journal for Innovative Research in Science & Technology, Vol. 3, Issue 02, 2016, pp. 488-493.
22. Vinay Ashok Rangari, Sriramoju Sai Prashanth, "Simulation of Urban Drainage System using a Storm Water Management Model (SWMM)," Asian Journal of Engineering and Applied Technology, Vol. 7, No. S1, 2018, pp.710.
23. Lee, J.G. and Heaney, J.P., "Estimation of Urban Imperviousness and its Impacts on Storm Water Sys-Tems," J. Water Resour. Planning Management, 2003, Vol. 129, Issue 5, pp. 419–426.

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