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SENSITIVITY ANALYSIS OF STORM WATER RUNOFF MANAGEMENT MODEL

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This paper presents a sensitivity analysis of the Storm Water Management Model (SWMM), which is the popular rainfall-runoff model estimating runoff from a rain event using physical characteristics of the area. To this end, the data of a planned industrial complex (located in peninsular coastal India) subdivided into four sub-watersheds having quite different geophysical settings has been employed. The analysis finds the runoff curve number to be the most sensitive parameter.

Keywords: *Flash floods, Industrial area, Rainfall-Runoff Model, Storm Water Management Model, Sensitivity analysis.*

INTRODUCTION

Storm Water Management Model (SWMM) is a model popularly used world over for design of drainage systems in urban/industrial complexes. It is developed by the U.S. Environmental Protection Agency (EPA, 1971). It is a dynamic rainfall-runoff model capable of simulating the movement of rainfall-generated runoff over the ground surface, through pipe/channel networks, and finally, to water body. This non-linear routing is governed by the width of the sub-

The model has undergone a number of upgradations since its inception and has witnessed numerous field applications worldwide. This model can be typified as a continuous model using long-term precipitation data (Lahlou, Choudhury, & Baldwin, 1995). It has been employed in planning of flood control works (Wanniarachchi & Wijesekera, 2012), sizing of detention ponds for water quality protection (James & Toan, 2015), flood plain mapping of natural channel system (Giron, 2005) and designing control strategies for minimizing combined sewer overflows (Ferreri, Freni, & Tomaselli, 2010).

Krebs et al. (2013) conducted a sensitivity analysis for Taapelipolku watershed in the city of Lahti (Finland) to determine the most influencing key model parameters with the aim to minimize the number of calibration parameters. Three criteria, viz., Nash-Sutcliffe efficiency, linear correlation coefficient, and sum of squared errors were used for performance evaluation. In sensitivity analysis, the parameters in model were changed independently within the predefined range to evaluate their impact on the output. The performance of model was seen to be have been dominated by the depression storage in impervious area and also by the Manning's roughness coefficient of the channel carrying storm water runoff. A similar study by Beling et al. (2011) using the data of four basins of Southern Brazil revealed that in steep basins, parameters 'storage height' and 'percentage of impervious area' were more sensitive in computation of runoff peaks and volumes. On a large area of Southern California, Barco et al. (2008) 'percent imperviousness' and 'depression storage' for impervious area were most sensitive affecting peak flow and total runoff. On the other hand, Manning's n for

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catchment and Manning's n (El-Sharif & Hansen, 2013). Sovann et al. (2015) applied SWMM for planning the city of Phnom Penh, Cambodia as an eco-friendly city involving the design of waste water management of wetlands using its results of surface flooding. Lai S.H.et al. (2008) employed SWMM for flood management in an urban area located at Peringgit Town in Melaka Tengah District of Melaka state, Malaysia.
overland flow was least sensitive.

Although SWMM requires a number of input variables for its application, only a few parameters have been subjected to evaluate for sensitivity. In this study, sensitivity analysis has been carried out comprehensively using the data of four widely varying small watersheds of a planned industrial complex and it is the primary objective of this paper. First, a storm water drainage network has been designed using SWMM for all the four watersheds and then all the involved parameters are subjected to sensitivity.

STORM WATER MANAGEMENT MODEL (SWMM)

SWMM (version 5.1 used in this study) is a physically based, discrete-time simulation model based on the principles of conservation of mass, energy, and momentum. It computes the runoff from rainfall in any catchment by dividing it into a number of sub-catchments. This runoff is routed to the respective outlets and, through aligned conveyance system, water is finally diverted to outfall and this outfall joins the natural streams around the study area. SWMM provides the output in variety of formats including drain network map, water elevation profiles in channels, time series graph, statistical report and tables. It also computes the volume of runoff and flow rate from each sub-catchment, depth of water at each node, inflow of storm water at each node, node surcharge, channel surcharge, loading at different outfalls, and depth of water attained in different channels, useful in design of channels. Further details are available elsewhere (Rossman, 2008).

STUDY AREA

SWMM was employed for drainage study of the Super Thermal Power Project (STPP) planned in coastal Pudimadaka District of Andhra Pradesh (India). The study area shown in Fig. 1 is about 885 acres (≈ 358 ha) having different land uses. Elevation of area ranges from 14 m to 6 m above msl. It is planned to consist boiler unit, pump house, crushed coal stock pile unit, desalination plant, ash pond, transmission line etc. The study area slopes from west to east with Doraipalem drain forming eastern boundary; Rambilli drain, the southern boundary; and Krishnampalem drain, the south-eastern boundary.

is connected to the next node through conduit. Water from these outfalls is taken to different drains located around the boundary of the study area through spillway with adequate energy dissipation arrangements. Separate drainage system and outfalls are proposed for the middle portion of STPP (Fig. 2).

Table 1: CN values for different parts of study area

Description of Area	CN	Description of Area	CN
Residential and office complex area	70	Pump House and desalination unit	61
Crushed coal stock pile unit	55	Transmission line corridor	70
Boiler unit	90	Forest cover	70

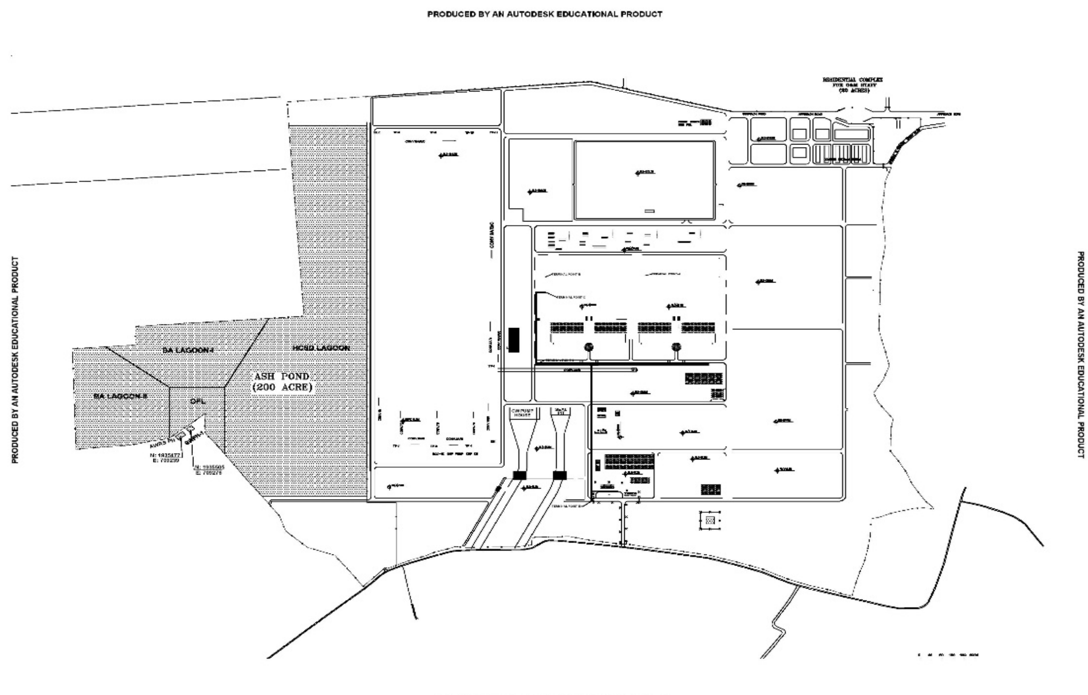


Fig. 1: Plan of study area

According to land use/cover and soil conditions, curve numbers were assigned as shown in Table 1.

Input Data

Fig. 2 shows the proposed layout of drainage channels (open rectangular section) and runoff contributing sub-catchments. Sub-catchments (SC) are divided based on the different properties of area, the layout of drains contains four outfalls, which join the natural river stream along the outer side of the plant area. SCs SC1 to SC3 (Pervious area) contribute runoff to Outfall 1, SCs SC4 to SC16 (Pervious area) to Outfall 2, SCs SC17 to SC31 (Impervious area) to Outfall 3, and SCs SC32 to SC45 (Pervious area) to Outfall 4. SCs SC4 to SC15 drain the area identified for crushed coal stock pile unit, SC23 to SC31 for boiler and desalination, SC37 to SC42 for lay-down and pre-assembly, SC32 to SC36 for residences and office complex, and the remaining area on the eastern side of the plant for green belt. Each SC has its one outlet node and it

Storm runoff from this area reaches Outfall 2 through channels (C4 to C21). Channel C22 to C43 convey the runoff to Outfall 3, and Channel C44 to C59 to Outfall 4. Runoff from Outfall 1 goes to Krishnapalem drain, from Outfall 2 & 3 to Rambilli drain, and from Outfall 4 to Doraipalem drain. The input data/parameters used in this study are described below.

Rainfall: In this study, drainage network is designed for 25 year of return period of rainfall. Design storm duration is taken as 6 hours considering the geomorphological characteristics of the area. Employing a distribution factor, this design storm is then distributed at 1 hour interval for the first six hour duration, as follows (CWC, 1987):

Time (hour)	1st	2nd	3rd	4th	5th	6th
Incremental Rainfall (mm)	77.78	28.8	17.28	8.64	8.64	2.88

Sub-catchments: The whole study area is divided into 45 sub-catchments. These sub-catchments differ in their topography, land use, and soil type and finally discharge their runoff to outlet point as shown in Fig. 2 and described in Table- 2b. Additionally, these sub-catchments are further divided into pervious and impervious areas. Runoff infiltrates while travelling through pervious areas and not from impervious areas. These pervious areas have some undulations which are accounted for by depression storage on the pervious sub-area. On the other hand, impervious areas do not retain water and therefore starts contributing runoff immediately. Thus, their depression storage is assumed to be zero. Associated properties of each sub-catchment based on their physical properties are described in Table 2a & 2b.

Junction Node Properties: In a drainage network, junction/node is the point of intersection of channels and also an outlet point of a sub-catchment which receives runoff from that sub-catchment (Fig. 2). Its properties are defined by invert elevation (m) and maximum depth (m), which range from 13.5 to 4.5m and 5.9 to 0.9m, respectively.

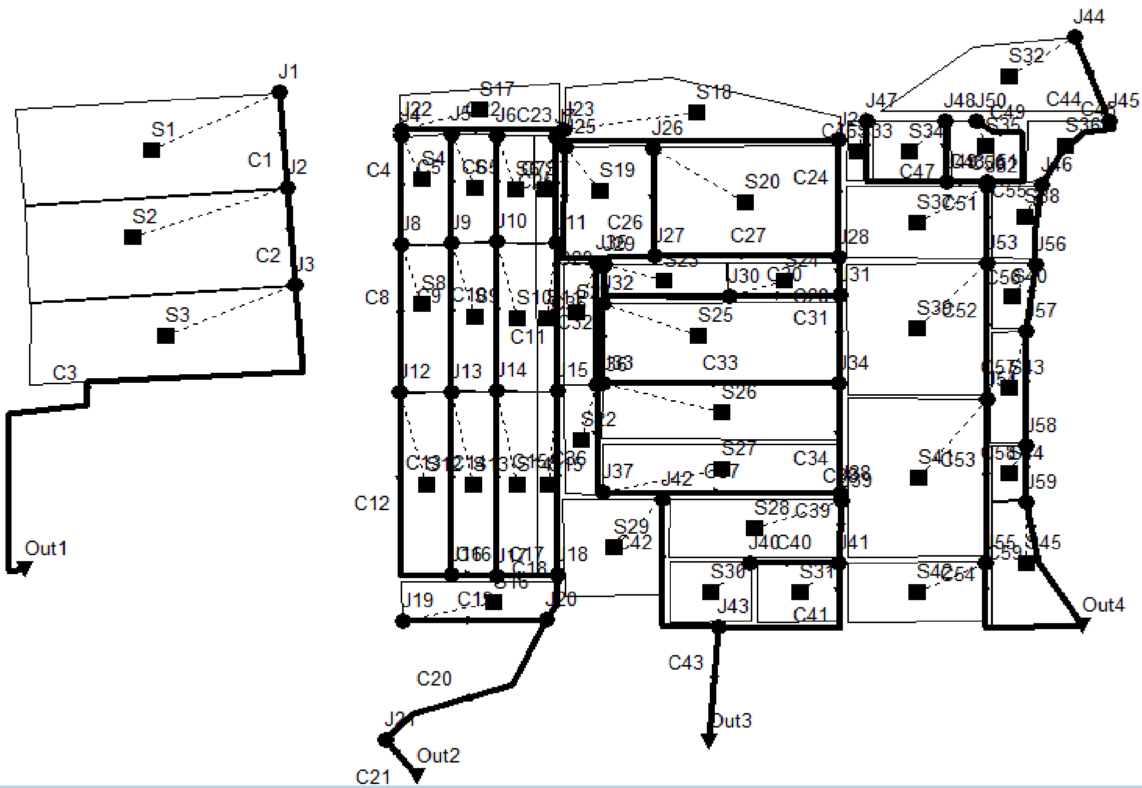


Fig. 2: Proposed layout of drainage channels and contributing catchments

Table 2a: Definition of terms and their possible values/ranges

Term	**Definition**
Rain gauge	Raingage associated with the sub-catchment.
Outlet	Name of one outlet of sub-catchment receiving runoff.
Area	Area of sub-catchment (hectares)
% slope	Average % slope of the sub-catchment (assumed 0.1% for all sub-catchments)
% Imperv	% of area which is impervious. It ranges from 0- 95%
n_i	Manning's n for overland flow over the impervious portion of sub-catchment. It is taken as 0.012.
n_p	Manning's n for overland flow over pervious portion of sub-catchment. It is taken as 0.05.
D_i	Depth of depression storage on the impervious portion of the sub-catchment. It is taken as zero.
D_p	Depth of depression storage on the pervious portion of the sub-catchment. It is taken as 2.54mm.
% Zero- Imperv	Percent of the impervious area with no depression storage. Assumed to be 100%
Subarea routing	Runoff from pervious and impervious route directly to the outlet.
Infiltration	Infiltration modelled using Curve Number technique. CN varies from 55 to 90.

Table 2b: Properties of sub-catchment provided in SWMM

Name	Area(ha)	%Imperv	Width(m)	CN	Name	Area(ha)	%Imperv	Width(m)	CN
S1	19.0	0	239.3	70	S24	2.83	90	283	90
S2	17.0	0	214	70	S25	16.18	90	226.8	90
S3	19.48	0	243.5	70	S26	11.33	90	159.5	90
S4	4.85	0	328.8	55	S27	10.12	90	142.5	90
S5	4.45	0	316.5	55	S28	8.54	0	163.86	61
S6	4.04	0	346.48	55	S29	8.45	50	293.4	70
S7	1.61	0	234.8	55	S30	3.64	0	160.8	61
S8	6.47	0	438.6	55	S31	4.04	0	165.9	61
S9	6.07	0	431.7	55	S32	8.45	75	136.57	70
S10	5.66	0	485.4	55	S33	0.81	5	119.1	70
S11	2.02	0	294.6	55	S34	3.64	75	165.9	70
S12	8.09	0	548.4	55	S35	3.23	75	165.2	70
S13	7.28	0	517.7	55	S36	1.62	75	65.6	70
S14	7.28	0	624.3	55	S37	8.45	20	202.15	61
S15	2.83	0	412.7	55	S38	2.83	0	162.6	70
S16	5.26	95	426.08	90	S39	16.18	20	387.1	61
S17	5.26	0	372.42	70	S40	2.02	0	151.1	70
S18	11.33	0	540.3	70	S41	16.18	20	385.2	61
S19	8.09	0	302.5	61	S42	6.48	20	154.3	61
S20	16.99	0	311.65	61	S43	2.83	0	297.8	70
S21	3.64	90	331.8	90	S44	1.62	0	170.5	70
S22	2.83	90	257.3	90	S45	6.88	0	229.3	70
S23	3.64	90	365.4	90					

Conduit Properties: Conduits are used to convey the water to the outfall, it can be an open channel or closed conduit. These are joined with nodes to divert the water and provided with a minimum slope of 0.7% so that the water flows by gravity. To avoid excessive excavation and filling drops have been provided in channels. Conduit properties are defined by various terms described in Table 3.

Outfall: It is the final output obtained in any catchment area and is a combination of all sub-catchments which in turn contribute to total runoff in the whole catchment area. Conveyance system routes the runoff and discharges into the river or any storage unit. Four outfalls have been proposed as shown in Fig 2 to economize the cost of drainage and improve drainage efficiency. Properties of these four outfalls are described in Table 4.

All the above properties were provided as input and trials were made for fixing channel dimensions (all rectangular in shape) such that there is no overflow in the channel. To avoid excessive excavation, the width to depth ratio was taken as 0.5. The channel dimensions are proposed using SWMM (Table 5) and these were fixed to convey maximum design flow (without exhibiting surcharge) with capacity utilization factor ≈ 1. This study based on the following considerations:

Table 3: Conduit Properties

Particular	Definition	Range/Value
Name	Name of conduit assigned by user.	C1 – C59
Inlet Node	Node at the inlet of conduit.	-
Outlet node	Node at the outlet of conduit.	-
Length	Length of channel in meters.	121- 1764.2 m
Roughness	Manning’s n (for concrete lined open channel).	0.016
Inlet offset	Difference in height of end of conduit and node at its u/s.	0
Outlet offset	Difference in height of end of conduit and node at its d/s.	1 – 4.6 m

Table 4: Outfall Node Properties

Name	User-assigned outfall name	Remark
Invert El.	Invert elevation of the outfall	Range (1.3 – 4.1 m)
Tide Gate	Tide gate for backwater effect	No tide gate is provided
Type	Type of outfall boundary condition	Free outfall assumed

Table 5: Section of Channels for proposed layout drainage plan using result from SWMM

S. No.	Channel Name	Length (m)	Q (m^3/sec)	U/S Inv. Level (m)	Slope	D/S Inv. Level (m)	$Qn/(S)^{1/2}$	Bed Width (m)	Estimated Normal Depth (m)	Vel. (m/s)	Adopted Depth (m)
1	C1	302.19	0.676	12	0.0017	11.5	0.20	1.5	0.43	1.07	0.8
2	C2	271.29	1.28	11.5	0.0010	10	0.49	1.8	0.67	1.31	0.8
3	C3	1764.2	1.972	10	0.0020	4	0.53	2.2	0.6	1.57	1.2
4	C4	346	0.203	13	0.0008	12.74	0.09	1.2	0.3	0.59	0.6
5	C8	434	0.47	12.74	0.0008	12.4	0.20	1.4	0.45	0.75	0.8
6	C12	721.11	0.801	12.4	0.0007	11.9	0.37	1.5	0.65	0.83	0.9
7	C5	346	0.187	13	0.0008	12.74	0.08	1.2	0.3	0.75	0.6
8	C9	434	0.44	12.74	0.0008	12.4	0.19	1.4	0.43	0.73	0.8
9	C13	576.2	0.741	12.4	0.0009	11.9	0.30	1.5	0.57	0.88	0.9
10	C6	346	0.179	13	0.0008	12.74	0.08	1.2	0.26	0.56	0.6
11	C10	434	0.423	12.74	0.0008	12.4	0.18	1.4	0.42	0.72	0.8
12	C14	576.2	0.732	12.4	0.0010	11.8	0.27	1.5	0.53	0.93	0.9
13	C7	346	0.092	13	0.0008	12.74	0.04	0.8	0.23	0.49	0.6
14	C11	434	0.196	12.74	0.0008	12.4	0.08	1	0.32	0.61	0.6
15	C15	576.2	0.338	12.4	0.0030	5.7	0.07	1	0.3	1.21	0.8
16	C16	132.32	1.542	11.9	0.0008	11.8	0.67	2	0.78	0.99	1.3
17	C17	176.41	2.26	11.8	0.0080	5.7	0.30	2	0.44	2.6	1.3
18	C18	159.67	2.548	5.7	0.0006	5.6	1.22	2	1.2	1.05	1.3
19	C19	420.79	1.151	6	0.0010	5.6	0.44	1.9	0.6	1.05	0.9
20	C20	654.42	2.957	5.6	0.0009	1.5	1.18	2.5	0.95	1.26	1.3
21	C21	134.03	2.957	1.5	0.0015	1.3	0.92	2.5	0.8	1.49	1.3
22	C22	474.7	0.383	13.5	0.0010	12.65	0.15	1.1	0.44	0.97	0.6
23	C23	786.5	1.012	12.65	0.0007	12.07	0.45	1.5	0.76	0.9	1
24	C24	357	1.01	12.07	0.0007	10.2	0.46	1.5	0.77	0.9	1
25	C25	570.12	0.346	11	0.0008	10.57	0.15	1	0.5	0.69	0.7
26	C26	333	0.54	10.9	0.0010	10.57	0.20	1	0.63	0.85	0.7
27	C27	505	0.88	10.57	0.0007	10.2	0.39	1.7	0.61	0.85	0.9
28	C28	121	1.852	10.2	0.0020	7.6	0.50	1.8	0.3	1.61	1
29	C29	441.47	0.8	8.13	0.0007	7.8	0.35	1.75	0.55	0.9	0.8
30	C30	314.39	1.39	7.8	0.0006	7.6	0.66	2.3	0.67	0.92	1
31	C31	253	2.344	7.6	0.0016	7.2	0.71	2.3	0.7	1.44	1
32	C32	157.9	3.043	7.5	0.0006	7.4	1.45	2.3	1.2	1.11	1.5
33	C33	680.5	5.041	7.4	0.0003	7.2	3.53	3	1.8	0.99	2
34	C34	331.4	7.165	7.2	0.0006	7	3.50	3	1.8	1.35	2
35	C35	384.02	0.796	8.18	0.0007	7.9	0.35	1.6	0.6	0.89	0.7
36	C36	384.02	1.395	7.9	0.0006	7.66	0.67	1.8	0.86	0.95	0.9
37	C37	680.5	3.261	7.66	0.0010	7	1.26	2.6	0.95	1.36	1.2
38	C38	12	10.226	7	0.0008	6.99	4.25	3.4	0.8	1.65	2
39	C39	187.5	10.4	6.99	0.0015	6.7	3.17	3.4	1.7	1.83	2
40	C40	345.9	0.164	7	0.0009	6.7	0.07	1	0.3	0.64	0.7

41	C41	345.9	10.668	6.7	0.0009	6.4	4.35	3.5	1.8	1.7	2
42	C42	394.8	1.221	7	0.0015	6.4	0.38	1.5	0.7	1.26	0.9
43	C43	351.2	11.51	6.4	0.0008	1.5	4.88	3.5	1.9	1.73	2
44	C46	432.2	0.164	9	0.0005	8.8	0.09	0.75	0.46	0.58	0.5
45	C47	192.6	0.693	9	0.0010	8.8	0.26	1.3	0.6	0.94	0.8
46	C48	120.3	0.847	8.8	0.0008	8.7	0.35	1.3	0.7	0.9	0.8
47	C49	400	0.622	9	0.0005	8.8	0.33	1.3	0.7	0.84	0.8
48	C50	12	1.468	8	0.0040	5.5	0.28	1.75	0.52	1.82	0.9
49	C51	243.3	1.988	5.5	0.0008	5.3	0.83	2	0.9	1.11	1
50	C52	427	2.982	5.3	0.0009	4.9	1.17	2	1.2	1.31	1.2
51	C53	512.6	3.932	4.9	0.0008	4.5	1.69	2.5	1.24	1.3	1.3
52	C54	530.3	4.262	4.5	0.0008	4.1	1.81	3.2	1.02	1.29	1.5
53	C44	326	1.419	9.25	0.0008	9	0.60	1.75	0.8	1	0.9
54	C45	288	1.696	9	0.0008	8.78	0.74	2	0.8	1.04	0.9
55	C55	235.6	1.874	8.78	0.0008	8.6	0.81	2.2	0.8	1.05	1
56	C56	215.2	2.019	8.6	0.0009	8.4	0.79	2.2	0.8	1.15	1.1
57	C57	357.3	2.239	8.4	0.0008	8.13	0.98	2.2	0.9	1.11	1.1
58	C58	191.2	2.362	8.13	0.0012	7.9	0.82	2.2	0.8	1.31	1.1
59	C59	464.3	2.672	7.9	0.0006	4.1	1.31	2.3	1.1	1.09	1.1

(i) Drainage channels carry safely the storm runoff due to 25 year design storm.

(ii) Channel slopes are kept such that the minimum flow velocities are maintained to avoid siltation and channel invert such that it avoids deep cutting.

(iii) Channels are concrete-lined and they are rectangular in shape.

(iv) Vertical drops are provided to negotiate high level difference.

(v) Outfalls are proposed at suitable locations following natural topography.

(vi) Channel slope, length, bed width are provided such that their capacity is generally utilized fully.

(vii) CN method is used for modelling infiltration.

(viii) Kinematic wave routing is used for flow routing in channels.

SIMULATION RESULTS

The assumptions made in the analysis of this model are as follows: (i) Water contribution at nodes is only from sub-catchment runoff, not from ground water,(ii) dry weather inflow into the node is zero,(iii) evaporation is negligible during simulation period and hence neglected, and (iv) Surface runoff generated from user defined catchment rainfall is only considered. Table 6 summarizes the SWMM simulation results. As seen, the total rainfall corresponding to uniform design storm of 144 mm is equivalent to 46.011 ha-m, volumetrically, and infiltration is of the order of 40%. Continuity in runoff generation is maintained at -0.187%, and in routing, it is -0.493%, and these are tolerable. Thus, the simulation is satisfactory. Runoff coefficients (Table 7) are seen to range from 0.368 (sub-catchments SC4, SC8 & SC12) to 0.989 (sub-catchments SC23 & SC24) with average for the entire plant area being 0.589.

Table 6: Runoff Quantity and Flow Routing Continuity Summary

Runoff Quantity Continuity	Volume (hectare-m)	Flow Routing Continuity	Volume (Hectare-m)
Total Precipitation	46.011	Final Stored Volume	0.178
Infiltration Loss	18.187	Wet Weather Inflow	26.596
Surface Runoff	26.606	External Outflow	26.550
Continuity Error (%)	-0.187	Continuity Error (%)	-0.493

Table 7: Determination of runoff coefficient for sub-catchment

Sub-catchment	Total Rainfall (mm)	Total Infiltration (mm)	Total Runoff (mm)	Runoff Coeff.	Sub-catchment	Total Rainfall (mm)	Total Infiltration (mm)	Total Run-off (mm)	Runoff Coeff.
SC1	144	64.67	67.99	0.472	SC24	144	2.4	142.6	0.989
SC2	144	64.67	67.98	0.472	SC25	144	2.4	140.3	0.974
SC3	144	64.67	67.91	0.472	SC26	144	2.4	140.3	0.975
SC4	144	89.92	53.02	0.368	SC27	144	2.4	140.3	0.975
SC5	144	89.76	53.13	0.369	SC28	144	80.37	57.04	0.396
SC6	144	89.42	53.54	0.372	SC29	144	32.33	110.8	0.769
SC7	144	88.41	54.47	0.378	SC30	144	80.37	60.87	0.423
SC8	144	89.92	53.02	0.368	SC31	144	80.37	60.64	0.421
SC9	144	89.76	53.13	0.369	SC32	144	16.17	126.8	0.88
SC10	144	89.42	53.54	0.372	SC33	144	16.01	128.6	0.894
SC11	144	88.41	54.47	0.378	SC34	144	16.17	128.2	0.889
SC12	144	89.92	53.02	0.368	SC35	144	16.17	128.2	0.89
SC13	144	89.76	53.13	0.369	SC36	144	16.17	127.2	0.888
SC14	144	89.42	53.54	0.372	SC37	144	64.3	76.59	0.532
SC15	144	88.41	54.47	0.378	SC38	144	64.67	76.45	0.531
SC16	144	1.2	143.4	0.997	SC39	144	64.3	76.59	0.532
SC17	144	64.67	76.88	0.534	SC40	144	64.67	76.98	0.535
SC18	144	64.67	75.98	0.528	SC41	144	64.3	76.57	0.532
SC19	144	80.37	60.33	0.419	SC42	144	64.3	76.57	0.532
SC20	144	80.37	56.73	0.394	SC43	144	64.67	77.54	0.539
SC21	144	2.4	142.1	0.988	SC44	144	64.67	77.54	0.539
SC22	144	2.4	142.1	0.988	SC45	144	64.67	74.79	0.519
SC23	144	2.4	142.7	0.989					

Table 8: Occurrences of maximum discharges/depths at each Node

Name of Node	Maximum Depth (m)	Maximum Total Inflow (CMS)	Name of Node	Maximum Depth (m)	Maximum Total Inflow (CMS)
J1	0.42	0.676	J33	1.82	5.153
J2	0.54	1.28	J34	1.79	7.161
J3	1.54	1.97	J35	0.59	0.78
J4	0.29	0.203	J36	0.85	1.384
J5	0.28	0.188	J37	0.97	3.294
J6	0.28	0.187	J38	1.81	10.193
J7	0.25	0.1	J39	1.81	10.378
J8	0.45	0.471	J40	0.26	0.165
J9	0.43	0.441	J41	1.79	10.664
J10	0.42	0.429	J42	0.67	1.23
J11	0.34	0.205	J43	1.91	11.503
J12	0.66	0.804	J44	0.83	1.433
J13	0.57	0.743	J45	0.83	1.706
J14	0.53	0.738	J46	0.83	1.882

J14	0.53	0.738	J46	0.83	1.882
J15	0.33	0.341	J47	0.45	0.158
J16	0.78	1.542	J48	0.58	0.691
J17	0.78	2.266	J49	0.74	0.851
J18	5.04	2.549	J50	0.6	0.616
J19	0.6	1.131	J51	0.73	1.467
J20	1.22	2.959	J52	3.61	1.991
J21	4.44	2.957	J53	1.19	3.019
J22	0.38	0.401	J54	1.25	3.971
J23	0.78	1.05	J55	1.24	4.292
J24	0.76	1.012	J56	0.82	2.024
J25	0.51	0.35	J57	0.94	2.249
J26	0.64	0.54	J58	0.93	2.364
J27	0.64	0.884	J59	1.09	2.691
J28	2.35	1.851	Out1	2.58	1.972
J29	0.54	0.78	Out2	0.79	2.957
J30	0.67	1.384	Out3	6.51	11.484
J31	2.63	2.343	Out4	4.58	6.826
J32	1.2	3.057			

Table 9: Conduit flow summary

Conduit Name	Maximum Flow (CMS)	Velocity (m/sec)	Maximum / Full Depth	Conduit Name	Maximum Flow (CMS)	Velocity (m/sec)	Maximum / Full Depth
C1	0.676	1.07	0.53	C31	2.342	1.44	0.71
C2	1.28	1.31	0.68	C32	3.043	1.11	0.8
C3	1.972	1.57	0.48	C33	5.041	0.99	0.89
C4	0.203	0.59	0.48	C34	7.134	1.35	0.89
C5	0.187	0.57	0.46	C35	0.796	0.89	0.85
C6	0.179	0.56	0.45	C36	1.395	0.95	0.95
C7	0.092	0.49	0.39	C37	3.261	1.36	0.79
C8	0.47	0.75	0.57	C38	10.193	1.65	0.91
C9	0.44	0.73	0.54	C39	10.371	1.90	0.73
C10	0.423	0.72	0.53	C40	0.164	0.64	0.37
C11	0.196	0.61	0.55	C41	10.637	1.71	0.89
C12	0.801	0.83	0.72	C42	1.221	1.26	0.74
C13	0.741	0.88	0.63	C43	11.484	1.73	0.95
C14	0.732	0.93	0.59	C44	1.419	1	0.91
C15	0.338	1.21	0.35	C45	1.696	1.04	0.92
C16	1.542	0.99	0.60	C46	0.164	0.58	0.89
C17	2.266	1.27	0.33	C47	0.693	0.94	0.72
C18	2.548	1.05	0.93	C48	0.847	0.9	0.92
C19	1.151	1.05	0.67	C49	0.622	0.84	0.75
C20	2.957	1.26	0.73	C50	1.467	1.82	0.58
C21	2.957	1.49	0.61	C51	1.988	1.11	0.91
C22	0.383	0.97	0.6	C52	2.984	1.3	0.98
C23	1.012	0.9	0.76	C53	3.934	1.3	0.95
C24	1.009	0.9	0.75	C54	4.264	1.29	0.7
C25	0.346	0.69	0.72	C55	1.874	1.05	0.82
C26	0.54	0.85	0.91	C56	2.019	1.15	0.73

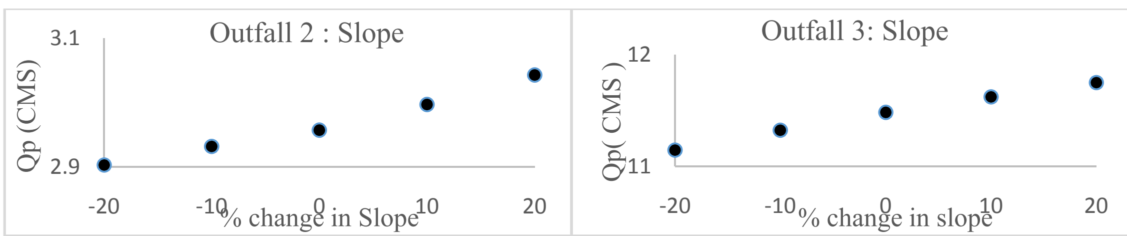
C26	0.54	0.85	0.91	C56	2.019	1.15	0.73
C27	0.88	0.85	0.68	C57	2.239	1.11	0.85
C28	1.851	1.94	0.53	C58	2.362	1.31	0.74
C29	0.8	0.9	0.68	C59	2.676	1.09	0.98
C30	1.39	0.92	0.67				

Table 8 shows the summary results of nodes, the maximum depth and total runoff inflow into the nodes from SCs. As seen, none of the nodes show flooding or surcharge condition. Table 9 shows the occurrences of maximum flows in different drainage channels/conduits. The velocities in different channels range from 0.49 m/sec (C7) to 1.94 m/sec (C28). The maximum velocity attained in each channel is generally below 2 m/s, which is safe.

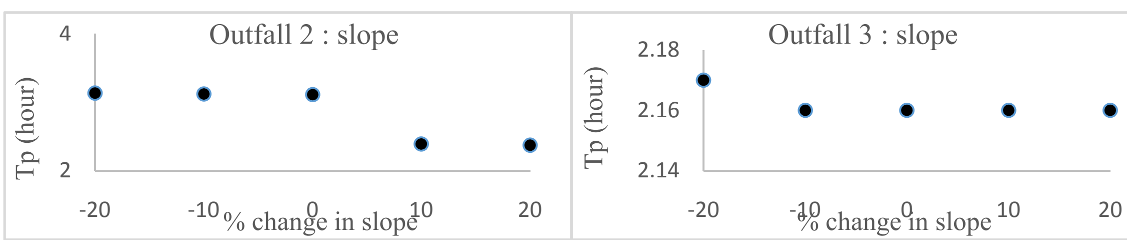
SENSITIVITY ANALYSIS

Sensitivity analysis (Table 10) was carried out to evaluate the effect of change in SWMM input variables on its output. Each of the above sub-catchments has been characterized by Area (ha), Imperviousness (%), Slope (%), D_p, D_i, n_p, n_i and infiltration method adopted. These characteristics show the runoff generation potential from that area. For sensitivity analysis, only one variable is changed at a time and the other parameters/variables are kept at their normal value. The resulting output is compared with each other for Peak Discharge (Qp), Time of Peak Discharge (Tp), and Volume of Hydrograph (V) at different outfalls. In sensitivity analysis, only one variable, i.e. D_i, does not change because in the SWMM percent of the impervious area with no depression storage is assumed as 100%. All the four parts (with individual outlets) of the whole study area are different from each other because of their significantly varying properties. For comparison of parameters, out of four outlets of the study area, only two outfalls 2 and 3 have been chosen as these are relatively more pervious and impervious, respectively, and sensitivity of each parameter presented in Figs. 3 through 9. In these figures, the % change in parameter value is shown with respect to the above normal condition used for drainage/channel design. Notably, the sensitivity results of the other Outlets 1 and 4 were, in general, similar, and therefore, not shown here.

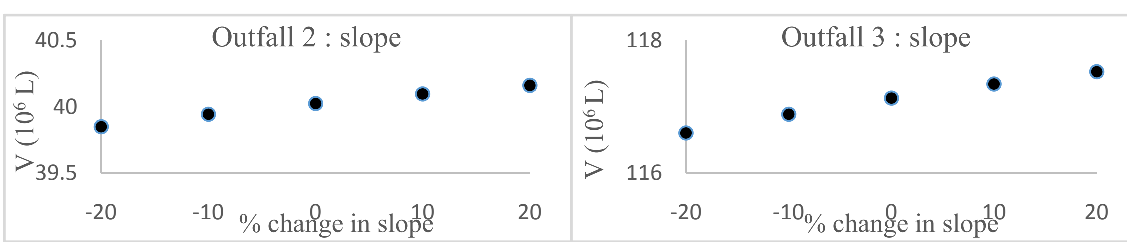
Sensitivity of Slope: Fig. 3 shows that, with increasing slope, both Peak Q_p and V increases, and T_p decreases. As an example, with increasing value of slope from 10% to 20% of that given in Table 10, Q_p increases by 0.046 and 0.128 CMS at outfalls 2 and 3, respectively.On the other hand, T_p for Outfalls 2 and 3 remains constant up to a certain slope value and then reduces rapidly.



(a) Peak discharge Q_p



(b) Time to Peak Discharge T_p



(c) Hydrograph Volume

Fig. 3: Sensitivity of Slope at different Outfalls

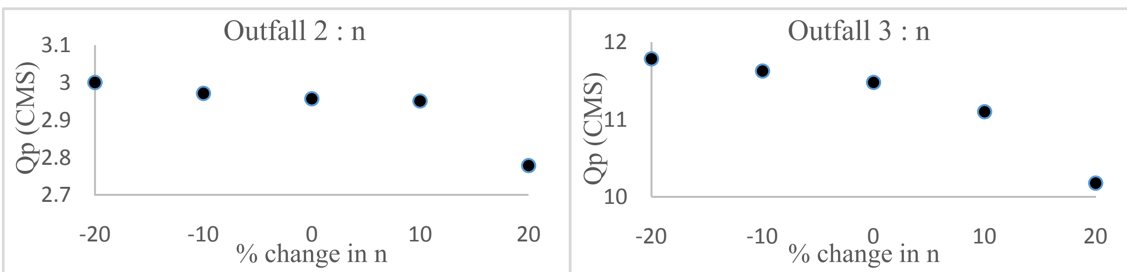
Table 10: Values of input parameters

Parameter	Symbol	Values/Range
Slope (%)	S	0.1
Manning's n for pervious overland flow	n_p	0.05
Manning's n for impervious overland flow	n_i	0.012
D-Store Pervious (mm)	D_p	2.54
D-Store Impervious	D_i	0
Channel Roughness Coefficient	n	0.016
Imperviousness (%)	I	0-90
Curve Number	CN	55-90

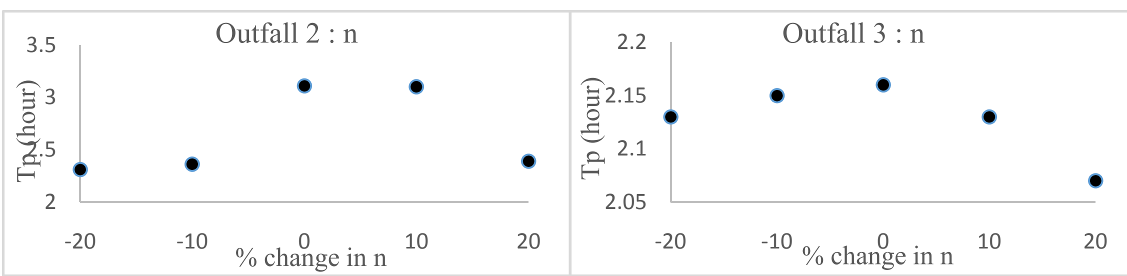
Sensitivity of Channel Roughness Coefficients: Fig. 4 shows that both Q_p and V decrease with increasing n. With 10% to 20 % change as above, Q_p decreases by 0.172 and 0.926 CMS for outfall 2 and 3 respectively. On the other hand, T_p deacreases with both increasing and descreasing n.

Sensitivity of n_p: Fig. 5 shows that an increase in n_p in any sub catchment decreases both Q_p and V, and vice versa. However, the trend of change in Tp contrasts for the two outlets. Notably, the change in n_p doesnot affect much T_p in impervious area.

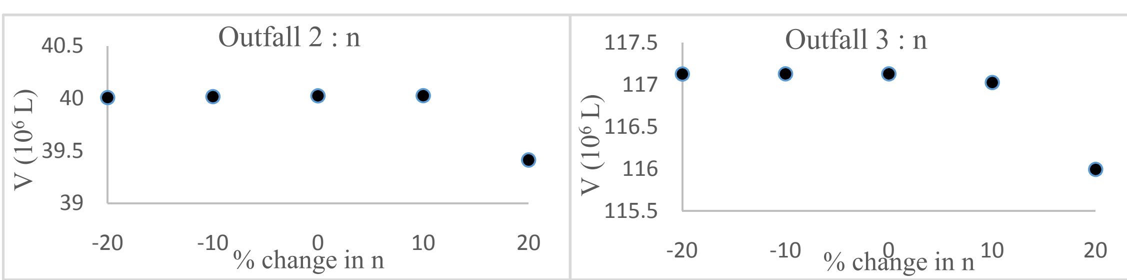
Peak Discharge Q_p



(a) Peak Discharge Q_p

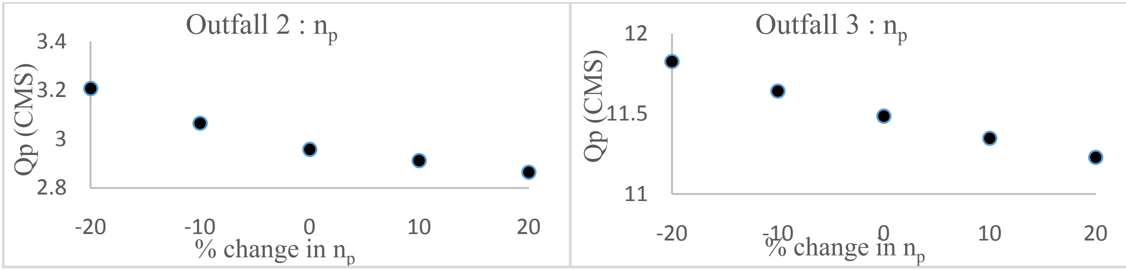


(b) Time of Peak Discharge T_p

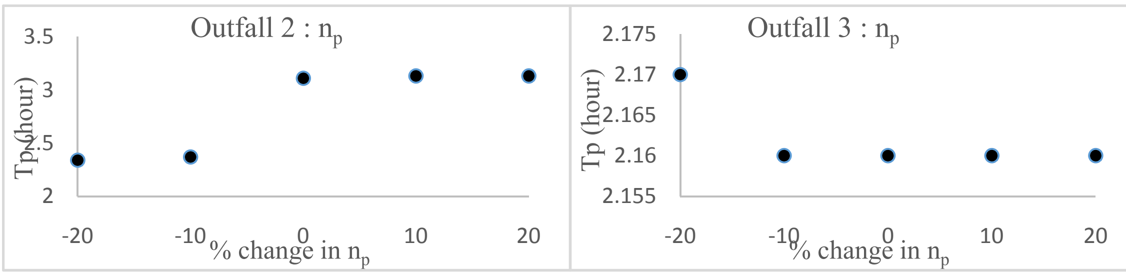


(c) Hydrograph Volume

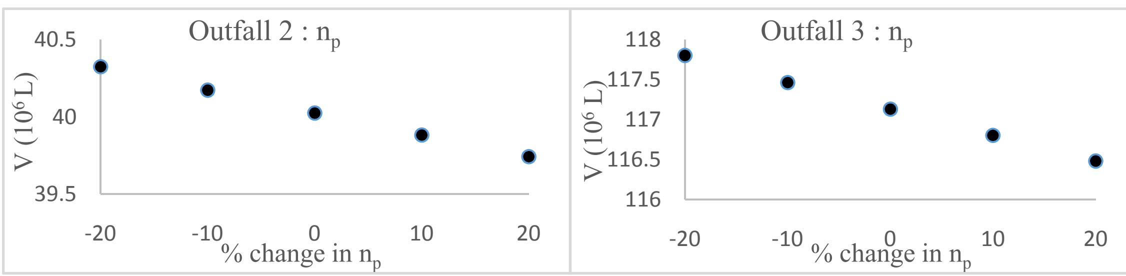
Fig. 4: Sensitivity of Channel Roughness Coefficients (n) at different Outfalls



(a) Peak Discharge Q_p

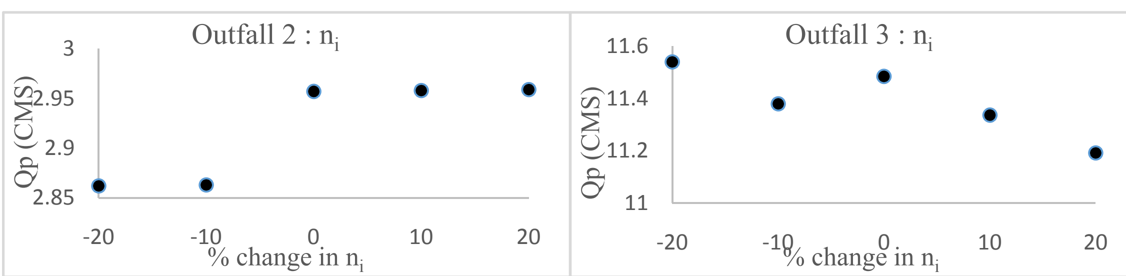


(b) Time of Peak Discharge T_p

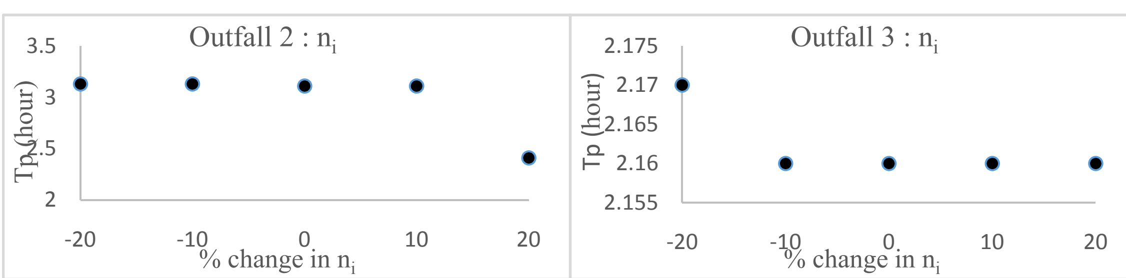


(c) Hydrograph Volume

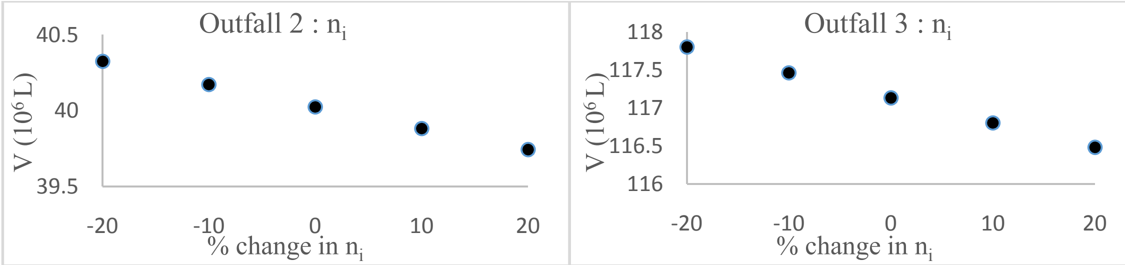
Fig. 5: Sensitivity n_p at different Outfalls



(a) Peak Discharge Q_p

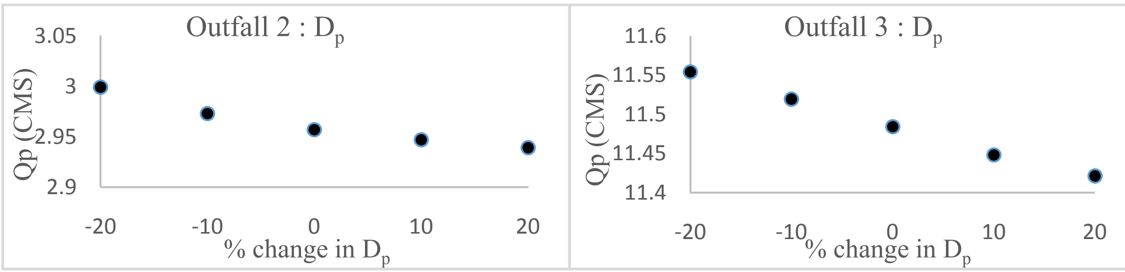


(b) Time of Peak Discharge T_p

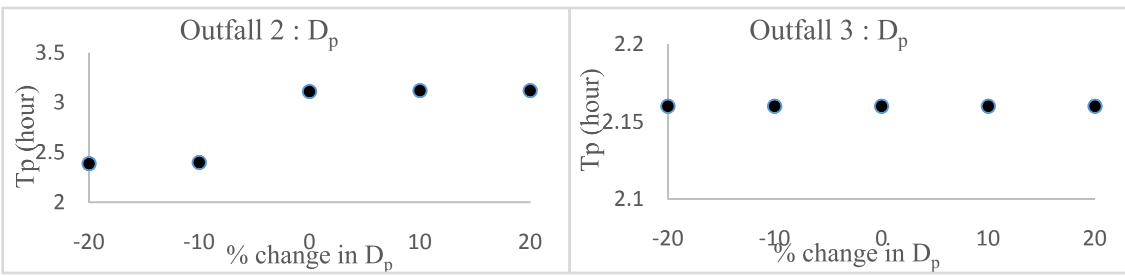


(c) Hydrograph Volume

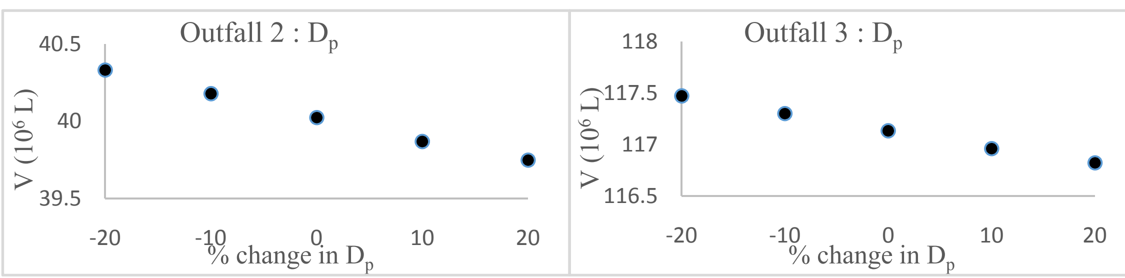
Fig. 6: Sensitivity of n_i at different Outfalls



(a) Peak Discharge Q_p



(b) Time of Peak Discharge T_p



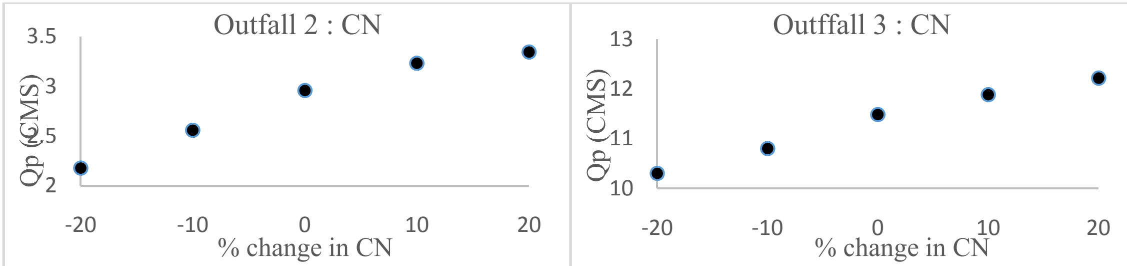
(c) Hydrograph Volume

Fig. 7: Sensitivity of Depression storage in pervious area at different Outfalls

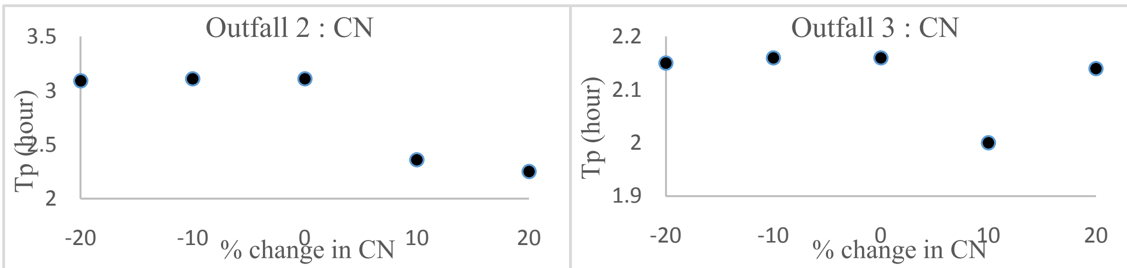
Sensitivity of n_i: From Fig. 6, as n_i increases, V consistently decreases. On the other hand, consistency in trends for Q_p and T_p for the two outfalls is not apparent, rather opposite behaviour is seen. Such an abnormal behaviour may be attributed to the fact that both n_p and/or n_i effect the flow behaviour in conjuntion with the energy slope, according to Manning's formula, which is a dynamic, and perhaps the most perplexing, variable to decide the flow behaviour.

Sensitivity of D_p: Fig. 7 shows that with increase in D_P, both Q_p and V decrease, which is quite obvious as it affects the watershed storage that is lost through evaporation/seepage, and hence, reducing the surface runoff. As also seen for Outlet 1, D_p is expected to increase T_p as with reduction of surface runoff, flow velocities are also reduced.

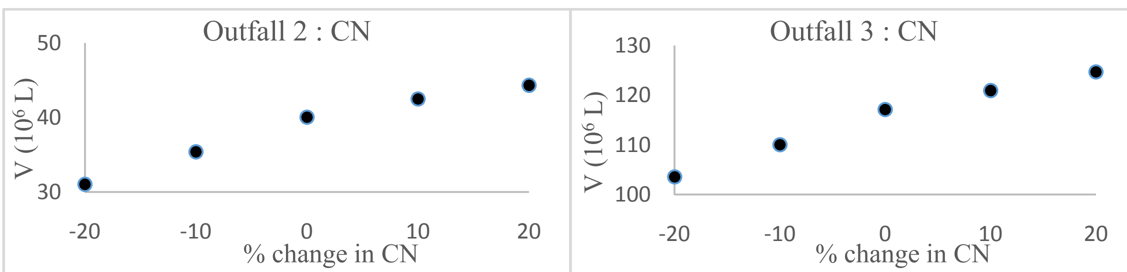
Sensitivity of Curve Number: Fig. 8 shows that with increase in CN, both Q_p and V increase, but T_p decreases. It is consistent with the general expectaton that as CN increases, surface runoff (both in rate and volume) increases and, in turn, velocity increases leading to reduction in T_p.



(a) Peak Discharge Q_p



(b) Time of Peak Discharge T_p

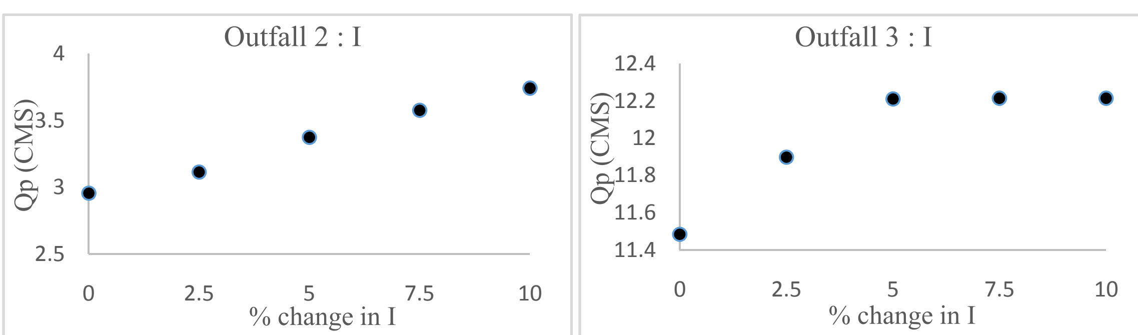


(c) Hydrograph Volume

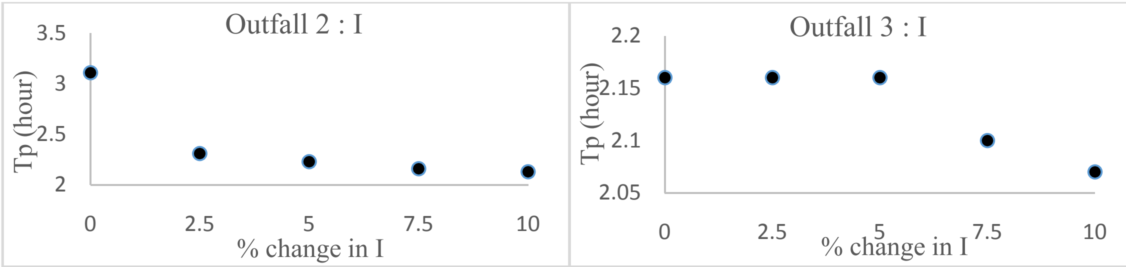
Fig. 8: Sensitivity of Curve Number at different Outfalls

Sensitivity of Imperviousness: Fig. 9 shows that with increase in Imperviousness of an area, as expected, both Q_p and V increase, but T_p decreases. As compare to impervious area pervious area shows higher variation in T_p, because increase in % of I does not affects the area much which is already impervious in nature. The increased imperviousness decreases the infiltration losses and therefore increases both surface runoff and flow velocities.

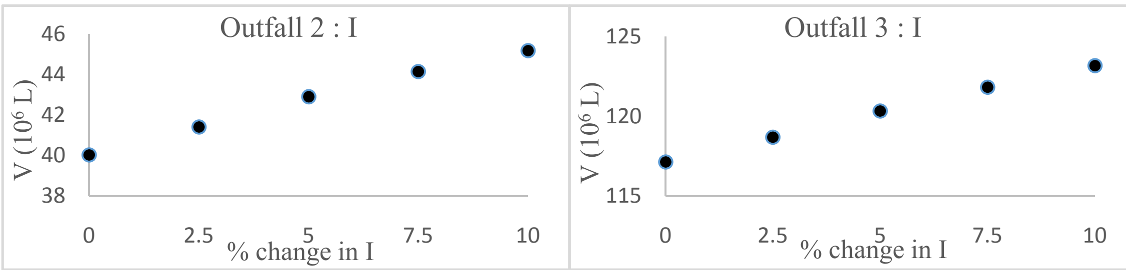
The results obtained from several runs of the model can be summarized on using the values of Q_p at different outfalls, and according to the difference in Q_p for the same % change in parameter values, the sensitivity of these parameters can described in order of their ranking CN > %Imperviousness > Manning's Roughness > Flow Width > N_p > % slope > N_i> D_p As seen, D_p is the least sensitive parameter, and Curve Number the most sensitive in prediction of runoff peak discharge.



(a) Peak Discharge Q_p



(b) Time of Peak Discharge T_p



(c) Hydrograph Volume

Fig. 9: Sensitivity of Imperviousness at different Outfalls

CONCLUSION

The study designed the channel network in a planned industrial complex of an area of 885 acres using SWMM. The model exhibited an error of -0.182% in continuity, which is quite tolerable. When subjected to sensitivity, Curve Number was found to be the most sensitive parameter in runoff peak prediction and D-Perv is found as the least sensitive parameter.

REFERENCES

1. *Barco, J., Wong, K. M., & Stenstrom, M. K., 2008. "Automatic Calibration of the U.S. EPA SWMM Model for a Large Urban Catchment". JOURNAL OF HYDRAULIC ENGINEERING , 134, 466-474.*

2. *Beling, F. A., B., G. J., Paiva, E. M., Bastos, G. A., & Paiva, J. B., 2011." Analysis of the SWMM Model Parameters for Runoff Evaluation in Periurban Basins from Southern Brazil". Porto Alegre/Brazil,: 12nd International Conference on Urban Drainage,.*

3. *CWC, C. W., 1987. "Flood estimation Report for Eastern Coast Region (Upper, Lower and South)" Subzones- 4(a), 4(b) & 4(c). New Delhi.*

4. *Elliott, A. H., Trowsdale, S. A., & Wadhwa, S., 2009. "Effect of Aggregation of On-Site Storm-Water Control Devices in an Urban Catchment Model". JOURNAL OF HYDROLOGIC ENGINEERING , 14(9), 975-983.*

5. *El-Sharif, A., & Hansen, D., 2013. "Application of SWMM to the Flooding Problem in Truro, Nova Scotia". Canadian Water Resources Journal /Revue canadienne des ressources hydriques , 26:4 (10.4296/cwrj2604439), 439-459.*

6. *Ferreri, G. B., Freni, G., & Tomaselli, P., 2010. "Ability of software SWMM to simulate transient sewer smooth pressurization". The International Water Association .*

7. *Giron, E., 2005. "Development of a SWMM-GIS Flood Model for New Orleans Drainage Pumping Station No 4 Basin". New Orleans: University of New Orleans Theses and Dissertations.*

8. *Irvine, K., Chansopheaktra, S., Suthipong,Sthiannopkao, Kok, S., & Chea, E., 2015. "Application of PCSWMM to Assess Wastewater Treatment and Urban Flooding Scenarios in Phnom Penh, Cambodia: A Tool to Support Eco-City Planning". Journal of Water Management Modeling (10.14796/JWMM.C389).*

9. *James, C. G., & Toan, M. L., 2015. "Hydrologic Model Developed for Stormwater Infiltration Practices". ASCE J. of Hydrologic Engineering, , 20 (9), 1943-5584.*

10. *Krebs, G., Kokkonen, T., Valtanen, M., Koivusalo, H., & Setälä, &. H., 2013. "A high resolution application of a stormwater". Urban Water Journal , 10:6 (10.1080/1573062X.2012.739631), 394-410.*

11. *Lahlou, M., Choudhury, S. H., & Baldwin, K., 1995. "SWMM Windows Interface User's Manua". Washington: United States Environmental Protection Agency.*

12. *Lai, S., Ghani, A., Zakaria, N., Leow, C., Chang, C., & Yusof, M., 2008. "Application of SWMM for Urban Stormwater Management: A Case Study with Modelling. Pisa, Italy".*

13. *Rossman, L. A., 2008. "STORM WATER MANAGEMENT MODEL USER’S MANUAL" Version 5.0. CINCINNATI: U.S. Environmental Protection Agency (EPA).*

14. *Sharifana, R. A., Roshanb, A., Aflatonia, M., Jahedi, A., & Zolghadr, M., 2010. "Uncertainty and Sensitivity Analysis of SWMM" Model in. ELSEVIER, 2 (10.1016/j.sbspro.2010.05.205), 7739–7740.*

15. *Wanniarachchi, S. S., & Wijesekera, N. T., 2012. "Using SWMM as a Tool for Floodplain Management in Ungauged Urban Watershed". The Institution of Engineers , XXXXV (01), 1-8.*