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# Urban Stormwater Management Policy- Linking of Urban lakes for West Part of Vadodara city

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***Abstract*— Now days one of the most prominent activity focusing in Indian cities is the Up-gradation of the urban drainage system and utilization of Best Urban Stormwater Management Practices. Large amount of investment spent in construction of stormwater drains and adoption of Low Impact Development concepts in towns and cities to prevent flooding during heavy storms. Stormwater drains extend several kilometers across the town or city are expected to feed all the collected surface runoff into the nearest surface water body such as a lake or a river. Recently Vadodara city has declare as one of the smart cities of India but it has very big history of urban flooding due to heavy intense rainfall in short duration also flash floods takes place due to flah river Vishwamitri flowing in centre of the city. West part of the city has six lakes suffers serious issue of overflowing in monsoon season absorbing large runoff from its large impervious catchment area. Therefore, this study has been taken to interlink these lakes by Stormwater drainage system using Stormwater Management Modelling (SWMM) V5.1 software, which will reduce impact of flooding and inundation in nearby areas and will maintain sufficient water level in these lakes throughout season. This ultimately increased Stormwater absorbing capacity of lakes.***

***Keywords*— Lake Interlinking, Urban Stormwater Management, River-lake Linkage, BMP's, SWMM***

## I. Introduction

Stormwater is part of Precipitation becomes surface runoff flowing on ground surface which is not infiltrated from it. The fast infrastructure development increased urbanization results change in hydrological and hydro metrological conditions. Change in natural land cover and becoming impervious day by day will create question of an effective management of stormwater, which now assumes more and more importance for developing cities, the up-gradation of existing infrastructure becomes critical. To correct existing situations and to effectively manage stormwater, it's utilization and diversion programs are essential. Urban stormwater management is one of the prominent basic infrastructure facilities growing fast in India. The fast infrastructure development has not included the proper drainage system. These critical issues must be addressed in parallel to any infrastructure development plan and a comprehensive plan on urban drainage and sanitation must be organized and implemented accordingly. Lakes or ponds absorbs large quantity of stormwater coming from impervious catchment area, assist groundwater recharge. Now days global warming effect harming natural hydrological cycle and eco-system of world badly, High intensity of rainfall in short duration called flash flood is one of the biggest example of different hydrological conditions under effect of global warming, which results intense surface runoff in urban area. Natural ponds/lakes or detention basins, river flowing through urban cities may not able to absorb the whole completely so they started overflowing and inundate surrounding area. Moreover, these issues become even more important for such cities having natural water bodies like lakes/ or ponds. In this case best management practices for urban stormwater control and planning should be adopted. Low Impact Development (LID) controls e.g. pervious pavement-parking lots and other surfaces, constructed wet lands, bio retention swales, rain gardens, green roofs, stormwater harvesting are adopted by smart cities. Detention/Retention basin concepts, Green infrastructures and River-Lake interlinking system are also best management practices adopting now days as urban stormwater management. Different tools or software are available to model this BMP's. To analyse and design quantity and quality of stormwater SWMM, SUSTAIN, MIKE, STORMCAD, HEC-HMS etc. Various input parameters are to be consider before model preparation, even they comprise with other tools or software like ARCGIS/Q-GIS for inundation planning and generating thematic maps for input consideration and output comparisons. This study conducted to create efficient linkage of lakes for west part of Vadodara city, which declared recently as a smart city using SWMM V5.1 with ARCGIS V10.3.

## II. STUDY AREA AND DATA COLLACTION

. Vadodara city (22.3072° N, 73.1812° E) is taken for analysis of rainfall pattern for which efficient river-lake interlinking system will be designed. The city is situated in the fertile plane between the river Narmada and Mahi and on bank of Vishwamitri. The city limits under 162 sq km.of total area of Vadodara Mahanagar Seva-Sadan (VMSS). The city of Vadodara has south-west monsoon (June-September). The highest temperature recorded is 47 °C and the lowest is 15 °C. The average annual rainfall in Vadodara is 930 mm. The natural stormwater drainage system is composed of the river Vishwamitri and another river Jambuva which joins the river Vishwamitri further southwards. City is also consists with number of man-made and natural water bodies. There are many watercourses called "Kaans" receives stormwater

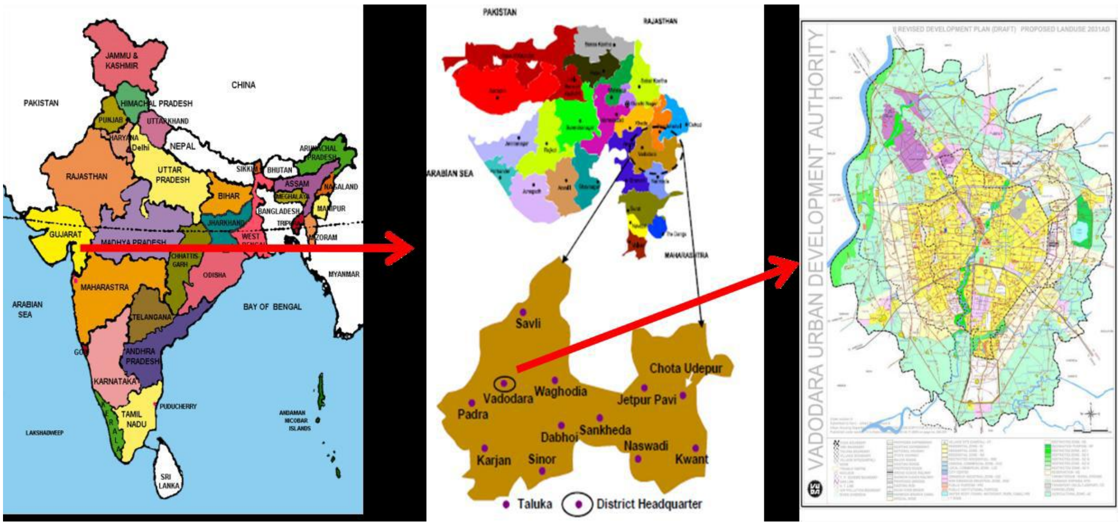



*Figure 2.1 Study area*

from entire city. Thus, the network of the two rivers, kaans and manmade stormwater drains serves stormwater drainage system for Vadodara city. At present the overall area of Vadodara Mahanagar Seva Sadan is divided into following 4 (Four) Zone. Which are East, West, North, South zone respectively. Vadodara city has 23 lakes situated all over the city among of them 6 lakes situated at west part of the city.

(1) To carry out this study successfully first priority is gathering of required data.
(2) Daily Rainfall Data of Vadodara city (1970-2015) & Historical Flood data of Vadodara City collected from SWDC, Gandhinagar.
(3) DEM (30 M) & soil map collected from VMC.
(4) Catchment area of Lakes, Coordinates of Lakes, F.R.L of Lakes Capacity, Invert Levels at Lakes, Inlet-Outlets details collected from Lake interlinking report given by Special Project Department.
(5) Data of Existing Stormwater Drains, Boundary of Vadodara city, Vadodara city water bodies (.dwg), Topographical map showing layout of existing Stormwater drainage system and Road network for Vadodara city (.dwg/map) collected from Storm Water & Drainage department.

## III. DATA ANALYSIS AND MODEL PREPARATION

**3.1 Data Analysis:** Before creating model of lake interlinking system, Rainfall Analysis has conducted for obtaining Short duration intensity of rainfall and developing Intensity-Duration-Frequency curve that will become input parameter in SWMM V5.1 for Rain gauge station Time series pattern. In addition, Model needs backdrops that support thematic maps in .map, bitmap, Meta file, jpeg formats. These thematic maps also helps for results and output comparison.

***3.1.1 Rainfall analysis for development of Rainfall Intensity-Duration-Frequency Relationships (1970-2015)*:**

Statistical analysis of collected daily rainfall data for Vadodara City from SWDC, Gandhinagar gives an average annual rainfall value. In climate change analysis an average rainfall was determined at every 5 years and 10 years interval, the average value of rainfall prepared by plots and trend lines that were added to examine the change in the rainfall pattern. Analysis further shows moving average which follows basic principle is that for several data sets of time range n years starting from first stage of n years of data, the average of the data for n years is calculated and placed in the middle year of the range n. Usually the value of n is odd one.

The number of rainy days for each month and year were worked out for period of 1970-2015(46 years) and the change was observed by plotting them along with the average values for the period. The change in the maximum daily rainfall pattern over a large span can be determined by working out an average value for each decade and a plot prepared to observe the change. The analysis carried out for monthly rainfall pattern for the study period along with the number of rainy days in each month.

Probability frequency analysis for one-day annual maximum rainfall gives relation between magnitude of event and its probability of exceedance. It is a simple empirical technique to arrange the given annual extreme series in descending order of magnitude until the last event for which m equals the total number of record N and to assign an order number m (5542-2003). The probability P of an event equaled to or exceeded is given by the Weibull formula,

$$P = m/N+1 \quad (3.1)$$

The recurrence interval or return period,

$$T = 1/P \quad (3.2)$$

According to (IS: 5542-2003) 15 % increase shall be made in the daily maximum raw data and then after the data can be used for analysis.

Gumbel's Extreme value distribution method can used for development of IDF relationships. The extreme value series is used to generate shorter duration series (60, 90, 120, 180, 240, 360, 480, 720, 1440) by employing the IMD formula given as:

$$Pt = [P24\ (t/24)\ (1/3)\ ] \tag{3.3}$$

Pt = rainfall of t mins duration in mm, P24 = daily rainfall value in mm, t = time duration in mins

Rainfall intensity for Pt for different duration of time is obtained using standard formula,

$$i = Pt / D \tag{3.4}$$

Where, D = Duration of event in hours
Method refers following equation to evaluate Rainfall intensity (XT) in mm/hr.

$$(XT) = Xm + Kt\ s \tag{3.5}$$

Xm = Mean, s = standard deviation, Kt = Frequency factor for return period T.

$$\text{Where, } Kt = \sqrt{6}/\square\ [\ 0.5772 + \ln\ \{\ln(T/T-1)\}] \tag{3.6}$$

The values of intensity and duration obtained from (3.5) were used to obtain the constants in the intensity equation suggested by CPHEEO manual, India by equation,

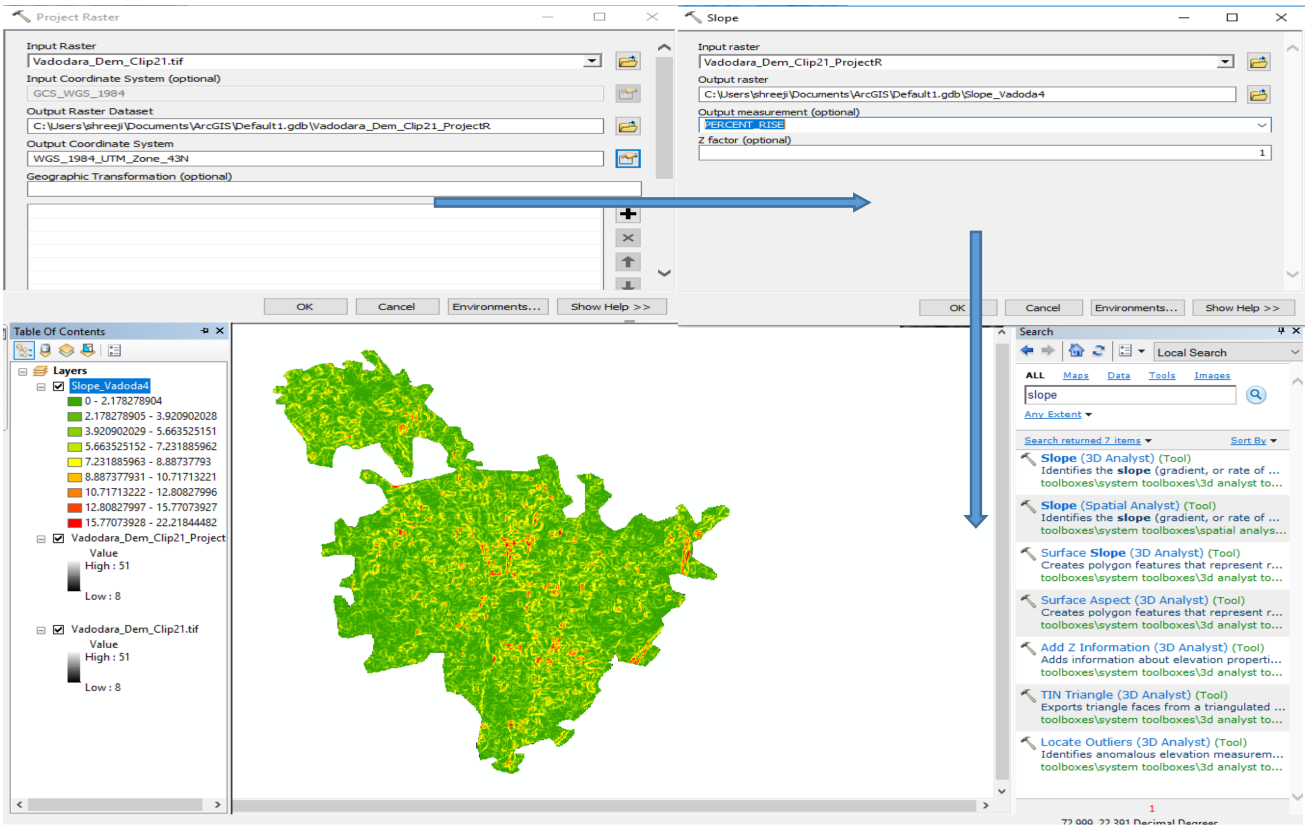
$$Log(i) = \log\ (a) - n\ \log\ (T) \tag{3.7}$$

Where, i = Rainfall intensity in mm/hr, T = Duration event of the storm in minutes, 'a' & 'n' are constants
The log-log plot can be obtained using intensity (i) and duration (t) values from table for 1 year and 2 year return period.

***3.1.2 Generation of slope map and contour map from DEM using ARCGIS V10.3:***

DEM (30 M) of city requires for creating slope & contours map for Vadodara city in ARC GIS V10.3**,** that will be utilize as a backdrop for the tool SWMM V5.1. Slope map generated from DEM used for classification of slope for different area of the city. Contour maps required for calculating gradient of interlinked system.

Under process of Project Raster data Management DEM (30 M) in tiff format can be feed in input raster then Project co-ordinated system is set as UTM WGS 1984 → Northern hemisphere →43 N. Then, Slope evaluated under spatial analysis. During this analysis project DEM file converted in slope file and can be save again. Reclassification slope is necessary for close and precise arrangement of slope for each area of city. In Reclassify (spatial analysis) tool, project slope file can feed as input raster then classify method and classes can choose. Finally, Output raster set as reclass slope.



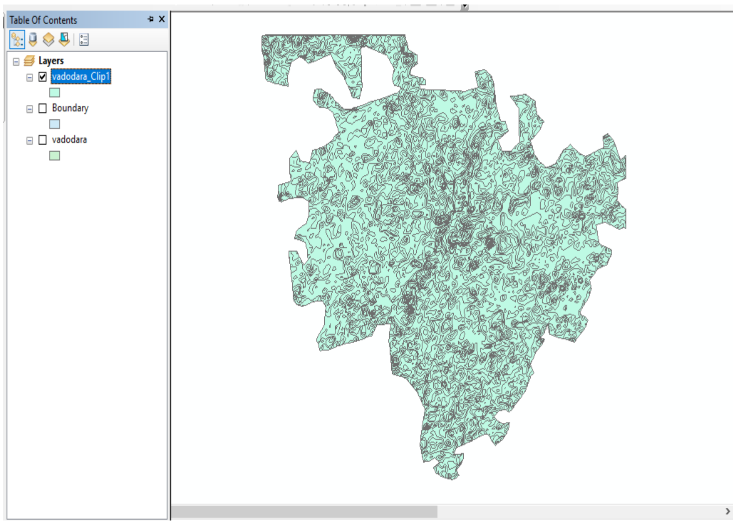



*Figure 3.2 Contour map of Vadodara city*

### 3.1.3 Classification of Curve numbers for different city part from soil map:

Soil map of Vadodara city shows that city covered with five types of soil that are (i) Fine, Mixed (ii) Coarse, Loamy (iii) Fine, Loamy (iv) Fine (v) Very fine. Most part of the city covers with Fine, Mixed soil type soil spread over centrally to east corner part of the city. Corner west-north part and corner north of the city covered with Fine, Loamy type soil. Corner north-east part Coarse Loamy & Fine type soil. Corner south part of city covers with very fine type soil.

*Table 3.1 Classification of Curve Number from Soil type*

| **Soil Type of city** | **Land use** | **CN** |
|---|---|---|
| Coarse Loamy (Group- B) | Residential, commercial | 85,92 |
| Fine Loamy, Fine Mixed ( Group-C) | Residential, Commercial, Industrial, less cover zones | 90, 94, 91, 79 |
| Fne, Very Fine (Group-D) | Slight cover, Residential, Industrial | 80, 92, 93 |

### 3.1.4 Flood Analysis:

For Vadodara city the floods are not new. The devastating flood of 1927 called as Ghoda poor was the worst flood experienced by the city. Highest recorded rain level 92 inches at that year swelled Vishwamitri river so much that floodwater had touched the feet of Kala Ghoda statue near the river. Vadodara had suffered from floods in several years mentioned below.

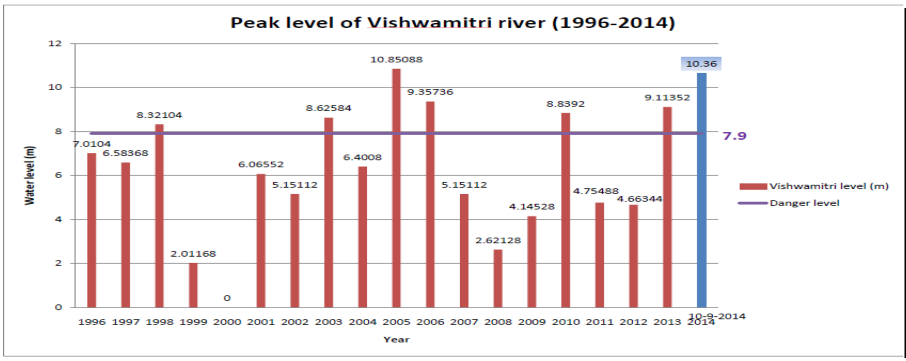



*Figure 3.3 Peak level of Vishwamitri River*

*Table 3.2 Flood Analysis*

| **Flood Year** | **One Day Maximum Rainfall (mm)** | **Seasonal Rainfall (mm)** |
|---|---|---|
| 1970 | 226 | 2160.6 |
| 1978 | 224 | 1074.1 |
| 1994 | 256.2 | 1350.7 |
| 2005 | 315 | 1986 |
| 2008 | 274 | 876 |
| 2013 | 232 | 1726 |
| 2014 | 219 | 1075 |

Even in the year, 2006 and 2010 Seasonal Rainfall (mm) observed 1742, 1550 respectively. Those were noted mark on FRL of river. In addition, city has many low laying areas that are Ellora park, Gotri, Laxmipura, Ajwa road, Waghodia road area, Warashia, Kishanwadi area, Manjalpur area known as flood spots of the city.

### 3.2 Model Preparation:

An efficient lake interlinking system prepared in SWMM V5.1 that covers six lakes of west part city that are Sama Lake, Gorwa Lake, Gotri Lake, Saiyodvasna Lake, Tandalja Lake, Atladra Lake. In SWMM V5.1 for this particular study storage basin represents as lakes, each lakes having their catchement area that has to be made in model with tool subcatchments, links are catching overflowing water from basins connected with junctions. Free Outfall is given after final interlinked Atladra Lake which discharging flood in to Vishwamitri river.

Before preparing model backdrop is set as Vadaodara city map in Meta file format converted from CAD file in .dwg format that contains water bodies, existing SWD network, Road-Railway network, City boundary. Each components of model needs input parameters.

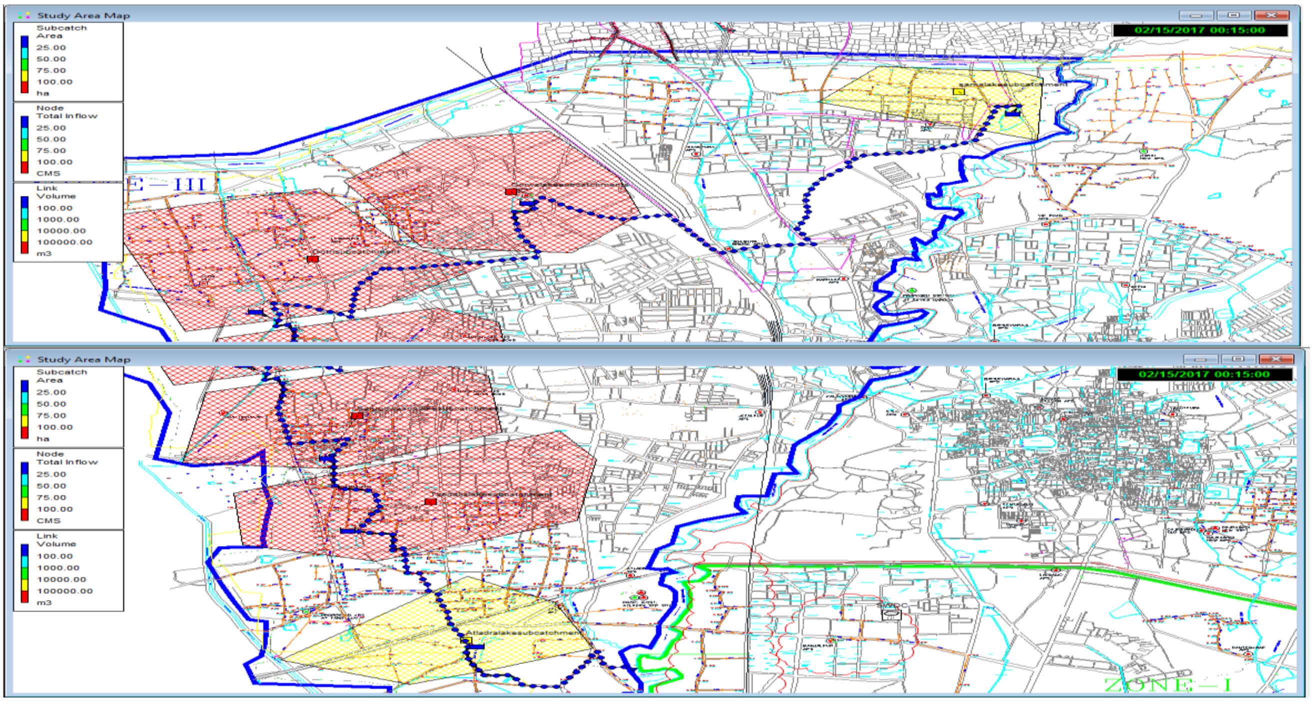


*Figure 3.4 Lake Interlinking Model of West part of Vadodara city in SWMM V5.1*

### *3.2.1 Sub-catchment:*

Sub-catchment tool in SWMM can used to add delineated areas and other pertinent information concerning the drainage area, such as width of overland flow. Percentage impervious cover can estimated for different area, CPHEEO suggested 65 to 75 % for highly dense residential area and commercial or industrial area. All sidewalks, roofs, and roadways assumed impervious. Some of the other inputs that exist in SWMM for sub catchments are slope, depth of storage, Manning's N value, percent zero impervious, and choice of an infiltration method (Horton, Green-Ampt, Curve Number). In the initial model, these all held constant for sensitivity analysis. According to CPHEEO, India manual Manning's N value can be assume in between 0.015 to 0.017 for drainage area containing RCC conduits. For this study, Curve number method selected as infiltration method for sub-catchement.

| Data Category | Name | Rain Gage | Outlet | Area | %Imperv | Width | %Slope | CurbLen | SnowPack |
|---|---|---|---|---|---|---|---|---|---|
| [TITLE] | samalakesubcatchment | SWDC | Samalake | 99.46 | 65 | 900 | 2.6 | 0 | |
| [OPTIONS] | Gorwalakesubcatchments | SWDC | Gorwalake | 536.46 | 75 | 2200 | 2.1 | 0 | |
| [EVAPORATION] | Gotrisubcatchment | SWDC | GotriLake | 699.80 | 75 | 2500 | 2.0 | 0 | |
| [RAINGAGES] | Saiyodwasnalakesubcatchment | SWDC | Saiyodvasnalake | 511.84 | 75 | 2000 | 2.4 | 0 | |
| [SUBCATCHMENTS] | Tandaljalakesubcatchment | SWDC | TandaljaLake | 726.18 | 75 | 2500 | 1.9 | 0 | |
| [SUBAREAS] | Atladralakesubcatchment | SWDC | AtladraLake | 83.18 | 65 | 850 | 1.9 | 0 | |

*Figure 3.5 Sub-catchment input details in SWMM V5.1*

| Data Category | Subcatchment | N-Imperv | N-Perv | S-Imperv | S-Perv | PctZero | RouteTo | PctRouted |
|---|---|---|---|---|---|---|---|---|
| [TITLE] | samalakesubcatchment | 0.017 | 0.05 | 0.05 | 0.05 | 25 | OUTLET | |
| [OPTIONS] | Gorwalakesubcatchments | 0.017 | 0.05 | 0.05 | 0.05 | 25 | OUTLET | |
| [EVAPORATION] | Gotrisubcatchment | 0.017 | 0.05 | 0.05 | 0.05 | 25 | OUTLET | |
| [RAINGAGES] | Saiyodwasnalakesubcatchment | 0.017 | 0.05 | 0.05 | 0.05 | 25 | OUTLET | |
| [SUBCATCHMENTS] | Tandaljalakesubcatchment | 0.015 | 0.05 | 0.05 | 0.05 | 25 | OUTLET | |
| [SUBAREAS] | Atladralakesubcatchment | 0.017 | 0.05 | 0.05 | 0.05 | 25 | OUTLET | |
| [INFILTRATION] | | | | | | | | |

*Figure 3.6 Subareas input details in SWMM V5.1*

| Data Category | Subcatchment | CurveNum | | DryTime |
|---|---|---|---|---|
| [TITLE] | samalakesubcatchment | 90 | 0.5 | 8 |
| [OPTIONS] | Gorwalakesubcatchments | 88 | 0.5 | 7 |
| [EVAPORATION] | Gotrisubcatchment | 94 | 0.5 | 8 |
| [RAINGAGES] | Saiyodwasnalakesubcatchment | 91 | 0.5 | 8 |
| [SUBCATCHMENTS] | Tandaljalakesubcatchment | 94 | 0.5 | 9 |
| [SUBAREAS] | Atladralakesubcatchment | 78 | 0.5 | 6 |
| [INFILTRATION] | | | | |

*Figure 3.7 Infiltration input details in SWMM V5.1*

### *3.2.2 Nodes/ Junction/ Storage basin/ Divider:*

Within each sub-catchment each storm drain needs to be represented, which is done by placing a node in the model. For the storm drain inlets, a junction node is used. One piece of information needed is the invert elevation, which is geographical elevation of the bottom most part of the conduit pipe that enters the storm drain. Other inputs that needed for each junction are ponded area, initial depth, maximum depth and surcharge depth. For this study, surcharge depth and ponded area for the model kept at zero. In addition, flood situation is considered to simulate interlinked system so all lakes are assumed completely filled with its F.R.L (Full Reading Level) so maximum depth and initial depth of lake is assume to be equal. Storage basin stands for storage or source of fixed water transport, water bodies like lake, reservoir, elevated storages, basins etc. Inputs are almost same as other junction's excepts storage curve, tidal curve, or rating curve required to describe amount of water stored within body n amount of release from the body. For nodes, there is an additional option for water treatment for performing water quality analysis. Most pipe networks involve intersections of multiple pipes. Within the SWMM program, it is possible to incorporate these merged pipes with a Divider. Divider requires same inputs as junctions but it requires receiving pipe and conditions. The final type of node that used in the model is the outfall. The only piece of information needed for the outfalls was the invert elevation, which allows flow direction to be computed.

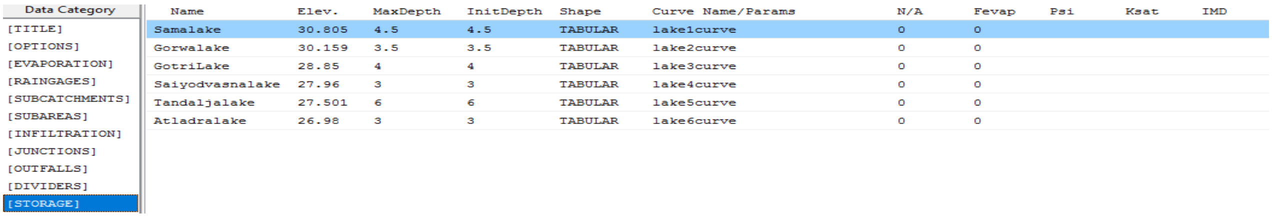



*Figure 3.8 Storage Parameters in SWMM V5.1*

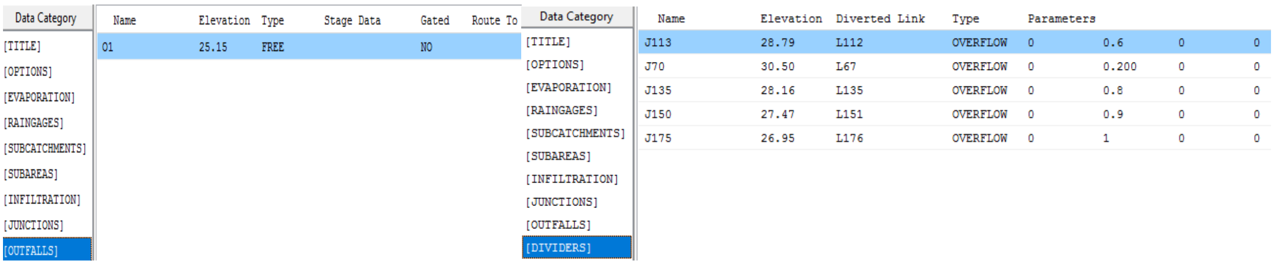



*Figure 3.9 Outfall and Divider Parameters in SWMM V5.1*

### *3.2.3 Links/ Conduits:*

The pipe network mapped out connecting all the sub catchments and nodes. The pipe input variables allow an in – depth analysis of the storm sewer network hydraulics that occurs with the given hydrology. The input data used is length, roughness, diameter, as well as entrance/exist loss coefficients. Standard values from the Indian Standard (IS:458-1988) were used for roughness (0.011-0.017) depending on the age of the pipe and for the loss coefficient (0.5) for entrance and exit locations.

*Table 3.3 Conduits details*

| **Lakes connection** | **Route Length (m)** | **Conduit Diameter (m)** | **Gradient** | **Manning's Roughness** |
|---|---|---|---|---|
| Sama Lake to Gorwa Lake | 6630 | 0.2 | 15887.241 | 0.015 |
| Gorwa Lake to Gotri Lake | 4270 | 0.6 | 3269.525 | |
| Gotri Lake to Saiyodvasna Lake | 2180 | 0.8 | 2441.209 | |
| Saiyodvasna Lake to Tandalja Lake | 1420 | 0.9 | 3093.681 | |
| Tandalja Lake to Atladra Lake | 2550 | 1 | 4894.434 | |
| Atladra Lake to Vishwamitri River outfall | 2390 | 1 | 1306.010 | |
| | | | | |

***3.2.4 Raingauge station:*** For each of the sub catchments documented within the model, there must be a linked rain gauge to convey information concerning wet weather from either time series input or .DAT data files. The rainfall data can be in the form of intensity, volume or a cumulative rainfall.

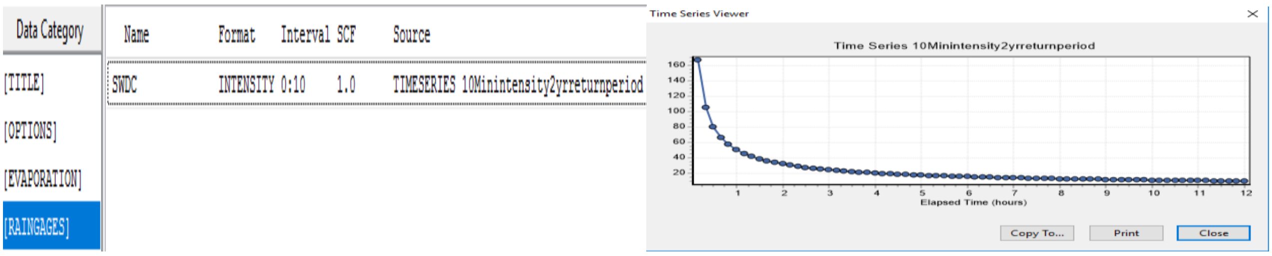



*Figure 3.10 Raingauge Station parameters in SWMM V5.1*

## IV. RESULTS AND DISCUSSION

### 4.1 Results of Rainfall Analysis:

Annual Rainfall analysis gives Average annual rainfall - 947.37 mm, Maximum rainfall period – July and September Minimum Rainfall – 303.60 mm, Maximum Rainfall – 2160.60 mm. The Change observed by plotting monthly rainfall values and Rainy days with monsoon period (months). Average number of rainy days for the study period 9.8 days per month and the average monthly rainfall is 194.07 mm.

Probability (P) for maximum One Day Maximum Rainfall of 362.25 mm is 0.0213 and Return period (T) is 47 years. Probability (P) for minimum One Day Maximum Rainfall of 36.34 mm is 0.9787 and Return period (T) is 1 year.

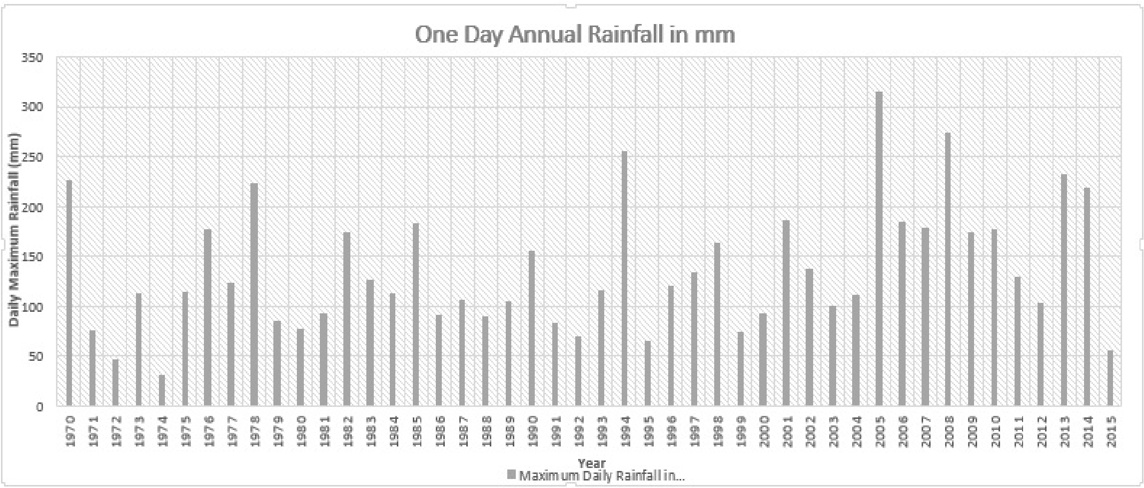



*Figure 4.1 One day Maximum Rainfall (mm)*

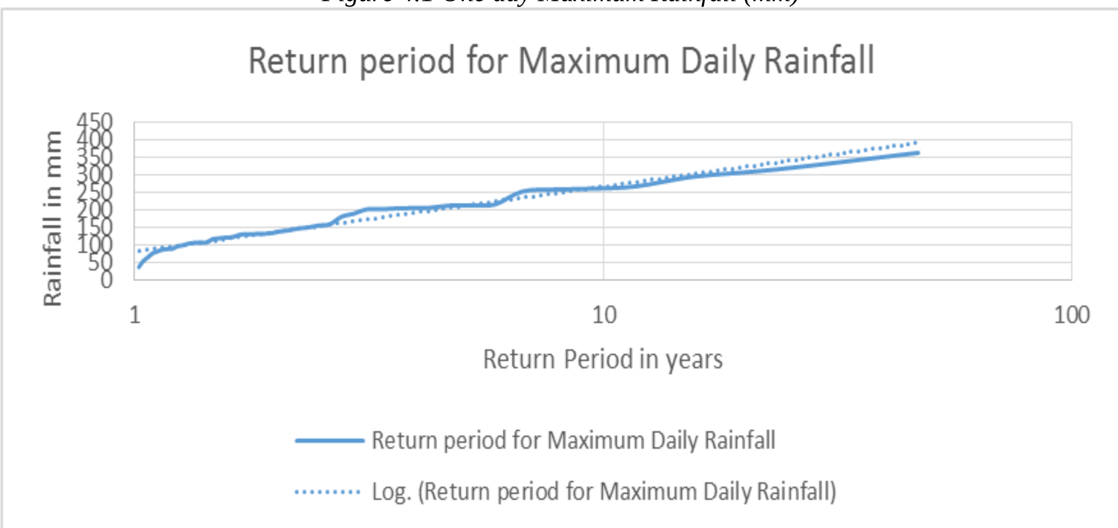



*Figure 4.2 Return period for maximum Daily Rainfall*

Derivation of IDF curves follow Gumbel's extreme value distribution, by applying equations (3.3), (3.4) the extreme value series (rainfall intensities) were presented for shorter duration series (60, 90, 120, 180, 240, 360, 480, 720, 1440) to have Mean and standard deviation. values of mean and standard deviation were applied in equation (3.5) to have rainfall intensities in mm/hr in which frequency factor can be obtained from equation (3.6) which are -0.450, -0.164 for 1 and 2 years return periods (Mentioned in CPHEEO journal, India for parameter considerations of storm water management system) respectively. Table 4.1 shows the intensity duration relationships for 1 and 2 year return periods.

*Table 4.1 Intensity Duration Relationship for 1-2 year Return period (1970-2015)*

| Duration (Mins) | Rainfall Intensities (mm/hr) | Rainfall Intensities (mm/hr) |
|---|---|---|
| | For Year 1 | For Year 2 |
| 60 | 43.520 | 50.560 |
| 90 | 33.212 | 38.585 |
| 120 | 27.416 | 31.851 |
| 180 | 20.922 | 24.307 |
| 240 | 17.271 | 20.065 |
| 360 | 13.180 | 15.312 |
| 480 | 10.880 | 12.640 |
| 720 | 8.303 | 9.646 |
| 1440 | 5.230 | 6.076 |

Values of Intensity and duration obtained in Table 4.1 were used in equation (3.7) and its log log plot gives constants 'a' and 'n' value '666.960' and '0.666' for 1 year return period & '774.818' and '0.666' for 2 year return period.

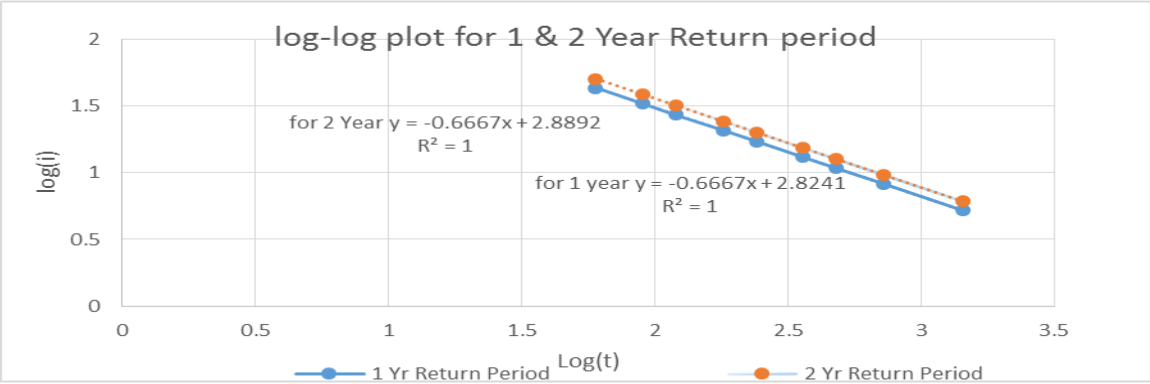



*Figure 4.3 Log-Log plot 1-2 year Return period (SWDC Daily Data)*

Using these constants, IDF curves were developed 10 mins intervals (figure 4.4)

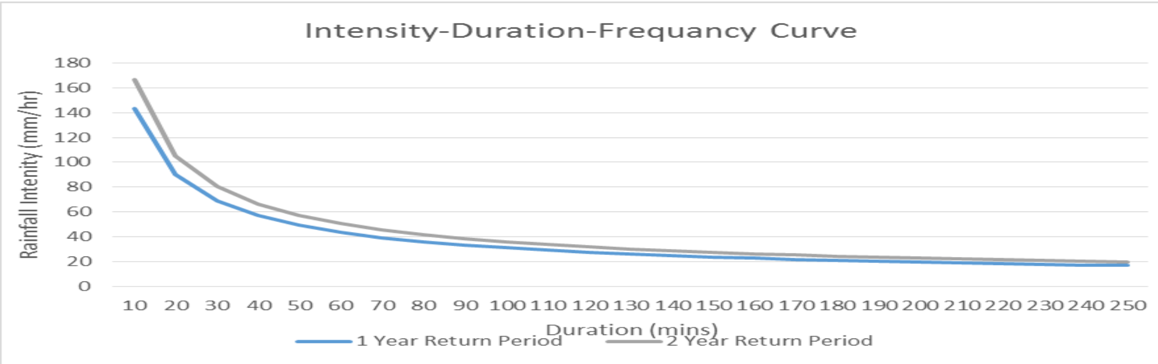



*Figure 4.3 Intensity-Duration-Frequency Curve for 10 min interval (SWDC Daily Data)*

**4.2 Simulation Results of interlinked Model:**

Simulation of model shows different output. Following are different simulation results of proposed interlinked model.

***4.2.1 Water Elevation Profile from Sama Lake:***

In SWMM V5.1 Profile plot can obtain after running simulation. Following Figure 4.4 shows Water Elevation Profile from Sama Lake to Outfall placed at Vishwamitri River. Conduit links gathered water from Sama Lake, Gorwa Lake, Gotri Lake, Saiyodvasna Lake, Tandalja Lake, Atladra Lake and finally outfall set to Vishwamitri river total Linkage covers more than 10000 m distance. Maximum Flow Velocity is about 4.72 m/sec at link 179-180 when water comes from Atladra Lake and joins completely interlinked system. Minimum Flow Velocity 0.22 m/sec at adjacent links of Sama and Gorwa Lake.

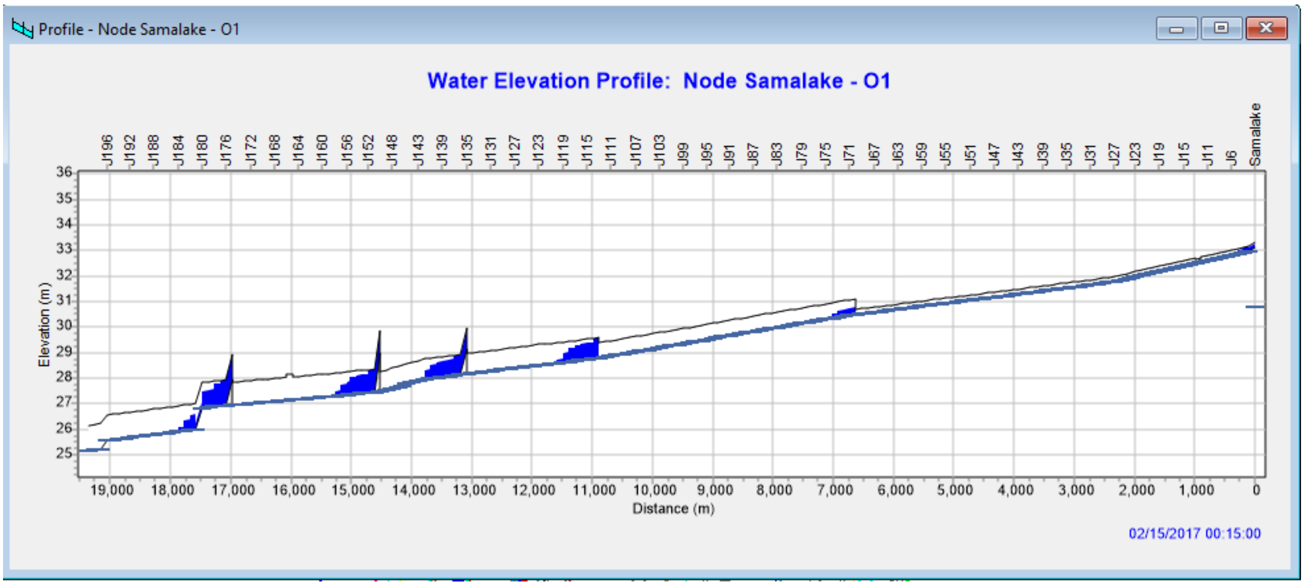



*Figure 4.4 Water Elevation Profile from Sama Lake to Outfall O1*

### *4.2.2 Simulation Results of Lake Sub-catchments:*

Figure 4.5 shows Total & Peak Runoff with their coefficients for Sub-catchments. Maximum Runoff takes place 186.24 mm and Maximum peak runoff 127.34 CMS from Tandalja Lake Sub-Catchment. Minimum Runoff is 179.28 mm and Minimum peak Runoff 16.47 CMS from Atladra Lake Sub-catchments. Assumption were made during study that No Evaporation consider in flood situation.

Summary Results

Topic: Subcatchment Runoff    Click a column header to sort the column.

| Subcatchment | Total Precip mm | Total Runon mm | Total Evap mm | Total Infil mm | Total Runoff mm | Total Runoff 10^6 ltr | Peak Runoff CMS | Runoff Coeff |
|---|---|---|---|---|---|---|---|---|
| samalakesubcatchment | 206.19 | 0.00 | 0.00 | 8.69 | 189.32 | 188.30 | 22.11 | 0.918 |
| Gorwalakesubcatchmen | 206.19 | 0.00 | 0.00 | 7.41 | 183.98 | 986.97 | 93.76 | 0.892 |
| Gotrisubcatchment | 206.19 | 0.00 | 0.00 | 3.76 | 185.90 | 1300.95 | 121.70 | 0.902 |
| Saiyodwasnalakesubcat | 206.19 | 0.00 | 0.00 | 5.60 | 185.96 | 951.81 | 91.67 | 0.902 |
| Tandaljalakesubcatchm | 206.19 | 0.00 | 0.00 | 3.76 | 186.24 | 1352.44 | 127.34 | 0.903 |
| Atladralakesubcatchme | 206.19 | 0.00 | 0.00 | 18.61 | 179.28 | 149.13 | 16.47 | 0.870 |

*Figure 4.5 Sub-catchments Runoff*

### *4.2.3 Lake flooding summary routed by system:*

Following figure 4.6 shows Flooding rate and consecutive hours for each lakes. Maximum flooding rate is 124.460 CMS from Tandalja Lake and Maximum Hours flooded is 6 hours for Gorwa Lake.

Summary Results

Topic: Node Flooding    Click a column header to sort the column.

| Node | Hours Flooded | Maximum Rate CMS | Day of Maximum Flooding | Hour of Maximum Flooding | Total Flood Volume 10^6 ltr | Maximum Ponded Volume 1000 m3 |
|---|---|---|---|---|---|---|
| Samalake | 5.83 | 22.068 | 0 | 00:31 | 187.260 | 0.000 |
| Gorwalake | 6.00 | 94.817 | 0 | 00:50 | 1005.888 | 0.000 |
| GotriLake | 5.78 | 120.717 | 0 | 00:50 | 1275.329 | 0.000 |
| Saiyodvasnalake | 5.78 | 90.417 | 0 | 00:50 | 920.807 | 0.000 |
| Tandaljalake | 5.75 | 124.460 | 0 | 00:50 | 1285.485 | 0.000 |
| Atladralake | 5.66 | 13.416 | 0 | 00:31 | 83.162 | 0.000 |

*Figure 4.6 Node Flooding summary*

### *4.2.4 Storage volume of lakes with Maximum outflow:*

Figure 4.7 shows Storage volume of lakes with maximum outflow. Maximum volume of storage (1000 $m^3$) value 458.310 of Tandalja Lake. Maximum outflow from Atladra Lake 3.032 CMS.

Summary Results

Topic: Storage Volume    Click a column header to sort the column.

| Storage Unit | Average Volume 1000 m3 | Average Percent Full | Evap Percent Loss | Exfil Percent Loss | Maximum Volume 1000 m3 | Maximum Percent Full | Day of Maximum Volume | Hour of Maximum Volume | Maximum Outflow CMS |
|---|---|---|---|---|---|---|---|---|---|
| Samalake | 252.265 | 100 | 0 | 0 | 252.266 | 100 | 0 | 00:11 | 0.011 |
| Gorwalake | 123.582 | 100 | 0 | 0 | 123.581 | 100 | 0 | 00:00 | 0.042 |
| GotriLake | 156.789 | 100 | 0 | 0 | 156.800 | 100 | 0 | 00:13 | 0.916 |
| Saiyodvasnalake | 167.984 | 100 | 0 | 0 | 168.000 | 100 | 0 | 00:14 | 1.241 |
| Tandaljalake | 458.268 | 100 | 0 | 0 | 458.310 | 100 | 0 | 00:15 | 2.821 |
| Atladralake | 139.546 | 100 | 0 | 0 | 139.617 | 100 | 0 | 00:21 | 3.032 |

*Figure 4.7 Storage volume summary*

### *4.2.5 Storage inflow summary of Lakes:*

Figure 4.8 shows Storage inflow of all lakes. Maximum total inflow value is 127.28 CMS in Tandalja Lake 0.026 Flow Balance Error Percent. Minimum value of Maximum total inflow 16.47 CMS with Flow Balance Error percent 0.003.

Summary Results

Topic: Node Inflow    Click a column header to sort the column.

| Node | Type | Maximum Lateral Inflow CMS | Maximum Total Inflow CMS | Day of Maximum Inflow | Hour of Maximum Inflow | Lateral Inflow Volume 10^6 ltr | Total Inflow Volume 10^6 ltr | Flow Balance Error Percent |
|---|---|---|---|---|---|---|---|---|
| Samalake | STORAGE | 22.115 | 22.115 | 0 | 00:30 | 188 | 440 | 0.015 |
| Gorwalake | STORAGE | 94.881 | 94.881 | 0 | 00:50 | 1.01e+003 | 1.13e+003 | 0.034 |
| GotriLake | STORAGE | 121.705 | 121.705 | 0 | 00:50 | 1.3e+003 | 1.45e+003 | 0.033 |
| Saiyodvasnalake | STORAGE | 91.666 | 91.666 | 0 | 00:50 | 948 | 1.12e+003 | 0.030 |
| Tandaljalake | STORAGE | 127.338 | 127.338 | 0 | 00:50 | 1.35e+003 | 1.8e+003 | 0.026 |
| Atladralake | STORAGE | 16.473 | 16.473 | 0 | 00:30 | 149 | 288 | 0.003 |

*Figure 4.8 Storage volume summary*

### *4.2.6 Outfall Loading summary:*

Outflow from outlet is Avg. Flow 0.288 CMS with Flow Freq. Pcnt. 84.03 as shown in figure 4.9

Summary Results

Topic: Outfall Loading    Click a column header to sort the column.

| Outfall Node | Flow Freq. Pcnt. | Avg. Flow CMS | Max. Flow CMS | Total Volume 10^6 ltr |
|---|---|---|---|---|
| O1 | 84.03 | 0.288 | 0.294 | 5.231 |

*Figure 4.9 Outfall Loading*

### *4.2.7 Status report of interlinked report:*

Following Figure 4.10 shows Runoff quantity continuity, Runoff Routing Continuity, Routing Time Step Summarythat shows total precipitation of volume 547.83 hectare-m and 206.193 m depth, Wet Weather inflow volum 490.753 hectare-m. In figure 4.10 Highest Flow Instability indexes mentioned.

```
**************************        Volume       Depth
Runoff Quantity Continuity     hectare-m          mm
**************************     ---------     -------
Total Precipitation ......       547.830     206.190
Evaporation Loss .........         0.000       0.000
Infiltration Loss ........        14.613       5.500
Surface Runoff ...........       492.957     185.537
Final Storage ............        42.599      16.033
Continuity Error (%) .....        -0.427
```

```
**************************        Volume         Volume
Flow Routing Continuity        hectare-m       10^6 ltr
**************************     ---------      ---------
Dry Weather Inflow .......         0.000          0.000
Wet Weather Inflow .......       490.753       4907.586
Groundwater Inflow .......         0.000          0.000
RDII Inflow ..............         0.000          0.000
External Inflow ..........         2.426         24.256
External Outflow .........         0.523          5.231
Flooding Loss ............       492.089       4920.940
Evaporation Loss .........         0.000          0.000
Exfiltration Loss ........         0.000          0.000
Initial Stored Volume ....       129.843       1298.442
Final Stored Volume ......       130.307       1303.080
Continuity Error (%) .....         0.017

*******************************
Highest Flow Instability Indexes
*******************************
Link L8 (3)
Link L7 (2)
Link L5 (1)
Link L6 (1)
```

```
*************************
Routing Time Step Summary
*************************
Minimum Time Step           :    30.00 sec
Average Time Step           :    30.00 sec
Maximum Time Step           :    30.00 sec
Percent in Steady State     :     0.00
Average Iterations per Step :     1.02
Percent Not Converging      :     0.00
```

*Figure 4.11 Status report from SWMM V5.1 Simulation Run*

***4.2.8 Graphical representation of system:***

Figure 4.12 shows Time series plots between Time and System Runoff, Precipitation, Total Inflow, Flooding, Outflow. System Runoff increases rapidly with intense precipitation and will retard gradually and remains constant after 6 hrs.

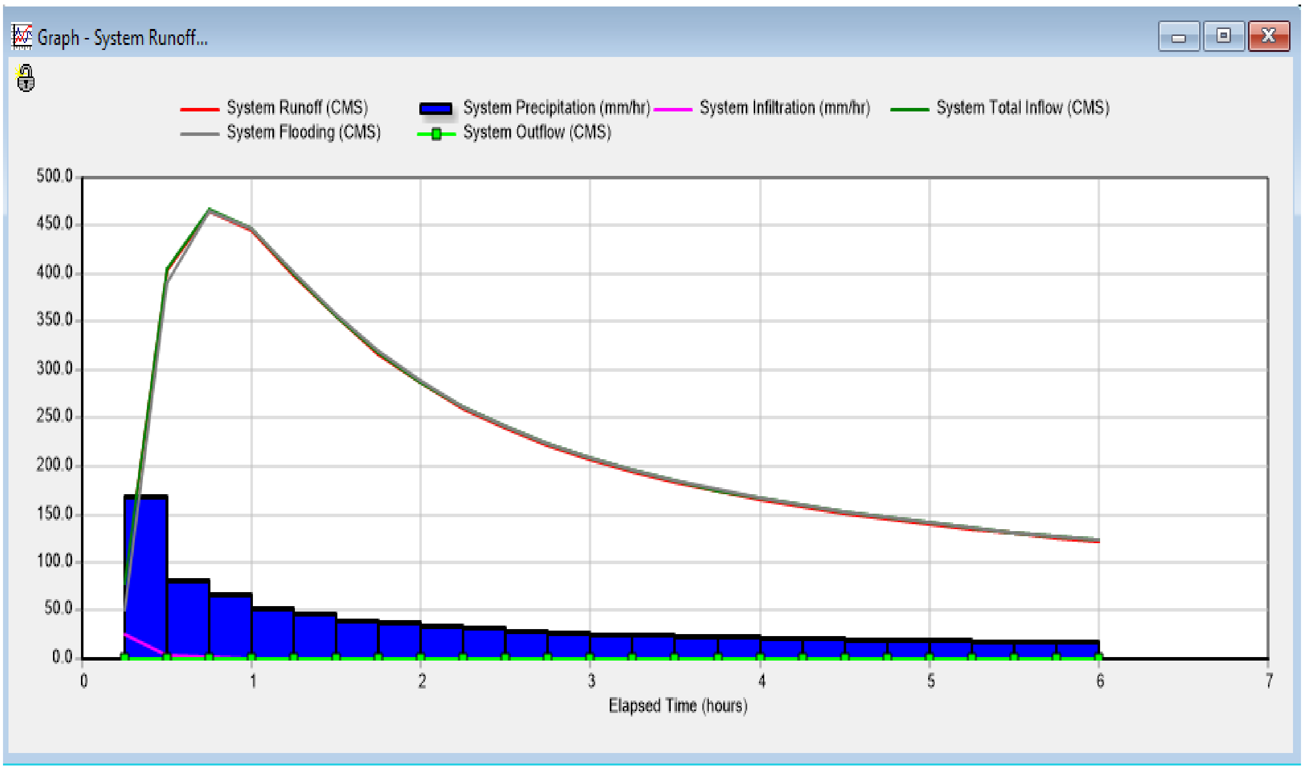



*Figure 4.12 System Time-series plots*

## V. CONCLUSION

- Vadodara city has already suffered serious floods in past years specially in year 1970, 2005, also in 2014 heavy rainfall occurred on upstream (Ajwa reservoir area) results city suffered serious losses. Vadodara city situated between river mahi and narmada and on banks of vishwamitri. It is vulnerable to flooding due to many reasons such as high intensity of rainfall in city area as well as on upstream (Ajwa reservoir area), loss of drainage capacity due to design faults, development of reclaimed areas and improper adoption of intensity of rainfall in designing the drainage system.
- Monsoon of Vadodara city is very quite unusual and unsteady as 5 year and 10 year average rainfall for climate change analysis shows variability
- One day Maximum rainfall was 315 mm in 9th month of 2005, which was flood year, and one day minimum rainfall was 31.6 mm in 7th month of 1974 in which season of monsoon was below average. So, maximum recurrence interval is 47 years for probability of exceedance 0.0213 and minimum recurrence interval is 1 year for probability of exceedance is 0.9787.
- Results of log log plot shows very accurate linear relationships. This indicated that the empirical formula obtained to estimate intensity in the study area is good for short durations. Values of constants ‘a’ & ‘n’ are 666.960’ and ‘0.666’ for 1 year return period, ‘774.818’, and ‘0.666’ for 2 year return period with 1 $R^2$ error.
- As observed in this study, Gumbel’s Extreme Value Distribution method shows the best approximation of rainfall intensity for return periods of 1 and 2 years, gives proper relationships of rainfall Intensity-Duration-Frequency. The results shows a good match as the correlation.
- System simulation shows Continuity error for Surface Runoff -0.43% and Continuity error for of Flow routing 0.02, which represents model status with maximum accuracy.
- Total route length of Linkage is 19440 m and fall between inverts is 5.665 m So, gradient of whole system is 1 in 3437.665 that will be Avg. gradient of system.
- In proposed interlinked system, Minimum water level will available throughout season in all lakes : Sama Lake-2.3 m, Gorwa lake- 2.5 m, Gotri Lake- 2.9 m, Saiyodvasna lake- 2.6 m, Tandalja lake- 3.2 m, Atladra Lake- 2.2 m.
- Inundation reduction in surrounding catchments of urban lakes will be 91%. Flood control is just near to 100% for catchments as in front of 492 ha-m of runoff flooding volume Routing volume is 489 ha-m.
- to reduce the flooding in the city, strict actions can be taken for removal of encroachments of the drains as well as the river to allow maximum passage of the stormwater through them.

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