Study on Drainage Capacity by using Modified Rational Method and Storm Water Management Model

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Abstract: *This paper focuses on analyzing the performance of the existing drainage capacity by using Modified Rational Method and then to propose the appropriate drain size with effective drainage capacity for the study area. Due to inadequate size, lack of proper maintenance and tidal effect, the existing drains in most of the places are not serving the purpose during rainy season. Therefore, new dimension of drain sections were proposed by using Manning's equation. In this study, HEC-HMS, hydrological model is used to evaluate the design discharge for external catchments. To simulate rainfall-runoff process, SWMM is used for checking the proposed drain size capacity. According to simulation result from SWMM, almost all the major drain and minor drain can carry the peak discharge for 10 year Average Recurrence Interval. Thereafter, EPA SWMM can also simulate the response of catchment events in which runoff, water depth profile, pressured pipeline flow and outflow hydrograph are obtained.*

Key Words: *Drainage network, HEC-HMS Model, Modified Rational Method, Storm Water Management Model.*

1. INTRODUCTION:

Urban drainage systems are generally designed to drain out surface runoff from urban areas during storm events. However, storm water exceeding the drainage capacity can cause urban flooding and result in traffic interruption, economic loss and health issues. An increase in impervious land cover leads to more surface runoff, faster runoff concentration and higher peak flow rate. Thus there is an increasing need to improve drainage capacity to reduce flooding in rapidly urbanizing areas. Conventionally, the improvement of drainage capacity relies on expanding and upgrading the existing storm drainage system [1].

Proper drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two main forms: the abstraction of water from the natural cycle to provide a water supply for human life, and the covering of land with impermeable surface that divert rainwater away from the natural system of drainage[2]. Nowadays, as a consequence of urbanization and climate change, urban water managers have to rethink the ways in which water is managed today, taking into account economic, environmental and social factors as well [3].

The concept of storm water management is strongly related to urban areas where conveyance system exists. Despite flooding, storm water also is interesting regarding the urban water balance. The expansion of impervious land-cover implies both larger storm water runoff volumes and peak flows and consequently reduces other components of the hydrologic cycle [4].

Yangon is geographically situated in a region that is influenced directly by the southwest monsoon. Severe floods occur frequently in every monsoon season in some parts of Yangon City since storm water increases due to the rapid growth of urbanization. It has annual rainfall of 2500 mm. However, rainfall intensity that mainly induces flooding problem is considerably high. Maximum 24 hour rainfall observed during the last 35 years was 343 mm, 13.54 inches in 2007[5]. Urban storm drainage system in Yangon city consists of about fifty open channels flowing out into six major rivers and canals and fourteen drainage networks were constructed in Central Business Downtown area [6].

2. CHARACTERIC OF STUDY AREA:

The study catchment is located in the south-western part of Yangon City. Yangon city has a total area of 637 sq. kilometres and a population of over six million and is the most important commercial centre. It compose of 33 township. The study area, Kyeemyindaing Township is located at the bank of Yangon River which has substantial flow from Ayeyarwaddy River. The area of Kyeemyindaing Township is 5.6 km^2 and residential area mainly consisting buildings, pavement and crowded population. The study area receives the runoff from the largest amount of

Sanchaung Township. There have 11 outlets drain to Yangon River. The main constraint of the drainage system to cause flooding in study area is downstream tide which can force periodically to close the outlet.

This paper was to analyze the existing drain capacity for four outfalls. Yangon River and Hlaing River tidal curve were used for analyzing tidal condition. Maximum spring tide for Yangon and Hlaing River are (3.95) meter and (3.94) meter. The drainage system will be designed to have a capacity to drain the surface runoff from the design storm with 10-year, 50-year and 100-year respectively.

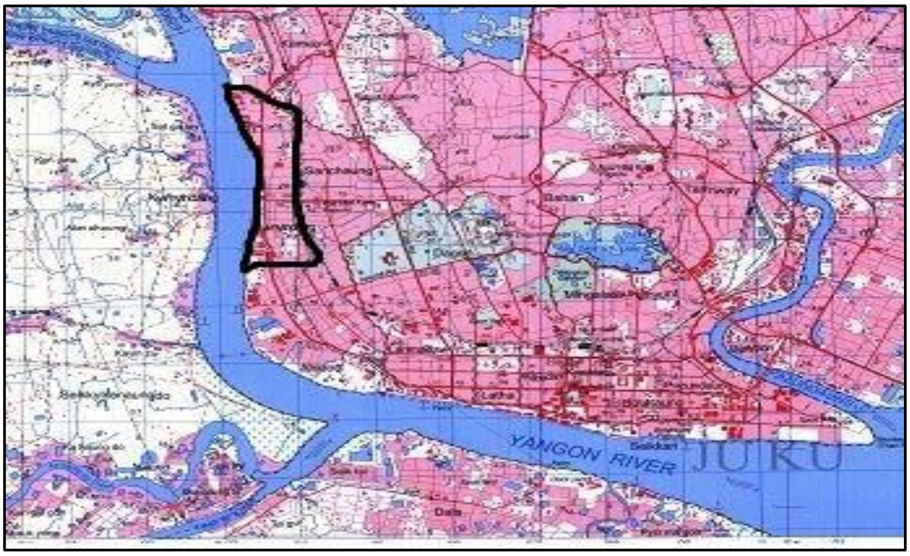

Figure 1.Study area map

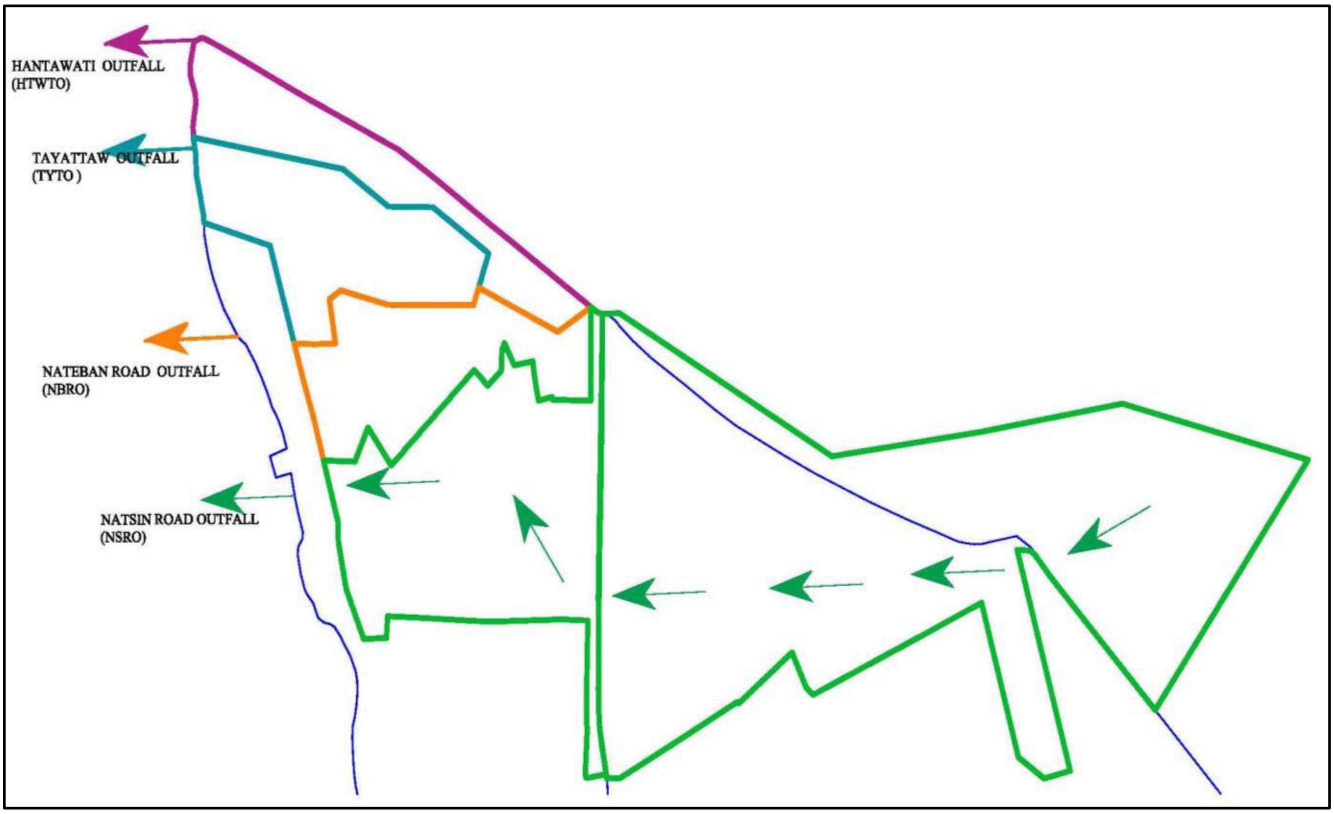

Figure 2.Drainage Network for Four Outlets with External Catchment

3. METHODOLOGY:

The methodology used in this study consists of two main parts. The first one was used modified rational method to estimate design flood for all sub-catchments. HEC-HMS model was also used to estimate design flood for external catchments. The existing drainage capacity was checked by using Manning's equation. Modified rational method is based on the rational method which is based on a simple formula that relates runoff-producing potential of watershed, the average intensity of rainfall for a particular length of time and the watershed drainage area. All drainage system are arrange with network system. The alternative one was used storm water management system to cover network flow condition system for proposed drain capacity. In storm water management model, dynamic wave routing and Green-Ampt approaches were applied to analyse flow routing and infiltration processes. Tidal hydrographs of Yangon River and Hlaing River were applied for this study.

Modified Rational Method:

This method was developed so that the concepts of the rational method could be used to develop hydrographs for storage design, rather than just flood peak discharges for storm sewer design. Increase understanding of the rainfall-runoff process has led to further development of the rational method.

The modified rational method is recommended in the Wallingford procedure (DoE/NWC 1981) and shown to be accurate for catchment sizes up to 150 ha. In this approach, the runoff of rainfall is integrated from other routing effects, thus, the runoff coefficient C is considered to consist of two components. This method was developed so that the concepts of the rational method could be used to develop hydrographs for storage design, rather than just flood peak discharges for storm sewer design. Design flood for each structure is estimated by using the following formula [7].

$$Q = 0.278\ C\ Cs\ i\ A \qquad (1)$$

Where, Q = Design Flood in cubic meters per second
C = Runoff coefficient
Cs = Storage coefficient
i = Average rainfall intensity in mm per hour
A = Area in Sq. kilometre

Sizing of culverts and drains are carried out using the well-known hydraulic formula of Manning's formula.

$$\text{Design discharge } Q = \frac{1}{n} A\ R^{2/3} S^{1/2} \qquad (2)$$

Where, n = Manning's roughness
A = Area of proposed drain or culvert
R = Hydraulic radius of drain or culvert
S = Hydraulic gradient

By applying Manning's formula, the channel carrying capacity was calculated by using the existing dimensions of the drains which were obtained from Yangon City Development Committee. The roughness coefficient "n" was taken as 0.014 for the normal concrete lining value [8].

Time of concentration (tc):

The time of concentration, tc is defined as the time which would be required for the surface runoff from the most remote part of the catchment to reach the point considered as the sum of overland flow time, t_0, and the time of flow in the channel, t_d.

For natural and landscaped catchments and mixed flow paths, the time of concentration (t_c) can be found by the use of Bransby-William's Equation [8].

$$t_c\ (min) = \frac{F_c L}{A^{1/10} S^{1/5}} \qquad (3)$$

Where, F_c = conversion factor (58.5 if A is in sq. Kilometres)
(92.5 if A is in hectares)
A = catchment area
L = stream length (m)
S = slope of stream flow path (m/km)

Rainfall intensity-duration-frequency relationship:

The total storm rainfall depth at a point, for a given rainfall duration and Average Recurrence Interval, ARI, is a function of local climate. Rainfall depths can be further processed and converted into rainfall intensities (intensity =depth/duration), which are then presented in IDF curves. Such curves are particularly useful in storm water drainage design because many computation procedures require rainfall input in the form of average rainfall intensity. The three variables, frequency, intensity and duration are all related to each other. The data are normally presented as curves displaying two of variable, such as intensity and duration, for a range of frequencies. These data are then using as the input in most storm water design processes [8]. Rainfall intensities of different return periods (ARI) for various durations at Yangon City were developed by joint effort of Myanmar Meteorology & Hydrology Department and Irrigation Department. The Intensity-Duration-Frequency curve for Yangon Project Area is shown in figure 3. In this regard, the maximum daily rainfall of Kabar-Aye station from 1962 to 2016 was used in conjunction with the research paper of 1986 [9].

The temporal distribution of rainfall within the design storm is an important factor that affects the runoff volume, and the magnitude and timing of the peak discharge. Design rainfall temporal patterns are used to represent the typical variation of rainfall intensities during a typical storm burst. The standard durations recommended for urban storm water studies are listed in Table 1 [8].

Table 1. Standard Duration for Storm Water Drainage

Standard duration	Number of Time Intervals	Time Interval (minutes)
10	2	5
15	3	5
30	6	5
60	12	5
120	8	15
180	6	30
360	6	60

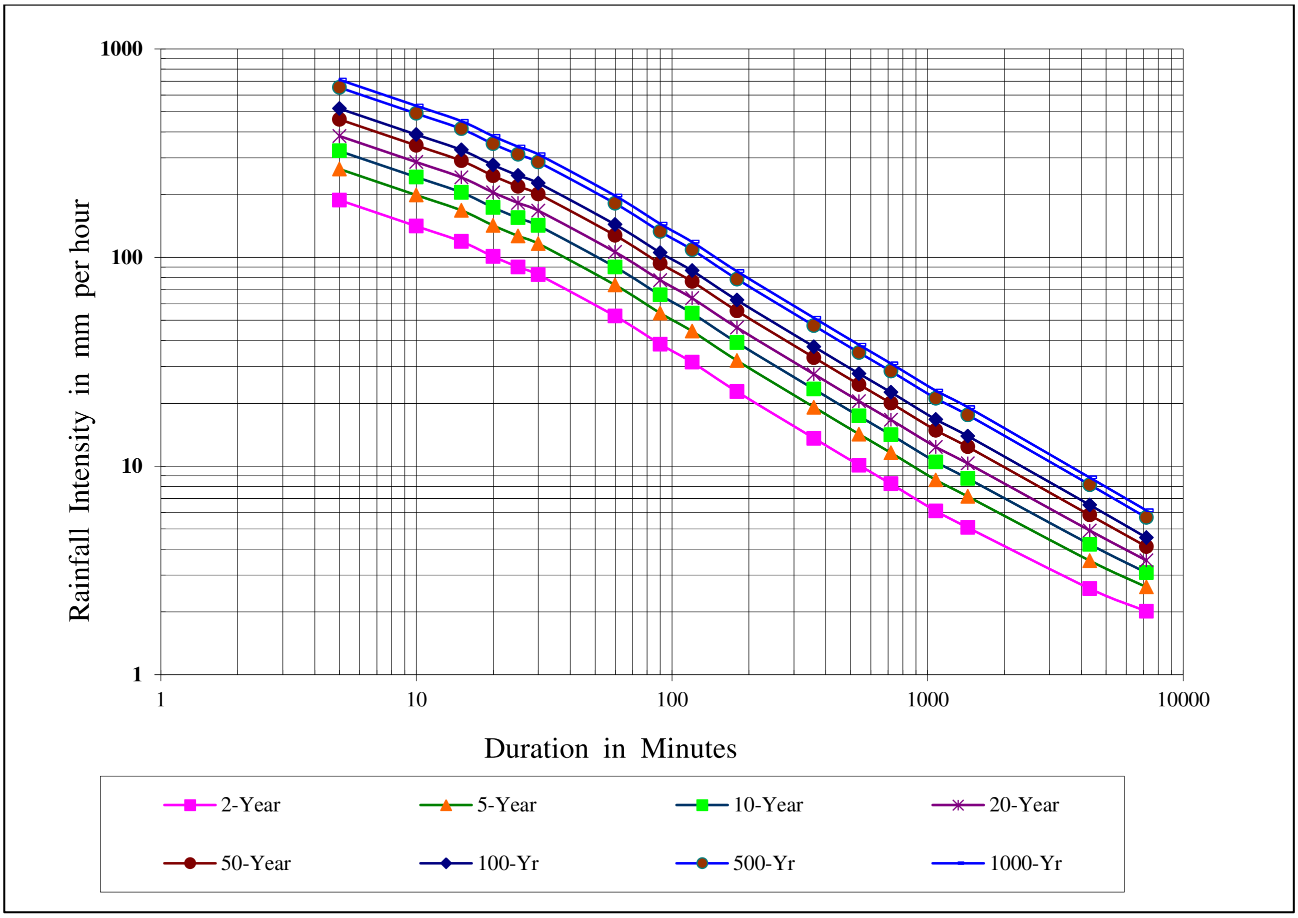

Figure 3. Rainfall Intensity-Duration-Frequency curve for Yangon [9]

HEC-HMS Hydrological Model:

Hydrologic Modelling System (HEC-HMS) was developed by Hydrologic Engineering Centre of the U.S Army Corps of Engineers. It was designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of problems. This includes a large river basin water supply and flood hydrograph, small urban or natural watershed runoff. Hydrographs produced by the program are use directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, flood plain regulation, and system operation. In HEC-HMS model, there are four main components for hydrological modelling; loss method, transform method, base-flow method and routing method [10].

In this study, HEC-HMS was used as hydrological model to evaluate design discharges from external catchments. Initial and constant losses and SCS unit hydrograph were selected for loss and transform method respectively. Recession and lag methods were assigned for base-flow and routing method respectively and applied for rainfall-runoff simulation in the study area. The following table show input parameter for HEC-HMS model.

Table 2. Input Parameter for HEC-HMS model

Initial Loss	23mm
Constant Rate	4 mm/hr
Recession Constant	0.7
Initial Discharge	0.0547 m^3/sec
Ratio to Peak	0.02
% impervious	Present Condition/ Future Development

Storm Water Management Model (SWMM):

The US EPA Storm Water Management Model (SWMM) is chosen to evaluate the capacity of proposed drain capacity and tidal effect in this study. SWMM is a dynamic rainfall-runoff simulation model, developed by the United States Environmental Protection Agency, which computes the quantity and quality of urban runoff in storm water and combined systems. The model is widely used for planning, analysis and design related to drainage systems in urban areas. SWMM consists of multiple functional computational blocks. The runoff block calculates the surface runoff and water quality constituents from rainfall. The transport block calculates the flows and water quality of drainage system with no surcharge through dynamic. The storage treatment block traces flows and water quality through a storage control device. The external block calculates hydraulic, flows by steady flow, kinematic wave and dynamic wave tracing [11].

The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth and quality of water in each pipe and channel during a simulation period comprised of multiple time steps [12]. SWMM uses a nonlinear reservoir model to estimate surface runoff produced by rainfall over a sub catchment. Assuming that flow across the sub catchment's surface behaves as if it were uniform flow within a rectangular channel of width W(m), height (d-ds), and slope (S), the Manning's equation can be used to express the runoff's volumetric flow rate Q(m^3/sec) as:

$$Q = \frac{W}{n}\,(d - ds)^{5/3}\, S^{1/2} \tag{4}$$

SWMM accounts for the spatial variability of rainfall by allowing the user define any number of Rain Guage objects along with their individual data sources, and assign any rain gauge to a particular SWMM sub-catchment object from which runoff is computed [13].

In this research, the general options for SWMM are used rainfall-runoff process model, dynamic wave routing model and Green-Ampt infiltration model. Sub catchments are divided into pervious and impervious areas. Surface runoff in pervious and impervious is given by the Manning's equation. SWMM also allows to describing additional characteristics and processes within the study area. Flow routing in channels and pipes is governed by the conservation of mass and momentum equations for gradually varied and unsteady flow (Saint Venant) equations. Time of concentration is one of the most important parameters effective in rainfall-runoff simulation.

4. RESULT AND DISCUSSION:

Firstly, modified rational method was used to estimate design flood for 10year, 50year and 100 year respectively. Maximum duration of travel time from Sanchaung Township is nearly 120 minutes. Therefore, 120 minutes standard duration design rainfall was applied in HEC-HMS model. In this study, HEC-HMS was used as hydrological model to evaluate design discharges from external catchments. Initial and constant losses and SCS unit hydrograph were selected for loss and transform method respectively. Recession and lag methods were assigned for base-flow and routing method respectively and applied for rainfall-runoff simulation in the study area. The following table show summary result of design flood from this model. Runoff flood peaks from this simulation are shown in the following figure for 10-year, 50-year and 100-year ARI.

Table 3. Summary Result of Design Flood from External Catchment

Return period	Design flood (m^3/sec) for current condition	Design flood (m^3/sec) for future development
10yr	11.2	12.3
50yr	15.80	16.8
100yr	18.80	19.9

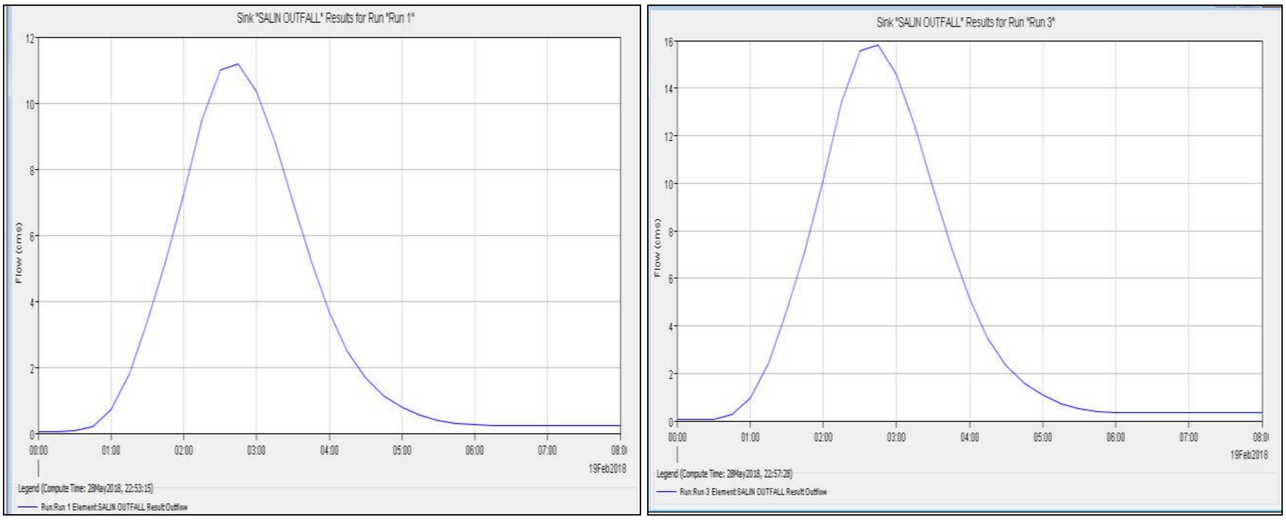

Figure 4. Simulation Runoff Hydrograph for 10-year and 50-year

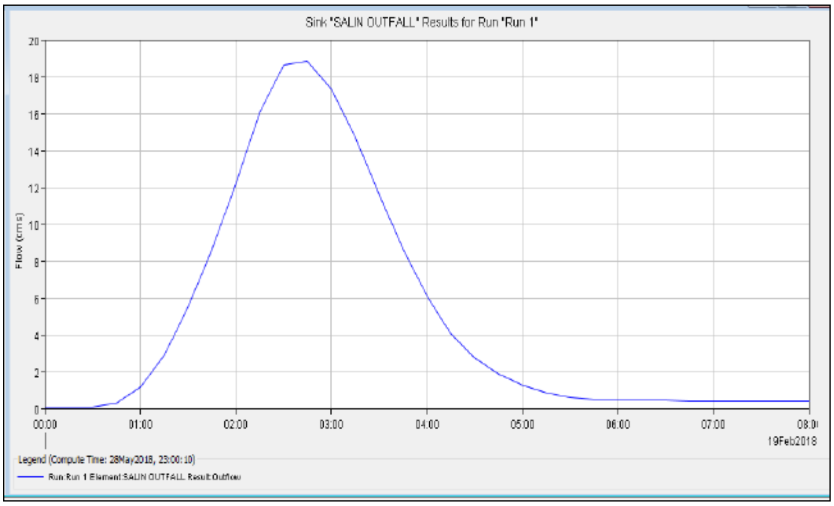

Figure 5. Simulation Runoff Hydrograph for 100-year

The capacity checked for existing drains were evaluated by Manning's formula. It is observed that all existing drain sizes were not enough to carry the design flood of 10yr return period. Therefore, proposed drain sizes were required for the study area. The capacity of proposed drain sizes were also analysed by using storm water management model (SWMM). The study area contains 113nos of sub catchments, 223nos of nodes and 224nos of conduit links. The value of sub catchment width depends on the value of area and runoff length. The runoff process for pervious and impervious surface are simulated by different methods. The imperviousness of the urban surface is closely related to the land cover type. Manning's value which can describe the influence of roughness coefficient of conduit or surface on the runoff process. For sub catchment properties, n-Manning's coefficient of impervious and pervious area, and the percentage of impervious areas were identified as influencing factors on variations of peak flood.

Watershed time of concentration is one of the most important parameters effective in rainfall-runoff simulation. Rainfall duration time was assumed equal to watershed time of concentration. In this paper, rain gauge (1) and (2) were represented for (15) min design rainfall and two hours design rainfall respectively. The temporal distribution of rainfall within the design storm is an important factor that affects the runoff volume and the magnitude and timing of peak discharge.

According to the results from the storm water management model (SWMM), it was founded that there is no pressure pipeline flow for 10yrs return period. Therefore, proposed drain sizes are enough to carry design discharge for 10yrs return period. To overcome tidal effect condition, sluice gate should be installed for the outlet where the associated road levels are lower than the spring tide levels. The following table 4 shows summary result of total inflow from SWMM and modified rational method for 10yr return period. The following figure shows model description for sub-catchments, nodes and conduits for four outfalls.

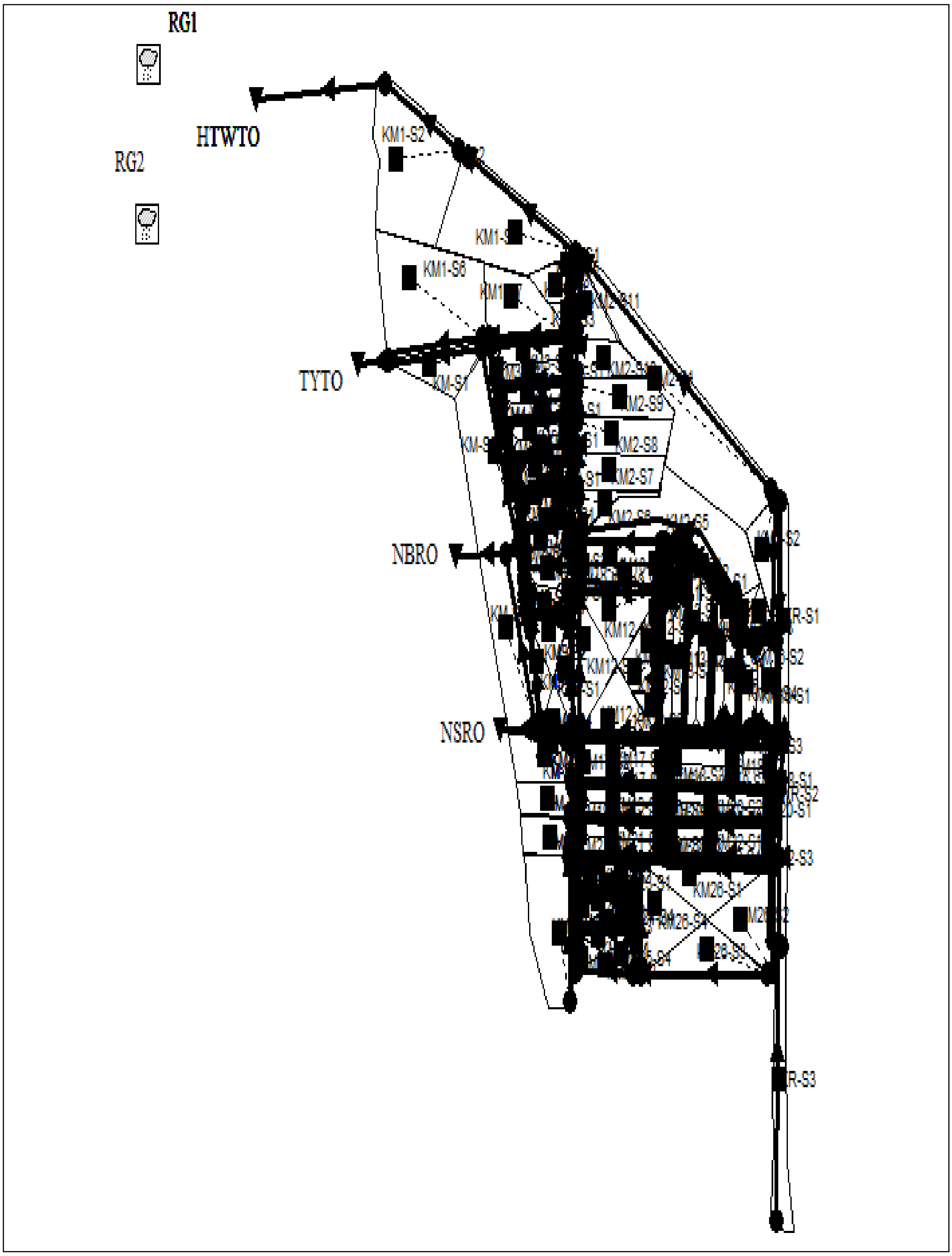

Figure 6. Catchment Visualization in SWMM software

Table 4. Summary Result of Simulated Design Flood from SWMM and Modified Rational Method

Outfall Name	**SWMM (Current Condition)**	**Modified Rational Method**

Hanthawaddy outfall (HTWTO)	3.803	4.23
Thayettaw outfall (TYTO)	5.705	6.55
Nate ban Road outfall (NBRO)	5.801	6.03
Nat zin Road outfall (NSRO)	11.347	18.81

5. CONCLUSION:

Modified rational method was applied for estimation of runoff for all sub catchments. Proposed drain sizes were checked by storm water management model. This paper focused on the drainage capacity for the study area. In modified rational method, the runoff coefficient was considered for future land use pattern. For SWMM software, runoff coefficient was classified into various impervious according to the land use pattern. From this study, it was noted that all the existing drain sections are not enough in most of the places to accommodate the 10yrs runoff. All channels in the study area should be improved such as lining to increase carrying capacity. In addition, sluice gate should be installed to prevent the tidal flooding. The SWMM software was run considering the proposed drain dimensions of the drainage network. From this model simulated result, it was found that when the return period is 10yrs, there is no pressured pipeline flow. Pressured pipeline flow is another index for urban flooding. According to this result, we can say that all proposed drain sizes can convey 10yrs design flood. Therefore, the existing drainage system for the study area should be upgraded as proposed. However, the SWMM parameters need calibration for more reliable results. The application of SWMM achieves catchment responses to peak flow and runoff volume, which are the two most essential catchment responses in urban drainage planning.

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