Analysis of Drainage Capacity by Using Rational Method and Storm Water Management Model

Mi Pale Kyi and Win Win Zin

Abstract**—**Inadequate drainage capacity can cause flooding in urban area. Therefore, the drainage network and drainage capacity are considered as an important and indispensable infrastructure for the city. 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 the rainfall-runoff process, SWMM was used for checking the proposed drain size capacity. Modified rational method considers for future development effect and SWMM is applied for both current condition and future condition.

Keywords**—** Drainage network, external catchment, HEC-HMS Model, Modified Rational Method, Storm Water Management Model.

I. 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].

II. Characteristics 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. kilometers and a population of over six million and is the most important commercial center. 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. 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. 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

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respectively. The following figure shows study map and existing drain network.

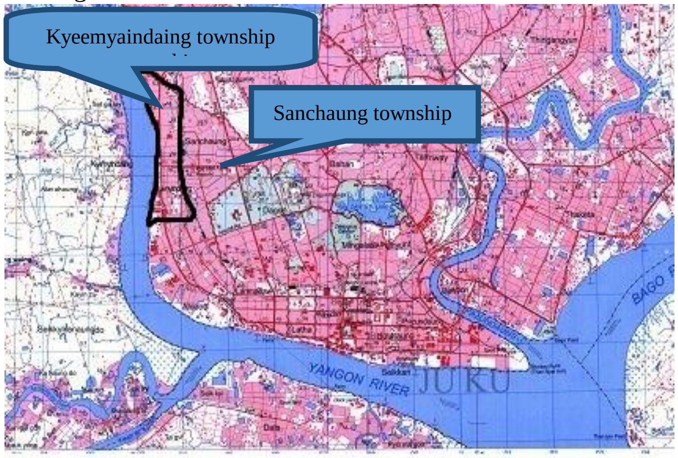

Fig. 1 Study area map

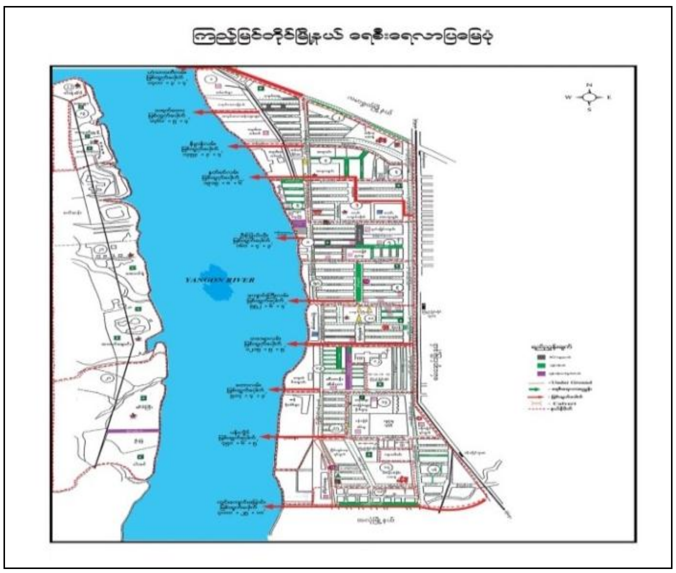

Fig. 2 Existing drainage network of Kyeemyaindaing township

III. Methodology

The methodology used in this study consists of the 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. The alternative one was to consider with storm water management model (SWMM) to check the capacity of proposed drain. In storm water management model, dynamic wave routing and Green-Ampt approaches were applied to analyze flow routing and infiltration processes. Tidal hydrographs of Yangon River and Hlaing River were applied for this study.

A. 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].

$$Q = 0.278\, C\, Cs\, i\, A \tag{1}$$

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. kilometer

Runoff coefficient was adopted as 0.9 in this study for future condition.

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

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

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].

B. 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].

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

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

C. 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. Rainfall intensities of different return periods (ARI) for various durations at Yangon City were developed. The Intensity-Duration-Frequency curve for Yangon Project Area is shown in figure 1.3. .In this research, the maximum daily rainfall of 1962 to 2016 was used for Kabar-Aye station.

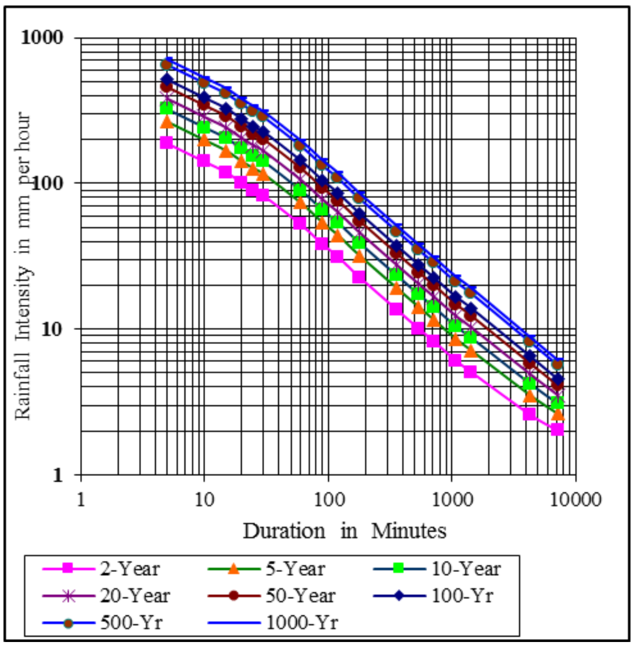

Fig. 3 Rainfall Intensity-Duration-Frequency curve for Yangon

D. Design Tidal Hydrograph

Tidal hydrograph for Yangon River and Hlaing River are collected from Myanmar Port Authority and only maximum and minimum water levels with corresponding times are available. Typical constituted tidal hydrograph for spring and neap tide for Yangon and Hlaing Rivers in month August are shown in the following figures.

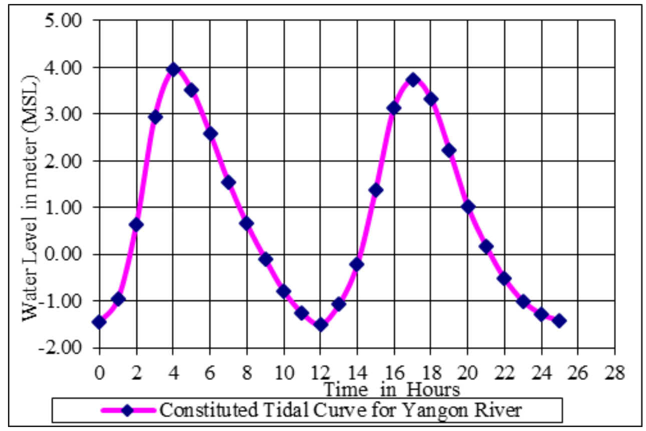

Fig. 4 Consituted tidal curve for Yangon River (one complete spring tide cycle)

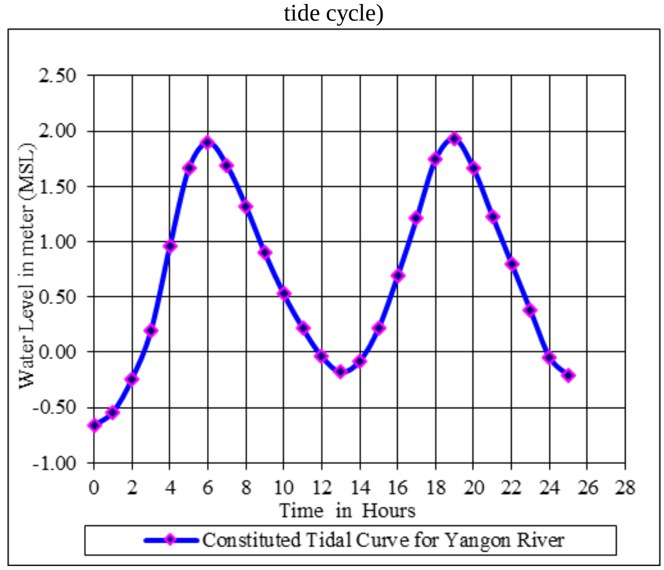

Fig. 5 Consituted tidal curve for Yangon River (one complete neap tide cycle)

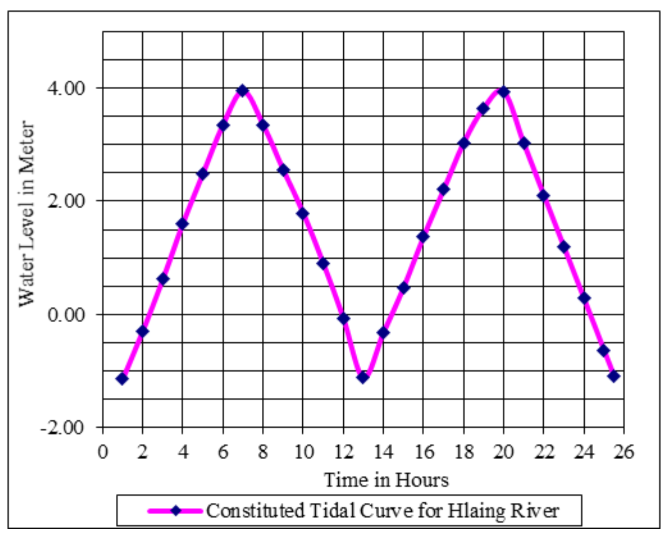

Fig. 6 Consituted tidal curve for Hlaing River (one complete spring tide cycle)

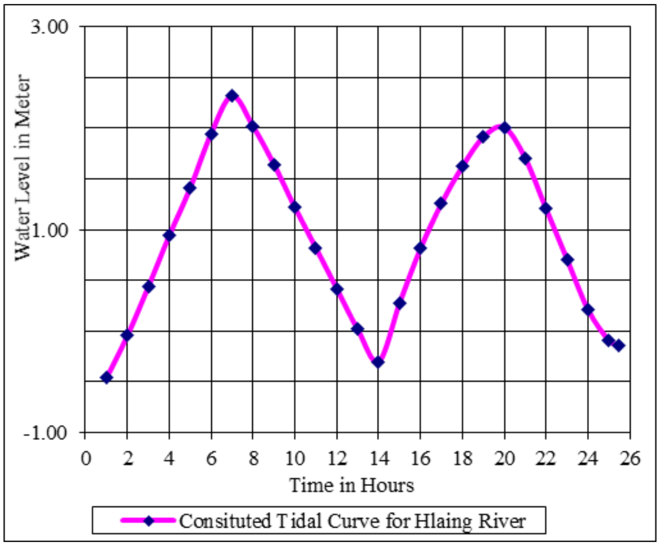

Fig. 7 Consituted tidal curve for Hlaing River (one complete neap tide cycle)

E. .HEC-HMS Hydrological Model

Hydrologic Modeling System (HEC-HMS) was developed by Hydrologic Engineering Center 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 modeling; loss method, transform method, base-flow method and routing method [9].

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.

F. .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 [10].

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 [11].

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.

IV. Result and Discussion

In this paper, first method was developed by the Modified Rational method to estimate design flood for 10year, 50year and 100 year respectively. The following table show the summary result of simulated design flood for external catchment from that flow to saline underground.

TABLE I

Summary Result of Simulated Design Flood from External Catchment

Return period	Design flood (cumecs) for current condition	Design flood (cumecs) for 90% impervious
10yr	11.2	12.3
50yr	15.80	16.8
100yr	18.80	19.9

The following figures show the simulated runoff hydrograph for 10yr return period for current condition.

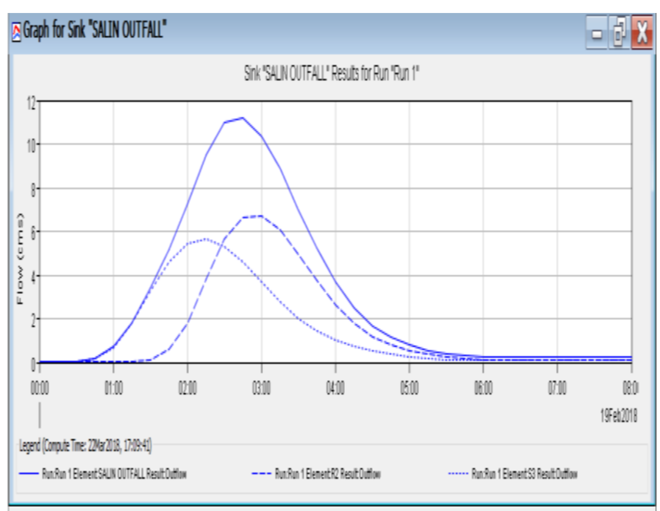

Fig. 8 Simulated runoff hydrograph of 10yr return period with 2 hour rainfall (HEC-HMS)

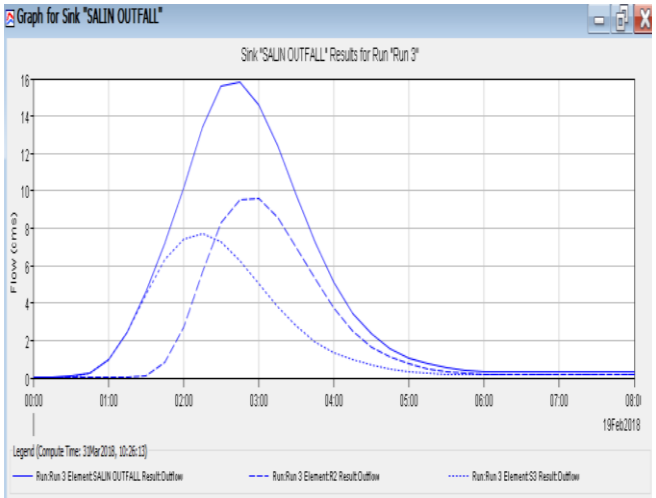

Fig. 9 Simulated runoff hydrograph of 50yrs return period with 2 hour rainfall (HEC-HMS)

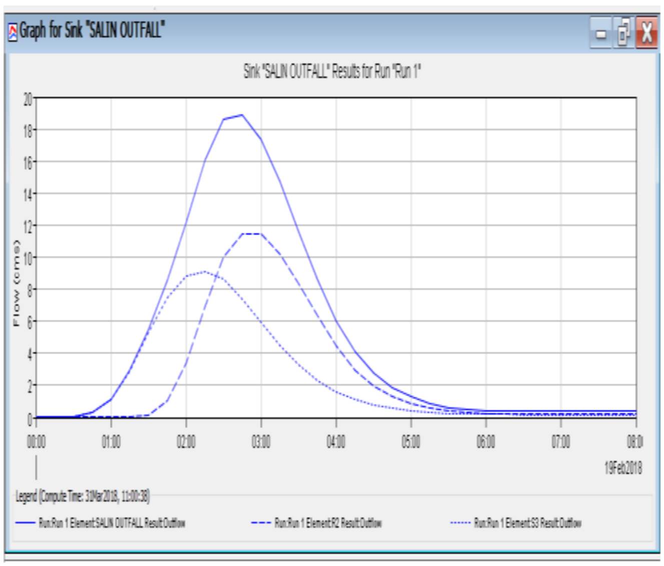

Fig. 10 simulated runoff hydrograph of 100yrs return period with 2 hour rainfall (HEC-HMS)

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 analyzed by using storm water management model (SWMM). In this study, sub catchments were divided into 113nos, 223nos of nodes and 224nos of conduit links.

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 I(15min rainfall) and rain gauge II(2hrs rainfall) were applied. 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. Design rainfall temporal patterns were used to represent the typical variation of rainfall intensities during a typical storm bust. The following tables show temporal rainfall pattern for rain gauge pattern I and rain gauge pattern II.

TABLE II
TEMPORAL RAIN GAUGE PATTERN I

Time (H:M)	Volume (mm)
00:05	14.52
00:10	22.69
00:15	8.17

TABLE III
TEMPORAL RAIN GAUGE PATTERN II

Time (H:M)	Volume (mm)
00:15	3.52
00:30	13.96
00:45	36.38
01:00	24.41
01:15	10.56
01:30	13.96
01:45	11.03
02:00	3.52

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.

According to the results from the storm water management model, it was found 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 shows summary result of total inflow from SWMM (90% impervious area and current condition) and modified rational method for 10yr return period. The following figure shows model description for sub-catchments, nodes and conduits for four outfalls.

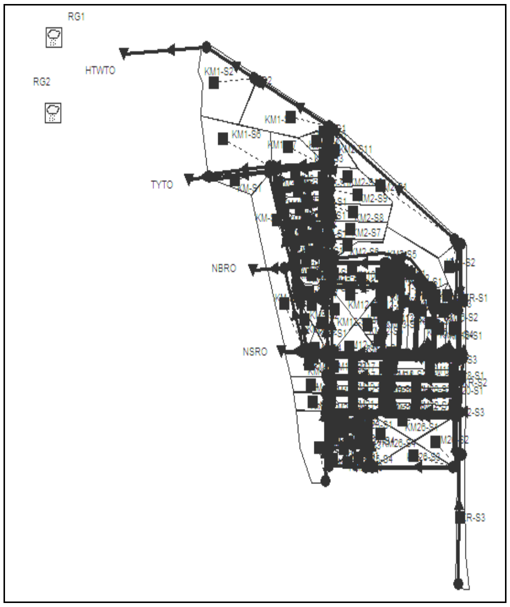

Fig. 10 Catchment visualization in SWMM

According to the results from the storm water management model, it was found 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 shows summary result of total inflow from SWMM (90% impervious area and current condition) and modified rational method for 10yr return period.

TABLE IV
SUMMARY RESULT OF SIMULATED DESIGN FLOOD FROM SWMM AND MODIFIED RATIONAL METHOD

Outfall Name	**SWMM (90%)**	**SWMM (Current Condition)**	**Modified Rational Method**
Hanthawaddy outfall (HTWTO)	3.885	3.803	4.23
Thayettaw outfall (TYTO)	5.969	5.705	6.55
Nate ban Road outfall (NBRO)	6.095	5.801	6.03
Natzin Road outfall (NSRO)	12.868	11.347	18.81

V. CONCLUSION

Modified rational method was applied for existing drainage size capacity. 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, two types of runoff coefficient were applied. From this study, it was noted that all the existing drain sections are not enough in most of the places to accommodate the 10yr 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, all proposed drain sections are adequate for the study area. Therefore, the existing drainage system for the study area should be upgraded as proposed. However, the SWMM parameters need calibration for more reliable results. For future study, all outfalls should be developed by storm runoff model.

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About Author :

[All drainage systems in my study area are not arrange systematically. And then the study area is located near Yangon River. Nowadays, due to climate change, urbanization, unplanned urban pattern are projected to lead to an increase flooding in urban area. Therefore, proper drainage systems are needed to prevent flooding in urban area.]