

## SUSTAINABLE STORM WATER DRAINAGE SYSTEM DESIGN FOR SYLHET AGRICULTURAL UNIVERSITY

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### Abstract

Drainage system of Sylhet Agricultural University is often blocked by sediment and solid waste consequences in a water-logged situation. To eradicate this problem, a study was conducted to design of sustainable storm water drainage system for Sylhet Agricultural University. The rainfall data from the secondary sources and relevant data of topography and vegetation from the primary and secondary sources were collected to endure the study. An endeavor to analyze the present scenario of drainage system in this university was accomplished through questionnaire survey, informal interview and open discussion. Hence, hydrological data analysis paves the way to design the most economical and efficient hydrologic design of drainage system. 100 years return period and 1-hour rainfall depth was estimated to prepare an Intensity-Duration-Frequency curve. The study area was dividing into three catchments based on topography. The time of concentration of 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> catchments were 5.21, 4.72 and 5.75 min., respectively. However, peak discharges of three catchments were calculated using rational formula and the values were  $1.19 \text{ m}^3 \text{ s}^{-1}$ ,  $1.2 \text{ m}^3 \text{ s}^{-1}$  and  $2.2 \text{ m}^3 \text{ s}^{-1}$ , respectively. Rectangular cross-sections of drains for three catchments were designed using Manning's equation according to peak discharge. Therefore, total cost was also estimated. A proper management system for storm water drainage was also suggested to reduce the potential of flooding and clogging in the campus area.

**Keywords:** Drainage system, hydrologic design, peak discharge.

### Introduction

Drainage is the process of interception and removal of water from over and under the vicinity of the road surface. Drainage can be surface or subsurface (Tank and Shinkar, 2016). Surface and subsurface drainage of roads critically affect their structural integrity, life and safety to users and is thus important for highway design and construction. Drainage facilities are required to protect the road against damage from the surface and sub-surface water. Traffic safety is also important as poor drainage can result in dangerous conditions like hydroplaning. Poor drainage can also compromise the structural integrity and lifespan of a pavement. Rapid urbanization along improper drainage systems most often lead to flooding, making unsafe and unhygienic conditions for humans and animals and damaging numerous establishments. Though necessary, storm water drainage can have a significant impact on the environment. Unfortunately, toxic substances, such as lawn fertilizers, cigarette butts, motor oil, pesticides, and other chemicals are often washed into storm water drainage systems. These chemicals lead to polluted water bodies, where it proves unhealthy for fish, plants, and other water life, even killing them. Proper drainage system plays an important role in controlling the water-related diseases such as water-related vector-borne diseases. Lack of judicious planning has given rise to a number of problems and their ill-effects experienced have been considerably profound.

Storm water, defined as runoff caused by rain and snowmelt in urban areas, and domestic wastewater are the main flows that are handled by the urban drainage system (Sundberg *et al.*, 2004). Urban drainage systems should be designed to handle wastewater and storm water with the aim of minimizing the problems caused by humans and the environment (Butler and Davis, 2004). A storm drainage system is a tool that received, conveyed and controlled storm water runoff in response to precipitation and snowmelt. Such systems include: ditches, culverts, swales, subsurface interceptor drains, roadways, curb, and gutters, catch basins, manholes, pipes, attenuation ponds and

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service lateral lines. The major drainage system comprises the natural streams and valleys and manmade streets, channels, and ponds. It is designed to accommodate runoff from less frequent storms.

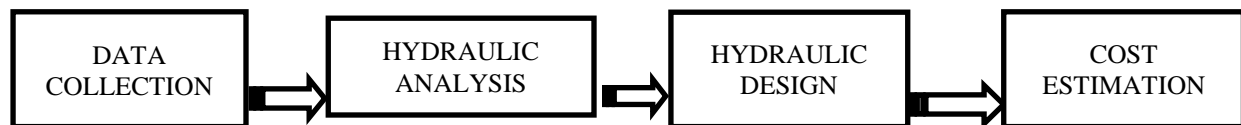
The existing drainage system of Sylhet Agricultural University consists of earthen and concrete drains. The overall condition of existing drains is not satisfactory. Because, there are blocking in the drains due to indiscriminate disposal of solid wastes like polythene, teaching aids, and waste materials. Moreover, several ponds and lakes in this area are going to block with sediments followed by several heavy rainfalls. In water-logged areas, during and after heavy rainfall, many inconveniences are experienced by residents. Also, water-borne diseases spread thereupon. To address the above situation and mitigate problem arising from uncontrolled disposal of excreta and waste, it is needed to study for “Sustainable Storm Water Drainage System Design for Sylhet Agricultural University” as a part of “Development of a land use plan for Sylhet Agricultural University” project funded by Sylhet Agricultural University Research System (SAURES). In order to attain the above challenge, the present study was undertaken with the following objective:

- To design an efficient storm water drainage system for Sylhet Agricultural University.

## Materials and Methods

The study was conducted in 2016 at the Department of Agricultural Construction and Environmental Engineering (ACEE), Sylhet Agricultural University (SAU), Sylhet. The existing drainage system of Sylhet Agricultural University is not in a satisfactory condition. So, the study was conducted to analyze the drainage system scenario and to design a sustainable system by using 100 years return period data.

Working procedure that has been carried out in this work is shown in the flow diagram:



**Fig. 1. Working process flow diagram**

### Collection of data

To fulfill the objective of the study both primary and secondary data were needed. All the necessary data was collected from various sources.

### Collection of maps

To endure the present study, different types of maps was collected. These are map of master plan of Sylhet Agricultural University, Google map and Google Earth map of SAU from internet and 3D map of this study area from project of land use of SAU. First two types of maps were collected from Engineering section of SAU and Google Earth map of SAU from internet and 3D map of this study area was collected from project report on land use of SAU. The existing drainage layout map was also needed and this has been collected from the project work designed by chairman of department of ACEE which is funded by SAURES.

### Secondary data

Secondary data were collected from Bangladesh Meteorological Department, journal papers and hydrology selected books. The past and present data on natural drainage system was collected by reconnaissance survey.

### Collection of photographs

A lot of photographs were also needed to illustrate the situation of water logging, related obstacles into the smooth drainage of urban runoff and its effects on urban life. Some of these photographs were collected directly from field survey and some other from daily newspapers as well as from internet websites.

### Questionnaire survey and informal interview

To find out inherent causes of water logging in Sylhet Agricultural University and its associate impact on life and better sustainable drainage system, a field survey as questionnaire survey, informal interview and open discussion was conducted with the authorities of different concerned persons, experts and people living in different parts of

SAU. The questionnaire was designed in such a way that it would track down the problems from the inception and the impact of the water logging in the locality.

### **Climate of study area**

The climate of the region is greatly influenced by the onset and withdrawal of the annual monsoon. The climate of Sylhet is a tropical monsoon. Annual average rainfall is 3334 mm. Average annual temperature is around 24°C. warmest months is April. The coolest month is January. A lot of rain (rainy season) occurs in the months: April, May, June, July, August, September and October. Sylhet has dry periods in November, December and January. August is the wettest month. December is the driest month.

### **Hydrologic analysis**

Most hydrological studies require short duration rainfall-runoff data and generally in Bangladesh, such short duration data are not available. However, daily data are collected. Hence efforts have been made first to develop short duration data from daily data to aid in hydrological studies in general, and storm water management in particular for the study area hydrologic methods frequently used in the runoff computation and design work can be classified into peak discharge methods and hydrograph methods. The former metalloid is commonly used for design problems on small watersheds where storage effects are unimportant; this would include design of street drainage, inlets and storm sewers. Hydrograph methods are most often applied to larger watersheds where effects of storage must be taken into account, such as in the design of regional detention facilities (ASCE, 1996).

### **Catchment of study area**

Sylhet Agricultural University is situated in a hilly region. The study area was divided into three catchments based on topography characteristics like hilly, low and plain.

1. The first catchment starts from Humayun Rashid Chowdhury Hall to Kataltoli road. It includes four halls, an auditorium, playground and a Research Centre.
2. The second catchment area of SAU starts from the last point of the first catchment to new veterinary building and includes many academic buildings, administration building, mosque, some residential area, and lake.
3. The third catchment area was selected from new veterinary building to the last hill of SAU. It includes a major portion of a hilly area, teacher quarter, lady's hall, guest house and Vice-Chancellor residential building.

### **Rainfall data presentation**

Sylhet region has many rainfall stations of Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD). For the present study; Sylhet branch of BMD station has been selected. A total of 22 years (1994-2015) of daily rainfall data were collected. The yearly 1-day maximum rainfall from the Sylhet station was extracted from the computerized data.

### **Estimation of 1-hour rainfall from 24-hour rainfall**

1-hour rainfall data have been estimated from 24-hour rainfall by using the empirical reduction formula given below  
 $P_t = P_{24} (t/24)^{1/3}$

Where,  $P_t$  is the t-hour rainfall depth and  $P_{24}$ , is 24-hour rainfall depth.

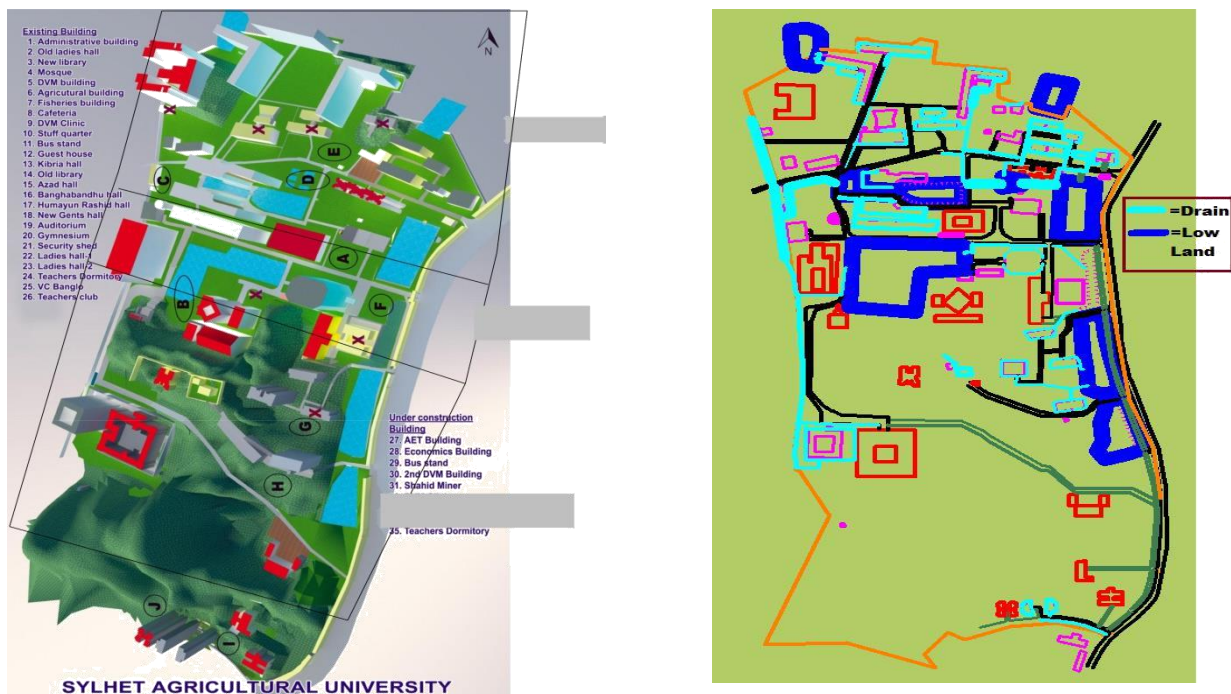


Fig. 2. Existing drainage system of Sylhet Agricultural University

### Frequency analysis of 1-hour rainfall

The estimated 1-hour maximum rainfall data of Sylhet station has been found to fit with Gumbel distribution method. According to Gumbel (1941) distribution functions:

$$X_t = x + \hat{\sigma}_n - 1$$

$$K = (y_t - y_n) / S_n$$

$$Y_t = -[\ln \ln (T/T-1)]$$

Where,  $X_t$  is the expected 1-hour  $T$ -year rainfall depth,  $x$  and  $\hat{\sigma}_n - 1$  are the mean and standard deviation of 1-hour rainfall respectively,  $y_n$  and  $S_n$  are reduced mean and reduced standard deviation, obtained from the chart as a function of sample size.

### Estimation of t-minute T-year rainfall depth

Rainfall depths for 5 min, 10 min, 15 min, 30 min and 2-hour durations have been computed by the depth-duration ratios viz. 0.29, 0.45, 0.57, 0.79 and 1.25 respectively for the same return period (Bell, 1969).  $T$ -minute rainfall depths for different return periods also calculated.

### Intensity - duration - frequency curve for Sylhet city

Average intensities of rainfall for different return periods have been calculated by dividing  $t$ -minute rainfall depths by the corresponding duration of  $t$  (hour). Intensity-Duration-Frequency curve has been developed by plotting average intensities against the duration of rainfall.

### Hydrologic design

**Calculation of runoff:** Design discharge was calculated by the rational formula (JICA, 1991). Rainfall intensity has been calculated from the IDF curve at the duration equal to time of concentration ( $T_c$ ). 100-years return period was selected for calculating rainfall intensity for SAU according to JICA (1991).

$$\text{Design Discharge } Q = (1/3.6) \times A \times i \times C$$

Where,  $Q$  = Peak Discharge ( $\text{m}^3 \text{s}^{-1}$ )

$C$  = Runoff coefficient

$T_c$  = Time of Concentration (min)

$i$  = Rainfall intensity ( $\text{mm hr}^{-1}$ )

$A$  = Drainage Area ( $\text{km}^2$ )

**Determination of runoff co-efficient:** The runoff co-efficient (C) represents the integrated effect of the catchment losses and hence depends upon the nature of the surface, surface slope and rainfall intensity (Subramany,2013). The effect of rainfall intensity is not considered in the available tables of values of C. Equation assumes a homogeneous catchment surface. However, the catchment is non-homogenous but can be divided into distinct sub-area each having and merged in proper time sequence. Sometimes a non-homogenous catchment may have component sub

areas distribution such a complex manner that distinct univalent zones cannot be separated. In such cases,  $C = \frac{\sum_{i=1}^N c_i A_i}{A}$

Where,  $A_i$ = the areal extent of the sub area i having a runoff coefficient  $C_i$  and

N =number of sub area in the catchment

**Estimation of time of concentration:** The time of concentration  $t_c$  of a watershed is often defined to be the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet.

Time of concentration  $t_c$  can be easily determine according to Kirpich Method (1940).

The equation is given below:

Time of concentration  $t_c = 0.0078L^{0.77} \times S^{-0.385}$  min

Where  $t_c$  is Time of concentration (min),

L is length of channel/ditch from headwater to outlet (ft) and

S is average watershed slope (ft ft<sup>-1</sup>)

**Estimation of required cross section:** According to the Garg (1987), for natural channel with loose to normal sandy bed, maximum velocity is 0.915m/s. Cross sectional area required at the outfall of each catchment is below

$A=Q/V$

Where, A= required cross section, m<sup>2</sup>

Q= Design peak discharge, m<sup>3</sup> s<sup>-1</sup>

V= velocity of flow m s<sup>-1</sup>

Rectangular Section =W×D

W= width

D= depth

## Culvert

Culverts are defined as structures which provide a passage over a gap without closing the way beneath which may be needed for the passage of railways, roadways, footpaths and even for carriage of fluids. Box culverts are used to transmit water during brief runoff periods. These are usually used by wildlife because they remain dry most of the year. They can have an artificial floor such as concrete. Box culverts generally provide more room for wildlife passage than large pipe culverts. Box culverts are usually made up of Reinforced Cement Concrete (RCC). A box culvert was already designed for this campus.

## Results

The campus area divided into three catchments for easily designing drainage system. This area was divided based on topography. First catchment is from north boundary wall to Kataloli road. The average area of 1<sup>st</sup> catchment is 0.0504 km<sup>2</sup>. Second catchment is from 1<sup>st</sup> catchment to new veterinary building and the average area is 0.05012 km<sup>2</sup>. Third catchment is new veterinary building to last point of SAU. The average area of 3<sup>rd</sup> catchment is 0.101908 km<sup>2</sup>.

**1-hour rainfall depth - frequency relationship:** It has been calculated by Gumbel distribution method with EV-distribution function by substituting the value of  $y_n$  and  $S_y$  and S. Estimated 1-hour 2, 5, 10, 20, 50, 100-year rainfall depth for Sylhet. Formula of Gumbel after subtitling the value of x and  $\partial_n-1$  is

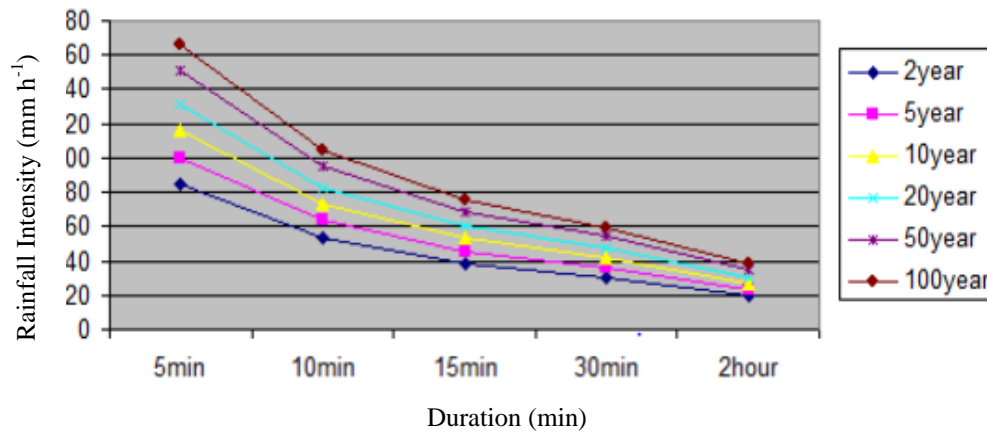
$X_t = 63.79 + 18.16 K$

$K = (y - y_n)/S$

**Table 1. 1-hour rainfall depths at different return periods**

Return Period	2-year	5-year	10-year	30-year	50-year	100-year
Rainfall (mm)	68.080	80.224	92.900	105.080	120.732	132.560

Rainfall depths for 5 min, 10 min, 15 min, 30 min and 2-hour durations have been computed by the depth duration ratios viz. 0.29, 0.45, 0.57, 0.79 and 1.25 respectively for the same return period (Bell, 1969). Intensity- Duration-Frequency curve has been developed by plotting average intensities against the duration of rainfall.

**Fig. 3. Intensity- Duration-Frequency curve for Sylhet city**

#### Runoff co-efficient

Runoff co-efficient is difficult to estimate directly. It was determined from different table based on soil type, slope and land type. Calculation of runoff co-efficient for 1<sup>st</sup> catchment-

Soil type: Sandy loam, Slope = 1.25%

Area type: Residential, C= 0.52

As same process, Runoff co-efficient for 2<sup>nd</sup> catchment C=0.52 and Runoff co-efficient for 3<sup>rd</sup> catchment C= 0.48.

#### Time of concentration

Time of concentration,  $t_c$  has been easily determined according to Keripich method (1940). The equation is, Time of concentration  $t_c = 0.0078L^{0.77} \times S^{-0.386}$  min

1st catchment

Length from HRC to kataltohi road = 518.57 ft

Height from ground level to plinth level of HRC  $H_1 = 6.58$  ft

Slope,  $S = \text{Height/Length}$

Thus,  $S = 6.58/518.57 = 0.0125$

$t_c = 0.0078 \times 518.57^{0.77} \times 0.0125^{-0.386}$  min = 5.21 min

Now, time of concentration  $t_c$  for 2<sup>nd</sup> catchment and 3<sup>rd</sup> catchment  $t_c = 4.726$  min and  $t_c = 5.75$  min

#### Runoff

Design discharge has been calculated by the rational formula (JICA, 1991).

Design discharge,  $Q = (1/3.6) \times A \times i \times C$

Calculation of peak discharge for 1<sup>st</sup> catchment,

$Q_1 = (1/3.6) \times A_1 \times i_1 \times C_1 = (1/3.6) \times 0.0504 \times 164 \times 0.52 = 1.19 \text{ m}^3 \text{ s}^{-1}$

Similarly, Peak discharge for 2<sup>nd</sup> catchment,  $Q_2 = 1.2 \text{ m}^3 \text{ s}^{-1}$  and peak discharge for 3<sup>rd</sup> catchment  $Q_3 = 2.2 \text{ m}^3 \text{ s}^{-1}$

#### Peak discharge

Here, peak discharge has been calculated according to JICA (1991).

**Table 2. Calculation of peak discharge  $Q = (1/3.6 \times A \times i \times C)$** 

Catchment Area	Runoff coefficient, (C)	Time of Concentration, $T_C$ (min)	Rainfall intensity, $i$ ( $\text{mm hr}^{-1}$ )	Drainage Area, ( $\text{km}^2$ )	Peak Discharge, $Q$ ( $\text{m}^3 \text{s}^{-1}$ )
1 <sup>st</sup>	0.52	5.21	164	0.0504	1.19
2 <sup>nd</sup>	0.52	4.726	166	0.05012	1.2
3 <sup>rd</sup>	0.48	5.75	162	0.101908	2.2

**Required cross section of drain**

Required cross section of drainage system of SAU is given in Table 3.

**Table 3. Required cross section of drain**

Catchment	Cross- sectional area, $A = Q/V$ ( $\text{m}^2$ )	Rectangular = $W \times D$ ( $\text{m}^2$ )	Main Drain of rectangular section ( $\text{m}^2$ )	Trapezoidal = $(B + zh)h$ ; $z=2$ ( $\text{m}^2$ )	Main Drain of trapezoidal section ( $\text{m}^2$ )
1 <sup>st</sup>	1.30	1.0×1.30		0.5×0.7	
2 <sup>nd</sup>	1.31	1.0×1.32	1.2×2.0	0.5×0.7	0.5×1.0
3 <sup>rd</sup>	2.40	1.2×2.0		0.5×1.0	

The required cross-sectional area of drain is highest in 3<sup>rd</sup> catchment (Table 3). So, the main drain of rectangular size through the campus would be the highest depth of 2.0 m. In case of, trapezoidal section the depth would be 1.0 m along slope of 1:2.

**Comparison between existing and design drain**

The study area has comparatively very narrow drain size than it was required to make the system sustainable. Comparison between existing and design drains is given in Table 4.

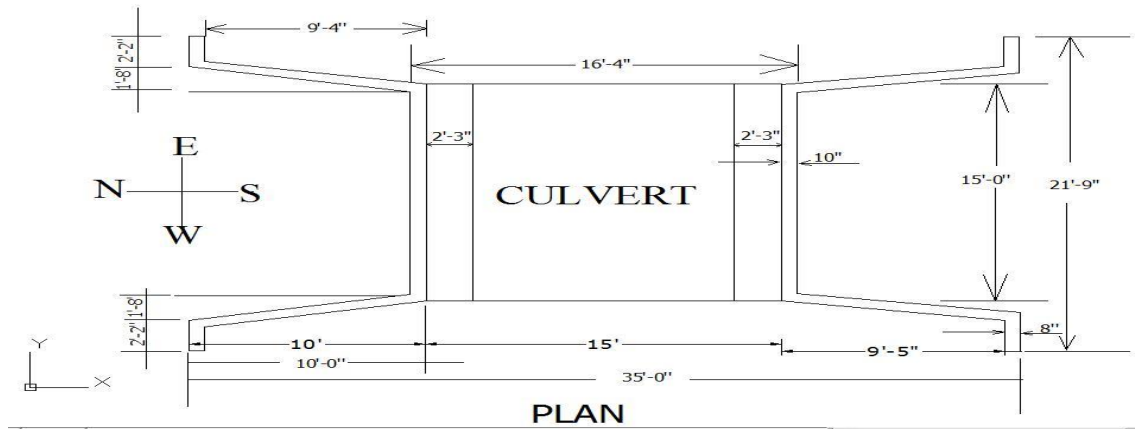
**Table 4. Comparison between existing and design drain**

Catchment	Existing Drain (Rectangular)	Design Drain (Rectangular)
1 <sup>st</sup>	0.304×0.304 $\text{m}^2$	1.0×1.3 $\text{m}^2$
2 <sup>nd</sup>	0.45×1.18 $\text{m}^2$	1.0×1.32 $\text{m}^2$
3 <sup>rd</sup>	0.69×0.77 $\text{m}^2$	1.2×2.0 $\text{m}^2$

The required storm drain size was 60% more than the existing drain according to Table 4.

**Culvert design**

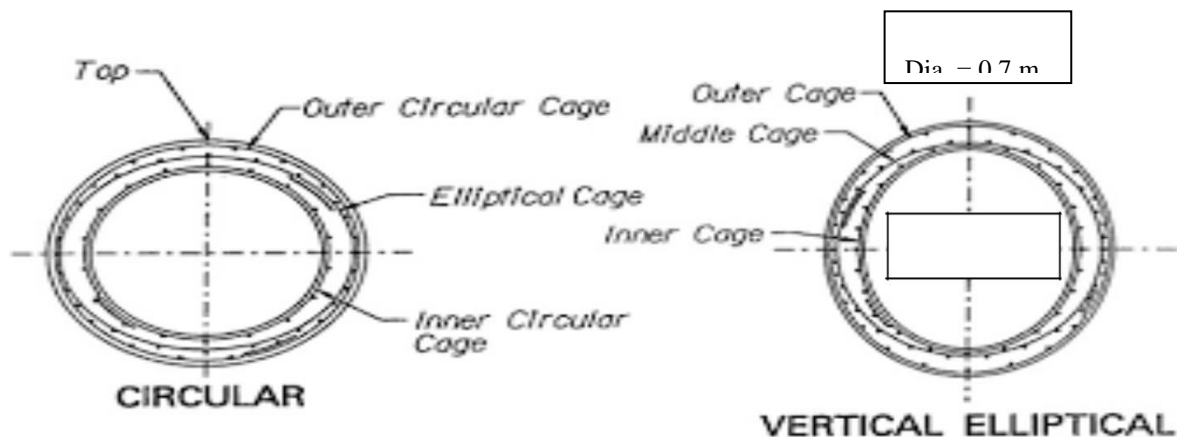
The study area has various size of road. The drain should be cross the road. Cross drainage system is badly needed for proper and sustainable drainage design. Several structures were made to convey the storm water under the road like culvert, box drain, pipe drain etc. In Sylhet Agricultural University, most of roads are small sized road. So, only one road has fulfilled the specification of design to culvert. The culvert was already design by SAU engineering section. The plan of designed culvert design is given below:



**Fig. 4. Plan view of culvert**

## Pipe and box drain

Pipe drain should be provided under the small size road of SAU. This specification is that diameter is around 0.7 m and thickness is around 8cm and length is greater than road size.

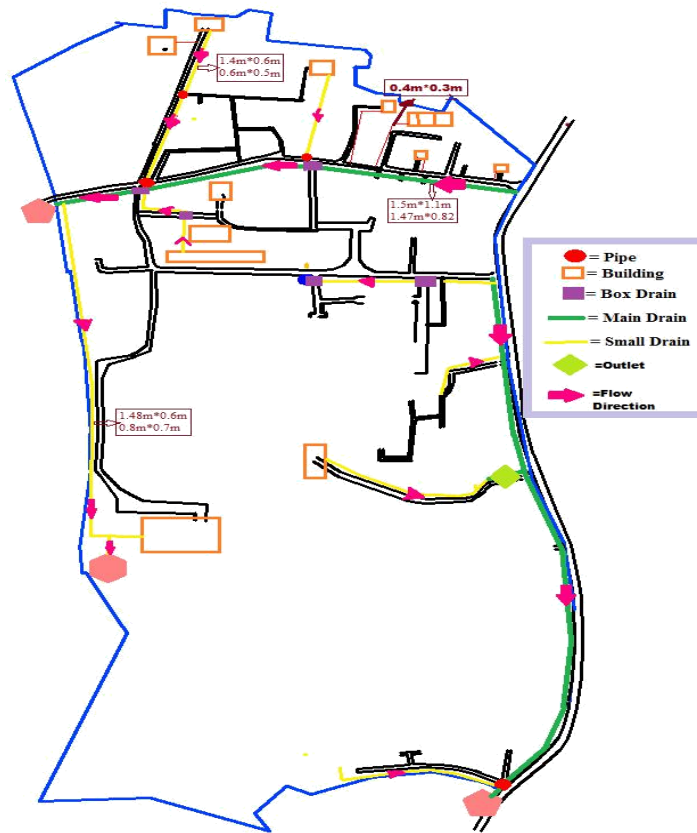


**Fig. 5. Pipe section**

### Box drain

Box drain should be provided at four places. First place is kataltoil point. Second, 3<sup>rd</sup> and 4<sup>th</sup> place is in front of Shah A. M. S. Kibria hall, in front of veterinary academic building and besides the administration building. Its section should be greater than rectangular section drains. The proposed drainage system of SAU was given below:





**Fig. 6. Proposed drainage system of Sylhet Agricultural University**

### Cost estimation

Cost estimation of rectangular section drain which has 10-inch brick wall (1:6) and one-layer flat brick soling (1:4) and 0.5-inch-thick cement plaster (1:4). The cost of rectangular sized main drain was calculated and shown in Table 5.

**Table 5. Cost calculation of rectangular drain**

SI. No.	Items	Amount	Total Amount	Rate (Tk)	Cost (Tk)
1	Earth work	95913	95913 m <sup>3</sup>	5000%	479565
2	Brick	267192+26532	293724 (Nos)	8500%	2496654
3	Sand	6870+1769+2284	10923cft	25 cft <sup>-1</sup>	273075
4	Cement	916+354+457	1727 bags	500 bag <sup>-1</sup>	863500

Total cost= 41,12,794 Tk.

With 5% contingency and 10% contractor's profit the grand total cost = 47,29,716 Tk. and unit cost of main rectangular drain is 672 Tk. Hence, the total cost estimated for the trapezoidal section was 67,11,765 Tk. and unit cost of this main trapezoidal section was 910 Tk. The rectangular section could be the economical section and trapezoidal section is the efficient one.

### Discussion

In this study widely used rational method has been followed to design the storm water drainage system due to its accuracy. It is also most suitable for small watershed like Sylhet Agricultural University. In the present study utmost care has been taken to finalize the volume of runoff coefficient "C" considering the factors such as catchment basin,

land use pattern, soil cover, infiltration detail etc. In addition, Kirpich (1940) method was applied to calculate the time of concentration due to the limited drainage area. Hence, rational method doesn't consider the real storm pattern and soil characteristics analysis. Therefore, U.S. Soil Conservation Service developed SCS Runoff method (Subramany, 2013) could be the another option of designing the system on the basis of available data of soil characteristics and land use but this method accuracy depends on time that means the accuracy of runoff estimates is reduced for small amounts (0.5 in) of runoff.

The study concluded that the water logging condition of Sylhet Agricultural University would be eliminate by designing a sustainable storm water drainage system for this University. The hydrologic analysis showed that the existing drain size was 60% less than the required size to cope up with the changing rainfall pattern. Thus, rectangular size of the main drain was convenient than trapezoidal section. In those places where space constraints are acute, trapezoidal section may be placed with existing rectangular sections. A separate sewer system with sewage treatment facilities is required for maintaining storm runoff quality. Periodical maintenance of existing drains is essential to overcome the blockage of the drains in various points. Hence, the design drainage system will be more accomplished by proper evaluation of the hydrologic parameters related to storm water drainage design.

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