Study of Storm and Sewer Water Drainage System at Haldia in West Bengal based on SewerGEMS Software

A thesis submitted toward partial fulfillment of the requirements for the degree of

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submitted by

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<u>Declaration of Originality and Compliance of Academic Ethics</u>

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of my **Master of Engineering** in **Water Resources & Hydraulic Engineering** under the Faculty Council of Interdisciplinary Studies, Law and Management in Jadavpur University during academic session 2018-19.

All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

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This is to certify that the thesis entitled "**Study of Storm and Sewer Water Drainage System at Haldia in West Bengal based on SewerGEMS Software"** is a bonafide work carried out by **Mr. Chinmoy Ranjan Das** under our supervision and guidance for partial fulfillment of the requirement for the Post Graduate Degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2018-2019.

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This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for purpose for which it has been submitted.

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ABSTRACT

In modern times the world is undergoing rapid urbanisation. Urbanisation results overall development of the country. But on contrary, it also affects the balance between human society and nature. Combined storm and sewer water management is becoming more complicated day by day, due to increased urbanisation. And without proper storm and sewer water management there is a greater chance of flood, waterborne diseases etc. Detergents can reason kidney and liver damage, while sewer water carries syndromes such as giardiasis, amoebic dysentery and cholera. It also causes deterioration in the quality of water and thus disturbs the hydrological cycle at large.

One of the major challenges at Haldia and its surrounding areas is the storm and sewer water drainage problem. The present study mainly focuses on the evaluation of the existing storm and sewer water drainage system at Haldia using various analyses, SewerGEMS software. This study points out the deficiencies of the existing drainage system and suggests their possible remedies.

The main software used for this research is SewerGEMS software. The research clearly shows the details of the various input data and the obtained output results. Interpreting the obtained result, the shortcomings of the drainage system are mentioned. Finally the probable solutions to these problems are proposed which may help to develop a better drainage system at Haldia region.

CONTENT

CHAPTER 1

1.1 Introduction

1.1.1 General Background

Population density and urbanisation can create acute problems in urban water management. Proper functioning storm and sewer water drainage system is the utmost need to safely discharge the runoff water. Scientific drainage system to receive storm water is the lifelong goal of the community, particularly in developed cities. Hydroplaning is the need of the hour, especially for low lying areas. Most significant factor in designing drainage is the intensity of rainfall and the catchment characteristics. The drainage should be designed in such a way that it must have sufficient capacity to control the flood and reduce the pollution impact on runoff. In the design of every drainage system there are certain constraints with respect to social, environmental and economic factors.

Inappropriate drainage system gives rise to fatal nuisance in public's everyday life. In drainage design the main purpose is to identify a shape, dimension and lining materials that will satisfy to allow the peak flow rate at a reasonable cost. And it must also produce enough shear stress on the bottom of the channel to prevent solid accumulation under minimum flow condition. Drainage design is basically based on quantity estimation of excess water/ runoff. Developing countries like India should never be lagging behind in the field of urban drainage. Storm water management is required to save the preservation of water, health of the public, need to fight for sustainable environment, welfare and safety of the public etc.

1.1.2 Effect of Urbanisation on Storm Runoff

In recent times, the world is undergoing through a drastic phase of urbanisation. On one hand, urbanisation promotes overall development of the country but simultaneously, it also effects the inter relationship between human society and nature. The obvious claims of urbanisation such as roads, rooftops, parking lots, sidewalks, add imperviousness to the landscape. The consequences of these actions directly resist the rain and snowmelt water to soak into the ground. Here the most alerting scenario is that due to rapid urbanisation infiltration capacity of catchment surfaces, surface storage capacity and evapo-transpiration are decreased. In the other side of the story, the runoff velocity, runoff volume, discharges and flood peaks increases due to same reasons. The amount of waterborne waste increases due to the growth in population and building density. Urbanization has great impact on runoff quality, as the runoff water gathers pollutants when it flows over the urban environment. Solid and water borne waste deteriorates the quality of the ground water, ultimately creating a havoc disturbance in hydrological cycle.

In general urbanisation has a great impact on precipitation, evaporation and local temperature of a region. Air pollutants such as sulphur dioxide and other gases and dust particles diversely affect the atmosphere. Increased imperviousness, industrial energy consumption, domestic heating, automobile exhaust emissions, and decrease in natural landscape and changing thermal conditions affect directly the local temperature of a particular region.

1.1.3 Background of Drainage Structure of the Study Area

In Haldia, the storm water is discharged efficiently via rectangular/ trapezoidal pucca and kutcha drains and in turns they dispose of the storm water to various khals connecting to river Haldi and Hooghly. The drains are used to carry storm water and waste water produced from different residential, commercial and industrial areas.

In the aforesaid region, the main carriers of storm water runoff are the major natural khals namely Mansatala, Atafola, Jhikurkhali, Horekhali khal and Green belt channel. This major khals are connected to river Hooghly.

Another set of major carriers with similar purposes are Tarwan, Port Township, Chingra, Hatiberia, Dhobanala, Chunamara, Balughata and Anandakhali, having their outfalls in river Haldi.

The topographical features of Haldia region is bisected by a ridge line running along North-South direction. The eastern and the western catchments here have a natural sloping towards the river Hooghly and Haldi, respectively.

1.1.4 Statement of the Problem

In Haldia, population increases rapidly due to urbanisation and also the town is developing in unplanned way. Pervious surface reduces day by day as the city is now the period of rapid urbanisation. For the development, drainage line and vacant land of the town area are being occupied. As a result imbalance situation can create between impervious and pervious cover. New developments increases impervious area consequently increases peak storm water runoff with its associated problems of flooding, water quality degradation, erosion and sedimentation.

Some of the drainage structures are not efficient to carry the discharge. Improper drainage system can create water logging especially in low lying areas. It needs a modification either in the maintenance of proper invert level or provision of required cross sectional area for the flow.

Due to deficiency of periodic maintenances, all the drain sections are reduced by sediment deposition. Due to improper management of solid waste some drains are blocked. Local inhabitants are used to through the waste to drains causes reduction of the cross section.

1.2 Significance of the Study

The motive of this research is to evaluate the existing drainage conditions and identify the major deficiencies which create lot of drainage problems in Haldia. This study will also help to solve the drainage problem at study area and contribute better service in future.

To understand the causes of blockage of existing drains and water logging in low lying areas and recommend for taking correct measure to avoid damage of the structure and improve the drainage facility in future.

The result of this study will also help whether the existing drainage system is adequate to carry storm runoff and also indicates the renovation, modification, addition and alteration of all the existing drains along with construction of new drains.

1.3 Objectives

1.3.1 General Objective

- The goal of this research work to solve the drainage problem at Haldia region.

1.3.2 Specific Objectives

- To evaluate the present condition and problem related to existing drainage system at Haldia.
- To measure the hydraulic performance of existing drainage systems at Haldia.
- To check whether the existing drain sections are adequate to maintain the storm runoff and sewer loads.
- To know about the periodic maintenances of the existing drains and whether maintained in a standard way or not.
- To recommend accurate measure, if required.

1.4 Scope of the Study

This study is about the present scenario of drainage system as well as the study about the hydraulic performance of existing drainage system at Haldia. The major scope of work includes the following:

- Handle storm water runoff and control water logging especially in low lying area in future.
- Improper drainage system can create overflow in sewer line. This study will help to control the overflow in sewer line.

- Due to urbanization, there is lack of infiltration of rainwater in ground so it requires to recharging of groundwater.
- This study will also help to prevent the blockage in the existing drains due to deposition of solid waste and due to erosion of land.

CHAPTER 2

2.1 General Concept

2.1.1 Historical Perspectives of Urban Drainage

If we reconsider the vast history of human development in this planet, urban drainage system has a very wide and various perspectives from time being. Urban drainage system from ancient times has huge impact on the prevailing civilizations. Modern day science has reached a supreme era of technological advancements. But despite, having several drawbacks, ancient civilization had also shown great potential in response to the drainage systems of their time.

Ruins of Indus Valley Civilization showed that the cities had state- of- the- art-class drainage system, during third century B.C., as reported by Webster (1962) and Kirby (1956). We may look at other instances of similar case in Ur and Babylon City of Mesopotamian Empire, where drainage system has been broadly divided into two parts. They used vaulted sewers and drains for household waste and separate drains for storm runoff water.

In nineteenth century, the Roman Empire takes this benchmark to a new level, when they introduced the concept of intricate network of open channels and underground sewers (called Cloaca Maxima). These networks of channels ultimately fall into Tiber River (Gest, 1963). Not only this, rainfall on rooftops was collected in a cistern located in the interior of the house (Hodge, 1992).

Up to nineteenth century urban drainage was usually viewed as a vital natural resource, convenient cleansing mechanism or a transmitter of diseases. The drainage system altogether got a brand new perspectives under the efforts of engineer Pierre-Emmanuel Bruneseau (Reid, 1991), on their works on Paris sewer system. H.C. Emmery, head of Paris sewer system, furthered this development by replacing open channels running along the centre of the streets, with gutters constructed under sidewalks. In later years, this becomes a role model for the rest of the world.

During late nineteenth century the public perspectives of urban drainage changed from neglected afterthought to vital public works system for the first time in history. Mankind was then ushered in the most developmental phase of urban drainage, incorporating the new perspective of giving immense importance to the opinions of technical expert/numerical calculations.

2.1.2 Review of Earlier Works

Sharifi and Hosseini (2011) carried out a study on methodology for identifying the best equations for estimating the time of concentration of watersheds in a particular region. In this study, they proposed strategies for pick out the finest equations for evaluating the time of concentration (T_c) of catchment area located in a distinct geographic region. In that study, preliminary they worked on the basis of altering accessible equations to reduce their partiality for any specific area of interest. They considered T_c as “reference” for each watershed and it was determined by the Natural Resource Conservation Service (NRCS) velocity method employed in the TR-55 model and geographic information systems data. Furthermore they developed ranking-based selection strategy for assessing and sort out the ideal performing techniques. They applied the strategy to 72 catchments and sub catchments in Khorasan Razavi region, Iran. As per their observation, the California equation (with a correction factor of 1.715), the Kirpich (Tennessee) equation (with a correction factor of 1.721), and the Arizona DOT equation (with a correction factor of 1.126) had given finest result for picked watershed.

Ebrahimian *et al.* (2012) made a study on Application of NRCS-curve number method for runoff estimation in a mountainous watershed. In that study they focused on to determine the runoff depth by using (NRCS-CN) method together with GIS in Kardeh watershed, Iran. They prepared HSG, land use map and slope maps with the help of GIS tools for that purpose. With the help of HSG and land use map they produced CN values map for calculation of runoff depth. They used CN method to estimate runoff depth for selected rainfall events in that catchment area. To evaluate the validity of estimated data and familiarity between estimated and observed runoff depth, they were used Nash-Sutcliffe efficiency, pair-wise comparison by the t-test, Pearson correlation and percent error. In that study they observed that Nash-Sutcliffe efficiency ($E = -0.835$) is low and there was no serious distinction within estimated and observed runoff depths ($P > 0.05$). They also detected that there was clean interrelation between estimated and observed runoff depth ($r = 0.56$; $P < 0.01$). They found that about 9% of the estimated runoff values were within ±10% of the recorded values and 43% had error percent greater than ±50%. They concluded that the combination of GIS and CN method may be applied in semi-arid hilly watersheds with about 55% precision only for management and preservation intentions.

Needhidasan *et al.* (2013) made a study on design of storm water drains by rational method in Palayam area of Calicut city in Kerala, India. In that area rational method had been effectively used to design the storm water drains. In that study they noted that the various factors such as catchment basin, land use pattern, soil cover, infiltration details are required for the estimation of runoff coefficient. To estimate these parameters laborious efforts are required for determination of runoff coefficient. To calculate and finalize the value of runoff coefficient *C* extreme care was taken in that study. They had taken intensity of rainfall 46 mm/hr from IDF curves, the value of ‘*C*’ between 0.7 to 0.9, Manning’s constant 0.015, dry weather flow 100 litre/head/day, projected population for next 20 years, self cleaning velocity 0.6 m/s for this study. They concluded that the drainage sections are inadequate in most of the region to carry the discharge. They also observed that due to the blockage of the drains in various points, flooding may occur in that area. They advised that periodical maintenance of existing drains was vital in that area. They also suggested that trapezoidal sections may be replaced with existing rectangular sections in those places where space constraints are acute.

Adaba *et al.* (2014) carried out a study on adequacy of drainage channels in a small urban watershed in university of Nigeria Nsukka campus. To get the discharge and capacities of the channels they had been used topographic map, meteorological data, geometric measurement of drainage channels and application of Rational models, Kirpich's equation, new equation of time of concentration and Manning's equation in their analysis. After analyse all the results they displayed a familiarity between the intensity of rainfall and the time of concentration. From this study they suggested that accurate design, computations, appropriate construction and maintenance of drainage systems are essential to satisfy the minimum velocity requirement. They also suggested that velocity can be increased with the increase of the slope and to prevent scouring on the drains the velocities more than 6m/s should be avoided.

Gajjar *et al.* (2014) carried out a study of storm water network design for Jodhpur Tekra area of city of Ahmedabad. In that study past 20 years rainfall data was considered and the system was designed considering in total of 65% of impervious area. For the estimation of storm water runoff, Rational method has been applied with runoff coefficient 0.65 in that study. They had taken coefficient of roughness 0.013 and 0.015. The outfalls of the system were directed to proposed lakes. After performing the design they concluded that Rational method is very effective and adequate for estimating the storm water runoff discharge.

Ahmad *et al.* (2015) made a study about the application of curve number method for estimation of runoff potential in GIS environment. In this study they computed the runoff depth with the help of SCS-CN method and remote sensing and GIS. In that research they used SCS-CN method for evaluating the runoff depth in the Sheonath river upper sub-basin of Chhattisgarh State of India. They had prepared Base map, soil map, land use / land cover map and other related map of the study area with the help of Indian Remote Sensing LISS-III data and Survey of India (SOI) topographic sheets. They were used CN and daily rainfall values as inputs in their GIS based SCS-CN model to compute daily runoff. They computed weighted curve number with considering AMC II condition for the study area. And after that they computed the daily runoff of study area. They suggested that the remote sensing and GIS based SCS-CN may be successfully used to evaluate the runoff from the catchment area of same geo-hydrological features.

Bajracharya *et al.* (2015) made a case study on effects of urbanization on storm water runoff of Kathmandu Metropolitan city, Nepal. In this research they concentrated on study about runoff condition in connection of urban areas. In this study they used Rational method to estimate the total runoff. In that study they used the various parameters like land cover data, soil data and slope of the area for determination of runoff coefficient. They observed that urbanization increases impermeable area and reduce the infiltration capacity of catchment surfaces. They concluded that the major challenge is to manage runoff issues because population density, deficiency of land, increase water demand and decrease in pervious surface were the main factors affecting the storm water runoff. They recommended that Government planning agencies should have to enhance the city development strategies. They also suggested that to update the city development regulations and building bye-laws. They advised to establish a new recharge point. To reduce water demand and water volume in drain, rainwater harvesting technique can be used. Finally they thought that different awareness campaign and community workshop can be organised for the people to give them proper knowledge about techniques and issues.

Bhadiyadra *et al.* (2015) carried out a study of storm water drainage problem of Surat city and its solutions due to flood in River Tapi. Their research showed that the major storm water drainage problem is the storm water backflow problem under high flood situation in river Tapi, when the drainage outlets are closed in Surat city. They noticed that the drainage system of Surat city is not much adequate at the time of flood especially at some low lying areas of Surat city. They have given the efficient solution of this problem in this case study. They applied some common as well as methodical drainage solution and also accurate design of storm water drainage system to overcome this problem. They examined the current condition of storm water drainage system and identified reasons of flood at low lying critical areas of Surat city. They observed that the pumping drainage system is inefficient for the high flooding situation of Surat city. They suggested that some improvements are essential of pumping system to get permanent solution of storm water drainage system. They concluded the permanent solution is necessary to control the storm water backflow. They also suggested that improvement is necessary of existing storm water drainage system to solve this problem. They advised to provide moderate capacity pump at low lying areas instead of high capacity pump which discharge storm water continuously at river bank. In that study they carried out general as well as technical solutions which is most accurate & effective for this problem.

Kumar *et al.* (2015*a*) performed a study on storm water drainage design in Vijayawada city in Andhra Pradesh, India. They used rational method for determination of storm runoff in Vijayawada city. In that study the value of runoff coefficient C was determined carefully. They considered the rainfall data from January 1994 to 2014, friction factor (n) 0.017, slope of energy gradient (S) 0.002, and coefficient of runoff (C) 0.85, rainfall intensity (i) 20 mm/hour. They extracted Vijayawada area by the use of GIS database for the calculation of discharge. They observed that the existing drainage sections are inadequate in most of the regions to convey peak discharge. They also observed that due to the blockage of the drains in various points, flooding may occur in that area. They advised that periodical maintenance of existing drains was vital in Vijayawada city.

Kumar *et al.* (2015*b*) made a comparative study of storm water drainage methods for urban storm water management in the northern part of Vellore town. In this study they had chosen a small urban region and considered three different storms sewer systems for that region. Three types of storm drainage systems are construction of a new underground circular sewer system (Alternative 1), repair and expansion of existing surface sewer system (Alternative 2) and construction swales (Alternative 3). They compared alternatives economically and they found that Alternative 2 be the most beneficial. They also suggested that Alternative 3 may be applied for recharging ground water aquifers including with storm water drainage.

Katti *et al.* (2015) made a comparative study of SEWER Version 3.0 and SewerGEMS V8*i* Software for sanitary sewer network design. In this study they analysed all sanitary and combined sewer system elements with Bentley SewerGEMS V8*i*. In this study they had taken sewer network, Vijayapur district (Karnataka state) as design example and compared the results got from SEWER Version 3.0 and SewerGEMS V8*i*. They compared velocity, *d/D* ratio and pipe diameter. They showed that maximum minimum velocity maintained by SewerGEMS V8*i*, *d/D* ratio was high in SEWER Version 3.0 and lowest diameter found in SewerGEMS V8*i*. They observed that in SewerGEMS V8*i* requires less time for project completion, efficiency is high and cost is low. After analysed the result they concluded that SewerGEMS V8*i* has given effective and optimal results and is favourable for design of large sewer network. They recommended the results got from SewerGEMSV8*i* for the entire sewer network.

Asfaw (2016) carried out a study on storm water drainage system in Kemise town. As per obtained results, the storm water drainage systems were inadequate to carry the peak discharge. The drainage systems blocked by haphazard dumping of waste and sediment. He noticed that the complications caused by ignoring of hydrology and hydraulic analysis of drainage design and unawareness of the community. He observed that proper slope is not provided most of the open drainage in that area. He also observed that due to lack of awareness the community was disposed their waste into drainage. Based on the results he concluded that due to improper drainage design and construction the existing drainage system are not adequate in that town.

Binesh *et al.* (2016) made a study on performance assessment of urban drainage system. In that study they aimed at simulation of urban drainage network of district 10 of Tehran Municipality in Iran, and focused on hydraulic assessment of drainage system's level of service. They were used indicators of reliability, resiliency, and vulnerability to evaluate the system's performance. They were determined inundation spots in the study area, and three performance indices were calculated for all conduits and the whole system. The results of their study indicated that some conduits in the urban drainage network are in critical condition and should be rehabilitated, while the others represent an acceptable performance in conveying the urban runoff and do a nice job in preventing urban flooding in the region. They concluded that reliability of the system is acceptable, and vulnerability is relatively low, and system represents a relatively high percent of resiliency. With considering climate change and continuous urban development, they also proposed that to apply sustainable drainage approaches.

Dabhekar *et al.* (2016) carried out a case study of Storm water Drainage system for Kamla Nagar area of Vadodara city. In that study past 20 years rainfall data was taken and the system was designed considering in total of 84% of impervious area. For the estimation of storm water runoff, rational method has been used with runoff coefficient 0.84. They had taken coefficient of roughness 0.11, the rainfall intensity of 3.5 cm per hour, the gradient of bed ranges between 1 in 1000 to 1 in 3000, velocity of flow between 0.6 m/sec. to 1.8 m/sec, the factor of imperviousness 0.845 for this study. The outfalls of the system were directed to

Kamla Nagar pond. After analysed they observed that the Q actual is coming less than the Q provided. So they concluded that the design for storm water drainage is safe.

Salimi *et al.* (2016) made a study on estimating time of concentration in large watersheds. For calculating time of concentration, they had taken 22 formulas from different references. They selected seven formulas for Shafaroud watershed, situated in the western Guilan province of northern Iran, for calculating time of concentration. They had chosen the seven formulas on the basis of specific conditions and limitations of the watershed with an area 345.4 km^2. They considered Bransby-Williams, Ventura, Passini, Johnstone-Cross, Carter, Papadakis-Kazan and Izzard formulas for calculating time of concentration. They calculated T_C values from the above mentioned method. They observed that Bransby-Williams method is most consistent to calculate the peak flow of the watershed.

Mukhopadhyay (2017) carried out a study on storm water drainage system at Agarpara in West Bengal based on Civilstorm software. In that study she focused on the assessment of storm water drainage system in Agarpara (ward no 8) town. She used Geographic Information System (GIS), Google Earth software and Civilstorm software for this study. She collected the required data from various sources. Based on the outcomes, she concluded that some drains are inadequate to carry storm runoff in that area. She recommended that periodic cleaning and modification of slope is required to avoid the drainage problem.

Parmar *et al.* (2017) carried out a case study on storm water management of Gandhinagar city Gujrat, India. To calculate the runoff volume they were collected past year rainfall data of that study area. After calculating runoff, they indentified the problems and also suggested BMPs (Best Management Practice) techniques. In that study they observed that runoff increases with urbanization. So generation of flood due urbanisation was the main problem in Gandhinagar city. They also found that the drainage systems are not efficient to discharge the storm runoff in Sabarmati River. They also noticed that storm drainage systems not properly work due to sedimentation. After analyzed all the data they identified the problems in that study area. To control the impacts of the storm water, they provided Best Management Practice in that area. They had planned for underground tank to collect the storm water and use the water for irrigation of garden in dry season. They also suggested that sedimentation control structure at the entrance of manhole should be provided. In this way they controlled the impact of storm water.

Ara and Zakwan (2018) made a study about estimating runoff using Soil Conservation Services (SCS) curve number method in Sone canal command area, India. For determination of runoff, they used SSC-CN model. For that purpose they considered parameters like slope, vegetation cover, and area of watershed. They developed the land cover map to analyze the runoff produced over the catchment area. They collected rainfall data and soil map for the study area to find Antecedent moisture condition (AMC) and Hydrologic soil groups (HSG). With the help of land use/cover and hydrological soil groups they determined the Curve number. They observed that Sone canal command area consists of four type of soil such as heavy alluvium, old alluvium, recent alluvium and sandy clay loam. Lastly they computed overall runoff in that study area. The calculated runoff was 17.98 mm for the year 2007. They also observed that the maximum contribution of runoff from the monsoon season.

2.1.3 Storm water

The natural phenomenon in which water droplets falls on the earth surface or come down as melting ice, as a part of hydrological cycle, called storm water. In later consequence water that does not get absorbed by the ground becomes runoff water. This runoff water either flows as surface waterways or through storm sewers. There are two critical points worth considering in this whole event one related to the volume and timing of runoff water (flood control and water supplies) and the other related to potential contaminants that the water is carrying, i.e. water pollution.

Storm water is a highly valuable natural resource because the global demand for water far exceeds the available quantity of water especially in urban centres. Proper storm water management can lead a society to sustainable techniques to harvest storm water from point source. Malpractices in this cause give rise to mixing of several debris such as construction and demolition wastes, household wastes, agro-allied wastes, industrial and human wastes with storm water.

2.1.4 Runoff

The water which originates from rain, snow melt etc. and ultimately flows over the land surface is called surface runoff. It forms a major component of water cycle. During its journey surface runoff water picks up contaminants such as petroleum, pesticides, or fertilizers. Urbanization increases the surface runoff by creating more impervious surface such as pavement and buildings, which does not allow percolation of water to the aquifer. Direct consequence of increased surface runoff lowers the ground water table rising, the clear chances of drought. The peak rate, volume, and timing of runoff are important characteristics in the planning and design of storm water management practice.

Urbanization causes increased runoff rate and runoff volume. If by any means, the downstream channel capacity is exceeded, flood will occur. Another related problem is channel erosion which depends on runoff rate and its duration. Urbanization not only increases runoff rate and runoff volume but also the frequency of runoff rate. This in turn has a direct impact on erosion and sediment transport of river channel. Studies have revealed that runoff from rural areas carries eroded sediments, nutrients from natural and/or agricultural sources, bacteria from animal droppings, and pesticides and herbicides from agricultural practices. On the contrary runoff from urban areas carries solids particles from automobile wear and tear, dust and dirt, and winter sand, nutrients from residential fertilizers, metals such zinc, copper, and lead, hydrocarbons leaching from asphalt pavement materials, spilled oils and chemicals, and bacteria from domestic animals. So, clearly there is a gradual degradation in the water quality of inflowing streams.

2.1.5 Storm Sewer

Storm sewers (also storm drains) are large pipes or open channels that transport storm water runoff from streets to natural bodies of water, to avoid street flooding. This water generally comes from paved streets, parking lots, sidewalks, and roofs. The design of storm drain may vary from large municipal system to small residential dry well. They are feed by street gutters on most motorways, freeways and other busy roads, as well as towns in areas which experience heavy rainfall, flooding and coastal towns. Most of this storm drainage system drains untreated polluted water to the main stream or river.

A combined sewer is a type of sewer system that collects sanitary sewage and storm water runoff in a single system. Combined sewer system has great disadvantages, in terms of water pollution. If there is a sudden surge of huge rainfall, practically exceeding sewage treatment capacity, then the rainfall will directly overflow the storm drains. The over flow of the combined sewer system is directly discharged into a river, stream, lake, or ocean. Due the occurrence of heavy rainfall, the combined sewer overflow is diluted. As cities become more densely populated, the per-household volumes of wastewater exceed the infiltration capacity of local soils and require greater drainage capacity and the introduction of sewer systems. In light of modern technologies there are several methods for managing this problem. One of them is storm water drain design.

2.1.6 Hydrologic Analysis of Drainage System

The main objective of hydrologic analysis is to determine the maximum quantity of water expected to reach the drainage system under consideration. For this analysis, rain fall data in the area including intensity duration and frequency of occurrence of storm are required. Rainwater flows by gravity from collecting surfaces. These surfaces are of various characteristics ranging from rough to smooth, pervious to impervious etc. The collected water flows to the nearest emerging drains directly through inlets and then to main drains. The size and the capacity of the carrier drains require progressively larger capacities till the flow is discharged into a natural drainage channel/ water body. The runoff from rainfall may be determined by the following methods.

- Empirical Formulae
- Rational Method
- Modified Rational Method
- SCS-CN Method
- Unit Hydrograph Method

2.1.7 Hydraulic Analysis of Drainage System

While considering the flow in sewers, the hydraulic analysis is made pretty simple by assuming steady flow condition. But in the case of large storm water channels or in pumping mains, where surge or water hammer predominant, the flow is considered to be unsteady. In most of the cases sewers have turbulent flows with stream line along the boundaries. An appropriate sewer will carry the peak flow for which it is designed and also at the same time transport the suspended solid in such a way that deposit in the sewer are kept to the minimum. For this analysis Manning's formula as given in Eq. 1 (CPHEEO, 1993) is effectively used.

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{1}$$

where,

V = average velocity of flow (m/s)
n = Manninng's roughness coefficient
R = hydraulic radius (m)
S = longitudinal slope

2.2 Sustainable Urban Drainage System

Urban water management is the very difficult job. Diffuse pollutants mix from the catchment area with the water while it is passing through the catchment. So the management strategies must involve in identification and subsequent eradication of this pollution sources. Other problem of runoff is that it has a high chance of flooding the downstream. The first flush after a heavy rainfall is very polluting. Sustainable drainage should involved collection, storage and clean runoff before it is released to the environment.

In recent times water is a very scares material. The need of the hour is to integrate drainage and surface water management plans to finish the problem of diffuse pollution. There are some sources of diffuse pollution which is identified at Global scale. Traditional drainage system comes with many disadvantages. Increased runoff always causes flooding situation in the downstream level. Not only this, water bodies are contaminated by pollutants like oil, organic matter and toxic metals. The source runoff must be managed very sincerely. Runoff affects biodiversity, amenity value and potential water abstraction.

Sustainable drainage system (SUDS) is an approach to manage rainfall runoff through scientific advancement that combines natural drainage with technological interventions. Diffuse pollution has varieties of sources distributed in nature and they are very difficult to monitor, control and regulate. Sustainable drainage system manages surface water runoff and thus decreases the risk of flood. It is applicable to both rural and urban areas. Sustainable drainage system uses natural land topography which allows natural drainage system to lessen the diffuse pollution.

In comparison to conventional drainage system, SUDS provide more space within the city. SUDS are essentially a disciplinary mechanism for drainage system. The most practical solution for diffuse pollution is the combination of conventional drainage system with SUDS. Maintenance of SUDS is a difficult task, so the responsibilities should be distributed properly. In this case local peoples are advised to be more responsive towards minimization of rainfall runoff. To discipline and modify the behaviour of water innovative structures are needed.

2.3 Function of Drainage System

The most important duty of urban drainage system is to collect storm water and waste water generated from residential, commercial and industrial area and conveys them smoothly and then ultimately discharges to particular point. The other major functions apart from these are

- To sustain environment that does not adversely effects public health.
- It should never give rise to an epidemic condition.
- It should always improve environmental quality to enable healthy ecosystem and comfortable habitation to human.
- Not only in general should it act as a preventive measure for the preservation of health of individual being.

2.4 Types of Drainage System

There are various types of storm water drainage system applied as per specific suitable criteria. The most common types of drainage system which are used in the society are:

- Open ditches.
- Closed ditch with pipe drains.
- Drainage through storm water drainage pipes.
- Channels and culverts.

2.5 Factors Influencing Runoff

During precipitation, there is subjected to some initial losses of water due to evaporation, interception by vegetative cover, infiltration into the soil and filling of low lying depressions, lakes and streams. After that the excess precipitation moves in the form of sheet over the ground surface as storm runoff. This surface runoff is highly variable. Propagation of surface runoff from a precipitation is dependent on various factors as follows:

1. Metrological characteristics:
    - Storm characteristics
    - Temperature
    - Humidity
    - Wind velocity
    - Pressure variation

2. Basin characteristics:
    - Size
    - Shape
    - Slope

- Elevation
- Topography
- Geology
- Land use/land cover
- Orientation

3. Storage characteristics:
    - Depressions
    - Pools and ponds / lakes
    - Stream
    - Channels
    - Flood plains
    - Ground water storage in pervious deposits

2.6 Important Parameters

2.6.1 Runoff Coefficient

It is a dimensionless parameter and it indicates that the amount of run off to the amount of precipitation received. It depends on the shape of the sub catchment, percentage of imperviousness and time of concentration. It also depends on evaporation, interception, infiltration, depression storage, soil moisture, antecedent precipitation etc. Initially coefficient of runoff increases gradually because pervious surface takes time to saturated. After that it will fairly constant for a given area. The coefficient of runoff is the product of the following.

- Coefficient of imperviousness.
- Coefficient of distribution of rainfall.
- Coefficient of retention.
- Coefficient of retardation.

The runoff co-efficient varies from 0 to 1. When watershed consists of many land uses and soil types, weighted runoff coefficient has to be calculated. The runoff coefficients are reported in table 2.1.

Table 2.1: Runoff coefficient as per CPHEEO (1993)

Duration (t) minutes	10	20	30	45	60	75	90	100	120	135	150	180
Weighted Average Coefficient												
Sector concentrating in stated time												
a)Impervious	.525	.588	.642	.700	.740	.771	.795	.813	828	.840	.850	.865
b)60% Impervious	.365	.427	.477	.531	.569	.598	.622	.641	.656	.670	.682	.701
c)40% Impervious	.285	.346	.395	.446	.482	.512	.535	.554	.571	.585	.597	.618
d)Pervious	.125	.185	.230	.277	.312	.330	.362	.382	.399	.414	.429	.454
Rectangle (length=4× width) concentrating in stated time												
a)Impervious	.550	.648	.771	.768	.808	.837	.856	.869	.879	.887	.892	.903
b)50% Impervious	.350	.442	.499	.551	.590	.618	.639	.657	.671	.683	.694	.713
c)30% Impervious	.269	.360	.414	.464	.502	.530	.552	.572	.588	.601	.614	.636
d)Pervious	.149	.236	.287	.334	.371	.398	.422	.445	.463	.479	.495	.522

2.6.2 Catchment Area

Catchment area is the particular portion of land surface that drains into a stream or water course in a given location. In American English this is also known as watershed. A catchment area is separated from its neighbouring areas by ridge. Catchment area is calculated by tracing the ridge on topographic map using a planimeter. In case of catchment area of a river, the station to which it pertains must also be mentioned. In terms of hydrology and water resource management catchment area is very important source of study area. It is one of the most important drainage characteristic used in hydrological analysis and design.

2.6.3 Time of Concentration

The time required for the drop of rainwater falling on the most remote point of a sub catchment to reach the outlet of the sub catchment is called the time of concentration. At this moment of time, the entire sub catchment starts contributing excess rainfall reaching peak flow in the form of runoff. The time of concentration at the outlet of any sub catchment in storm drainage system is the sum of time of overland flow and time of gutter flow connected to the outlet point of sub catchment (CPHEEO, 1993).

2.6.4 Intensity of Precipitation

The intensity of rainfall decreases with duration. Analysis of the observed data on intensity duration of rainfall of past records over a period of years in the area is necessary to arrive at a fair estimate of intensity-duration for given frequencies. The longer the record available, the more dependable is the forecast. In Indian conditions intensity of rainfall adopted in design is usually in the range of 12 mm/hr to 20 mm/hr. The relationship may be expressed by a suitable mathematical formula, several forms which are available. The following two equations 2 and 3 are commonly used (CPHEEO, 1993).

$$i = \frac{a}{t^n} \tag{2}$$

$$i = \frac{a}{t+b} \tag{3}$$

where,

i = intensity of rainfall (mm/hr)
t = duration of storm (minutes) and
a,b and n are constants.

The obtainable data on i and t are plotted and the values of the intensity can be estimated for any given time of concentration (T_c).

2.6.5 Manning's Roughness Coefficient

The Manning's n is a coefficient which indicates the roughness or friction applied to the flow by the channel. The choice of a value for roughness coefficient is subjective, based on one's own experience and engineering judgment. The values of roughness coefficient n to be adopted for various types of materials are reported in table 2.2.

2.6.6 Curve Number (CN)

Basically curve number is a dimensionless parameter which indicates the runoff potential of a watershed. The higher the CN value indicates the higher runoff potential. It depends on hydrological soil group, land use, land cover, hydrologic conditions and antecedent moisture condition (AMC).

2.6.7 Hydrologic Soil Groups (HSG)

As per National Engineering Handbook (NEH) developed by USDA, soils are classified in four groups A, B, C and D described below.

Table 2.2: Values of Manning's **c**oefficient of roughness (*n*) as per CPHEEO (1993).

Type of material	**Condition**	***n***
Salt glazed stone ware pipe	a) Good	0.012
	b) Fair	0.015
Cement concrete pipes (with collar joints)	a) Good	0.013
	b) Fair	0.015
Spun concrete pipes (RCC & PSC) with socket spigot joints (Design value)		0.011
Masonary	a) Neat cement plaster	0.018
	b) Sand and cement plaster	0.015
	c) Concrete, steel troweled	0.014
	d) Concrete, wood troweled	0.015
	e) Brick in good condition	0.015
	f) Brick in rough condition	0.017
	g) Masonary in bad condition	0.020
Stone-work	a) Smooth dressed ashlar	0.015
	b) Rubble set in cement	0.017
	c) Fine, well packed gravel	0.020
Earth	a) Regular surface in good condition	0.020
	b) In ordinary condition	0.025
	c) With stones and weeds	0.030
	d) In poor condition	0.035
	e) Partially obstructed with debris or weds	0.050
Steel	a) welded	0.013
	b) Riveted	0.017
	c) Slightly tuberculated	0.020
	d) With spun cement mortar lining	0.011
Cast Iron	a) Unlined	0.013
	b) With spun cement mortar lining	0.011
Asbestos Cement		0.011
Plastic (smooth)		0.011

Group A: Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (Chapter 7, USDA, 2007).

Group B: Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (Chapter 7, USDA, 2007).

Group C: Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (Chapter 7, USDA, 2007).

Group D: Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures (Chapter 7, USDA, 2007).

2.6.8 Antecedent Moisture Condition (AMC)

Antecedent moisture conditions have great impact on the runoff of a watershed. The moisture content of the soil at the start of the rainfall is indicated by AMC. Under different time circumstances, variation in curve number is determined by AMC. AMC I, AMC II, AMC III are the three types of AMC are given by SCS. The range of these three AMC groups (Ahmad *et al.*, 2015) is based on rainfall magnitude of preceding 5 days and season (dormant season and growing season) given in table 2.3.

Table 2.3: AMC for determination of CN value

AMC	**Total Rain in previous 5days**	
	Dormant season	Growing season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

2.6.9 Design Period

The length of time up to which the capacity of a sewer will be adequate is referred to as the design period. In fixing a period of design, consideration must be given for the useful life of structures and equipment employed, taking into account obsolescence as well as wear and tear. Because the flow is largely a function of population served, population density and water consumption lateral and sub main sewers are usually designed for peak flows of the population at saturation density as set forth in the master plan. Thus, the population estimate is guided by the anticipated ultimate growth rates of each community. These may differ in different zones of the same town. A design period of 30 years (excluding construction period) is recommended for all types of sewer (CPHEEO, 1993).

2.6.10 Self-Cleansing Velocity

It is necessary to maintain a minimum velocity or self-cleansing velocity in drainage to ensure that suspended solids do not deposit and cause blockage. Drainage must be designed to ensure that solids do not accumulate on the bottom of the channel and affect their carrying capacity. Drainage designed to prevent solids accumulation is called self-cleansing. Self-cleansing velocities using Shield's formula (Eq. 4) is considered in the design of sewers.

$$V = \frac{1}{n}(R^{\frac{1}{6}}\sqrt{K_s(S_s - 1)d_p}) \tag{4}$$

where,
n = Manning's coefficient
R = Hydraulic mean radius in m
K_s = Dimensionless constant with a value of about 0.04 to start motion of granular particles and about 0.8 for adequate self cleansing of sewers.
S_s= Specific gravity of particle
d_p = Particle size in mm

The above formula indicates that velocity required to transport material in sewers is mainly dependent on the particle size and specific weight and slightly dependent on conduit shape and depth of flow. The specific gravity of grit is usually in the range of 2.4 to 2.65. A velocity of 0.60 m/s would be required to transport sand particle of 0.09 mm with specific gravity of 2.65. Hence minimum velocity of 0.8 m/s at design peak flow and 0.6 m/s for present peak flow is recommended (CPHEEO, 1993).

2.6.11 Maximum Velocity

High velocities may cause erosion of the boundaries. As such, in unlined channel the maximum permissible velocities refer to the velocities that can be safely allowed in the channel without causing scour or erosion of the channel material. In lined channels, where the material of lining can withstand very high velocities, the maximum permissible velocity is determined by the stability and the durability of the lining and also on the erosive action of any abrasive material that may be carried in the stream. Maximum velocity 3 m/s is recommended (CPHEEO, 1993).

2.6.12 Per Capita Sewage Flow

The entire spent water of a community should normally contribute to the total flow in a sanitary sewer. However, the observed dry weather flow quantities usually are slightly less than the per capita water consumption, since some water is lost in evaporation, seepage into ground, leakage etc. In arid regions, mean sewage flows may be as little as 40% of water consumption and in well developed areas; flows may be as high as 90%. However, the conventional sewers shall be designed for a minimum sewage flow of 100 litres per capita per day or higher as the case may be (CPHEEO, 1993).

References

Ahmad, I., Verma, V. and Verma, K.M. (2015). Application of Curve Number Method for Estimation of Runoff Potential in GIS Environment. *2nd International Conference on Geological and Civil Engineering*, **80**(4), pp.16-20.

Ara, Z. and Zakwan, M. (2018). Estimating Runoff Using SCS Curve Number Method. *International Journal of Emerging Technology and Advanced Engineering*, **8**(5), pp. 195-200.

Asfaw, B. (2016). Assessment of Storm water Drainage Systems in Kemise Town. *M.E Thesis,* School of Graduate studies Addis Ababa Institute of Technology, Addis Ababa University, Ethiopia.

Bajracharya, R.A., Rai, R.R. and Rana, S. (2015). Effects of Urbanization on Storm Water Run-off: A Case Study of Kathmandu Metropolitan City, *Nepal Journal of the Institute of Engineering*, **11**(1), pp. 36-49.

Bhadiyadra, J.K., Goyani, V.C., Dobariya, T. M., Vaghani, C. R. and Gajera, D.J. (2015). Study of Storm Water Drainage Problem of Surat City & Its Solutions Due To Flood in River Tapi. *International Journal of Civil and Structural Engineering Research*, **3**(1), pp. 61-89.

Binesh, N., Niksokhan, H.M. and Sarang, A. (2016). Performance assessment of urban drainage system (Case Study: District 10 of Tehran Municipality). *Computations and Materials in Civil Engineering*, **1**(3), pp. 133-141.

Burian, S.J., Nix, S.J., Pitt, R.E., and Durrans, S.R. (2000). .Urban waste water management in the United States: past, present, and future. *Journal of Urban Technology*, **7**(3), pp. 33-62.

Burian, S.J. (2001). Developments in water supply and wastewater management in the United States during the 19th century. *Water Resources Impact*, **3**(5), pp. 14-18.

Burian, J.S. and Findlay G. Edwards, G.F. (2002). Historical Perspectives of Urban Drainage. Global Solutions for Urban Drainage.

Chapter 5, Hydrologic Analysis and Design, Central Oregon Storm water Manual, August 2010.

Chapter 7, USDA (2007). Hydrologic Soils Groups, National Engineering Handbook, National Resources Conservation Services. USA.

Chapter 10, Estimation of Direct Runoff from Storm Rainfall, National Engineering Handbook, National Resources Conservation Services, USDA, July 2004.

Chapter 15, USDA (2010). Time of Concentration, National Engineering Handbook, National Resources Conservation Services, USA.

CPHEEO (1993). Manual on Sewerage and Sewage Treatment (Second Edition), Ministry of Urban Development, New Delhi.

Dabhekar, C.N., Patil, M.H. and Panchal, A.R. (2016). Case Study of Storm Water Drainage System of Vadodara City. *International Journal for Scientific Research & Development*, **4**(3), pp. 1766-1767.

District Census Handbook, Purba Medinipur Village and Town Directory, Directorate of Census Operations, West Bengal, 2011.

Ebrahimian, M., Nuruddin, A.A., Soom, M.B.A.M. and Sood, M.A. (2012). Application of NRCS-curve number method for runoff estimation in a mountainous watershed. *Caspian Journal of Environmental Science*, **10**(1), pp. 103-114.

Gajjar, H.H. and Dholakia, B.M. (2014). Storm Water Network Design of Jodhpur Tekra Area of City of Ahmedabad. *International Journal of Engineering Development and Research*, **2**(1), pp.744-747.

Gest, A.P. (1963). .Engineering.. In: *Our debt to Greece and Rome*, Edited by G.D. Hadzsits and D.M. Robinson, Cooper Square Publishers, Inc., New York.

Hodge, A.T. (1992). *Roman aqueducts & water supply*. Gerald Duckworth & Co. Ltd., London.

Kirby, R.S., Withington, S., Darling, A.B., and Kilgour, F.G. (1956). *Engineering in history*. McGraw-Hill Book Company, Inc., New York, NY.

Kumar, P.K., Barik, K.D., and Manideep, C. (2015*a*). A Comparative Study of Storm Water Drainage Methods for Urban Storm Water Management. *Indian Journal of Science and Technology*, **8**(33), pp. 1-9.

Kumar, S.P., Santhi, T., Srivatsav, M.P., Reddy, S.V.S., Prasad, A.M. and Praveen, V.T. (2015*b*). Storm Water Drainage Design (Case Study Vijayawada). *International Journal of earth Science and Engineering*, **8(2)**, pp. 507-511.

Land Use & Development Control Plan: Extended Haldia Planning Area 2026.

Mali, D., Agrawal, D., Parmar, P., Kalsariya, J. and Beble, D. (2017). Estimation of Storm Runoff Quantity Using Rational Method and SWMM. *International Journal of Recent Advances in Engineering & Technology*, **5**(2), pp. 5-8.

Mukhopadhyay, R. (2017). Study of Storm water Drainage System at Agarpara in West Bengal based on CivilStorm Software *M.E Thesis,* School of Water Resources Engineering, Jadavpur University, Kolkata, West Bengal, India.

Nayak, T.R. and Narulkar, S.M. (2011). Effects of land use and land cover changes on water yield in Goi watershed of Narmada basin, *Journal of Indian Water Resources Society*, **31** (1-2), pp 35-44.

Needhidasan, S. and Nallanathel, M. (2013). Design of Storm Water Drains by Rational Method–an Approach to Storm Water Management for Environmental Protection. *International Journal of Engineering and Technology*, **5**(4), pp. 3203-3214.

Official website of Haldia Development Authority, https://www.hda.gov.in/

Official website Haldia Municipality, www.haldiamunicipality.org/

Parmar, B.S. and Bhavsar, D.V. (2017). Stormwater Management a Case Study of Gandhinagar City. *International Research Journal of Engineering and Technology*, **4**(12), pp. 1440-1442.

Poongothai, N.N. (2012). Spatial Mapping of Runoff from a Watershed Using SCS-CN Method with Remote Sensing and GIS. *Journal of Hydrologic Engineering,* **17**(11), pp. 1268- 1277.

Reid, D. (1991). *Paris sewers and sewermen*. Harvard University Press, Cambridge, MA.
Salimi, T.E., Nohegar, A., Malekian, A., Hoseini, M. and Holisaz, A. (2016). Estimating time of concentration in large watersheds. *Journal of the International Society of Paddy and Water Environment Engineering*, **15**(1), pp. 123-132.
SewerGEMS V8*i* User's Guide Manual, Bentley, January, 2016.
Sharifi, S. and Hosseini, M.S. (2011). Methodology for Identifying the Best Equations for Estimating the Time of Concentration of Watersheds in a Particular Region. *Journal of Irrigation and Drainage Engineering*, **137**(11), pp. 712-719.
Sharma, D. (2008). Sustainable Drainage System (SuDs) for Storm water Management: A Technological and Policy Intervention to Combat Diffuse Pollution.*11th International Conference on Urban Drainage, Edinburgh*, Scotland, UK.
Storm Water Drainage Master Plan for Haldia. Department of Civil Engineering, Indian Institute of Technology Kharagpur.
Subramanya, K. (2013). Engineering Hydrology. Fourth Edition McGraw-Hill Education (India) Private Limited, New Delhi.
Urban hydrology for small watersheds, USDA (1986). Natural Resources Conservation Service, Conservation Engineering Division, Technical Release 55.
Webster, C. (1962). The sewers of Mohenjo-Daro. Journal Water Pollution Control *Federation*, **34**(2), 116-123.