STUDY OF STORM AND SEWER DRAINS FOR RAJARHAT (WARD NO 4) IN WEST BENGAL USING SEWERGEMS SOFTWARE

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

MASTER OF ENGINEERING
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submitted by

KUNTAL CHAUDHURI

Exam Roll No: M6WRP19003

Under the guidance of

Dr. SUBHASISH DAS
Assistant Professor
School of Water Resources Engineering, Jadavpur University

School of Water Resources Engineering
M.E. (Water Resources & Hydraulic Engineering) course affiliated to
Faculty Council of Engineering & Technology
Jadavpur University
Kolkata 700032, India
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Name : **Kuntal Chaudhuri**

Exam Roll Number : **M6WRP19003**

Thesis Title : **Study of Storm and Sewer Drains for Rajarhat (Ward No 4) in West Bengal using SewerGEMS Software.**

Signature with Date :

M.E. (Water Resources & Hydraulic Engg.) **course affiliated to**
Faculty Council of Engineering & Technology
Jadavpur University
Kolkata, India

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This is to certify that the thesis entitled "**Study of Storm and Sewer Drains for Rajarhat (Ward No 4) in West Bengal using SewerGEMS Software**" is a bonafide work carried out by **Mrs. Kuntal Chaudhuri** under my 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.

THESIS ADVISOR
Dr. Subhasish Das
Assistant Professor
School of Water Resources Engineering
Jadavpur University

DIRECTOR
Prof. (Dr.) Asis Mazumdar
School of Water Resources Engineering
Jadavpur University

DEAN
Faculty of Interdisciplinary Studies, Law & Management
Jadavpur University

CERTIFICATE OF APPROVAL **

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Committee of
Final Examination
for the evaluation
of the thesis

** Only in case the thesis is approved.

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Date :

KUNTAL CHAUDHURI
Examination Roll No- M6WRP19003

ABSTRACT

India has been undergoing rapid urbanization since independence. With increasing urbanization and the pressures of population, the impervious surfaces in the metros are increasing, thereby increasing the volume of storm water runoff. In almost all of India's cities, developments in the water supply sector have outpaced those in the drainage sector. With increasing water supply to cities, drainage managers are faced with additional wastewater from the highly populated areas for which the existing drains are totally inadequate.

So, the study focuses on the assessment of drainage system in Rajarhat, ward number four under borough number one of Bidhannagar Municipal Corporation as a case study using SewerGEMS and Google Earth Software. Based on primary and secondary data collected and Bidannagar Municipal Corporation map, the problems in this area are categorized as mainly construction, management and design problem. The method used to investigate problem in the existing drainage network of the above mentioned area is field data collection and site visit. By using Google Earth Software, catchment area of ward no. four of Rajarhat has been defined.

SewerGEMS is the first and only fully-dynamic, multi-platform (GIS, CAD and StandAlone) sanitary and combined sewer modeling solution. SewerGEMS software allows projects to be accomplished in a short time, with high efficiency and low costs. As per the primary and secondary data collected, the inputs have been given in the software and accordingly the results are interpreted. Finally, appropriate mitigated measures are proposed for drainage system in order to serve the area from different negative effect and drainage structures for the future purposes sustainably.

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CHAPTER-1

1.1 Introduction

1.1.1 General Background

Drainage networks are an important part of the infrastructure of any society. The main purpose of providing the drainage network is to carry away sanitary waste and storm water from a municipal area in such a way that it does not cause any public health related problems. It is known that urban sewerage system provide one of the basic infrastructure facilities to transport sanitary waste as well as storm water to sewage treatment plant. Drainage network infrastructure conveys wastewater and storm water used by individuals, commercial and industrial establishments to wastewater treatment facilities, ultimately to be returned to the natural environment. A drainage network is just a reverse action of water supply network.

Drainage system has become an issue in urban planning and management, particularly in developed countries with substantial urban infrastructure in place. The magnitude of investments required to construct, operate and maintain urban storm drainage facilities and the potential for significant adverse social and environmental impacts mandate the use of the best possible methods for planning, analysis and design.

1.1.2 Effect of Urbanization on Strom Runoff

Problems with drainage in urban areas introduce flooding, water logging, land degradation, sedimentation, road degradation, etc. With urbanization, soil impermeability increases with the increase of impermeable surfaces with this change in drainage pattern, flooding and environmental problems such as increasing soil degradation. The existing and future road infrastructure is facing a crucial problem. To make them hydraulically smoother, natural channels are often straightened, deepened and lined. In the urbanized area, drains, storm drainage pipes and gutters are laid to quickly transmit runoff to stream channels. Two types of fluids viz waste water and storm water include urban drainage. Storm water is rainwater falling into the buildup area. It would cause inconvenience damage, flooding and further health risks if storm water were not drained properly. The interaction between human activity and the natural water cycle requires drainage systems in developed urban areas. Urban drainage includes two types of fluids viz waste water and storm water. Urban drainage includes two types of fluids viz waste water and storm water. Urban drainage includes two types of fluids viz waste water and storm water urban drainage includes two types of fluids viz waste water and storm water. Storm water is rainwater that has fallen on the buildup area. If storm water were not drained properly, it would cause inconvenience damage, flooding and further health risks.

Urban drainage system handle with the aim of minimizing the problems caused to human life and environment. 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.The concept of storm water 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.

Urbanization also has a significant impact on the area's climate. Precipitation, evaporation and local temperature have been found to increase as a result of urbanization. In addition, storm water directly transports harmful substances to downstream water systems from urban surfaces. Human activities in urban areas release into the environment a wide range of emissions including carbon dioxide, carbon monoxide, ozone, sulfur oxides, nitrogen oxides, lead, and many other pollutants. Cities often get more rain than the surrounding countryside as dust can cause water vapor to condense into rain droplets.Rapid development can lead to very high levels of river channels erosion and sedimentation. Pollutants are frequently dispersed throughout cities or concentrated in industrial or waste sites. Evaporation may decrease as transpiration (lack of vegetation) and soil moisture decreases as a result of urbanization. Evaporation reduction also increases the sensitive heat resulting from an increase in temperature.

In the last couple of years, a massive development work has been started, not only in Kolkata, but all through the adjoining areas and different municipalities in the form of construction of Hospitals, Hotels, high rise residential and commercial buildings including housing complexes, many of which are coming up in large vacant low lying areas, undertaken at different levels. Each outfall drainage channel has particular design discharge capacity and full drainage level.Therefore, any change in the land used plan in the Basin area of the respective Channel will impart excess pressure to particular drainage system to accommodate such additional discharge. So drainage system of Kolkata appears to be not satisfactory as per desired level**.** Even at some places, a little precipitation is creating a good inconvenience to the inhabitant**s.**

1.1.3 Background of Drainage Structures of the Study Area

The study area is characterized by extended and medium volumes of rainfall. Among access road for all most all part was providing rectangular drainage system. The average annual rainfall received by the area is about 511.30mm and rainfall is high in the month of July.

1.1.4 Statement of the Problem

Lack of Urban Storm Drainage (USWD) Management and sewer drainage are one of the most common sources of complaint from residents in many of Kolkata's urban centers, and with the increasing rate of rapid urbanization this problem is getting worse and worse.

Population in Rajarhat area is rapidly growing from last decades and massive development work has been done in this area such as high rise buildings, complexes and commercial buildings have been constructed in last few years. In respect of this, little number of hydraulic structures has been contracted in Rajarhat to be used for drainage system. The urban drainage of these structures failed to deliver the design yields. The problem is by now even become worse due to unexpected flooding that arise from climate change.

1.2 Significance of the study

The benefit to be derived from this study may contribute to Government and other authorities' current efforts to solve the problem of drainage schemes that contribute to better service coverage. Comprehending damage problems and preserving structures by avoiding further deterioration in order to take correct measures as well as reducing any inconvenience and disruption of travel due to overflow of water in the main road due to flooding.

The outcome of this study may also help to fill the gaps by identifying sustainability issues, proper design of storm water drainage system, and proper functioning of city drainage schemes. Overall, part of Rajarhat, which is ward number four, faces drainage problems, so further investigations are needed to contribute to the over flooding solution due to the problem of storm water drainage and sustainable drainage system for future use in this area.

1.3 Objectives

1.3.1 General Objective

- To contribute efforts that aim at improving the storm water and sewer drainage problem of Rajarhat.

1.3.2 Specific Objectives

- To assess the existing condition and problems related to drainage system of ward number four of Rajarhat in West Bengal.
- To assess the hydraulic performance of existing drainage systems of ward number four of Rajarhat.
- To recommend appropriate measure, if any.

1.4 Scope of the Study

This study focuses specifically on evaluating, proper designing the existing drainage system which may help the relevant government body in planning, implementing, operating and maintaining the storm water drainage systems to solve the problem in the study area. And also for sustainability that contributes to better service in drainage schemes. This research does not include structural design of all types of drainage structures except for the type and size of drainage structures that are required.

CHAPTER-2

2.1 General Concept

2.1.1 Historical Perspective of Urban Drainage

Historically, with different perspectives, urban drainage systems have been viewed. Urban drainage was considered a vital natural resource, a convenient cleaning mechanism, an efficient waste transportation medium, a flood concern, a nuisance wastewater, and a transmitter of disease over different periods of time and at different locations. In general, the local perspective of urban drainage has been influenced by climate, topography, geology, scientific knowledge, engineering and building capabilities, societal values, religious beliefs, and other factors. These factors have guided and constrained the development of urban drainage solutions for as long as human beings have been building cities. Two types of fluids are defined as urban drainage: wastewater and storm water. Wastewater is water that needs to be collected and disposed of appropriately to prevent nuisance and polluted conditions from developing in urban areas after use for life support, industrial processes, or life enhancement. Storm water is precipitation-generated runoff. During planning of the urban drainage system, both wastewater and storm water must be considered. Historically the two waters have either been combined into a single conduit (i.e., combined two sewers), or have been kept separate during collection and disposal (i.e., separate sewers).

2.1.2 Literature study

The need for a proper and efficient urban drainage system was described by Burian *et al.* (2000). They compared the drainage systems of the past and the present, which undoubtedly points to the fact that proper design and planning of drainage systems is inevitable for a healthy environment, especially in cities.

Lloyd *et al.* (2002) in Australia,introduced Water Sensitive Urban Design (WSUD) as a sustainable approach to urban water resource management in order to minimize the impact of urban development on the natural water cycle. The adoption of best planning practices and BMPs is essential to the application of WSUD. Best Planning Practices refer to the site assessment and planning component of the WSUD. BMPs refer to structural and non-structural control measures performing a water management scheme's functions of prevention, collection, treatment, conveyance, storage or reuse. The WSUD enables appropriate land-use requirements, including the layout and arrangement of a storm water management scheme, to be harmonized with landscape characteristics.

D'Asaro and Grillone (2010) described in detail the Curve Number (CN) procedure, which is largely and worldwide used for this easy application, allows to estimate the volume of direct runoff for a given rainfall event using a single parameter, CN, representing the storage of the basin infiltration and depending on the type of soil, land cover and land use.

Belete (2011) in Addis Ababa, Addis Ketema sub-city, conducted a study on road and urban storm water drainage network integration. According to him, the main causes of flooding in the study area are due to inadequate integration between road and urban storm water drainage lines followed by blocking drains by solid waste. Connection of sewerage and dumping of solid waste reduces the efficient capacity of drainage. It was recommended that the urban storm water drainage facilities should be revised and designed to securely discharge the flood generated within the study area (Addis Ketema sub-city). Urban storm water drainage facilities should also be contracted with roads for timely performance and a good ship for the worker. A wider integration gap has been created by the budget allocated for road and urban storm water drainage over the last three years.

Needhidasan *et al.* (2013) conducted a study on rational method design of storm water drains. In Calicut City, Kerala, a rational method was used to design the study area's storm water drains. The runoff coefficient in Rational Method includes many catchment basin factors, pattern of land use, soil cover, details of infiltration, etc. In order to reach the value of the runoff coefficient, diligent efforts were needed to estimate these parameters. The value of the runoff coefficient' C' was finalized with utmost care in that study. It was noted that the existing sections are not enough to accommodate the runoff in most places. The flooding of the study area was primarily due to the blockage of drains at different points; therefore, it is essential to maintain the existing drains periodically. They concluded that in those places where space constraints are acute, trapezoidal sections may be replaced with existing rectangular sections.

Gajjar *et.al.* (2014) presenteda design of storm water drainage system for Jodhpur Tekraarea of city of Ahmedabad. This design was based on rainfall data. Past 20 years rainfall data was taken for study. The system was designed considering in total of 65% of the impervious area. Different methods were used for runoff estimation. Here, rational method was used for estimation of storm water runoff. The outfalls of system were directed to proposed lakes.

Bhadiyadra *et al.* (2015) conducted a study on Surat City on the issue of storm water drainage. Their research showed that the problem of storm water flowing back in river Tapti under high flood conditions is the major problem of storm water drainage when drainage outlets for Surat city are closed. It indicates that Surat City's storm water drainage system during flooding is not very effective in some of Surat City's low-lying areas. In this case study, the feasible solution to this problem was achieved by designing some general as well as systematic drainage solution as well as a suitable design of the desired working objective storm water drainage system. In this situation, if storm water logging from drains takes place, it will lead to road traffic, inflection, and obstruction to the general public's routine life, etc. Earlier the problem pumping systems were used during storm water backflow to remove excess storm water from Surat City's low lying area. But the pumping system was not enough to pump large quantities of water from any location, and it was also very expensive to buy or hire both. Therefore, the current pumping system needed some improvements that resulted in a permanent solution to the storm water backflow needs a permanent solution, better storm water drainage facilities in any urban area that leads to better transportation facilities On the other hand, existing storm water drainage system is needed to solve this problem. For example, instead of supplying a high-capacity pump in low-lying areas, this water is diverted to the bank of the river and then at this location we can provide a moderate capacity pump that continually pumps storm water at the bank of the river.

Kumar *et al.* (2015) conducted a study in Vijayawada on storm water drainage design. Rational method was successfully used for Vijayawada city with a good determination coefficient of 0.871 to estimate storm wise discharge. In order to reach the value of the runoff coefficient, diligent efforts are needed to estimate these parameters. Care was taken in that study to determine the runoff coefficient value, C.Periodic maintenance of existing drains in Vijaywada was therefore essential.

Asfaw (2016) conducted a study in Kemise town to evaluate the storm water drainage system. According to the results obtained, the storm drainage facility was inadequate to transport the peak discharge over the required design period and the drainage system filled with sediment and other waste materials on the basis of these problems; due to the drainage design and construction practices adopted by ignoring hydrology and hydraulic analysis, the type of drainage system provided. Based on the results of this study, open drainage ditch type was practiced, due to the opening of the drainage system, it is simply filled with solid materials and storm water for improper aligned drainage system caused by various negative impacts to the community during the rainy season, such as malaria and other waterborn disease. Furthermore, the management problems were related to the body (municipality) and also the community was disposed of their waste into drainage due to lack of awareness on the impact of disposing of solid material on the drainage system according to the study area observation. The existing drainage alignment was not properly aligned; due to the nature of Kemise's location the runoff from the top of the mountain area was contributed.

Kyi *et al.* (2017) analyzed the existing drain condition and to propose the appropriate drain size and effective drainage system of Yangon city area. Increased frequency and intensity of heavy storm events predicted by climate changes effect will amplify the impact of urbanization on storm water runoff. Safe and dependable storm water drainage system is a long term ambition of society. The study area is situated in the south-western part of Yangon city area. The total study area is about 5.6 sq. km. At present, the study area receives the runoff from the largest catchment of Sanchaung Township. Due to the tidal effect of Yangon River and Hlaing River, insufficient drainage capacity and increase in surface runoff causes that lead to flooding in the study area. Here the modified rational method was used to estimate design flood for 10yr, 50yr and 100yr, respectively. After that, Manning's formula was used to estimate proposed drain size. Ten year average recurrence intervalwas used as design flood for conveyance structure and 50 year for culvert design. At first the existing drain capacity were checked by using 10 yrs design flood and it was founded that almost existing all drain size so small and not enough to carry design discharge. So, new dimension of drain size were proposed using Manning's formula by fixing existing bed slope. Yangon River is influenced significantly by the tide and the tidal effect is one of the main factors for flooding. To simulate the rainfall-runoff process, SWMM was used for checking estimation of proposed drain capacity. It was observed that almost all the major drain and minor drain cannot carry the peak discharge of 10year return period.

Raval (2018) analyzed the existing storm water drainage network of Ahmedabad. The augmentation of the existing storm water drainage (SWD) network of the city was assessed, followed by in depth analysis, planning and design. Ahmedabad city stands firm in Mega cities list of India and its rate of infrastructure development is very high. As there is no existing storm water drainage system in Bopal, an urban town-planning scheme of Ahmedabad was taken as a case study for design of storm water drainage system. The present design was based on the rainfall data observed in past 20 years, using rational method considering in total of 60% of the impervious area, which was supposed to increase in future with increasing urbanization and the population increase. The outfalls of the system were directed to Sarkhej Lake, after overflow meet in to Sabarmati River.

2.1.3 Storm and Sewer Drain

- A storm drain is that portion of the roadway drainage system that receives runoff from inlets to some point where it can be discharged into a ditch, channel, stream, pond, lake or pipe. Storm drains shall be designed using the following criteria where applicable:
- A storm drain, storm sewer, surface water drain/sewer or storm water drain is designed to drain excess rain and ground water from impervious surfaces such as paved streets, car parks, parking lots, footpaths, sidewalks, and roofs. Storm drains vary in design from small residential dry wells to large municipal systems.
- Drains receive water from street gutters on most motorways, freeways and other busy roads, as well as towns in areas with heavy rainfall that leads to flooding, and coastal towns with regular storms. Even gutters from houses and buildings can connect to the storm drain. Many storm drainage systems are gravity sewers that drain untreated storm water into rivers or streams—so it is unacceptable to pour hazardous substances into the drains.
- Minimum self- cleansing velocity of 0.45 m/s should be maintained wherever possible.
- The drainage layout should seek to avoid conflicts with existing underground utilities such as utility poles, water supply lines, telephone cables, etc.
- Precast manholes or inlets should not be used for 1350 mm or larger diameter pipes or when three or more pipes are connected to each other and at least two

of them are connected at certain angles. Cast-in-place inlets or manholes are more practical when these conditions exist.

- Cleaning existing drainage pipes and structures shall be incorporated into all projects where there is a significant accumulation of sediments in the existing drainage system.
- In projects where contaminated areas have been identified, the drainage system should, where possible, be designed to avoid such sites. If avoidance is not feasible, a fully watertight conveyance system should be designed to prevent contaminated groundwater or other pollutants from entering the system, including structures such as manholes, inlets and junction chambers.
- Existing drainage facilities not to be included in the proposed drainage system shall be removed completely if they conflict with any element of the proposed construction.

2.1.4 Storm Water

Storm water, also spelled storm water, is water that originates during precipitation events and snow/ice melts. Storm water can soak into the soil (infiltrate), be held on the surface and evaporate, or runoff and end up in nearby streams, rivers, or other water bodies (surface water).In natural landscapes such as forests, the soil absorbs much of the storm water and plants help hold storm water close to where it falls. In developed environments, unmanaged storm water can create two major issues: one related to the volume and timing of runoff water (flooding) and the other related to potential contaminants that the water is carrying (water pollution).Storm water is also an important resource as the world's human population demand exceeds the availability of readily available water. Techniques of storm water harvesting with point source water management and purification can potentially make urban environments self-sustaining in terms of water. In urban areas storm water is generated by rain runoff from roofs, roads, driveways, footpaths and other impervious or hard surfaces. In Australia the storm water system is separate from the sewer system. Unlike Sewage, storm water is generally not treated before being discharged to waterways and the sea. Poorly managed storm water can cause problems on and off site through erosion and the transportation of nutrients, chemical pollutants, litter and sediments to waterways, Well-managed Storm water can replace imported water for uses where high quality water is not required, such as garden watering.

2.1.5 Runoff

New developments directly affect existing drainage infrastructure and the environment surrounding it. They increase the area of paved surfaces, thereby reducing infiltration while causing surface runoff to exhibit higher peak flows, larger volumes and shorter times to peak and accelerate pollutant and sediment transport from urban areas. This results in watercourses receiving pollution and increased flood risk in the course of development. Thus, controlling surface runoff becomes a key component of urban sustainability work.

2.1.6 Flooding

Floods generally occur over a period of days when there is too much rainwater to fit in the rivers, and water spreads over the surrounding land. However, when a lot of heavy rain falls over a short period of time, they can happen very quickly. These flash floods occur with little or no warning and cause human life's greatest loss than any other type of flooding.

2.1.7 Flood Types

- Flash Flood
- Coastal Flood
- Urban Flood
- River Flood
- Pluvial Flood

Flash Flood: “Flash flood” is a term widely used by flood experts and the general population. The National Weather Service defines a flash flood as “A rapid and extreme flow of high water into a normally dry area, or a rapid rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam). However, the actual time threshold may vary in different parts of the country. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters.” Flash floods are also characterized by a rapid rise in water, high velocities, and large amounts of debris. Major factors in flash flooding are the intensity and duration of rainfall and the steepness of watershed and stream gradients. Flash flooding occurs in all 50 states, most commonly in steeply sloping valleys in mountainous areas, but can also occur along small waterways in urban environments. Dam failure, release of ice jams, and collapse of debris dams also can cause flash floods.

Coastal Flood: Coastal flooding occurs when normally dry, low-lying land is flooded by seawater. The extent of coastal flooding is a function of the elevation inland flood waters penetrate which is controlled by the topography of the coastal land exposed to flooding. The seawater can inundate the land via several different paths:

- **Direct inundation** — where the sea height exceeds the elevation of the land, often where waves have not built up a natural barrier such as a dune system
- **Overtopping of a barrier** — the barrier may be natural or human engineered and overtopping occurs due to swell conditions during storm or high tides often on open stretches of the coast. The height of the waves exceeds the

height of the barrier and water flows over the top of the barrier to flood the land behind it. Overtopping can result in high velocity flows that can erode significant amounts of the land surface which can undermine defense structures.

- **Breaching of a barrier** — again the barrier may be natural or human engineered, and breaching occurs on open coasts exposed to large waves. Breaching is where the barrier is broken down by waves allowing the seawater to extend inland.
- Coastal flooding is largely a natural event, however human influence on the coastal environment can exacerbate coastal flooding. Extraction of water from groundwater reservoirs in the coastal zone can enhance subsidence of the land increasing the risk of flooding. Engineered protection structures along the coast such as sea walls alter the natural processes of the beach, often leading to erosion on adjacent stretches of the coast which also increases the risk of flooding.

Urban Flood: Urban flooding is significantly different from rural flooding as urbanization leads to developed catchments, which increases the flood peaks from 1.8 to 8 times and flood volumes by up to 6 times. Consequently, flooding occurs very quickly due to faster flow times (in a matter of minutes). Urban areas are densely populated and people living in vulnerable areas suffer due to flooding, sometimes resulting in loss of life. It is not only the event of flooding but the secondary effect of exposure to infection also has its toll in terms of human suffering, loss of livelihood and, in extreme cases, loss of life.

Urban areas are also centers of economic activities with vital infrastructure which needs to be protected 24x7. In most of the cities, damage to vital infrastructure has a bearing not only for the state and the country but it could even have global implications. Major cities in India have witnessed loss of life and property, disruption in transport and power and incidence of epidemics. Therefore, management of urban flooding has to be accorded top priority.

Increasing trend of urban flooding is a universal phenomenon and poses a great challenge to urban planners the world over. Problems associated with urban floods range from relatively localized incidents to major incidents, resulting in cities being inundated from hours to several days. Therefore, the impact can also be widespread, including temporary relocation of people, damage to civic amenities, deterioration of water quality and risk of epidemics.

River Flood: During an extended period of rainfall and an extended area, major rivers may overflow their banks. Water can cover vast areas. Downstream areas may be affected, even though they themselves have not received much rain. The process is relatively slow with big rivers. In many ways, rain water enters the river. Some rain will fall directly into the river, but that alone will not cause the river to rise high. When the soil is saturated or hard, a lot of rain water will run off the surface. It will flow into small rivers flowing into larger rivers and flowing into larger rivers. Thus, in this one very large river, all the rain that fell in a large area (catchment area) comes together. It takes time for all the rainwater to reach the river when there is plenty of rain over a long period of time. While the water level rises slowly, officials may decide to evacuate individuals before the river overflows. The flooded area can be huge. Cattle would normally graze villages surrounded by large stretches of water. Whole communities can isolate themselves from the rest of the world as roads are blocked and communities are down. When a dike or dam breaks and a lot of water is suddenly released, a flash flood speed can be compared to the speed of the water at the breach. The speed will be reduced as a larger area becomes covered. Before slowly rising, the water spreads out to the lower lying areas as much as possible. For the people living near it, a breach is very dangerous. The water's strength can carry away cars, trees, and even houses, causing loss of life.

Pluvial Flood: Pluvial is a type of flood that is relatively flat areas that can occur. Rain water that falls in an area is normally stored in the ground, in canals or lakes, or drained or pumped out. Flooding occurs when more rainwater enters a system of water that can be stored or can leave the system. In this case, rain is the source of the flood: on its way to the river, not water coming from a river, but water. That's why it is also called "pluvial flood". Puddles and ponds develop on the ground, canals are filled to brim and spill over; the land is gradually covered by a layer of water. It's like urban flooding, but in more rural areas without sewage systems. People have time to go indoors or leave the area due to the gradual character. The water layer is not higher than centimeters or maybe decimeters and does not cause any immediate threat to the lift of people. It can cause enormous economic damage depending on the economic activity and the size area covered.

2.1.8 Causes of Flooding

Floods are one of those hydrological phenomena that occur due to an exceedingly complex sequence of natural events. Therefore, prediction of such events is possible only when there is complete understanding of causes of flood-proceeding events in a basin. The frequency, duration and magnitude of floods are determined by numerous factors. Flooding is often thought of as a result of heavy rainfall, but floods can arise in a number of ways that are not directly related to ongoing weather events. Thus, a complete description of flooding must include processes that may have little or nothing to do with metrological events. Flooding, by its very nature, is usually a result of both metrological and hydrological processes; the character of a flood is determined both by the detailed behavior of the precipitation and by the nature of situation in which the event is likely to occur.

2.1.9 Effects of Flooding

By cutting off roads and railway lines, as well as communication links when telephone lines are damaged, floodwater can seriously disrupt public and personal transport. Floods disrupt city-based normal drainage systems, and sewage spills are common, posing a serious health hazard along with home-based water and wet materials. Floods can distribute large quantities of water and suspended sediment across vast areas; restore valuable soil nutrients to agricultural land. Bacteria and viruses, cause disease, trigger allergic reactions, and continue to damage materials long after a flood. Floods can distribute large quantities of water and suspended sediment across vast areas; restore valuable soil nutrients to agricultural land. By contrast, large amounts of fast-flowing water can erode soil, ruin crops, destroy agricultural land / buildings, and drown farm animals. Severe floods not only ruin homes / businesses and destroy personal property, but also cause further damage to property and content by the water left behind. There is also a risk to the environment and wildlife when damage to business causes accidental release of toxic materials such as paints, pesticides, gasoline, etc. By cutting off roads and railway lines, as well as communication links when telephone lines are damaged, floodwater can severely disrupt public and personal transportation. Unfortunately, flooding not only disrupts the lives of many people every year, but when people are swept away and drowned, it often creates personal tragedies.

2.2 Sustainable Urban Drainage Systems

A sustainable drainage system (also known as SuDS or SUDS) is designed to minimize the potential impact on surface water drainage discharges of new and existing developments. Sustainable drainage systems are often used in urban centers or other areas where impervious surfaces such as pavement, concrete, asphalt, etc. prevent rainfall from entering soil or water sources. As urban sprawl and population growth exacerbate stress on water management systems, SuDS has gained prominence. The term sustainable urban drainage system is not the accepted name, the reference to ' Urban ' has been removed to accommodate sustainable practices in rural water management.

Increasing urbanization has caused problems following sudden rain with increased flash flooding. The area loses its ability to absorb rainwater as vegetation areas are replaced by concrete, asphalt, or roofed structures, leading to impervious surfaces. Instead, this rain is directed towards surface water drainage systems that often overload them and cause flooding.

The goal of all sustainable drainage systems is to use naturally occurring rainfall to recharge the water sources of a given site. These water sources are often underlying the water table, nearby streams, lakes, or other similar freshwater sources. For example, if a site is above an unconsolidated aquifer, then SuDS will aim to direct all rain that falls on the surface layer into the underground aquifer as quickly as possible.

SuDS use various forms of permeable layers to ensure that water is not captured or redirected to another location to accomplish this. These layers often include soil and vegetation, although they may be artificial materials as well.

SuDS solutions should be that of an easy - to - manage system that requires little or no energy input (except from environmental sources such as sunlight, etc.), is resilient to use, and is both environmentally and esthetically attractive. Examples of this type of system are basins (shallow landscape depressions that are dry most of the time when it's not raining), rain gardens (shallow landscape depressions with shrub or herbaceous planting), swales (shallow normally-dry, wide-based ditches), filter drains (gravel filled trench drain), bio retention basins (shallow depressions with gravel and/or sand filtration layers beneath the growing medium), reed beds and other wetland habitats that collect, store, and filter dirty water along with providing a habitat for wildlife.

The term SUDS were originally used to describe the UK approach to sustainable urban drainage systems. These developments may not necessarily occur in "urban" areas, so the "urban" part of SuDS is now generally dropped to reduce confusion. Other countries use a different terminology, such as best management practices (BMP) and low-impact development in the United States, and water-sensitive urban design in Australia, similar approaches.

The idea behind SUDS is to attempt to replicate natural systems that use low - impact, cost - effective solutions to drain dirty and surface water runoff by collecting, storing, and cleaning before allowing it to be slowly released back into the environment, such as waterways. This is to counteract the effects of conventional drainage systems that often allow flooding, environmental pollution— with the resulting damage to wildlife— and contamination of groundwater sources used to supply drinking water. The paradigm of SUDS solutions should be that of an easy-to-manage system requiring little or no energy input (except from environmental sources such as sunlight, etc.), resilient to use, and both ecologically and esthetically attractive. Examples of this type of system are basins (shallow landscape depressions that are dry most of the time when it’s not raining), rain-gardens (shallow landscape depressions with shrub or herbaceous planting), swales (shallow normally-dry, wide based ditches), filter drains (gravel filled trench drain), bio retention basins (shallow depressions with gravel and/or sand filtration layers beneath the growing medium), reed beds and other wetland habits that collect, store, and filter dirty water along with providing a habitat for wildlife.

A common misconception of SUDS systems is that on the development site they reduce flooding. Indeed, the SUDS system is designed to reduce the impact on other sites of one site's surface water drainage system. Sewer flooding, for example, is an issue in many places. Paving or building on land can lead to flash flooding. This happens when flows exceed the capacity of a sewer and it overflows. The SUDS system aims at minimizing or eliminating site discharges, thereby reducing the impact, with the idea that if all development sites incorporated SUDS then urban sewer flooding would be less of a problem. In contrast to traditional urban storm water drainage systems, SUDS can also help protect and improve groundwater.

2.3 Function of Storm and Sewer Water Drainage System

Storm and sewer water drainage systems have the function of collecting minor storm runoff and sanitary sewage design and transmitting major storm and sanitary sewage design (flood) runoff to a discharge point. A system of storm and sanitary sewage water drainage can be as simple as a ditch that flows into a stream or as complex as a system that includes numerous intakes, manholes and pipes along with ditches, storm water retention or detention basins, and pump stations.One of the functions of the drainage system is to collect and direct surface water and/or ground water, thus keeping the bed drained from the ballast. The drainage system must also protect the substructure from erosion, suddenness, and loss of load-bearing capacity and stability. Another main goal of storm and sanitary sewage is to protect:

- Public health and safety
- Environmental protection
- Sustainable development
- Occupational health and safety

Drain and sewer systems are provided to prevent disease and other waterborne waste from spreading, to protect drinking water sources from waterborne waste contamination, and to remove runoff and surface water while minimizing public hazards. In addition, the impact of drainage and sewage systems on the receiving waters must meet the requirements of any national or local regulations or authority concerned.

2.4 Types of Storm Water and Sanitary Sewage Drainage System

A drainage system will include all the components needed to ensure that the substructure is properly drained and may be formed of components such as:

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

2.5 Storm and Sanitary Sewer Design

Population growth and urban development may create severe urban water management problems. An adequate and properly functioning storm water drainage system is one of the most important facilities to preserve and improve the urban water environment. Building houses, commercial buildings, parking lots, paved roads and streets increases a watershed's impermeable cover and reduces infiltration. The spatial flow pattern in the watershed is also changed with urbanization and the hydraulic efficiency of flow through artificial channels, curbing, gutters and storm drainage and collection systems is increased.These factors increase runoff volume and velocity and result in greater peak flood discharges from urbanized water sheds than in the pre-urbanized condition. Many urban drainage systems are now operating under a higher level of urbanization and have adequate capacity.

The following constrains and assumptions are commonly used in storm and sanitary sewer design practice:

1. Free surface flow exists for discharges designed for "gravity flow" by the sewer system; pumping stations and pressurized sewers are not considered.
2. A minimum permissible flow velocity at design discharge or at barely full pipe gravity flow is specified to prevent or reduce excessive deposition of solid material in sewers.
3. At junctions, the sewers are joined in such a way that the upstream sewer's crown elevation is no lower than the downstream sewer.
4. The downstream sewer can’t be smaller at any junction or manhole than any of the upstream sewers at that junction.
5. A maximum allowable flow velocity is also specified to prevent scouring and other undesirable effects of high-velocity flow.

2.6 Design Criteria

Along with determining the required pipe sizes for flow conveyance and the HGL, storm sewer system design should consider the following guidelines:

1. **Soil Conditions:** Soil with adequate bearing capacity must be present to interact with the pipes and support the load imparted by them. Surface and subsurface drainage must be provided to assure stable soil conditions. Soil resistivity and pH must also be known so the proper pipe material will be used.

2. **Structure Spacing and Capacity:** Structures (catch basins, grate inlets, and manholes) should be placed at all breaks in grade and horizontal alignment. The desired pipe run length between structures is 150 feet (46 m) and shall not exceed 300 feet (92 m) for pipes less than 48 inches in diameter and 500 feet (152 m) for pipes greater than 48 inch (1.22 m) in diameter.

3. **Existing Systems:** Criteria for repair and/or replacement of existing systems be provided in future revisions to the Hydraulics Manual.

4. **Future Expansion:** If a storm sewer system may be expanded in the future, provision for the expansion shall be incorporated into the current design. Additionally, prior to expanding an existing system, the existing system shall

be inspected for structural integrity and hydraulic capacity using the Rational Method.

5. **Velocity:** The design velocity for storm sewers shall be between 2 to 10 feet per second (0.6-3.0 m/s). This velocity is calculated using Manning's equation, under full flow conditions even if the pipe is only flowing partially full with the design storm. When flows drop below 0.6 m/s, pipes can clog due to siltation. Flows can be designed to as low as 0.45 m/s with justification in the hydraulic report.

6. **Pipe Elevations at Structures:** Pipe crowns differing in diameter, branch, or trunk lines shall be at the same elevation when entering structures. For pipes of the same diameter where a lateral is placed so the flow is directed against the main flow through the manhole or catch basin, the lateral invert must be raised to match the crown of the inlet pipe. Matching the crown elevation of the pipes will prevent backflow in the smaller pipe. (A crown is defined as the highest point of the internal surface of the transverse cross section of a pipe.) It is also generally acceptable to have the crown elevation of the upstream pipe in the structure be higher than the crown elevation of the downstream pipe in the same structure. The minimum pipe diameter shall be 12 inch (0.3 m).

7. **Increase in Profile Grade:** In cases where the roadway or ground profile grades increase downstream along a storm sewer, a smaller diameter pipe may be sufficient to carry the flow at the steeper grade. Consideration could be given in running the entire length of pipe at a grade steep enough to allow use of the smaller diameter pipe. Although this will necessitate deeper trenches, the trenches will be narrower for the smaller pipe and therefore the excavation may not substantially increase. A cost analysis is required to determine whether the savings in pipe costs will offset the cost of any extra structure excavation. Additional considerations for discharge locations include energy dissipaters and tidal gates. Energy dissipaters prevent erosion at the discharge location.

8. **Location:** Wide medians usually offer the most desirable storm sewer location. It is recommended when a storm sewer is placed beyond the pavement edge that a one-trunk system with connecting laterals be used instead of running two separate trunk lines down each side of the road.

2.7 Factors Effecting Runoff

1. **Climatic factors –**

- Rain and snow fall,
- Rainfall intensity,
- High intensity rainfall causes more rainfall,
- Duration of rainfall,
- When duration increases, infiltration capacity decreases resulting more runoff,
- Rainfall distribution.

2. Direction of prevailing wind – If the wind direction is towards the flow direction, peak flow will occur quickly.

3. Other climatic factors –Temperature, wind velocity, relative humidity, annual rainfall etc. affect initial loss of precipitation and thereby affecting runoff.

4. **Physiographic factors-**

- Larger the watershed, longer time needed to deliver runoff to the outlet.
- Small watersheds dominated by overland flow and larger watersheds by runoff.
- Shape of watershed.
  i) Fan shaped – runoff from the nearest tributaries drained out before the floods of farthest tributaries. Peak runoff is less.
  ii) Broad shaped – all tributaries contribute runoff almost at the same time so that peak flow is more.

2.8 Hydraulics of Storm and Sewer Drainage System

2.8.1 Flow Type Assumptions

The design procedures presented here assume that the flow is consistent and uniform within each storm drain segment. This means that each segment's discharge and flow depth is assumed to be constant in time and distance. Also, since storm inlet conduits are typically prismatic, the average systems are variable and the flow conditions at each inlet are not really steady or even. Since the usual hydrological methods used in the design of storm drains are:

- **Rational Method**- only for drainage areas less than 50 hectares (0.5 km^2).
- **SCS and other Unit Hydrograph Methods**- for drainage areas greater than 50 hectares (0.5 km^2).

- **Watershed Regression Equations**- for all routine designs at sites where applicable.
- **Log Pearson III Analyses**- preferable for all routine designs provided there is at least 10 years of continuous or synthesized record for 10-years discharge estimates and 25 years for 100-year discharge estimates, and
- **Suitable Computer Programs**- such as HYDRAIN’s HYDRO, HEC 1 and TR-20 will be used to facilitate hydrologic calculations.

2.8.2 Design frequency

A design frequency shall be selected in proportion to the cost of the facility, traffic volume, potential flood hazard to property, expected level of service, strategic considerations and budget constraints, as well as the magnitude and risk associated with damage from major flood events. With long roads without a practical detour, where many sites are subject to independent flood events, the design frequency at each site may need to be increased to avoid frequent flood interruptions. When selecting a design frequency, potential upstream land use that could reasonably occur during the drainage facility's anticipated lifetime is considered.

2.8.3 Hydraulic Capacity

A storm drain's hydraulic capacity is controlled by its resistance to size, shape, slope, and friction. Several formulas for flow friction that define the relationship between flow capacity and these parameters have been developed. The most widely used formula in Manning's equation for gravity and pressure flow in storm drains.

2.8.4 Hydraulic Design Elements

General principles relating to channels, culverts, bridges, and other storm drainage elements are listed below.

- The design of artificial drainage channels or other facilities should take into account the frequency and types of maintenance expected.
- A stable channel is an important aspect for highway drainage structures to function properly.
- The range of discharges from the design channel shall be selected on the basis of geometric design standards; traffic interruption consequences flood hazard risks, economics and local site conditions.
- Coordination with the Ministry of Water Resources in the planning of highway facilities shall have high priority.

CHAPTER-3

3.1 What is SewerGEMS

SewerGEMS is the first and only comprehensive multi-platform sanitary and combined sewer modeling solution (MicroStation, ArcGIS, AutoCAD, and Stand-Alone). With SewerGEMS, you will analyze all sanitary and combined sewer system elements in one package and have the option of performing analyzes with the SWMM algorithm or our own implicit solution of the full Saint Venant equations. Simply put, SewerGEMS offers the most comprehensive solution available to optimize Best Management Practice (BMP) designs.

With Bentley SewerGEMS, the following can be done-

- Develop system master plans
- Assess the impact of inflow and infiltration.
- Optimize lift station and system storage capacities
- Determine developer connection fees
- Implement real-time control strategies
- Model relief sewers, overflow diversions, and inverted siphons
- Accurately simulate operations with variable-speed pumping and logicalcontrols.
- Simulate out-of-service or proposed sewers within the same model
- Tabular reporting (FlexTables) - Customize tabular views of all or portions of the network; view all elements in a model, all elements of a specific type, or any subset of elements. FlexTables can be filtered, sorted, and globally edited.
- Model-Level Options - Modify global options including unit settings, drawing layout and display settings, and element labeling.

3.2 Laying Out Nodes and Links

The term Nodes refers to any of the available point element types:

- Catch basins
- Manholes
- Cross Section Nodes
- Junction Chamber
- Pressure Junction
- Outlet Structures
- Outfalls
- Wet Wells
- Pumps

The term links refers to any of the available line elements:
- Pressure Pipe
- Conduits
- Channels
- Gutters

3.3 Uses of SewerGEMS

SewerGEMS users enjoy the power and versatility of working across CAD, GIS, and stand-alone platforms while accessing a single, shared, source of project data. With SewerGEMS, utilities and consultants have built-in support for four interoperable platforms, all packaged in one product: stand-alone Windows for ease of use, accessibility and performance, ArcGIS for GIS integration, thematic mapping and publishing, Micro Station for bridging geospatial planning and design environments, and AutoCAD for integrated compatibility. Utilities and consultants can use different interfaces to share a single dataset, and modeling teams can leverage engineering skills from various departments. Engineers can flatten learning curves by selecting the environment they already know and delivering results that can be viewed on multiple platforms.

3.4 Hydrology

Hydrologic theory gives us a behind-the-scenes look at what the SewerGEMS software is using to manipulate the data we have entered.

3.4.1 Rainfall

SewerGEMS design storms include:
- Rational design storms
- Cumulative rainfall curve storms

Rational Design Storm

One of two methods can be used to create storms for use with the rational method.

- The I-D-F table method uses a duration vs. intensity table to describe rainfall events of a specific frequency (return time).
- The method e, b, d coefficients uses a collection of three coefficients (e, b, d) to define the mathematical relationship between the intensity of the rainfall and the duration of the rainfall event at the frequency.

  Both methods yield the equivalent of an I-D-F rainfall curve and must therefore be developed for use in a specific geographic location.

Cumulative Rainfall Curve Storms

Hydrograph methods, such as the procedure SCS Unit Hydrograph, can't use I-D-F curves for rainfall data (as used in the method Rational). Instead, complex methods of hydrography require curves of rainfall based on time. One of two methods can be used to create design storms for use with hydrograph methods (e.g., SCS Unit Hydrograph): time-depth or synthetic.

"Time-depth To" describes the rainfall event, the time-depth curve method uses a time table versus rainfall depth values. This method is typically used when measured data are available from actual storm data. The synthetic curve method uses a time table versus rainfall depth fraction values, a duration multiplier, and a total rainfall depth to describe the rainfall event. This arrangement is very flexible because for storms of different durations and total depth, the same rainfall event shape can be used.

I-D-F Data

Intensity-duration-frequency (I-D-F) data includes:
I-D-F Curves
I-D-F Tables
I-D-F e, b, d Equation

I-D-F Curves

I-D-F (Intensity-Duration-Frequency) curves provide the engineer with a means of determining the rainfall intensity for the frequency and duration of a given storm.

Reading an I-D-F Curve the resulting average intensity is 5 inches (12.7 cm) an hour for 12 minutes, for example, a 5-year frequency. In other words, if for a period of 12 minutes an average intensity of 5 cm / hour falls, it would be considered a 5-year event.

I-D-F Tables

Bentley SewerGEMS allows you to enter I-D-F data into a table and save data so that other models can use it again. Entering the design intensities is a very simple process of searching and entering data from a graph into the I-D-F table.

I-D-F e, b, d Equation

I-D-F curves can be fit to equations. The most common form of these equations is:

$$i = b/(T+d)^e \qquad (3.1)$$

where,

i = rainfall intensity (cm/hr.)
T = rainfall duration (min.)
e,b,d = rainfall equation coefficients

This equation represents the mathematical relationship between the intensity of the rainfall and the duration of the rainfall for a storm at a given frequency and location. The coefficients of the rainfall equation vary with the frequency of storm data and the location of storm data.

Using rainfall equations properly requires that they yield results consistent with the design locale's historical rainfall data. If this consistency is not provided by the preceding equation, it is not appropriate for your design.

Rainfall Curves

Rainfall curves fall into two categories:
Gauged (Time versus Depth)
Rainfall Tables

Gauged (Time versus Depth)

A curve of rainfall is the measure of total depth of rainfall as it varies throughout a storm. Visualizing the Y-axis as a rainfall gage is a good way to understand a rainfall curve. The gauge begins to fill as the storm progresses. The curve describes the gage depth of rainfall during the storm at each point.

A steeper slope on the curve indicates that, for a less steep curve, the gauge fills faster than it would; therefore, the rainfall rate is more intense.

Gauged Rainfall Event

Curves of rainfall are a mathematical means of simulating various storms. The following figure shows conditions for two storm types. The other two show dramatic differences between these two events of rainfall, although for each storm the total depth and volume are the same.

Rainfall Tables

Tables can represent rainfall hydrographs. The table refers to the cumulative depth of rainfall from the start of a storm to the time. The following table is an example of a rainfall table time versus depth developed from data taken from a rain gage recording.

Synthetic Rainfall Distributions

In most cases, drainage engineers design facilities (not actual gauged storms) for future rainfall events. Distributions of rainfall provide a way to model events of different magnitudes that are statistically predicted. Sometimes these distributions are referred to as synthetic storms, as they are not actual gaged events.
Rainfall distributions fall into two categories:

- Dimensionless Depth—The Y-axis for these distributions range from 0.0 to 1.0 (0% to 100%) of total rainfall depth. The total storm duration is defined on the X-axis, in units of time.
- Dimensionless Depth and Time—these are similar to dimensionless depth curves, except that the X-axis is also dimensionless.

3.4.2 Time of Concentration

Concentration time (T_c) is found by summing the time within the drainage area for each individual flow segment. The T_c calculator models both single and multiple flow segments.

$$T_c = \sum_{n}^{i=1} T_i \tag{3.2}$$

where,
T_c= Total time of concentration
T_i = Flow travel time through segment i
$T_i = (L_i / V_i)$
L_i = Length of flow segment i
V_i= Average velocity through segment i

The T_c equations provided in Bentley SewerGEMS can be categorized into two broad categories:

Equations that solve for velocity then use velocity to solve for travel time through a flow segment. Equations that solve directly through a flow segment for travel time — in these cases, the software retrieves speed and includes it in the output report.

Minimum Time of Concentration

Some hydrological methods for computing runoff hydrographs require concentration time to exceed a certain minimum value. For instance, the TR-55 methodology dictates that the minimum T_c to be used is 0.1 hr. When the calculated T_c is smaller than the minimum, the minimum T_c is used instead of the calculated T_c.

User-defined

The user-defined concentration time (T_c) is a method that enables the T_c to be directly input rather than calculated using an equation. This method would be used when the T_c needs to be calculated using a methodology not supported by Bentley SewerGEMS, or when the analysis requires a quick estimate of T_c.

Carter (1961)

$$T_c = 0.0015476L^{0.6}S^{-0.3} \tag{3.3}$$

where,

T_c = Time of concentration (minutes)

L = Flow length (m)

S = Slope of the catchment

- Developed for urban watersheds and area less than 20.72 km^2
- Channel length less than 11.27 km
- Significant flow in the basin

FAA (1970)

$$T_c= 0.0165626(1.1-C)L^{0.5}(100S)^{-0.333} \tag{3.4}$$

where,

T_c = Time of concentration (minutes)

L = Flow length (m)

S = Slope of the catchment

- Developed from airfield drainage data.
- Valid for small watersheds where sheet flow and overland flow dominate.

Kirpich (Tennessee) (1940)

$$T_c = 0.01947\, L^{0.77}S^{-0.385} \tag{3.5}$$

where,

T_c = Time of concentration (minutes)
L = Flow length (m)
S = Slope of the catchment

- Area from 0.00405–0.4532 km^2 (1–112 acres)
- Slope from 3 to 10%

3.4.3 Rational Method

The Rational method solves for peak discharge based on watershed area, rational coefficient, and rainfall intensity for the watershed. The following equation is used to compute flow using the rational method:

$$Q = CiA \tag{3.6}$$

Q = Flow (m^3/hr) for drainage area A
C = Weighted runoff coefficient for drainage area A
i = Intensity (cm/hr) for the given design frequency and storm duration (this value is taken from the I-D-F curves for your design area).
A = Drainage area (acres)
For different storm frequencies, some locations have C adjustment factors.

The rational coefficient$C$ is the parameter most open to judgment in engineering. In many cases, for the entire drainage area, an area weighted average C coefficients are used as the C. For drainage areas, Bentley SewerGEMS calculates the weighted C.

Basic Assumptions about Rational Method

There are several assumptions that form the basis for rational method hydrology:

- Drainage areas are smaller than 300 acres (120 hectares).
- Peak flow occurs when the entire catchment is contributing.
- Rainfall intensity is uniform over duration of time equal to or greater than the time of concentration.
- Rational coefficients are irrespective of rainfall intensity.

The Rational Method was tested on up to 150 hectares of urban catchments in area with concentration times of up to about 30 minutes and pipe diameters of up to about 1 metre. The tested catchments had reasonably uniform slopes and impermeable distributions of the area. These tests showed that the method for calculating peak runoff is as accurate as other more sophisticated urban runoff methods. (Environment Department, Standing Technical Committee, National Water Council, 1981). The method's accuracy for conditions beyond those described above is unknown and therefore the method in those cases can't be recommended positively.

Weighting C Values

If the drainage area consists of more than one sub-area, it is necessary to calculate a weighted C value for the area. For a drainage area, the weighted C is calculated by dividing the sum of all sub-area CAs by the total area, where CA is sub-area C multiplied by sub-area area.

3.4.4 SCS CN Runoff Equation

Using the SCS Unit Hydrograph method, the SCS Runoff equation is used to turn rainfall into runoff. It is an empirical method that expresses how much a certain volume of rainfall generates runoff volume.

The equation's variable input parameters are the amount of rainfall for a given duration and the number of the runoff curve (CN) of the basin. The runoff quantity is typically referred to as a volume of runoff for convenience although it is expressed in depth units (in, mm). This runoff depth is actually a standardized volume as it is generally distributed over a sub-basin or catchment area.

The SCS runoff equation is applied against an incremental rain burst to generate a runoff quantity in hydrograph analysis. This runoff quantity is then distributed according to the procedure of the unit hydrograph, which ultimately develops the hydrograph of the full runoff.

The general form of the equation (U.S. customary units) is:

$$Q = (P\text{-}Ia)^2/(P\text{-}Ia)+S \tag{3.7}$$

Where,

Q = Runoff depth (cm)

P = Rainfall (cm)

S= Maximum retention after runoff begins (cm)

I_a= Initial abstraction

The initial abstraction includes vegetation-captured water, storage of depression, evaporation, and infiltration. For any P, before any runoff is possible, this abstraction must be satisfied. The equation gives the universal default for the initial abstraction:

$$I_a = 0.2S \tag{3.8}$$

The ratio, 0.2, is rarely, if ever, modified.

The potential maximum retention after runoff begins, S, is related to the soil and land use/vegetative cover characteristics of the watershed by the equation:

$$S = (1000/CN) - 10 \tag{3.9}$$

Where the runoff curve number is developed by coincidental tabulation of soil/land use extents in the weighted runoff curve number parameter, CN.

The Runoff Curve Number

In SewerGEMS, for each watershed, the sub-basin runoff is defined exclusively by the CN input. SewerGEMS features built-in spreadsheet shapes that help you automatically calculate weighted CN values as a function of the hydrological class of the soil and cover features.

The USDA has classified its soil types into four hydrologic soil groups. The CN values for various land uses and cover characteristics for each soil classification are described below. To describe a sub-basin using CN, you must overlay a land cover layer over a hydrologic soil mapping overlay and a delineated drainage basin mapping overlay. You then determine the component CN areas that comprise each sub-basin, and enter these into SewerGEMS, which develops the actual weighted CN for use in hydrograph generation.

Group A

Group A soils, even when thoroughly wetted, have low runoff potential and high infiltration rates. They consist mainly of deep, well-drained sands or gravel and have a high water transmission rate (greater than 0.12 cm/hr).

Group B

Group B soils have moderate infiltration rates when thoroughly wetted and consist mainly of moderately deep to deep, moderately well-drained to well-drained soils with moderately fine to moderate texture. These soils have a moderate transmission rate of water (0.06 to 0.12cm/hr).

Group C

When thoroughly wetted, Group C soils have low infiltration rates and consist mainly of soils with a layer that impedes downward movement of water and soils with moderately coarse textures. These soils have a moderate transmission rate of water (0.02-0.06 cm/hr).

Group D

Group D soils have a high potential for runoff. When thoroughly wetted, they have very low infiltration rates, consisting mainly of clay soils with a high swelling potential, soils with a permanently high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over almost impervious material. These soils have a very low transfer rate of water (0.00 to 0.02 cm/hr).

TR-55 provides a comprehensive table of land uses, soil types and associated CN values.

3.4.5 Hydrograph Methods

In virtually every case, with the exception of a sanitary sewer system with no wet weather inflows, it is necessary to enter the wet weather flow directly or perform some type of hydrological calculation to convert precipitation (or snow melt) into a flow rate. Methods can be described based on how time is handled, whether nodes, links or catchments are applied, and whether they are based on SWMM or hydrology methods.

The first modeling decision is whether to conduct the analysis over time and require a hydrograph or whether it will be a peak flow analysis using the rational method or a fixed flow.

In the GVF-rational solver, calculations for a single flow rate are made using the rational method. Steady flows can be specified as a known flow link, as an inflow to any node or as an infiltration into a conduit in the GVF-convex solver.

The user can directly input a hydrograph along any duct in any node or in the case of the GVF-convex solver. These values are, and complement, independent of precipitation. A variety of hydrological methods are available to convert precipitation hyetographs into surface flow for a catchment. Hydrographic calculation methods can be divided into two categories

- SWMM Hydrology
- Bentley Hydrology

The catchment runoff method is set to EPA-SWMM Runoff when using SWMM hydrology and a loss method must be provided. When using the SWMM-RTK method, no method of loss is required and the runoff appears in a manhole node rather than in a catchment.

When using Bentley hydrology, the user must first select a hydrograph method that may include Unit Hydrograph, Modified Ration Method, or User Defined Hydrograph. If the Unit Hydrograph method is selected, the user must select one of the types of Unit Hydrographs: SCS, RTKor Generic Unit Hydrographs. A loss method is required for the SCS and Generic unit hydrograph methods. For most hydrograph methods, storm data is required as a hyetograph (precipitation vs. time).The exception is the modified rational method [Storm Data and Runoff Methods] driven from IDF storm data.

It is also very important to be aware of whether the flow calculated in a storm water or combined sewer model is to be used as a runoff or whether the wet weather inflow / infiltration into a sanitary sewer model is required. Generally speaking, the methods of EPA-SWMM and SCS are better for surface runoff while the method of RTK tends to be preferred for sanitary sewer although a calibrated generic hydrograph unit is also acceptable.

Unit Hydrograph

The theory of the unit hydrograph assumes that a linear system is the watershed. This means that, regardless of the magnitude of the inflow, the outflow is proportional to the inflow. However, this is not usually the case. As the flow increases in stream channels and overland flow surfaces, the velocity also increases, resulting in a reduction in travel time to the outlet. However, the velocity increases for most natural streams as the depth only increases until the overbank flow begins. The velocity at this point tends to remain constant, which meets the linearity requirement. Unit hydrographs should therefore be derived for a specific watershed only from the larger floods.

The Unit Hydrograph theory also assumes that over the watershed the input rainfall excess is uniform and the response to this input is invariable. Typically, rainfall spatial variation and the difference in watershed characteristics may cause the rate of runoff to vary widely at any time from place to place. However, many watersheds experience similar rainfall patterns from event to event, so the unit hydrograph can effectively characterize the response to that rainfall excess.

The theory of the unit hydrograph depends on the superposition principle. This principle states that the unit hydrograph applied to the incremental rainfall excess during each period can build up a flood hydrograph for a particular storm data. In other words, a series of inputs can be applied to the unit hydrograph, and the resulting hydrographs can be added to form the total hydrograph.

Generic Unit Hydrographs

Users can use a triangular or curvilinear hydrograph as provided by the SCS or RTK methods to calculate a runoff hydrograph from rainfall data. However, if a hydrograph does not follow these shapes closely, if the user has sufficient rainfall and runoff data for the catchment, the generic unit hydrograph method may be used to develop a more accurate unit hydrograph.

Setting the Runoff Method to Unit Hydrograph and the Unit Hydrograph Method to Generic Unit Hydrograph is selected for a catchment. The hydrograph values entered by the user are a collection of excess precipitation (rainfall minus loss) per unit runoff over time. These values should be based on the collection of data from the field. For each catchment, these values are unique and are not scaled by the area.

The time step size on which the resulting hydrograph is based is called the "time step of conversion." It must be higher than zero and less than or equal to the increase in rainfall. If the time step is smaller, the hydrograph will be smoother, but there is no benefit in making it smaller than the increase in output set in the options for calculation.

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