A DISSERTATION PHASE - I

ON

"URBAN DRAINAGE SYSTEM PERFORMANCE ANALYSIS IN FLOOD-PRONE AREAS OF THE BHARALU BASIN USING SWMM 5.1"

Submitted in Partial Fulfillment for the Requirements for the award of Degree of

MASTERS OF TECHNOLOGY (CIVIL ENGINEERING)

UNDER

ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY

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CANDIDATE DECLARATION

I hereby certify that the work presented in the project entitled **"URBAN DRAINAGE SYSTEM PERFORMANCE ANALYSIS IN FLOOD-PRONE AREAS OF THE BHARALU BASIN USING SWMM 5.1"** is the authentic record of our own work carried out under the guidance of **Dr. BHARATI MEDHI DAS**, Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari. The project is submitted in partial fulfillment of requirements for the award of the degree of "Master of Technology in Civil Engineering" under specialization on Water Resources Engineering to the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-781013, Assam.

The matter embodied in this dissertation has not been submitted to any other institute for the award of any other degree. We have followed the guidelines provided by the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-781013, Assam. Whenever materials from other sources are used, due acknowledgement is given to them by citing them in the text of this project and giving their details in the references.

This is to certify that the above statement made is correct to the best of my knowledge.

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This is to certify that the dissertation report **entitled "URBAN DRAINAGE SYSTEM PERFORMANCE ANALYSIS IN FLOOD-PRONE AREAS OF THE BHARALU BASIN USING SWMM 5.1"** is submitted by **Annajyoti Saikia, Roll No 230620061004,** a student of 3rd semester in the Department of Civil Engineering, Assam Engineering College, Guwahati in partial fulfilment for the award of degree of **MASTERS OF TECHNOLOGY** in Civil Engineering with specialization in **Water Resources Engineering** under **ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY** has been carried out under my guidance.

The content of this report has not been submitted to any other university for the award of any degree.

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It is to certify that the project report entitled **"URBAN DRAINAGE SYSTEM PERFORMANCE ANALYSIS IN FLOOD-PRONE AREAS OF THE BHARALU BASIN USING SWMM 5.1"** is hereby accorded our approval as a study carried out and presented in a manner in their 3rd semester courses for acceptance in partial fulfilment for the award of Master of Technology in Civil Engineering under specialization on Water Resources Engineering degree for approval does not necessarily endorse or accept every statement made, opinion expressed or conclusion drawn as recorded in the report. It only signifies the acceptance of the project report for the purpose for which it is submitted.

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ABSTRACT

Guwahati, a rapidly developing city in Northeast India, faces recurring urban flooding during the monsoon season due to intense rainfall, insufficient drainage capacity, and challenges from rapid urbanization and inadequate planning. This study centres on the Bharalu Basin, a flood-prone region within the city, aiming to identify key factors contributing to urban flooding and propose strategies to mitigate its impacts. The Storm Water Management Model (SWMM) 5.1 was utilized to evaluate the hydraulic performance of the drainage system under varying rainfall conditions and assess its efficiency in managing stormwater.

The research involved collecting and analysing rainfall data to develop Intensity-Duration-Frequency (IDF) curves using Gumbel's distribution for frequency analysis. These IDF values were converted into a 15-minute interval time series using the Alternate Block Method, providing precise inputs for hydrological simulations. Sub-catchments and drainage networks were delineated with Digital Elevation Models (DEMs) and ArcGIS tools, and land use/land cover (LULC) maps were prepared based on Landsat 8 satellite imagery.

Simulations conducted for a two-year return period and a one-hour design storm intensity revealed that the existing drainage system operates at near-full capacity (80%–100%) during peak flows, often resulting in localized flooding and waterlogging. Flood-prone areas were identified using data from the Assam State Disaster Management Authority (ASDMA). Simulations for higher rainfall return periods further highlighted the inadequacy of the drainage infrastructure in handling stormwater.

The study emphasizes the urgent need for upgrading drainage systems and adopting innovative stormwater management practices. By integrating SWMM-based hydrological modeling with GIS-based spatial analysis, this research offers a structured approach to understanding and addressing urban flooding. The findings highlight the necessity of climate-resilient urban drainage designs and sustainable planning practices to enhance Guwahati's resilience against monsoon-induced flooding.

Keywords: Urban Flash Flood, ArcGIS, SWMM, Simulation, Bharalu Basin, IDF (Intensity-Duration-Frequency), LULC (Land use/Land cover), Alternate Block Method.

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CHAPTER 1

INTRODUCTION

1.1 General Background

Urban flooding is a growing concern in rapidly developing cities like Guwahati, Assam. Factors such as unplanned urban expansion, inadequate drainage infrastructure, and intensified rainfall due to climate change have significantly increased the frequency and severity of flooding. The Bharalu Basin, one of Guwahati's most flood-prone regions, frequently experiences flooding due to its dense population, insufficient drainage systems, and rapid urbanization. High-intensity rainfall during the monsoon season, coupled with an increase in impermeable surfaces, has led to reduced infiltration and elevated surface runoff, resulting in waterlogging and flash floods (**Sarma et al., 2021; Gupta et al., 2017**).

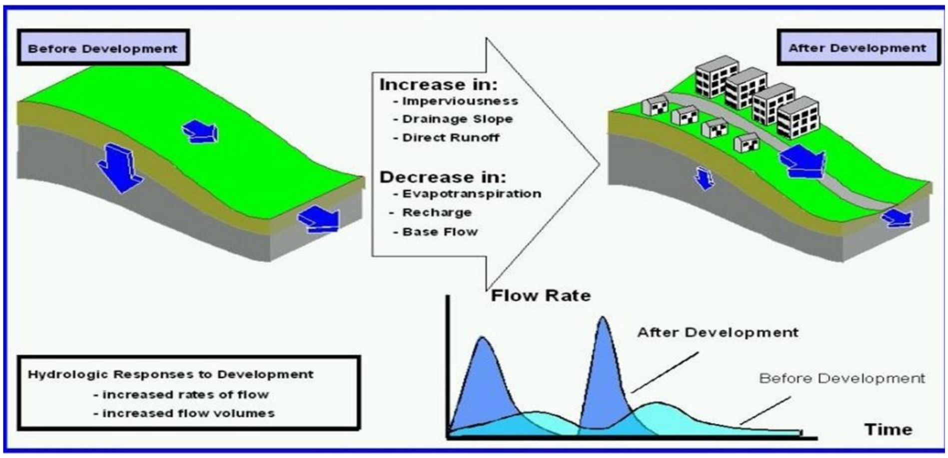

Fig: - 1.1 SWMM PROTOTYPE

This study aims to address urban flooding in Guwahati using the Storm Water Management Model (SWMM) version 5.1, integrated with Geographic Information Systems (GIS). Developed by the United States Environmental Protection Agency, SWMM is a widely used hydrological tool that models rainfall-runoff interactions and drainage network hydraulics. The integration of GIS allows for spatial analysis by incorporating topographical, land use, and rainfall data, enhancing the accuracy of flood simulations (**Rossman, 2015; Nasrin et al., 2020**). Rainfall data were analyzed to develop Intensity-Duration-Frequency (IDF) curves using Gumbel’s distribution, which were then converted into 15-minute interval time series using the Alternate Block Method. Sub-catchments and drainage networks were delineated using Digital Elevation Models (DEMs) and land use/land cover (LULC) maps derived from Landsat 8 satellite imagery (**Borah et al., 2019; Sahoo, 2017**).

Simulations for a two-year return period with one-hour design storm intensity showed that the existing drainage systems in Guwahati operate at 80%–100% capacity during peak flows, leading to localized flooding and waterlogging. Higher rainfall returns periods revealed the inadequacy of current infrastructure to manage stormwater, emphasizing the need for capacity upgrades. Flood-prone areas were identified using data from the Assam State Disaster Management Authority (**ASDMA**, **Sarma et al., 2021**).

This research highlights the effectiveness of SWMM in urban flood forecasting and mitigation. The integration of GIS with SWMM provides a comprehensive approach to assessing drainage performance and planning sustainable stormwater management systems. The findings emphasize the urgent need for upgrading drainage infrastructure in Guwahati and adopting climate-resilient urban planning strategies to mitigate the impacts of monsoon-induced flooding (**Nasrin et al., 2020; Sarma et al., 2021; Gupta et al., 2017**).

Watershed delineation is a fundamental step in simulating urban drainage systems, as it defines the boundaries of areas that contribute runoff to specific drainage points. This process is critical for understanding and managing the flow of water across a given area, particularly in urban environments where flooding is a persistent challenge. Watershed delineation involves the analysis of topographical features, such as slopes and elevation differences, to identify sub-catchments, flow paths, and drainage points. Tools like Digital Elevation Models (DEMs) and Geographic Information System (GIS) software are widely used for this purpose, providing detailed spatial data to delineate watershed boundaries accurately (**Jenson and Domingue et al., 1988**). Accurate watershed delineation is essential for understanding the behavior of surface runoff, estimating flow rates, and determining the capacity of drainage systems to handle stormwater. By identifying areas contributing to runoff, it provides crucial input data for hydrological and hydraulic modeling. This data includes information on land slopes, surface characteristics, and the structure of drainage networks, which are indispensable for simulating and designing effective urban drainage systems (**Tarboton et al., 1997**).

In urban settings, where impervious surfaces such as roads, rooftops, and pavements dominate, watershed delineation becomes even more critical. These impervious surfaces significantly alter natural runoff patterns by reducing infiltration and increasing the speed and volume of surface water flow. Through precise delineation, flow accumulation areas can be identified, which are key to pinpointing flood-prone zones and potential bottlenecks in the drainage infrastructure. This information is vital for planning, designing, and evaluating urban drainage systems to manage stormwater effectively and mitigate flooding risks (**Rodriguez et al., 2003**). Watershed delineation forms the foundation of urban flood management efforts, as it integrates hydrological data with spatial analysis to create a comprehensive understanding of drainage behavior. By employing advanced GIS tools and hydrological models, urban planners and engineers can develop sustainable and resilient drainage systems tailored to the unique challenges of urban environments. This ensures that flooding risks are minimized, and the capacity of drainage networks is optimized to withstand varying rainfall intensities and patterns.

The Assam State Disaster Management Authority (**ASDMA**), in its report *Urban Floods in Guwahati*, comprehensively identified the flood-prone areas of Guwahati city and categorized them based on the likelihood of inundation. This analysis provides a detailed understanding of the city's vulnerability to urban flooding while aiming to guide targeted mitigation strategies. The city was divided into various zones representing different levels of flood risk—ranging from high to moderate to low. These zones were further subdivided into specific ward numbers to create a granular perspective on the spatial distribution of flood susceptibility (**Sarma et al., 2021**).

The report emphasizes key factors contributing to flooding, such as inadequate drainage systems, unregulated urban expansion, and Guwahati's natural topography, which includes low-lying areas highly susceptible to waterlogging. High-risk zones were particularly identified near water bodies like the Bharalu, Basistha, and Mora Bharalu rivers, as well as areas with insufficient drainage networks (**Borah et al., 2019**). The ward-level subdivision ensures that localized challenges are addressed effectively, facilitating the implementation of area-specific flood mitigation measures. By categorizing these flood-prone areas, **ASDMA** provides a foundational framework for urban planners, policymakers, and disaster management agencies to prioritize interventions, allocate resources efficiently, and enhance the city's resilience against urban flooding (**Sahoo et al., 2017**). Additionally, this zoning strategy supports the integration of advanced tools such as GIS and hydrological models for the design of sustainable urban drainage systems and flood risk reduction measures (**Nasrin et al., 2020**).

The EPA Storm Water Management Model (**SWMM**) is a sophisticated simulation tool developed to analyze the rainfall-runoff processes in urban areas, with a focus on both the quantity and quality of stormwater. It divides a given area into subcatchments, which are the units that receive rainfall and generate both runoff and pollutants. The model then simulates the routing of this runoff through a network of pipes, channels, storage facilities, and treatment systems, tracking essential parameters such as flow rate, water depth, and pollutant concentrations at each stage of the process (**Rossman, 2015**).

Since its initial release in 1971, **SWMM** has undergone several updates to improve its accuracy, flexibility, and capability to model complex urban drainage systems. It has become an essential tool for planning, designing, and analyzing stormwater management systems, sewer networks, and drainage infrastructures across both urban and rural areas worldwide (**Gironás et al., 2009**). The continuous improvements to **SWMM**, especially in its latest version, SWMM 5, have ensured its relevance in addressing the challenges posed by urban flooding, water quality management, and sustainable stormwater practices (**Nasrin et al., 2020**). SWMM 5 integrates advanced features such as enhanced water quality modeling, hydrological simulation of urban catchments, and integration with Geographic Information Systems (GIS), making it indispensable for modern stormwater management and flood risk mitigation (**Gironás et al., 2009**).

1.2 Significance of problem

Floods pose significant risks to settlements and human life, particularly in urban areas where the impacts can be severe and result in substantial economic losses. **Pune**, one of India’s largest cities, faces challenges related to urban flooding despite advancements in drainage and sewage systems. However, stormwater runoff, particularly during intense rain events, often follows open drainage systems. This leads to a variety of environmental and socio-economic issues, including flooding, the spread of waterborne diseases, disruption of daily life, and alterations to the urban landscape. These problems are exacerbated by reduced permeable land in urban areas due to the prevalence of impervious surfaces such as roads, driveways, sidewalks, parking lots, and rooftops, which significantly increase surface runoff.

Heavy rainfall frequently inundates low-lying areas of the city, primarily due to the limitations of open drainage systems and insufficient maintenance. Flooding not only causes direct damage to properties and infrastructure but also has secondary effects, such as displacement of affected populations and disruption to surrounding regions. Indirect damages, such as the costs associated with evacuation and the impacts on nearby communities assisting displaced individuals, can be substantial. Urban flooding is often caused by extreme rainfall over a short period, and preventing damage to all properties is neither technically feasible nor economically viable.

Effective flood hazard mitigation requires detailed understanding of the frequency, characteristics, and magnitude of potential flood events, along with an assessment of the vulnerability of people, buildings, infrastructure, and economic activities in the affected areas. Sustainable urban planning and flood management strategies must focus on calculating peak discharges, runoff volumes, and the capacity of drainage systems. The adoption of **Low Impact Development (LID)** techniques—such as bioretention cells, infiltration trenches, porous pavements, and vegetative swales—plays a critical role in reducing urban flood risks and promoting long-term resilience.

1.3 Types of Urban Flooding

1.3.1 Surface Water Flooding (Pluvial Flooding)

This type of flooding occurs when intense rainfall exceeds the capacity of urban drainage systems, causing water to accumulate on impermeable surfaces like roads, pavements, and rooftops. Urban areas are particularly vulnerable due to their high concentration of concrete and asphalt, which prevent water from seeping into the ground. Low-lying areas and regions with poor stormwater infrastructure are most affected. Studies by **Smith et al. (2020)** emphasize that inadequate urban planning exacerbates this flooding, as natural water infiltration zones are replaced by built-up environments.

1.3.2 River Flooding (Fluvial Flooding)

River flooding, also known as fluvial flooding, occurs when rivers exceed their banks due to prolonged or intense rainfall, snowmelt, or upstream flow surges. This type of flooding is common in cities located near rivers or within floodplains. **Johnson et al. (2019)** highlights that urban expansion into flood-prone areas has increased the vulnerability of communities to riverine floods. Additionally, riverbank encroachments and modifications, such as the construction of levees and dams, often reduce a river's natural ability to manage overflow.

1.3.3 Flash Flooding

Flash flooding is characterized by a rapid and intense surge of water, often caused by heavy rainfall over a short period or the sudden release of water from sources like dams or reservoirs. These floods occur with little warning and are especially destructive in hilly or mountainous urban regions where water flows quickly toward lower areas. Research by **Brown et al. (2021)** points out that poorly designed urban drainage systems and deforestation in catchment areas significantly contribute to the severity of flash floods in cities.

1.3.4 Drainage System Overload

Urban flooding often results from the failure of drainage systems to cope with excessive water volumes during storms or blockages caused by sediment, waste, or vegetation. When drainage channels are undersized, poorly maintained, or clogged, water backs up onto streets and enters residential and commercial buildings. **Chowdhury et al. (2020)** stress that rapid urbanization without corresponding improvements in drainage infrastructure is a major contributor to this type of flooding in cities worldwide.

1.3.5 Flooding from Wetland and Channel Encroachment

The encroachment of natural wetlands, floodplains, and drainage channels due to urban development reduces their capacity to manage stormwater. Wetlands act as natural buffers, absorbing excess water during heavy rainfall and gradually releasing it. When these areas are converted into construction zones, their hydrological functions are lost. According to **Goswami et al. (2022)**, cities that neglect wetland conservation face more severe flooding as the remaining infrastructure cannot handle the redirected water flow effectively.

1.4 Objectives

Watershed Analysis and 3D Terrain Modelling:

- Utilize Digital Elevation Model (DEM) data in ArcMap 10.4 to identify the boundaries of the watershed and analyze the slope and elevation of the study area. This information will help understand how water flows through the terrain.
- Create a 3D representation of the area using ArcScene 10.4 to visualize the topography and identify areas prone to water accumulation or runoff issues.

Rainfall Data Collection and Storm Analysis:

- Gather rainfall data to create Intensity-Duration-Frequency (IDF) curves for different return periods—specifically 5 years, 10 years, and 25 years. These curves will represent the relationship between the intensity and duration of rainfall events and their likelihood of occurrence.
- Develop a time series of rainfall data at 15-minute intervals using the alternating block method. This design storm will serve as an input for hydrological and hydraulic simulations.

Simulation of Urban Drainage System Performance:

- Employ the Storm Water Management Model (SWMM 5.1) to simulate how the existing urban drainage infrastructure performs during heavy rainfall events.
- Analyse the results to assess the system's capacity to manage runoff, identify bottlenecks, and determine areas at risk of flooding.

Design and Optimization of Drainage Channels:

- Conduct network simulations to determine the most effective sizes and configurations for drainage channels to ensure efficient removal of excess water during storms.
- Recommend improvements or modifications to the drainage system to reduce flooding risks and enhance urban resilience to extreme weather events.

1.5 STUDY AREA

Guwahati, the largest city in Assam and north-eastern India, is situated at **26.1445° N latitude and 91.7362° E longitude** and spans an area of approximately **216.79 square kilometres**. With a population of about **1.12 million**, the city has experienced rapid urbanization and is often referred to as the 'Gateway to North East India'. It also functions as the administrative headquarters of Assam, with Dispur, the state capital, located within its limits.

The topography of Guwahati consists of rolling plains with elevations ranging between **49.5 and 55.5 meters above sea level**. The city is surrounded by eighteen hills, such as **Narakasur, Chunsali, and Nilachal hills**, which add to its geographic diversity. These hills influence surface water flow and drainage patterns, significantly shaping the city's hydrology. However, they also heighten the risk of flooding during heavy rainfall. Guwahati lies along the southern bank of the Brahmaputra River, a major waterway that heavily influences the region's hydrology and geography. The **Bharalu River**, a tributary of the Brahmaputra, flows through the city and serves as a vital drainage channel. Nevertheless, its limited capacity and frequent blockages during heavy rains exacerbate flooding issues.

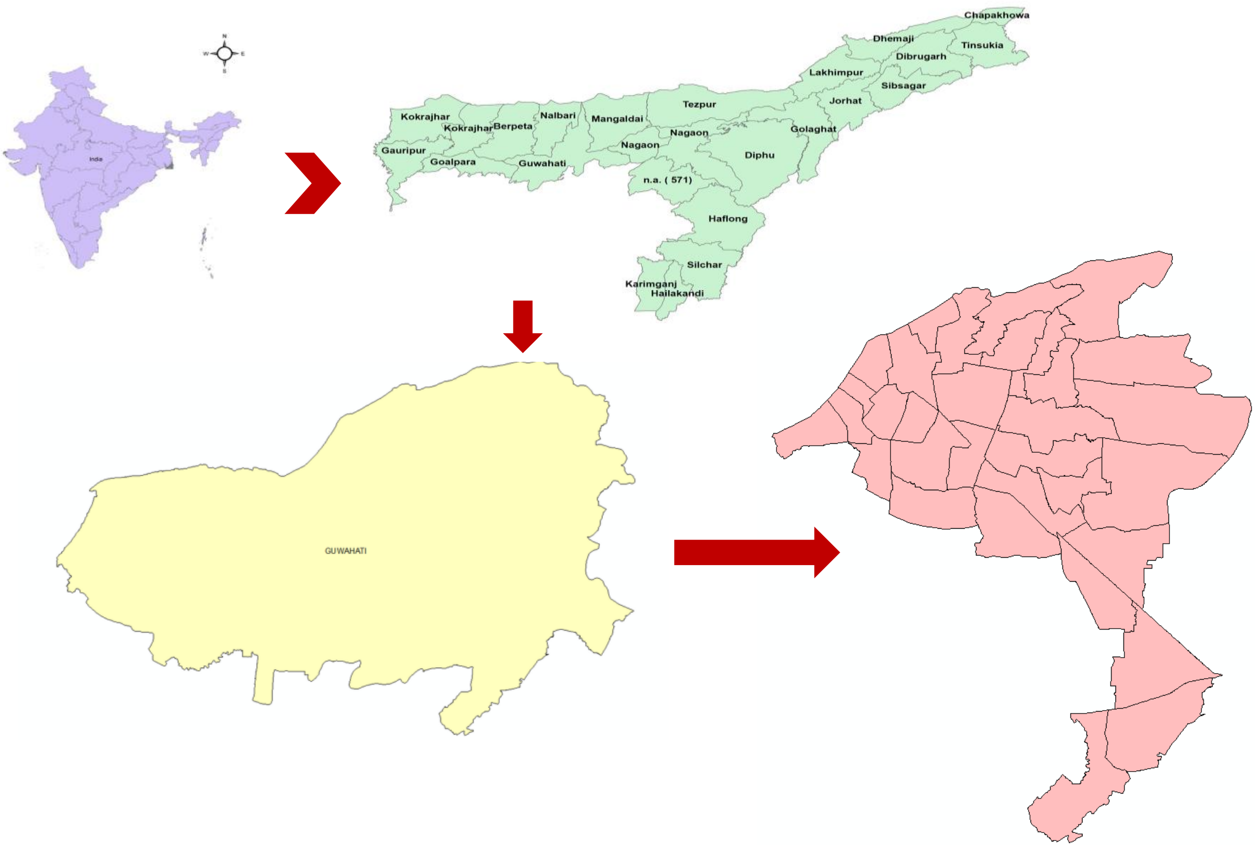

Fig: - 1.2 STUDY AREA

The city is home to several wetlands that are crucial for its ecological balance and flood management. Among these, **Deepor Beel**, located to the southwest, is particularly notable. Designated as a Ramsar Site, this permanent freshwater lake acts as a natural stormwater reservoir, absorbing excess runoff during the monsoon season and helping to reduce flood risks. However, encroachment and urban development threaten the wetland's ecological health and functionality.

Guwahati often faces flash flooding, especially during the monsoon months. Intense rainfall in the Meghalaya hills, part of the city's upstream catchment area, generates significant surface runoff that flows into Guwahati. The city's bowl-like terrain exacerbates waterlogging in low-lying areas. Furthermore, landslides and soil erosion in the surrounding hills deposit large amounts of sediment in rivers and drainage systems, reducing their capacity to manage stormwater. Urban growth has worsened the situation, as encroachment of wetlands and natural drainage systems limits the city's ability to handle excessive runoff. The **Bharalu River**, a key drainage system, often becomes clogged with sediment and solid waste, further reducing its effectiveness during heavy rains.

The declining health of Guwahati's water systems, including its wetlands, poses additional environmental challenges. Wetlands like Deepor Beel are losing their ability to prevent floods and support the region's biodiversity. Additionally, sediment-laden floodwaters deteriorate the water quality of the Brahmaputra and its tributaries, intensifying the city's hydrological challenges. These interrelated issues highlight the urgent need for effective management of both natural and engineered drainage systems to address urban flooding.

1.6 CLIMATE AND ENVIRONMENTAL CONDITIONS

The rainfall data for Guwahati City from **1993 to 2023** reveals notable inter-annual and seasonal variability. The monsoon months (**June to September**) consistently register the highest rainfall, while the winter months (**November to February**) experience minimal precipitation. Annual rainfall fluctuates significantly, with the highest recorded in **2007 (3302.4 mm)** and the lowest in **2006 (1098.7 mm)**. The **average annual rainfall** of approximately **1920.4 mm** underscores the region's predominantly wet climate, characterized by distinct monsoon dominance. This information is vital for effective urban planning, sustainable water resource management, and the formulation of flood and drought mitigation strategies. It also underscores the importance of addressing climate variability and its impacts on regional hydrology and infrastructure resilience.

Table: - 1.1 RAINFALL DATA

Years	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1993	75.1	8.5	91	146.6	272.4	420.7	357.9	583.7	379.8	71	31.1	0
1994	19.1	19.1	79.2	89.5	218.5	372.6	352.4	410.3	181.9	59.5	31.4	0
1995	5.4	23.6	30.7	98.9	269.6	584.4	506.9	366.9	332.4	48.5	38.9	10.6
1996	11.5	26.8	41.9	47	260.6	349.2	246.9	372	219.8	182.7	0	0.2
1997	20.5	30.7	59.7	233.3	228.1	390.3	443.7	314.5	256.9	69	16.6	37.9
1998	1.3	9.3	129.7	94.6	211.6	230.3	410.6	422.2	291.1	235.3	25.6	1.5
1999	0.5	0	21.9	54.2	456.4	410.6	693.7	227.3	229.2	570.2	7.5	1.3
2000	7	21.1	37.6	242.5	452.4	513.7	208.2	362.2	198.2	67.9	12	1.1
2001	0.3	52.3	36.7	241.7	298.9	315.8	329.2	309.1	239.1	164.3	25	0
2002	4.2	5	81.3	193.3	273.2	463.6	415.2	256.2	172	145.3	68.6	5.7
2003	8.6	39.7	104.6	152.8	140.7	321.4	387.6	338.7	268.8	238.3	6.8	3.4
2004	10.9	20.3	21.3	452.9	139.3	369.6	443.2	190.3	150.6	369.8	1.4	0.9
2005	16.3	0.9	122.4	109	248.4	265	301.6	427.5	226.2	232.3	0.4	1.1
2006	0	13.1	1.6	176.4	177.8	288.6	152.5	113.5	79.4	69.2	21.6	5
2007	0	114.5	41.9	147	210.7	490.3	882.8	638.6	525.8	176.4	74.2	0.2
2008	5.1	3.2	82.3	134.1	48.1	398.4	449.4	386.4	295.9	171.3	5.4	3.1
2009	0	0.4	21.7	79.5	264.4	176.4	312.6	825.4	421.7	101.9	1.7	0.8
2010	0	0.3	67.3	312.7	290.3	485	288.9	231.5	259.8	146.5	12	3.8
2011	9	11.7	84.5	112	222.9	135.2	296.2	232.4	191	11.4	6.9	0.3
2012	6.6	5.9	10.6	287.7	132.5	554.1	371.3	246.8	0	0	0	0
2013	0	14.2	37.7	114.7	345.7	332.1	220.8	247.7	193.7	160.3	0	0.8
2014	0.6	20.6	21.8	43.6	225.2	362	152.8	312.3	362.9	73.4	1.6	2.4
2015	11.5	16.5	33.2	180.5	342	268.4	177.8	437.6	265.2	62.5	24.8	13.3
2016	7	1.7	26.5	181.4	196	144.7	205.5	83.7	107.3	33.2	5.4	0.8
2017	0.6	3.9	98.8	144	76.2	186	143.2	176.8	106.4	144.6	2.8	1.5
2018	0.3	5.6	18.2	77.8	132.7	109.7	135.1	257.5	192.8	8.8	3.6	6.8
2019	0.4	13	22.2	191.2	314.6	253.4	356	196.2	306.1	175.2	23.3	1.5
2020	22.5	21.2	26.1	206.8	388.8	466.4	414.7	178.4	455.4	213	11.1	3.6
2021	0.7	2.3	39.9	79.3	208.6	426.3	275.1	344.3	152.7	91.1	0	3.1
2022	30.9	29.5	69.8	258.7	523.2	560.3	377.6	357.4	329.4	214.2	0.7	4
2023	0	2.1	115.4	84	140.6	382.5	405	192.8	126	163.9	0.9	17.9

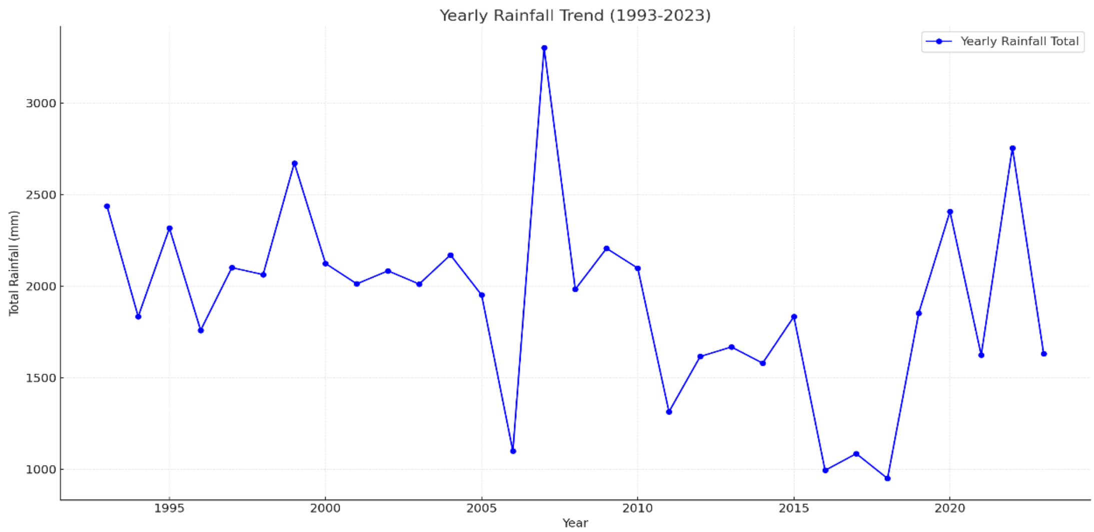

Fig: - 1.3 ANNUAL RAINFALL GRAPH

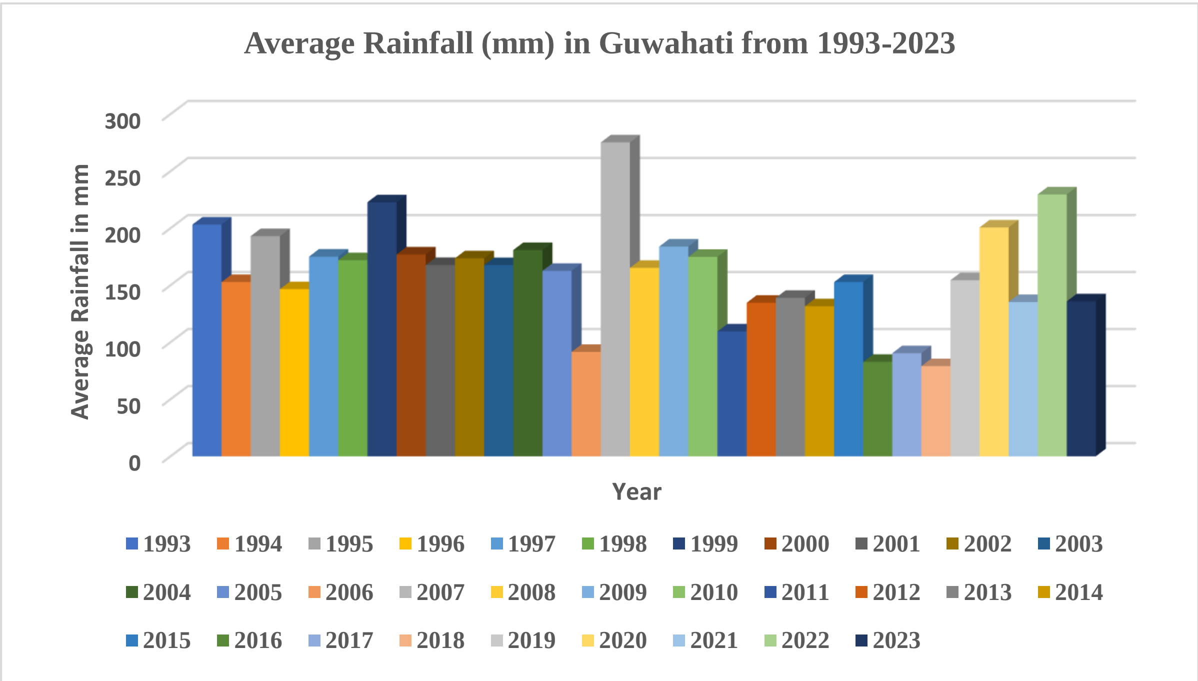

Fig: - 1.4 ANNUAL RAINFALL BAR GRAPH

1.7 TOPOGRAPHIC FEATURES

Guwahati, situated in Assam, features a diverse topography defined by hills, wetlands, plains, and the majestic Brahmaputra River. Prominent elevations such as **Nilachal Hill (200 meters above mean sea level - MSL)**, **Chandmari Hill (180 meters above MSL)**, and **Narakasur Hill (195 meters above MSL)** enhance its natural charm and cultural significance, hosting iconic landmarks like the Kamakhya Temple. The **Brahmaputra River**, flowing at an elevation of **50-55 meters above MSL**, shapes the city's hydrological profile and is home to **Umananda Island**, the smallest inhabited riverine island, rising **48 meters above MSL**. Key wetlands, including **Deepor Beel**, a Ramsar Site spanning **40 square kilometers at 50 meters above MSL**, along with Silsako and Borsola Beels, are crucial for biodiversity conservation and water flow management. The fertile alluvial plains, located at **50-60 meters above MSL**, support agriculture but are prone to seasonal flooding caused by annual monsoons bringing **2,200 millimeters** of rainfall. Green zones like the **Amchang Wildlife Sanctuary** and **Garbhanga Reserve Forest**, situated at elevations of **100-300 meters above MSL**, harbour diverse flora and fauna, while tributaries such as the **Bharalu** and **Basistha Rivers** form essential yet strained drainage networks. Tackling issues like waterlogging, soil erosion, and pollution through wetland protection, improved drainage infrastructure, forest conservation, and sustainable tourism is vital to preserving Guwahati's ecological balance and cultural heritage.

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1.8 RUN-OFF ESTIMATION

The **Rational Method** is a commonly used approach for estimating peak runoff rates in small to medium-sized drainage areas during rainfall events. It assumes that peak runoff occurs when the entire drainage area contributes simultaneously to the flow at the outlet. This method is particularly effective in urban environments, where impervious surfaces are prevalent, and the time of concentration is relatively short.

The formula for the Rational Method is:

$Q=C \cdot I \cdot A$

Where:

Q = Peak runoff rate (in cubic meters or feet per second)

C = Runoff coefficient, a dimensionless value indicating the portion of rainfall converted to runoff

I = Rainfall intensity (in mm/hour or inches/hour), based on the design storm and time of concentration

A = Drainage area (in hectares or acres)

The application of the Rational Method begins with identifying the drainage area, followed by determining the runoff coefficient, which is based on factors such as land use and surface characteristics. Next, rainfall intensity is calculated using intensity-duration-frequency (IDF) curves for a chosen storm return period, ensuring it aligns with the time of concentration (TcTc) of the catchment. These parameters are then applied in the Rational Method formula to estimate peak runoff. This calculated runoff is essential for designing urban drainage systems, including components like culverts, stormwater pipes, and retention basins.

Although the Rational Method is straightforward and commonly used, it has certain limitations. It assumes constant runoff coefficients and focuses solely on peak flow for a single rainfall event, which may not fully capture the complexity of larger or more intricate catchments. Nonetheless, it remains a valuable tool for initial design stages and for obtaining quick runoff estimates in urban drainage projects.

1.9 DESIGN OF SEWERS

The **design of sewers using Manning's equation** helps engineers determine the appropriate size and slope of sewer pipes for efficient flow conveyance. Manning's equation relates the discharge (flow rate) to the pipe's cross-sectional area, hydraulic radius, slope, and the roughness coefficient of the pipe material.

The general form of the equation is:

$$\mathbf{Q} = \frac{1}{n}\left(R^{\frac{2}{3}} S^{\frac{1}{2}} \right)$$

Where Q is the flow rate, A is the flow area, R is the hydraulic radius, S is the slope, and n is the roughness coefficient.

In sewer design, the equation helps estimate the required pipe size and slope by considering factors like expected flow, pipe material, and terrain. It ensures that the sewer system can efficiently handle wastewater or stormwater, minimizing flooding and operational costs while maintaining desired flow conditions.

1.10 GREEN AMPT EQUATION

The **Green-Ampt equation** is a widely used model in hydrology for simulating the infiltration of water into the soil during rainfall events. It is based on the assumption that infiltration is a combination of two main processes: the initial infiltration through the soil's surface and the subsequent flow of water into the unsaturated zone. The Green-Ampt equation is particularly useful for simulating runoff in urban drainage systems because it accounts for the effects of surface sealing, soil type, and saturation.

The equation is expressed as:

$$\mathbf{F} = \mathbf{K}\left(\Delta\theta + \frac{h}{\theta_s - \theta_i}\right)$$

where

- F = Cumulative infiltration (inches or millimeters)
- K = Hydraulic conductivity of the soil (inches or millimeters per hour)

- $\Delta\theta$ = Change in soil moisture (difference between the initial moisture content and saturation)
- h = Head (depth of the wetting front)
- θs = Saturation moisture content
- θ = Initial moisture content

The Green-Ampt model considers the wetting front, hydraulic conductivity, and the capillary pressure head in the soil, making it suitable for situations where infiltration is a significant factor in runoff generation.

The **Green-Ampt equation** is essential in urban drainage modeling as it calculates the rainfall infiltration into the soil prior to generating runoff. This capability is crucial for accurately estimating runoff volume and timing, particularly in urban areas with impervious surfaces or initially dry soil. By providing a more detailed representation of infiltration compared to basic models, the Green-Ampt equation improves the design and efficiency of stormwater management systems.

The equation is instrumental in determining infiltration rates during rainfall events, which aids in precise runoff predictions. It also supports the development of effective drainage infrastructure by considering the varying infiltration capacities of urban environments. Furthermore, it plays a significant role in flood management by simulating the interplay between infiltration and runoff, thereby reducing the risk of flooding during intense rainfall.

CHAPTER 2

MATERIALS

2.1 DIGITAL ELEVATION MODEL (DEM)

A **Digital Elevation Model (DEM)** is an essential resource for simulating urban drainage systems with the **Storm Water Management Model (SWMM)**. It provides a detailed depiction of terrain elevations, crucial for modelling surface water flow, defining catchment areas, and designing drainage infrastructure. DEMs enable the delineation of watersheds and sub-catchments, key elements for runoff calculations and analysing flow directions. They also help identify natural flow paths, low-lying zones, and overland flow patterns, ensuring the drainage model accurately mirrors real-world hydrology. Furthermore, DEMs offer precise elevation and slope data that aid in positioning conduits, manholes, and outlets while pinpointing areas prone to flooding.

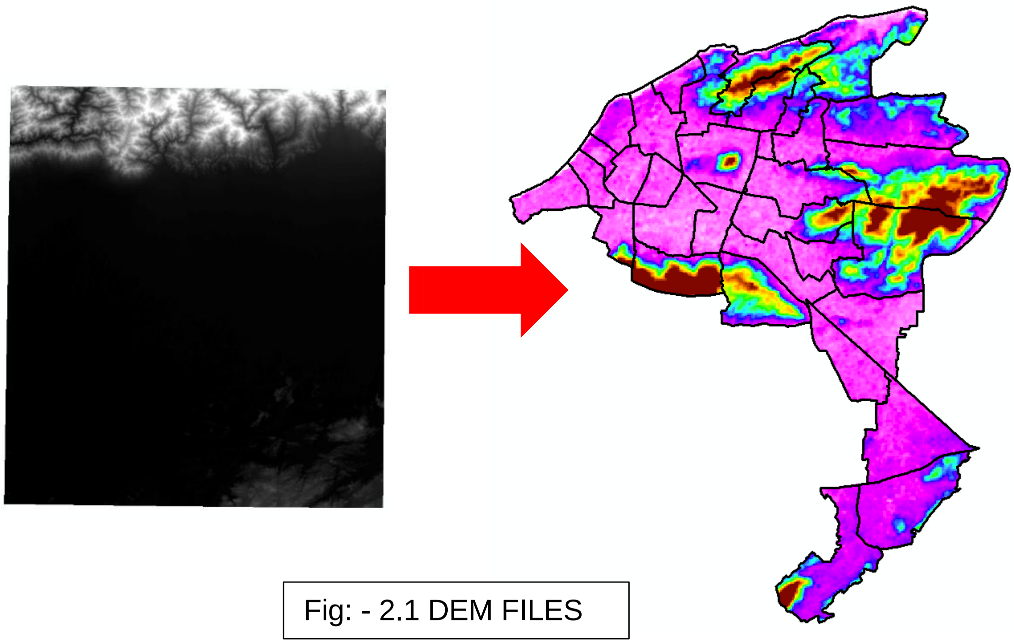


Fig: - 2.1 DEM FILES

In urban drainage modelling, DEMs are invaluable for simulating runoff behaviour under varying rainfall conditions, evaluating the impact of terrain alterations, and optimizing drainage systems to minimize flooding risks. They also play a critical role in analysing the effects of climate change on urban hydrology. By integrating DEM data, urban planners and engineers can develop sustainable and resilient drainage solutions, ensuring effective flood control and promoting balanced urban growth.

Feature	Description
Dataset Name	n26_e091_1arc_v3
Spatial Resolution	1 arc-second (approximately 30 meters)
Geographical Coverage	Region: Latitude 26° N, Longitude 91° E (or specific region)
Data Format	GeoTIFF, ASCII Grid, or other formats
Coordinate System	WGS84 or other standard geographic coordinate systems
Data Type	Elevation (height above sea level)
Elevation Range	Varies by region (specific range for this tile)
Source	Derived from satellite-based measurements (e.g., SRTM, ASTER)
Date of Data Collection	Typically corresponds to the dataset release date
Data Quality Notes	May include interpolation artifacts, water bodies as flat surfaces
Metadata Available	Yes (file-specific metadata, including spatial reference, accuracy, etc.)
Usage	Urban planning, flood modeling, hydrology studies, etc.

Table: - 2.1 DEM FEATURES

2.2 GUWAHATI MUNICIPAL CORPORATION (GMC) DRAINAGE SPECIFICATIONS MAP

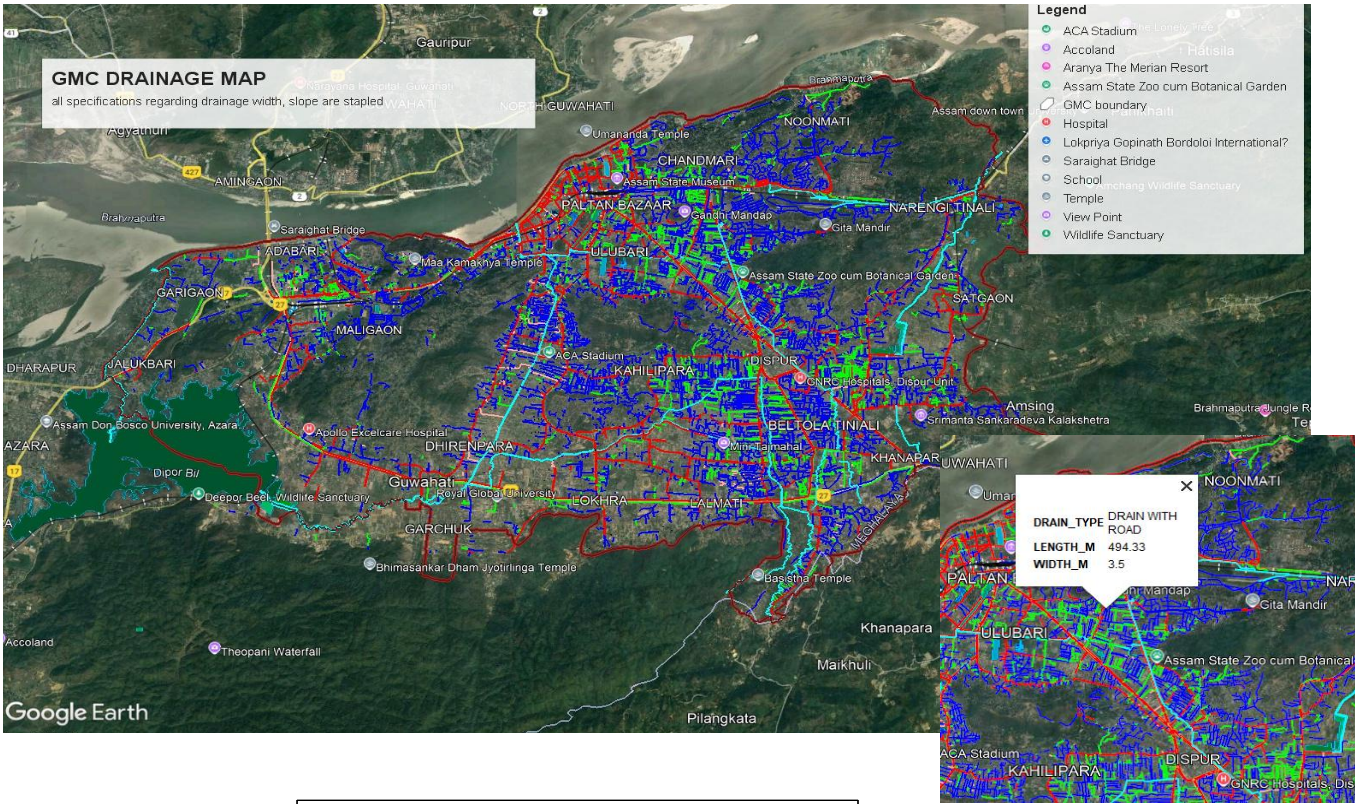


Fig: - 2.2 DRAINAGE SPECIFICATIONS

SOURCE – GMC DATA

The drainage layout of Guwahati city fig [], along with essential details such as drainage depth, width, and cross-sectional area, has been sourced from the Guwahati Municipal Corporation. This data will be used as input for simulations in the **Storm Water Management Model (SWMM)** software to evaluate the drainage system's performance during heavy rainfall events, particularly in the monsoon season. The primary aim is to assess how the system handles intense rainfall, which can cause flooding and waterlogging, allowing engineers and urban planners to identify potential weaknesses and plan for necessary improvements. The simulations will also help understand runoff dynamics, water flow, and storage capacity in the drainage network during high rainfall.

Additionally, the topographic data of the drainage layout provides valuable insights into how water moves across the urban landscape, considering elevation changes and terrain variations. This data can be directly traced in the SWMM interface, ensuring an accurate simulation of the drainage system's behaviour. By incorporating both the drainage specifications and topographic details, the simulation offers a comprehensive analysis of the system's performance under various rainfall scenarios. This approach will guide better decision-making for future infrastructure planning, enhancing flood resilience and improving urban water management.

2.3 LAND USE/LAND COVER MAP

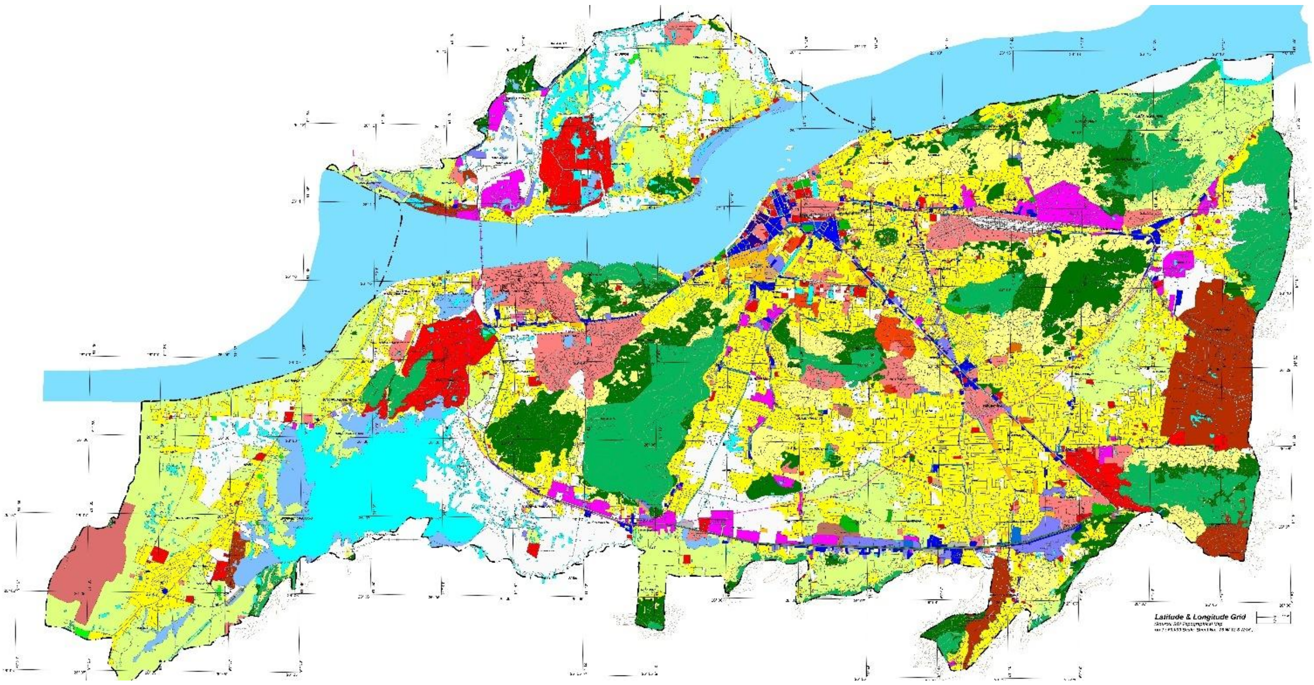


Fig: - 2.3 LU/LC MAP

Landuse Type	Area (Sq Km)	Percentage (%)
Residential	86.4	26.3
Commercial	6.4	
Industrial	5.75	
Mixed	2.72	
Public and Semi Public	22.98	
Public Utilities	0.76	
Recreational	2.22	
Transportation	17.64	
Vacant	43.7	
Total (Developed Land)	**144.87**	**44.6**
Agricultural	42.2	
Forest/Tree Clad	57.7	17.6
Barren Land	7.74	
Eco-Friendly	5.8	
Waterbody	16.46	5
Wetlands	8	2.4
Aquaculture	1.53	
Total (Underdeveloped Land)	181.13	55.8
Others (Dairy farm, Brick kiln, Poultry farm, etc.)	0.9	
TOTAL	**328**	

Table: - 2.2 LANDUSE DATA

The land use distribution for 2021, as provided by the GMC website, is categorized into developed and undeveloped land, offering insights critical for drainage simulation and urban planning. **Developed land accounts for 144.87 sq. km (44.6%)** of the total area, with **residential land being the most prominent use at 86.40 sq. km (26.3%)**. Other developed categories, such as commercial, industrial, public utilities, and transportation, collectively support urban infrastructure and services. These land types indicate significant urbanization and population-driven expansion.

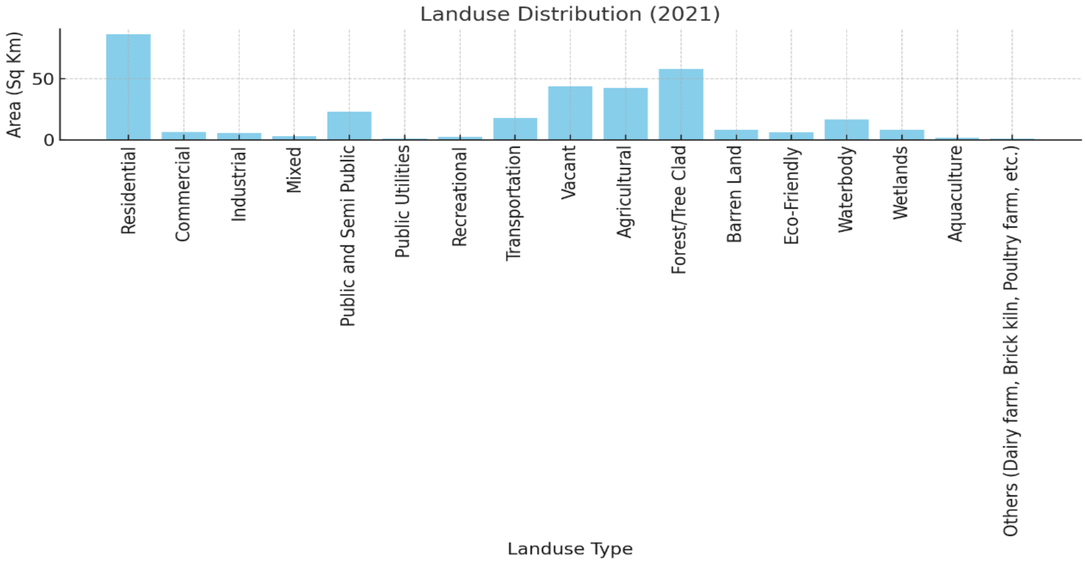


Fig: - 2.4 LANDUSE DISTRIBUTION

On the other hand, **undeveloped land constitutes 183.13 sq. km (55.8%)** of the total area. **Forest and tree-clad land cover 57.70 sq. km (17.6%)**, playing a vital role in ecological balance and carbon sequestration. **Waterbodies and wetlands account for 16.46 sq. km (5%) and 8.00 sq. km (2.4%)**, respectively, highlighting their importance in natural drainage and flood management. **Agricultural and vacant land collectively cover 85.9 sq. km**, offering potential for future development or conservation, depending on urban planning needs.

This data serves as a foundation for simulating drainage patterns, assessing flood risks, and planning sustainable development. It emphasizes the need to balance urban expansion with the conservation of natural resources such as wetlands, forests, and waterbodies to ensure ecological stability and effective water management.

2.4 WARD SHAPE FILE COLLECTED FROM GMC

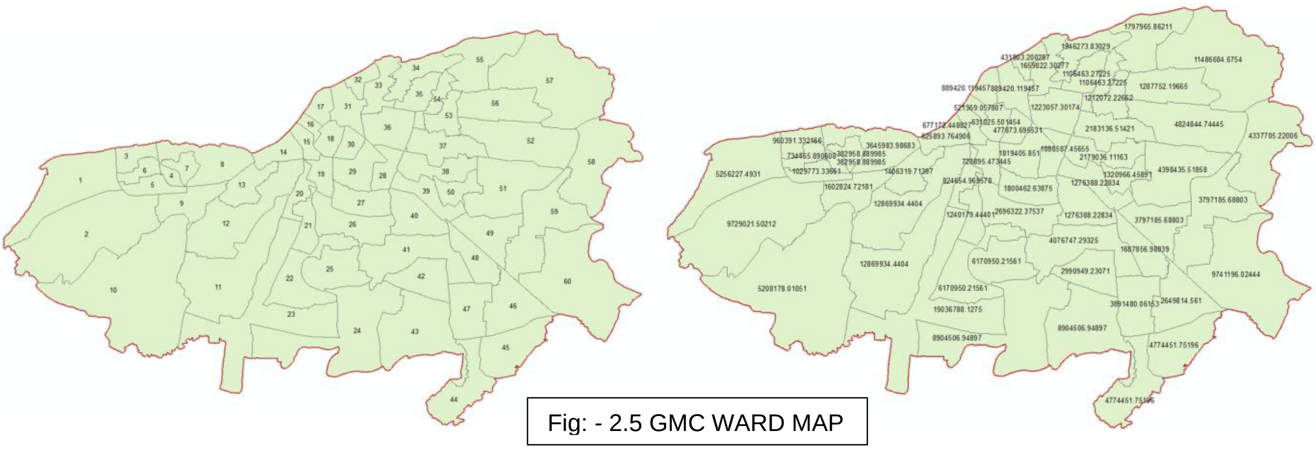


Fig: - 2.5 GMC WARD MAP

The dataset table [] by considering above fig [2.5] references outline the area measurements of various wards, providing valuable insights for drainage simulation and identifying regions prone to flooding. The ward sizes vary significantly, with Ward 10 being the largest at **13,346,100 sqm**, followed by Ward 2 at **9,729,020 sqm** and Ward 57 at **8,372,080 sqm**, highlighting expansive zones that could significantly impact drainage patterns and flood risks. Ward 60, with an area of **8,212,820 sqm**, is another substantial region that warrants attention.

In contrast, smaller wards like Ward 16 (**380,369 sqm**), Ward 4 (**359,116 sqm**), and Ward 17 (**831,355 sqm**) may present unique challenges due to their compact areas, potentially requiring localized drainage solutions. Understanding these variations in ward sizes is critical for identifying flood-prone areas and designing effective drainage systems. Larger wards with extensive surfaces, particularly those with low gradients or high levels of imperviousness, are more vulnerable to flooding. This data provides a foundation for spatial analysis and prioritizing flood management efforts in high-risk zones.

Table: - 2.3 WARD AREA DATA

WARD	Area_SQM
47	2460760
46	2980250
49	2440760
48	1687860
45	2997310
51	4398440
41	4076750
42	2189290
60	8212820
9	1994130
28	1088580
5	1031850
1	5256230
6	756611
11	6871020
14	1171530
13	1633810
19	956217
29	1819410
21	1239030
8	2905550
3	960391
20	882714
33	1481850
30	756784
34	1770080
35	1223910
58	4966380
23	8245080
32	686994
16	380369
26	2696320
53	1212070
57	8372080
55	3140200
56	3060130
38	1942580
39	1596570
50	1093820
37	2192830
10	13346100
2	9729020
31	1455590
25	2571110
18	879869
27	1800460
24	7597060
15	677166
59	4852940
43	5197160
44	2877560
52	4824850
22	3168670
12	5225800
7	740436
4	359116
17	831355
36	2084740
40	2254060
54	913977

2.5 DRAINAGE PLAN OF GUWAHATI

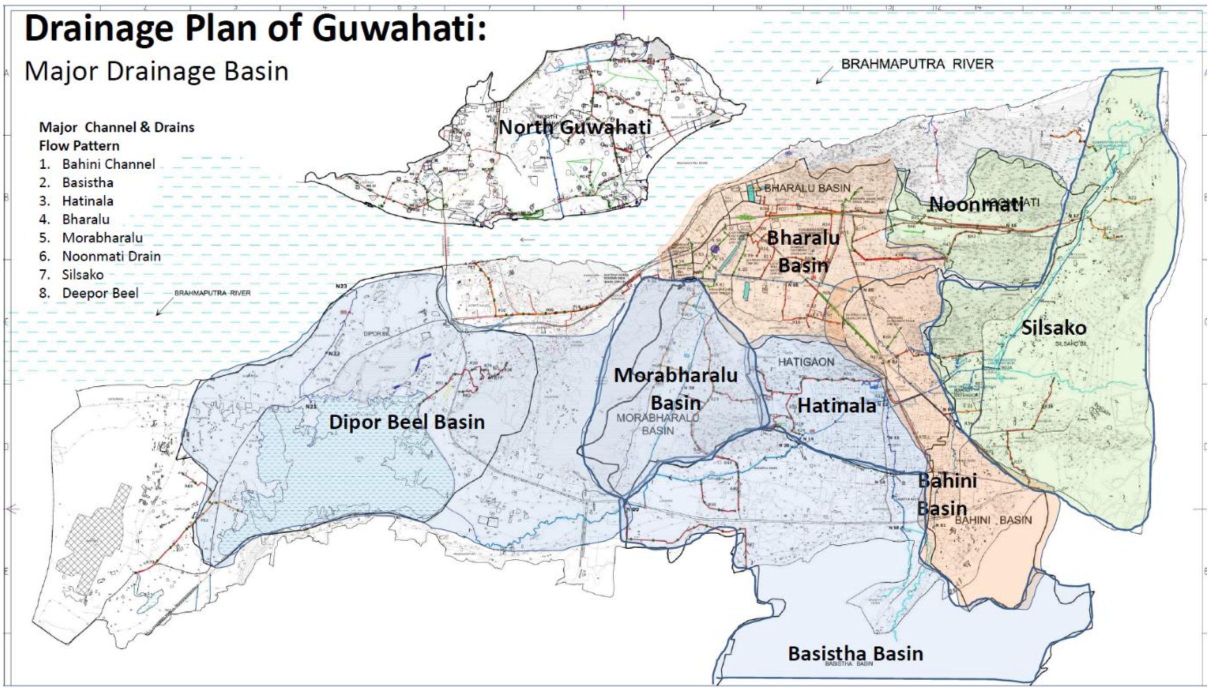


Fig: - 2.6 DRAINAGE PLAN MAP

SOURCE: GMDA DRAFT DATA

The drainage system comprises eight basins, each characterized by unique catchment areas, major channels, and discharge capacities. The **Basistha basin**, with the largest catchment area (83.74 sq. km) and the highest discharge capacity (274 cumecs), stands out, while smaller basins like **Morabharlu** and **Hatinala** handle more modest runoff. Key channels, such as the **Bharalu River** and **Dipor Beel-Pamohi Channel**, are vital in managing urban drainage.

The provided drainage layout is pivotal for hydrological simulations, offering detailed insights into basins, flow paths, and outfalls. This enables accurate modeling of water movement, runoff dynamics, and discharge efficiency, ensuring reliable analysis and validation. Such simulations support improved flood management, drainage planning, and infrastructure development for the area.

Here, table [ ] is signifies the specifications of respective basin along with its discharge intensity and variation graph is added for statistical analysis.

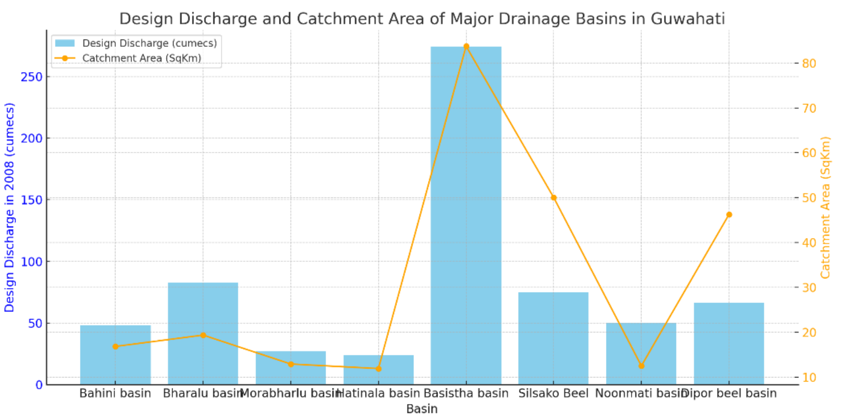


Fig: - 2.7 DESIGN DISCHARGE

Basin	Major Channel	Catchment Area SqKm	Length in Km	Design Discharge in 2008 (cumecs)
Bahini basin	Bahini channel	16.83	8.5	48
Bharalu basin	Bharalu river	19.36	4.8	83
Morabharlu basin	Morabharlu channel	12.91	6.5	27
Hatinala basin	Hatinala channel	11.9	5.1	24
Basistha basin	Basistha channel	83.74	8.7	274
Silsako Beel	Silsako Beel	50	5	75
Noonmati basin	Noonmati drain	12.5	5.2	50
Dipor beel basin	Dipor beel and Pamohi channel	46.24	7	66.3

Table: - 2.4 BASIN DATA

2.6 GEE GENERATED HYDROLOGICAL MAP OF GMC BOUNDARY

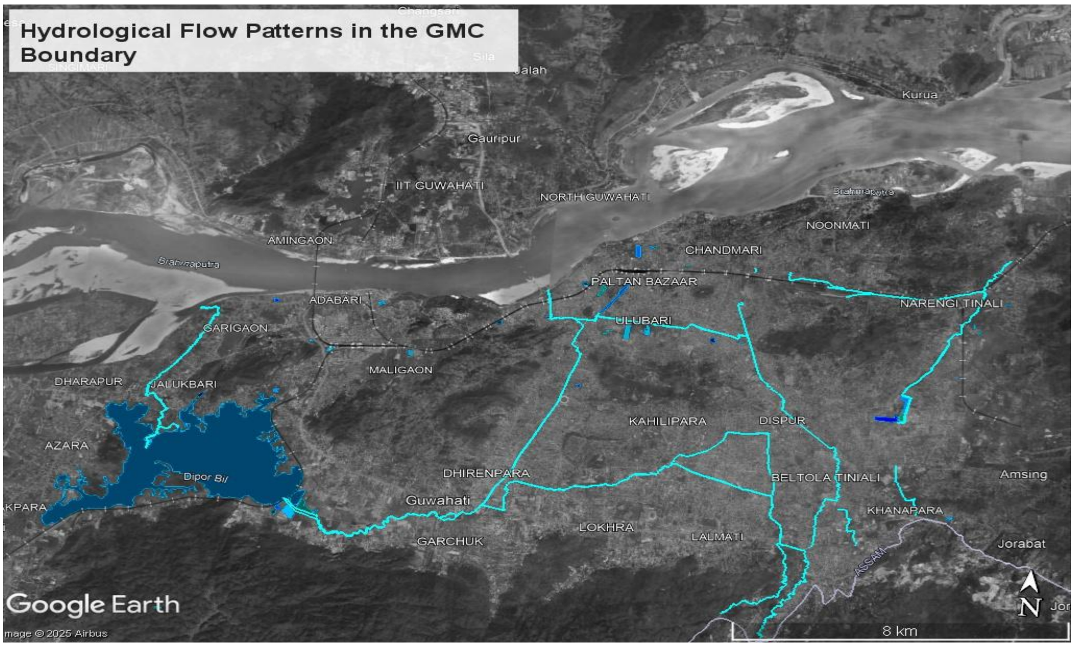


Fig: - 2.8 HYDROLOGICAL FLOW PATTERNS

The Guwahati Municipal Corporation (GMC) operates a sophisticated hydrological system that includes both natural and artificial drainage pathways, such as the Bharalu River, Bahini Channel, and Basistha Channel. Wetlands like Silsako Beel and Deepor Beel contribute to managing urban runoff and mitigating flooding. The system is organized into various drainage basins, with the Basistha Basin being the largest. Despite its importance, issues like waterlogging, silt accumulation, and urban encroachment hinder its effectiveness. To improve management and flood control, tools like Google Earth Engine (GEE) and SWMM are utilized for detailed mapping and monitoring, aiding in sustainable urban planning.

2.7 STORM WATER DISCHARGE FLOW CHART BY GMDA

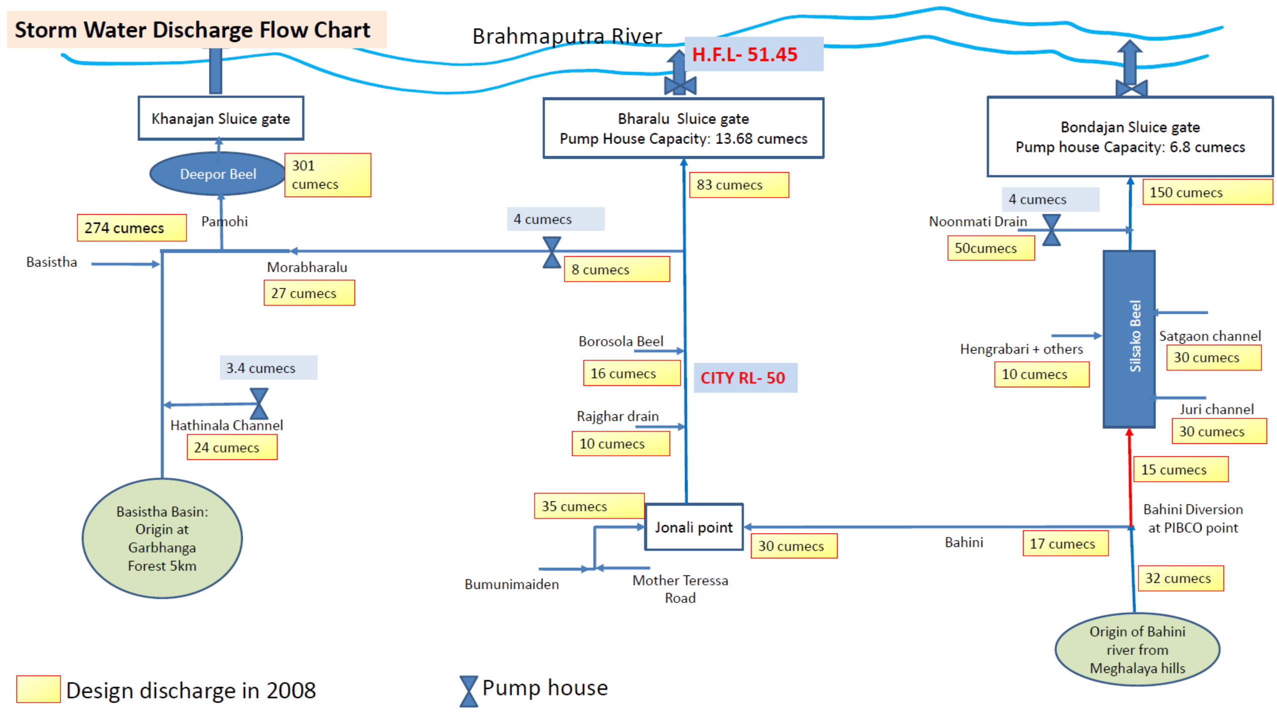


Fig: - 2.9 STORM WATER FLOW CHART

SOURCE: GMDA DRAFT DATA

The **Storm Water Discharge Flow Chart** illustrates the movement of stormwater from various channels and basins into the Brahmaputra River through the **Khanajan**, **Bharalu**, and **Bondajan Sluice Gates**. The **Khanajan Sluice Gate**, connected to **Deepor Beel**, had a design discharge capacity of **301 cumecs** in 2008, with **274 cumecs** directed towards the **Basista River**. Additional flows include **27 cumecs** from **Pamohi** to **Morabharalu** and **24 cumecs** from the **Hathinala Channel**, aided by a pump house handling **3.4 cumecs**.

The **Bharalu Sluice Gate** has a pump house capacity of **13.68 cumecs** and manages inflows from **Borosola Beel (16 cumecs)** and **Rajghar Drain (10 cumecs)**. At **Jonali Point**, **35 cumecs** is regulated, with **30 cumecs** flowing into the **Bahini River**, and the system ultimately discharges **83 cumecs** into the Brahmaputra River, functioning between the city's **Reduced Level (RL) of 50** and the **High Flood Level (HFL) of 51.45**.

The **Bondajan Sluice Gate** operates with a pump house capacity of **6.8 cumecs** and discharges **150 cumecs** into the Brahmaputra. It connects to **Silsako Beel**, which gathers water from the **Noonmati Drain (50 cumecs)**, **Satgaon Channel (30 cumecs)**, **Juri Channel (30 cumecs)**, and **Hengrabari (10 cumecs)**. The **Bahini Diversion at Pibco Point** adds **15 cumecs**, and the **Bahini River**, originating from the Meghalaya Hills, carries **17 cumecs** downstream.

2.8 MANNING’S N – VALUES

Manning's roughness coefficient (**n**) is a vital factor in stormwater management modeling as it measures the resistance to water flow in open channels, pipes, and drainage systems. It significantly impacts the calculation of flow velocity and discharge, both of which are crucial for the effective design and management of stormwater infrastructure. Accurately determining the Manning's **n** value allows for realistic simulation of water movement through various drainage components, aiding in flood risk prediction, system capacity evaluation, and the development of efficient stormwater management systems.

In stormwater modeling, Manning's **n** influences:

Flow Velocity: Higher roughness values reduce water speed, while lower values enable quicker flow.

Channel Capacity: Misjudging the **n** value can result in either underestimating or overestimating a channel's flow capacity.

Flood Risk Assessment: Precise roughness values are crucial for pinpointing areas prone to flooding.

Infrastructure Design: Selecting appropriate **n** values is essential for designing effective drainage systems, including pipes, culverts, and open channels.

Erosion and Sediment Control: Flow velocity, governed by the **n** value, directly impacts erosion processes and sediment transport.

Types of Manning’s N value –

1. **Conduits (Pipes and Channels)**
    - Represents the roughness inside pipes, culverts, and open channels.
    - Smooth Concrete Pipes: 0.012–0.015
    - Corrugated Metal Pipes: 0.022–0.027
    - Earth Channels: 0.020–0.035

2 **Overland Flow Surfaces**
    - Defines surface roughness for runoff over land before entering drainage systems.
    - Paved Roads/Concrete Surfaces: 0.010–0.015
    - Short Grass Lawns: 0.035–0.050
    - Forested Areas: 0.100–0.400

3. **Subcatchment Impervious Areas**

2.8.1 MANNING'S N – VALUES FOR OVERLAND FLOW

Manning's **n** values for overland flow represent the surface roughness that affects how quickly water moves across different land covers. These values vary based on surface type, with smoother surfaces (e.g., pavement) having lower **n** values and rougher, vegetated areas (e.g., forests or tall grass) having higher **n** values, impacting runoff speed and volume.

Table: - 2.5 MANNINGS CHART

Surface	n
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipes	0.024
Cement rubble surface	0.024
Fallow soils (no residue)	0.05
Cultivated soils - Residue cover < 20%	0.06
Cultivated soils - Residue cover > 20%	0.17
Range (natural)	0.13
Grass - Short, prairie	0.15
Grass - Dense	0.24
Grass - Bermuda grass	0.41
Woods - Light underbrush	0.4
Woods - Dense underbrush	0.8

Above table [] is mentioned in McCuen, R. et al. (1996), Hydrology, FHWA-SA-96-067, Federal Highway Administration, Washington, DC

2.8.2 MANNING'S N – VALUES FOR CLOSED CONDUITS

Manning's *n* values for closed conduits represent the roughness coefficient used in the Manning's equation for calculating flow in pipes. These values depend on the material, condition, and age of the conduit. For smooth pipes like new concrete, *n* values are typically around 0.010, while for rougher pipes, like old or corrugated steel, *n* values can range from 0.015 to 0.035. The exact value varies based on the pipe's surface texture, sediment, and any potential blockages.

Table: - 2.6 CONDUIT DATA

Conduit Material	Manning n
Asbestos-cement pipe	0.011 - 0.015
Cast iron pipe - Cement-lined & seal coated	0.011 - 0.015
Concrete (monolithic) - Smooth forms	0.012 - 0.014
Concrete (monolithic) - Rough forms	0.015 - 0.017
Corrugated-metal pipe (Plain)	0.022 - 0.026
Corrugated-metal pipe (Paved invert)	0.018 - 0.022
Corrugated-metal pipe (Spun asphalt lined)	0.011 - 0.015
Vitrified clay - Pipes	0.011 - 0.015
Vitrified clay - Liner plates	0.013 - 0.017

Above table [] is mentioned in ASCE (1982). Gravity Sanitary Sewer Design and Construction, ASCE Manual of Practice No. 60, New York, NY.

2.8.3 MANNING'S N – VALUES FOR OPEN CHANNELS

Manning's n values for open channels represent the roughness coefficient influencing flow resistance. These values vary based on factors like channel material, vegetation, and surface irregularities. Smooth channels, such as concrete, have lower n values (0.011–0.013), while those with dense vegetation or uneven surfaces exhibit higher values (0.035–0.15 or more).

Table: - 2.7 CHANNEL DATA

Channel Type	Manning n
Lined Channels - Asphalt	0.013 - 0.017
Lined Channels - Brick	0.012 - 0.018
Lined Channels - Concrete	0.011 - 0.020
Lined Channels - Rubble or riprap	0.020 - 0.035
Lined Channels - Vegetal	0.030 - 0.40
Excavated or dredged - Earth, straight and uniform	0.020 - 0.030
Excavated or dredged - Earth, winding, fairly uniform	0.025 - 0.040
Excavated or dredged - Rock	0.030 - 0.045
Excavated or dredged - Unmaintained	0.050 - 0.140
Natural channels - Fairly regular section	0.030 - 0.070
Natural channels - Irregular section with pools	0.040 - 0.100

Above table [] is mentioned in ASCE (1982). Gravity Sanitary Sewer Design and Construction, ASCE Manual of Practice No. 60, New York, NY.

2.9 ASSAM STATE DISASTER MANAGEMENT AUTHORITY (ASDMA)

The **Assam State Disaster Management Authority (ASDMA)** has been instrumental in tackling flood risks within the **Guwahati Municipal Corporation (GMC)** area by segmenting it into **60 blocks**. This division facilitates targeted and localized disaster management initiatives, enabling precise planning, monitoring, and the execution of flood control measures. Each block is evaluated based on factors such as **terrain and drainage systems**, **waterlogging-prone areas**, **population density**, **existing infrastructure**, and **encroachments** that contribute to flooding issues. These blocks are then categorized into high, moderate, or low vulnerability zones, with high-risk areas requiring immediate intervention due to frequent flooding, inadequate drainage systems, and densely populated regions.

To address these vulnerabilities, ASDMA, in coordination with GMC, has undertaken numerous measures. These include **enhancing drainage systems** by desilting and repairing channels, **revitalizing natural water bodies** like Deepor Beel to boost water storage capacity, and **establishing early warning mechanisms** for real-time flood alerts. Efforts are also directed toward **community engagement** through training programs and the formation of local disaster response teams, as well as **emergency readiness**, which involves stockpiling relief materials and setting up shelters in flood-prone blocks.

Leveraging **GIS technology** and field assessments, ASDMA has adopted a data-driven approach to flood risk management. This methodology helps pinpoint critical problem areas and prioritize mitigation efforts effectively. By dividing the GMC area into 60 blocks, disaster response has become more streamlined, fostering the implementation of customized flood control measures and bolstering the city's ability to cope with urban flooding challenges.

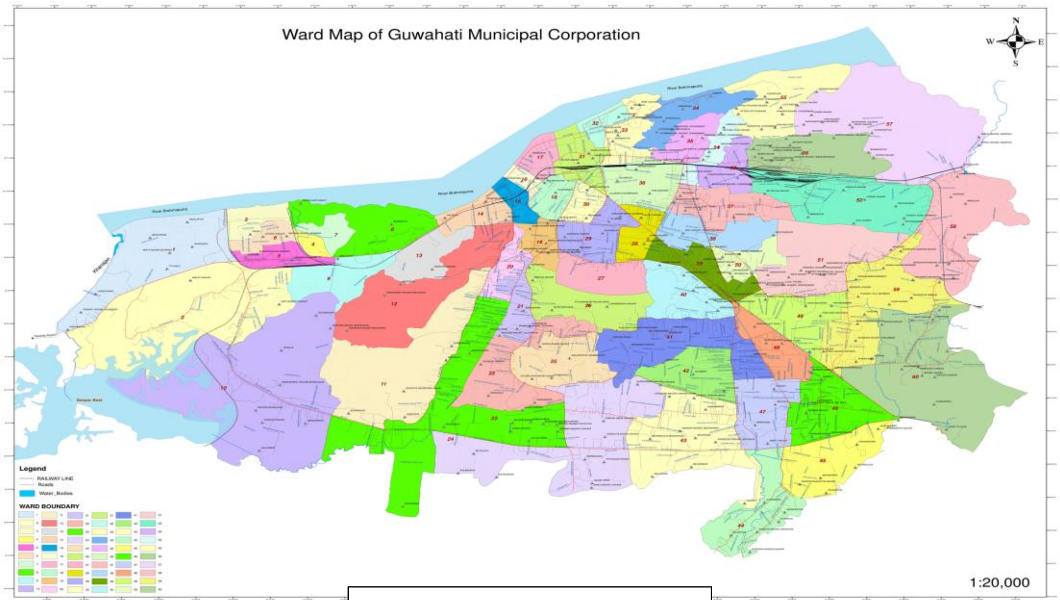


Fig: - 2.10 ASDMA MAP

2.9.1 PROPOSED FLOOD-ZONE BY ASDMA

Classification of flood vulnerability area is done in ArcGIS 10.4 by creating shape file of GMC map along with respective ward boundary.

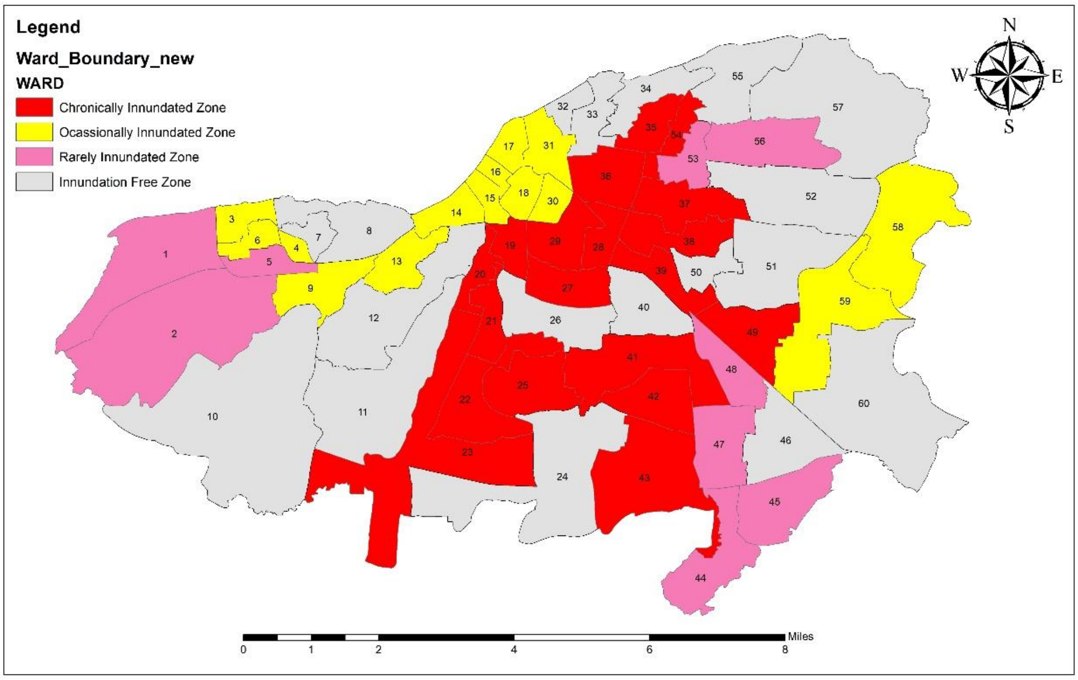


Fig: - 2.11 FLOOD ZONE MAP

The flood-affected areas, as reported by ASDMA, reveal a distribution of urban flood impacts with varying levels of severity across different regions. In this case, 30% of the urban areas, represented by the red and grey segments, have experienced severe flooding. These regions, likely including high-density neighborhoods, commercial districts, and key infrastructure hubs, have been overwhelmed by heavy rainfall, poor drainage, or inadequate flood control systems. The flooding here has caused extensive damage to buildings, roads, and utilities, necessitating urgent intervention to restore essential services and minimize further losses as shown in Fig[2.12]

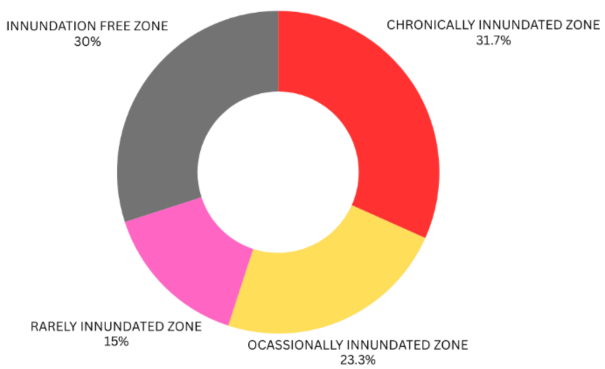


Fig: - 2.12 FLOOD PIE CHART

An additional 25% of the flood-affected urban areas, represented by the yellow segment, have experienced moderate flooding. These regions may face localized disruptions, such as transportation delays and temporary flooding in residential or commercial areas, though the overall damage is not as widespread. Despite being less affected, these areas still require attention to address the impact on critical infrastructure like schools, healthcare facilities, and businesses. Improvements in drainage systems, flood barriers, and urban planning can help mitigate these challenges in the future.

The pink segment, covering 15% of the affected regions, includes areas with the least flood impact. These areas, which may be situated at higher elevations, less urbanized zones, or places with more effective flood management measures, have experienced minimal damage. While still affected, the damage is relatively minor, enabling quicker recovery. Nevertheless, further improvements in stormwater management, flood forecasting, and urban planning remain crucial to reducing future flood risks.

This distribution highlights the varying degrees of urban flood damage, enabling ASDMA to adjust its response strategies. By focusing resources on the most severely impacted areas, especially the red and gray segments, ASDMA can address urgent needs in the hardest-hit communities. Meanwhile, attention to the yellow and pink segments can enhance urban flood resilience and prepare for future flood events.

2.10 IMPERVIOUS FACTOR

The impervious factor in the SWMM model represents the proportion of an area covered by impermeable surfaces, such as asphalt and concrete, which prevent water from soaking into the ground. This factor is crucial for estimating how much rainfall becomes surface runoff instead of infiltrating the soil. Urban areas with more impervious surfaces produce higher runoff, increasing the risk of flooding and placing stress on drainage systems.

It also plays a key role in designing efficient drainage solutions, such as stormwater pipes and retention basins, to manage excess water. Additionally, it helps identify areas where pollutants like oil and debris may wash off and degrade water quality. Urban planners can use this information to explore strategies like permeable pavements and green roofs to minimize runoff and pollution.

In summary, the impervious factor is vital for understanding water flow in urban environments. It supports flood prevention, improves water quality, and helps in planning sustainable and resilient cities.

Table: - 2.8 IMPERVIOUS FACTOR

Land Use Type	Typical Impervious Factor (Range)	Description
Residential - Low Density	0.20 - 0.40	Detached homes with larger yards, less paved area.
Residential - Medium Density	0.40 - 0.60	Suburban neighbourhoods with moderate yard sizes and driveways.
Residential - High Density	0.60 - 0.85	Apartment complexes or urban housing with minimal green spaces.
Commercial Areas	0.70 - 0.90	Shopping centers, offices, and parking lots with mostly paved surfaces.
Industrial Areas	0.60 - 0.80	Factories and warehouses with large paved spaces and roof areas.
Institutional Areas	0.50 - 0.75	Schools, hospitals, and public buildings with a mix of paved and landscaped areas.
Roads and Highways	0.80 - 0.95	Streets and highways with asphalt or concrete pavement.
Parks and Open Spaces	0.10 - 0.30	Recreational parks, sports fields, and natural green spaces.
Mixed-Use Urban Areas	0.50 - 0.85	Areas combining residential, commercial, and institutional uses.
Fully Developed Urban Core	0.85 - 1.00	Downtown areas with dense buildings and almost no pervious surfaces.

CHAPTER 3

LITERATURE REVIEW

3.1 URBAN FLOOD

Urbanization causes significant changes to natural landscapes by replacing them with impervious surfaces such as buildings, roads, and parking lots. This transformation increases surface runoff and reduces the ability of the soil to absorb water, leading to a shorter time of concentration during rainfall and an elevated risk of flooding. Construction activities further disrupt natural slopes and drainage patterns, worsening the problem. Inadequate maintenance of drainage systems, including blockages caused by solid waste and sewage, reduces their designed capacity, exacerbating flood severity (**Smith et al., 2015; Johnson et al., 2018**).

Climate change is another major factor contributing to urban flooding. Rising global temperatures result in more intense and frequent rainfall events with shorter intervals, which can overwhelm existing drainage infrastructure. Additionally, urban heat islands created by concentrated impervious surfaces raise local temperatures, potentially causing heavy downstream rainfall (**Rodriguez et al., 2017; Miller et al., 2020**). These climate-related factors significantly challenge flood management in urban areas.

Urban flooding is a fast-occurring, localized consequence of heavy or prolonged rainfall, often happening without warning. Compared to rural areas, urban environments with higher levels of impervious surfaces produce greater runoff volumes and faster water flow. Natural drainage routes are frequently altered in cities, reducing their capacity to manage excess water. The high population density and concentration of infrastructure in cities intensify the economic, social, and environmental impacts of flooding (**Taylor et al., 2016; Brown et al., 2019**).

The consequences of urban flooding extend beyond immediate physical damage. Contaminated floodwaters can expose communities to waterborne diseases, posing significant public health risks. Vulnerable populations, especially those in low-income areas, are disproportionately affected due to limited recovery resources. Flood events also disrupt livelihoods, damage properties, and can lead to loss of life in severe cases (**Chen et al., 2018; Martinez et al., 2020**).

In the future, urban flood risks are expected to increase due to climate change and urban population growth. Climate change is likely to intensify extreme weather events, while urban expansion will expose more areas to flood hazards. However, adopting sustainable urban planning measures, such as green infrastructure and permeable pavements, can help mitigate these risks. Collaboration between governments, urban planners, and communities is crucial to enhance resilience and reduce the adverse effects of urban flooding (**Williams et al., 2021; Lee et al., 2019**).

In Guwahati, the urban area faces multiple types of flooding, largely influenced by rapid urbanization, heavy monsoon rains, and insufficient drainage infrastructure. Given the city's location and urban challenges, the following flooding types are commonly observed:

1. **Pluvial (Surface) Flooding**

Guwahati is especially vulnerable to **pluvial flooding** because of its dense urban development, high population, and extensive areas of impervious surfaces like roads, buildings, and parking spaces. The drainage system is often inadequate to manage heavy rainfall, leading to water accumulation and flooding in low-lying areas during the monsoon.

Cause: Prolonged and intense rainfall during the monsoon season, coupled with blocked or poorly maintained drainage systems, causes water to gather on streets, leading to traffic issues, property damage, and health risks due to water contamination.

2. **River (Fluvial) Flooding**

Being located along the Brahmaputra River, **river flooding** is a critical concern for Guwahati. The river often overflows during the monsoon due to heavy upstream rainfall, resulting in flooding of low-lying areas, especially those near the riverbanks.

Cause: The Brahmaputra's overflow during monsoons, intensified by rainfall upstream and snowmelt from the Himalayas, causes river flooding.

Characteristics: This type of flooding can cause significant damage to infrastructure, homes, and agricultural areas, with places like Maligaon, Paltan Bazar, and other flood-prone regions experiencing regular inundation.

3. Flash Flooding

Guwahati can experience **flash flooding** due to the steep terrain surrounding the city, which causes rapid runoff during rainfall. In areas with poor drainage systems, even moderate rain can lead to sudden flooding.

Cause: Intense rainfall over short periods, especially in already saturated areas with limited water absorption, triggers flash floods.

Characteristics: Flash floods can develop with little notice, quickly inundating streets and low-lying areas, which presents a significant danger to residents and commuters.

4. **Sewer Flooding**

Sewer flooding occurs when the city's combined drainage system, designed to handle both sewage and stormwater, becomes overwhelmed by heavy rain, causing it to back up and overflow.

Cause: Insufficient sewer capacity, clogged drains, and poor system maintenance during rainfall events lead to sewer flooding.

Characteristics: This results in the overflow of untreated sewage and stormwater into residential streets and areas, which creates public health hazards.

5. **Urban Heat Island (UHI) Induced Flooding**

Although **urban heat island-induced flooding** is less significant in Guwahati compared to other types, the city's rapid expansion and increasing impervious surfaces could contribute to more rainfall and localized flooding in the future.

Cause: The high concentration of impervious surfaces, like roads and buildings, traps heat, increasing local temperatures and rainfall intensity.

Characteristics: Increased rainfall intensity could worsen other types of flooding, particularly in areas with poor drainage systems.

6. Tidal Flooding (Less Likely)

Tidal flooding is generally **not a major issue** in Guwahati, as it is far from the sea, but the river's water levels can rise during monsoons, leading to flooding conditions that resemble tidal flooding. This is primarily **fluvial flooding** caused by the rise in the Brahmaputra's water levels.

The types of flooding in Guwahati—pluvial, river, and flash flooding—are directly linked to its geographical features, climate, and the challenges posed by urban growth. The city's rapid development, coupled with the effects of climate change, increases the frequency and severity of these flood events.

Smith et al. (2015) conducted a study to examine the relationship between urbanization and flooding, focusing on the role of impervious surfaces, such as roads, buildings, and parking lots, in increasing flood risks. The research highlighted that rapid urbanization, particularly in areas with limited green spaces, exacerbates surface runoff, reducing the soil's ability to absorb water. This leads to an increased volume and speed of runoff, overwhelming drainage systems and causing frequent flooding in urban areas. The study emphasized the need for sustainable urban planning to address these issues, recommending the integration of green infrastructure solutions like rain gardens, permeable pavements, and increased green spaces. These solutions allow for better water infiltration and help reduce runoff, mitigating the impact of urban flooding. By improving urban drainage systems and incorporating natural water management strategies, cities can significantly reduce the risk of flooding as they continue to grow. The research calls for a shift toward more sustainable and resilient urban planning practices to better manage stormwater and protect vulnerable urban areas from flooding.

Rodriguez et al. (2017) explored the impact of climate change on urban flooding, highlighting that the increasing intensity and frequency of rainfall, driven by global warming, heighten flood risks in urban areas. The study noted that cities with outdated drainage systems are especially vulnerable to these extreme weather events. The authors called for the adoption of adaptive flood management practices, such as enhanced flood forecasting and the modernization of drainage infrastructure, to mitigate climate change-related urban flooding risks.

Miller et al. (2020) investigated the urban heat island effect and its contribution to urban flooding. Their findings showed that elevated temperatures in cities, caused by large amounts of impervious surfaces, intensify rainfall, which in turn increases the likelihood of flooding. The study linked these local temperature changes to more frequent and severe storm events. The authors recommended greening initiatives like tree planting and rooftop gardens to reduce the heat island effect and help mitigate flooding.

Taylor et al. (2016) examined the socio-economic impacts of urban flooding, particularly on vulnerable populations in low-income areas. The study found that these communities suffer disproportionately from flooding, facing health risks, displacement, and significant economic losses. The authors emphasized the need for flood risk management policies that address the needs of these vulnerable groups and promote fair recovery strategies after flooding events.

Brown et al. (2019) conducted a detailed risk assessment of urban flooding in major cities, revealing that many urban areas lack comprehensive flood risk management plans, especially in informal settlements. They also highlighted the importance of flood risk mapping and community involvement in flood mitigation. The authors advocated for better flood risk mapping and the involvement of local communities in flood management to strengthen resilience in urban areas.

Chen et al. (2018) investigated the public health risks associated with urban flooding, particularly the spread of waterborne diseases. The study found that floodwaters often become contaminated with sewage, leading to outbreaks of diseases such as cholera and dysentery. The authors recommended improving urban sanitation systems and raising public health awareness during flood events to mitigate these risks.

Williams et al. (2021) reviewed global practices in sustainable urban flood management and found that cities employing green infrastructure, such as rain gardens and bioswales, have seen reduced flood risks and improved stormwater management. The study recommended incorporating sustainable drainage systems (SuDS) into urban planning to more effectively manage stormwater and reduce urban flooding.

Lee et al. **(2019)** focused on the role of technology in urban flood management, exploring innovations such as real-time flood monitoring systems, GIS-based flood prediction models, and early warning systems. The study concluded that integrating advanced technologies could greatly enhance flood preparedness, response, and recovery, enabling better management of urban flood risks.

Johnson et al. (2018) emphasized the importance of maintaining and upgrading urban drainage systems to cope with increasing rainfall and urban expansion. Their research found that poorly maintained drainage systems are a major cause of localized flooding. The authors recommended regular maintenance, investment in modern drainage infrastructure, and a more integrated approach to flood management to address the causes and consequences of urban flooding.

3.2 CLIMATE CHANGE AND INCREASED RAINFALL

Climate change and increased rainfall are having a significant impact on the SWMM (Storm Water Management Model), which is crucial for predicting and managing stormwater runoff and flood risks. With climate change, rainfall events are becoming both more intense and frequent, leading to more severe storms. This results in larger volumes of water running off surfaces, potentially overwhelming existing stormwater drainage systems. In urban areas, where impervious surfaces like buildings and roads prevent water absorption, rainwater flows quickly into drainage systems, putting additional strain on the infrastructure. The increased rainfall intensity also leads to higher peak flows, putting even more pressure on these systems (**Goswami et al.**, 2020).

Additionally, extreme rainfall events that were once rare are now becoming more frequent due to climate change. This necessitates an update to the SWMM model, which was originally based on historical rainfall patterns, to account for the increase in both the frequency and intensity of storms (**Rodriguez et al.**, 2017). To properly adjust the model, updated rainfall data must be integrated, particularly through the use of revised intensity-duration-frequency (IDF) curves, which describe how rainfall intensity changes over time (**Lee et al.**, 2019).

By modifying the SWMM model with these updated insights, urban planners can design more effective stormwater management systems that are better equipped to handle the predicted increase in rainfall. This may involve improving drainage infrastructure, incorporating green infrastructure such as rain gardens and permeable pavements, and implementing flood control measures. These changes will help cities prepare for more intense storms, reduce the risk of flooding, protect properties, and ensure the safety of residents (**Williams et al.**, 2021). As cities grow and weather patterns become increasingly unpredictable, it is essential to adapt to climate change to address both urban expansion and the challenges posed by shifting weather conditions.

3.3 WATERSHED DELINEATION

Watershed delineation involves identifying the boundaries of a watershed, which is the land area that drains water into a common outlet such as a river, lake, or reservoir. This process is crucial for understanding the movement of water within a region, as the size and shape of a watershed affect the flow of water. Understanding these boundaries is vital for managing water resources, predicting flood risks, and designing infrastructure like stormwater systems. Proper watershed delineation helps hydrologists and engineers model water behavior during rainfall, which is important for flood forecasting, water quality control, and urban development (**Irwin et al., 2020**).

A key outcome of watershed delineation is the identification of flow accumulation and direction. Flow accumulation calculates the amount of water expected to flow through different parts of the watershed based on elevation data. This helps us understand the movement of water within the watershed. Flow direction, on the other hand, shows the path water will take based on the slope of the land, helping us predict where it will flow. These results are derived from analyzing digital elevation models (DEMs), which provide data on the land's surface features. By using Geographic Information Systems (GIS), we calculate the steepest downhill path for flow direction and determine where water accumulates from upstream. Together, these factors help map out major river channels and sub-catchments. Flow accumulation is especially important because it points to areas where water is likely to collect, which can lead to flooding during heavy rainfall (**Irwin et al., 2020**).

In relation to the Storm Water Management Model (SWMM), watershed delineation is essential for simulating runoff, water quality, and flood risks. The SWMM model relies on watershed characteristics such as land use, soil type, slope, and drainage systems to predict the quantity and quality of stormwater runoff. By delineating the watershed, hydrologists can define the catchment areas, which serve as inputs for the SWMM model. The results of flow accumulation and direction are especially useful in SWMM, as they help determine how stormwater moves through the watershed. Flow direction indicates the path runoff will follow during rainfall, assisting the model in simulating water flow through drainage systems. Flow accumulation helps the model identify areas with higher runoff, allowing it to account for varying runoff intensities across different parts of the watershed.

Watershed delineation also divides the watershed into smaller sub-catchments for easier analysis. Each sub-catchment is analyzed individually to estimate runoff and water quality parameters within the SWMM model. This approach enables the model to more accurately simulate water movement, taking into account local variations in land cover and terrain. By dividing the watershed into smaller units, the model provides more detailed predictions of water behavior during different rainfall events (**Rodriguez et al., 2017**).

The information obtained from watershed delineation, including flow direction and accumulation, is crucial for hydrological studies, especially in assessing flood risks and designing flood prevention systems. In urban areas, where impervious surfaces such as roads and buildings increase runoff, accurate watershed delineation is essential for creating stormwater systems that can handle heavy rainfall. The SWMM model plays a key role in simulating runoff, helping engineers design drainage systems that prevent flooding. Additionally, it supports the use of sustainable solutions like green infrastructure, which helps manage runoff and improve water quality (**Lee et al., 2019**). Watershed delineation is also valuable in regional studies, where watersheds are grouped by similar hydrological characteristics. This allows for more accurate estimation of hydrologic variables, such as flood frequency and rainfall-runoff relationships, leading to better models for stormwater behavior in regions with limited data (**Irwin et al., 2020**).

Lindsay et al. (2008) identified two primary applications for automated watershed delineation: (a) mapping or modeling spatial phenomena, and (b) establishing statistical relationships between basin characteristics and hydrological or water quality outcomes for predictive purposes. A series of studies have been conducted to explore the connection between watershed characteristics and water quality parameters at sampling sites located at watershed outlets. In their work, the boundaries of the watersheds were delineated using topographic data derived from the Institute of Hydrology Digital Terrain Models (DTMs) and various functions within the Spatial Analyst toolbox in ArcGIS. Once the boundaries were established, various attributes were assigned to the watershed polygons, including catchment area, average elevation, average slope, annual rainfall, geological features, and land use properties. These attributes were subsequently analyzed to explore their relationship with water quality parameters measured at the sampling sites, providing valuable insights into the impact of watershed characteristics on water quality.

Magesh et al. (2012) developed an automated extraction tool using the model builder technique within the ArcGIS environment to delineate basin morphometry. The model required Shuttle Radar Topographic Mission (SRTM) data along with a pour point shapefile to run effectively. The model produces essential data for morphometric analysis, including key parameters such as stream networks, aspect, slope, Digital Elevation Models (DEMs), drainage density, hillshade, and basin boundaries. The output of this model is invaluable to terrain analysts, hydrologists, and watershed managers, as it enables the precise delineation of watersheds and the extraction of important basin characteristics for further hydrological analysis.

Hussein A. Obaid et al. (2014) proposed a GIS-based catchment discretization approach that is based on digital elevation model (DEM) data. This methodology features an automated batch process for dividing sub-catchments, using both DEM data and GIS hydrologic analysis tools. The proposed approach was applied in the central urban area of Macau, China, where monitoring stations were installed in experimental sub-catchments for model calibration and validation. The results from the calibration and validation stages showed that the model performed well, confirming its suitability for obtaining various hydrological parameters in urban watersheds. This methodology holds potential for more accurate and efficient analysis of hydrological processes in urban areas where data collection may otherwise be challenging.

Tang et al. (2018) explored the application of high-resolution DEMs combined with remote sensing data for watershed delineation in mountainous regions of the Himalayas. Their study highlighted that the accuracy of watershed boundaries could be significantly improved by incorporating multi-source data, such as remote sensing imagery, alongside DEMs. By combining these data sources, the researchers achieved a higher level of precision in delineating watershed boundaries, emphasizing the importance of data fusion in improving watershed delineation techniques, particularly in complex or difficult-to-access mountainous areas.

Li et al. (2016) implemented an automated watershed delineation model in the Yangtze River Basin, utilizing both DEMs and land use data to assess the impact of land cover change on hydrological responses. Their findings revealed that changes in land use had a considerable impact on runoff and sedimentation patterns, underscoring the importance of accurate watershed delineation in environmental monitoring and management. The study highlighted how land cover changes, such as urbanization or agricultural expansion, can significantly influence hydrological behavior, thus reinforcing the need for up-to-date and precise watershed delineation models to inform water management strategies.

Kumar and Singh (2015) developed a watershed delineation model that incorporated climate data, land use, and DEMs to improve the prediction of flood risks in the Godavari Basin, India. Their study demonstrated that combining hydrological modeling with watershed delineation could significantly enhance the accuracy of flood prediction models. The incorporation of climate data, along with land use and DEMs, allowed for better simulations of flood events, providing valuable insights for flood mitigation planning and disaster preparedness in the region.

3.4 GENERATION OF (INTENSITY – DURATION – FREQUENCY) CURVE

An **IDF curve** is a graph that shows the rainfall intensity (I) for different durations (D) and frequencies (F) at a specific location. It helps to estimate how much rainfall intensity can be expected over varying durations and how often these events may occur. This relationship is essential for hydrological modeling and infrastructure planning.

- **Intensity (I)**: The rainfall rate, usually expressed in **mm/h** or **in/h**, reflects the amount of rain falling over a specific duration (D).
- **Duration (D)**: The length of time over which rainfall is measured, typically in minutes or hours.
- **Frequency (F)**: The probability that a certain rainfall event, with a given intensity and duration, will occur, often represented as a return period (e.g., a 10-year storm indicates a 10% chance of occurrence annually).

IDF curves are usually developed from historical rainfall data specific to a region, providing an estimate of the likelihood of different storm events.

Applications of IDF Curves

IDF curves are applied in various fields such as hydrology, urban planning, and water resource management:

1. **Design of Stormwater Management Systems**:
   Engineers use IDF curves to design drainage networks, culverts, stormwater detention basins, and flood protection structures. By considering different frequencies and durations, these curves ensure that infrastructure can manage both routine and extreme rainfall events. They also aid in determining the correct sizing for stormwater pipes, gutters, and sewers based on expected rainfall intensity and duration.
2. **Flood Risk Assessment**:
   Hydrologists rely on IDF curves to estimate the probability of flooding under various rainfall conditions. By identifying extreme rainfall events like a 100-year storm, these curves assist in assessing flood risks for specific areas. In addition, they help define floodplain boundaries and the extent of possible flooding when combined with hydrological models.
3. **Urban Planning and Development**:
   In urban areas, where impervious surfaces increase runoff, IDF curves are critical in designing systems that can handle excess runoff from heavy rainfall. These curves support the planning of sustainable urban drainage systems and green infrastructure, such as permeable pavements, rain gardens, and detention ponds, by providing insight into how rainfall interacts with land use.
4. **Agricultural and Ecological Management**:
   IDF curves are valuable for assessing soil erosion risks and understanding the impact of various storm durations and intensities on soil properties. Additionally, they are used to plan irrigation systems by providing valuable information on rainfall patterns in certain regions.

Importance of IDF Curves in the SWMM Model

The **Storm Water Management Model (SWMM)** is a widely used tool for simulating stormwater runoff and its quality, and IDF curves are crucial in its functioning. Here's how these curves contribute to the SWMM model:

1. **Runoff Calculation**:
   SWMM requires detailed rainfall data to simulate accurate stormwater runoff. The intensity, duration, and frequency of rainfall events, as defined by IDF curves, serve as essential inputs for these calculations. By applying specific rainfall intensities over different durations during simulations, IDF curves help ensure that SWMM models reflect realistic rainfall patterns and their effects on runoff.
2. **Flood Risk Simulation**:
   IDF curves help define extreme rainfall events, such as the 100-year storm, allowing SWMM to simulate flood scenarios for various return periods. This aids in flood mitigation planning and infrastructure design. By using IDF data, SWMM can predict peak flow rates during storms, assisting in the proper sizing of stormwater systems.
3. **Infiltration and Drainage Design**:
   IDF curves are essential for modeling infiltration in SWMM. The intensity and duration of rainfall influence how much water infiltrates the ground, which impacts runoff volumes and the design of infiltration systems. Additionally, IDF curves assist in determining the capacity and size of detention ponds, swales, and other stormwater management practices within the SWMM model, as these systems rely on accurate rainfall intensity for their performance.
4. **Model Calibration and Validation**:
   To ensure SWMM models are accurate, they must be calibrated using historical rainfall data that includes intensity, duration, and frequency from IDF curves. This calibration enhances the accuracy of simulations for runoff and flood conditions. IDF curves also play a role in validating the model by comparing simulated runoff predictions with actual observed storm data, ensuring that the outputs of SWMM are reliable for decision-making.

Chow et al. (1988): Chow and colleagues focused on foundational methods for generating IDF curves using historical rainfall data. They emphasized the role of statistical analysis in predicting rainfall intensities, which are crucial for models like SWMM. Their work highlighted the need to adjust IDF curves based on regional climate conditions, ensuring that they reflect local variations and are suitable for flood risk assessment and infrastructure design.

Singh and Kadhim (1993): Singh and Kadhim developed regionalized IDF curves tailored for flood prediction models, taking into account geographic variations. They explored how urbanization affects runoff behavior, modifying the IDF curves to reflect these changes. Their research contributed to improving the accuracy of flood prediction in SWMM by incorporating localized data for more precise rainfall modeling.

Maidment et al. (2005): Maidment and colleagues integrated IDF curve data into GIS-based models like SWMM, allowing for spatial analysis of rainfall patterns across urban landscapes. Their study examined how different storm durations impacted the accuracy of IDF curves. The integration of IDF curves with GIS improved the reliability of hydrological simulations for urban drainage systems by providing better data inputs for SWMM.

Burian and Slaughter (2009): Burian and Slaughter focused on refining IDF curve applications by accounting for climate change and urbanization. They identified how rainfall intensity and frequency in urbanized areas altered standard IDF curve predictions and proposed new methodologies to adjust for these changes. Their research aimed to make IDF curves more adaptable for stormwater management models like SWMM, especially in the face of future environmental conditions.

Al-Saadi and Izzeldin (2014): Al-Saadi and Izzeldin adapted traditional methods of generating IDF curves for use in arid and semi-arid regions, focusing on areas with less frequent but more intense rainfall. They ensured that IDF curves could be applied universally, particularly in dry regions where rainfall data is scarce. Their work improved the effectiveness of SWMM in regions with extreme rainfall events, which are less common in other climates.

Yang et al. (2016): Yang and collaborators worked on improving the temporal and spatial resolution of IDF curves for urban stormwater management. They introduced advanced statistical techniques to refine predictions based on urban land use and the evolving nature of rainfall events. Their research contributed to making SWMM simulations more accurate in urban areas undergoing rapid development and climate change.

Kuczera (2020): Kuczera's research emphasized the use of probabilistic models for IDF curves, addressing the uncertainty and variability in rainfall events. His approach incorporated climate modeling to assess how changing weather patterns would affect IDF curve predictions. This helped enhance the SWMM model by adding a layer of uncertainty, allowing for more resilient flood mitigation designs and infrastructure planning.

3.5 ALTERNATIVE BLOCK METHOD

The **Alternative Block Method** (ABM) is a highly effective approach for generating realistic time series data, particularly rainfall, in hydrological models like **SWMM**. This method works by breaking down storm events into blocks with different rainfall intensities and durations. This approach accurately mirrors the natural variability found in rainfall patterns, which is essential for forecasting stormwater runoff and creating effective drainage infrastructure.

One of the primary benefits of ABM is its adaptability in simulating a variety of storm types. It is capable of modeling diverse storm conditions, from short, frequent rainfall to prolonged, intense events. This flexibility helps ensure that stormwater management systems are designed to accommodate various weather scenarios, thereby strengthening infrastructure resilience in different conditions (**Chow et al.**, 1988; **Maidment et al.**, 2005).

ABM also enhances the calibration and precision of SWMM models. By generating more realistic rainfall data, ABM enables the model to better align with real-world conditions, improving the accuracy of runoff predictions. This is especially crucial for sizing flood mitigation measures and drainage systems to properly handle extreme rainfall events (**Burian & Slaughter**, 2009).

Another key advantage of ABM is its ability to address the limitations of traditional synthetic rainfall methods. While conventional techniques often assume uniform rainfall intensity, ABM allows for the creation of more varied and dynamic rainfall blocks. This results in more realistic stormwater runoff simulations, which are vital for designing effective stormwater management systems (**Al-Saadi & Izzeldin**, 2014).

In urban settings, where impervious surfaces like roads and roofs greatly influence water flow, ABM is particularly useful in capturing a wide range of rainfall intensities. This ability is beneficial for modeling the effects of heavy storms on urban drainage systems, helping to design infrastructure capable of handling intense storm events (**Yang et al.**, 2016). ABM is also valuable for simulating future climate scenarios. By modifying rainfall blocks, it can predict how storm events might change due to climate change, enabling engineers to design infrastructure that is resilient to future weather extremes (**Kuczera**, 2020). This makes ABM a crucial tool for planning stormwater infrastructure in the face of uncertain climate conditions.

Furthermore, ABM is highly efficient at generating long-term rainfall series, which are important for simulating stormwater behavior over extended periods. This efficiency is vital when assessing the cumulative effects of multiple storms, which is necessary for flood risk assessment and designing detention basins and other flood control structures (**Singh & Kadhim**, 1993).

3.6 STORM WATER MANAGEMENT MODEL (SWMM 5.1)

The **EPA Storm Water Management Model (SWMM)** is a dynamic tool employed for simulating rainfall-runoff events and analyzing both the quantity and quality of runoff, particularly in urban environments. It divides a catchment into sub-areas, where precipitation is collected, runoff is generated, and pollutants are transported. This model is widely used for both single-event and continuous simulations in stormwater management.

Rossman (2006), a comparison was made between SWMM versions 4.4h and 5.0.006 using dynamic wave flow routing computations. The results demonstrated that SWMM 5 provided more stable solutions and was capable of handling larger time steps than version 4, making it more efficient for sewer network simulations.

Barco et al. (2008) integrated GIS, SWMM, and optimization techniques for large-scale watersheds in California. Their approach notably reduced the time needed for data management and model calibration, highlighting the effectiveness of combining these tools for large and complex modeling scenarios.

Junaidi et al. (2018) used SWMM version 5.1 to model a small urban drainage system, utilizing hourly rainfall data to simulate surface runoff and drainage flow. Their findings showed that the model provided valuable insights into flood durations at various junctions, reinforcing its utility in drainage network modeling.

Peterson and Wicks (2006) applied SWMM to Missouri, USA, to assess how slight changes in conduit geometry affected fluid flow. Their findings revealed that even minor alterations in conduit dimensions, such as length and width, caused significant changes in the simulated flow, while slope and infiltration rate changes had less impact. Notably, they found that changes in Manning's roughness coefficient had a considerable effect on the results.

Shinmaa and Reis (2014) compared single-site and multi-site calibration methods, as well as single and multi-event approaches in SWMM. They concluded that combining multi-site and multi-event calibration yielded the best performance, reducing computational time and narrowing uncertainty in the results.

Cambez et al. (2008) used SWMM for continuous simulations with historical rainfall data on a catchment. While they achieved satisfactory calibration results, they highlighted limitations in importing long-duration rainfall series into SWMM5, with a maximum of 30 days being manageable for data inputs at 2-minute intervals.

Huber et al. (2005) conducted a comparison between SWMM version 5.0 and the older version 4.4, using eleven years of continuous simulation data with varying detention pond sizes. They found that although version 5.0 could match version 4.4 results after adjustments to treatment functions, the decay constants used in version 5.0 lacked physical meaning, limiting their applicability in ungauged watersheds.

Lei Jiang et al. (2015) applied SWMM to simulate urban flooding in Dongguan City, China, which has undergone rapid urbanization. Their findings indicated that SWMM was a promising tool for forecasting urban floods, suggesting its potential for managing flood risks in rapidly changing environments.

Aryal et al. (2016) used SWMM to investigate the effects of urbanization on rainfall-runoff behavior in eight catchments. Their simulations showed that increasing impervious surfaces led to higher runoff, with the impact being more complex and critical to interpret in larger catchments compared to smaller ones.

Kourtis et al. (2017) used SWMM to simulate a combined drainage network, extracting subcatchment data from a Digital Elevation Model (DEM) with ArcGIS. Their results demonstrated that SWMM is an effective tool for urban drainage network simulations, with results that closely aligned with observed flow data, further validating its reliability in modeling urban water systems.

CHAPTER 4

METHODOLOGY

4.1 SIMULATION OF EXISTING URBAN DRAINAGE AND PERFORMANCE ANALYSIS

The process of urban drainage simulation starts with **data collection**, a crucial step to ensure the hydrological analysis is accurate and dependable. This involves acquiring two main categories of data: attribute data and spatial data. Attribute data focuses on rainfall information, which is used to generate Intensity-Duration-Frequency (IDF) curves. These curves illustrate the statistical relationship between rainfall intensity, duration, and frequency, serving as a foundation for estimating storm intensities in various scenarios. Additionally, rainfall time series are created using methods such as the alternate block technique to simulate storm events over a specified timeframe for detailed analysis.

Spatial data, such as Digital Elevation Models (DEM), is equally important and provides essential information about the terrain. DEM data helps identify surface elevations, flow directions, and areas where water accumulates. This spatial information is critical for mapping drainage networks and defining subcatchments, which are smaller hydrological units that influence localized water flow. By integrating attribute and spatial data, a solid base is established for creating an accurate hydrological model.

After collecting the necessary data, a **hydrological model** is developed using tools like the Storm Water Management Model (SWMM 5.1). SWMM is a robust and widely-used software for modeling stormwater runoff in urban environments. It incorporates rainfall data, spatial characteristics, and details about drainage infrastructure, including conduits, manholes, and outfalls. The model is designed to simulate the physical and hydraulic processes within the urban catchment, offering a framework to evaluate stormwater behavior under different rainfall scenarios and configurations.

With the hydrological model in place, **model simulation** is carried out to analyze the performance of the urban drainage system. This involves examining how stormwater interacts with the drainage network under varying rainfall intensities and durations. The simulation identifies potential flooding areas, maps flow accumulation patterns, and evaluates the overall efficiency of the drainage system. It also provides estimates of critical parameters such as peak runoff rates, flow velocities, and water depths, which are vital for assessing vulnerabilities and planning system improvements.

Finally, the outcomes of the simulation are visualized through **profile plots**. These plots offer a detailed view of the system's response, illustrating water levels, flow paths, and hydraulic gradients throughout the drainage network. For engineers and planners, profile plots are invaluable in highlighting sections of the system that may require upgrades or modifications. Furthermore, these visualizations enhance the understanding of stormwater dynamics across urban landscapes, supporting the design of effective and sustainable stormwater management solutions.

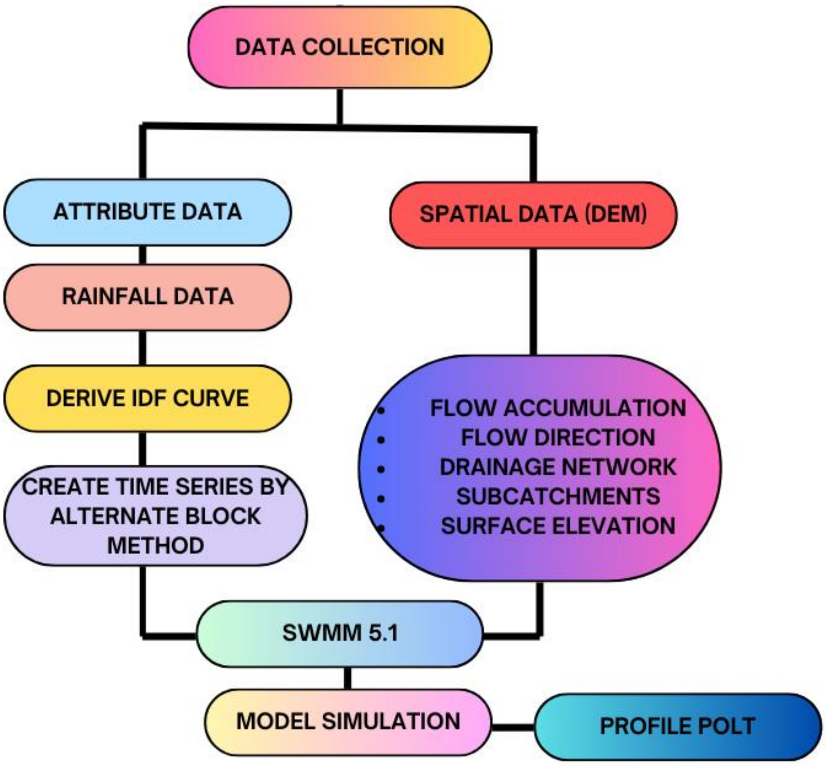


Fig: - 4.1 METHODOLOGY CHART

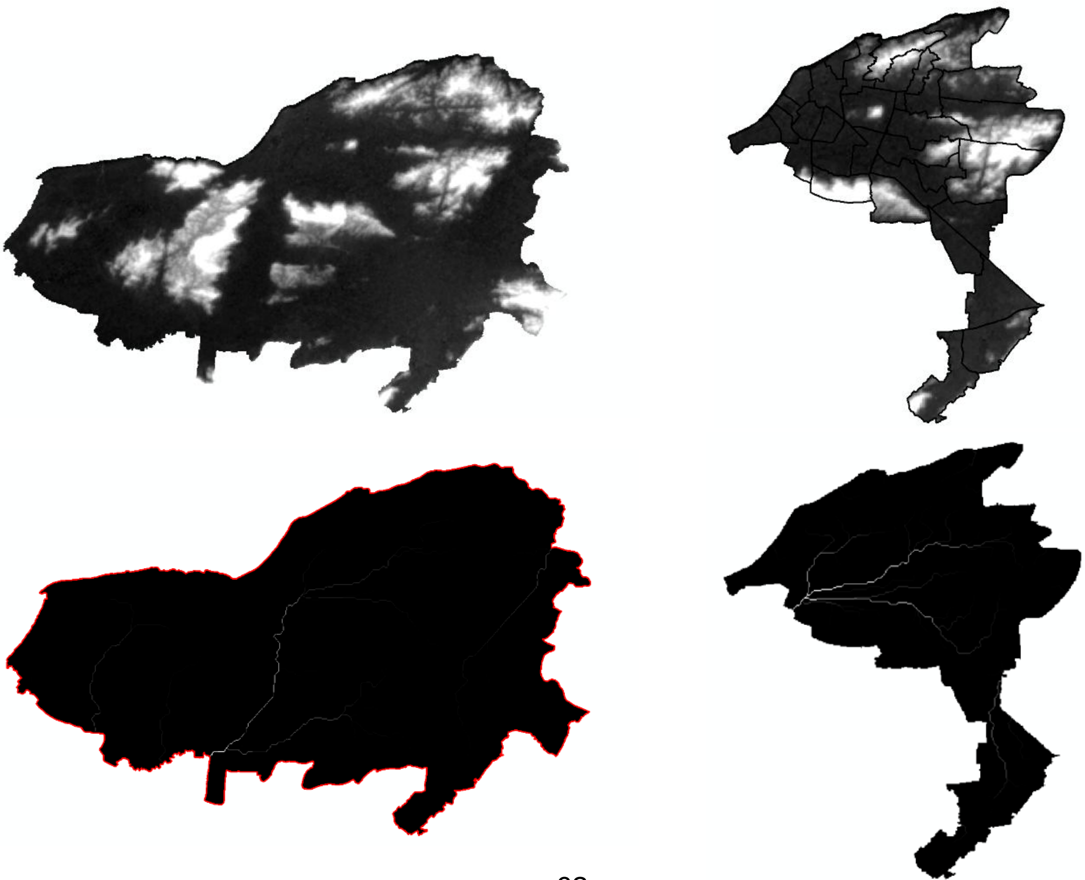
4.2 WATERSHED DELINEATION USING POUR METHOD

1. **Prepare Elevation Data (DEM)**
    - Ensure you have a **Digital Elevation Model (DEM)** of the region.
    - Check for any anomalies or missing data and clean the DEM before use.
2. **Create Flow Direction**
    - **Tool**: Flow Direction
    - Path: Spatial Analyst → **Hydrology** → **Flow Direction**
    - Input: **DEM**
    - Output: **Flow Direction raster**
    - This step generates a raster showing the direction of water flow from each cell.
3. **Identify and Define the Pour Point**
    - **Tool**: Manually digitize or use a point feature layer for the pour point.
    - Identify the **Pour Point**, typically the outlet where water flows out of the watershed.
4. **Create Flow Accumulation**
    - **Tool**: Flow Accumulation
    - Path: Spatial Analyst → **Hydrology** → **Flow Accumulation**
    - Input: **Flow Direction raster**
    - Output: **Flow Accumulation raster**
    - This raster shows the accumulated flow at each cell, identifying the drainage network.
5. **Define the Watershed Area**
    - **Tool**: Watershed
    - Path: Spatial Analyst → **Hydrology** → **Watershed**
    - Input: **Flow Direction raster**, **Pour Point**
    - Output: **Watershed delineation raster**
    - This step generates the boundary of the watershed, showing the contributing area.
6. **Visualize and Refine the Watershed**
    - Use visualization tools to display the watershed on the map.
    - **Tools**: Clip, Erase, or other spatial tools to refine the watershed boundary if necessary.
7. **Optionally, Delineate Stream Network**

- **Tool**: Stream Order or **Stream Definition**
- Path: Spatial Analyst → **Hydrology** → **Stream Order** (for stream classification)
- This step helps to identify and classify streams within the watershed.

8. **Export and Analyze Results**
    - **Export Formats**: Shapefiles, raster layers
    - Perform any additional analysis, such as examining land cover, soil types, rainfall data, etc., to assess the hydrological impacts of the watershed.

The watershed delineation steps using the **Pour Point Method** were initially implemented on the **GMC boundary map** to improve visualization and facilitate a more precise analysis of the **Bharalu Basin**. By following these steps, the watershed boundary and flow dynamics are more clearly defined, which is crucial for conducting detailed simulation studies. This method provides a deeper understanding of the hydrological characteristics of the Bharalu Basin, allowing for more accurate simulations and better decision-making regarding flood management, water flow, and environmental considerations within the basin. The enhanced watershed delineation ensures that the model is based on dependable and precise data, laying a strong foundation for advanced simulations and a thorough assessment of the basin's response to varying conditions.



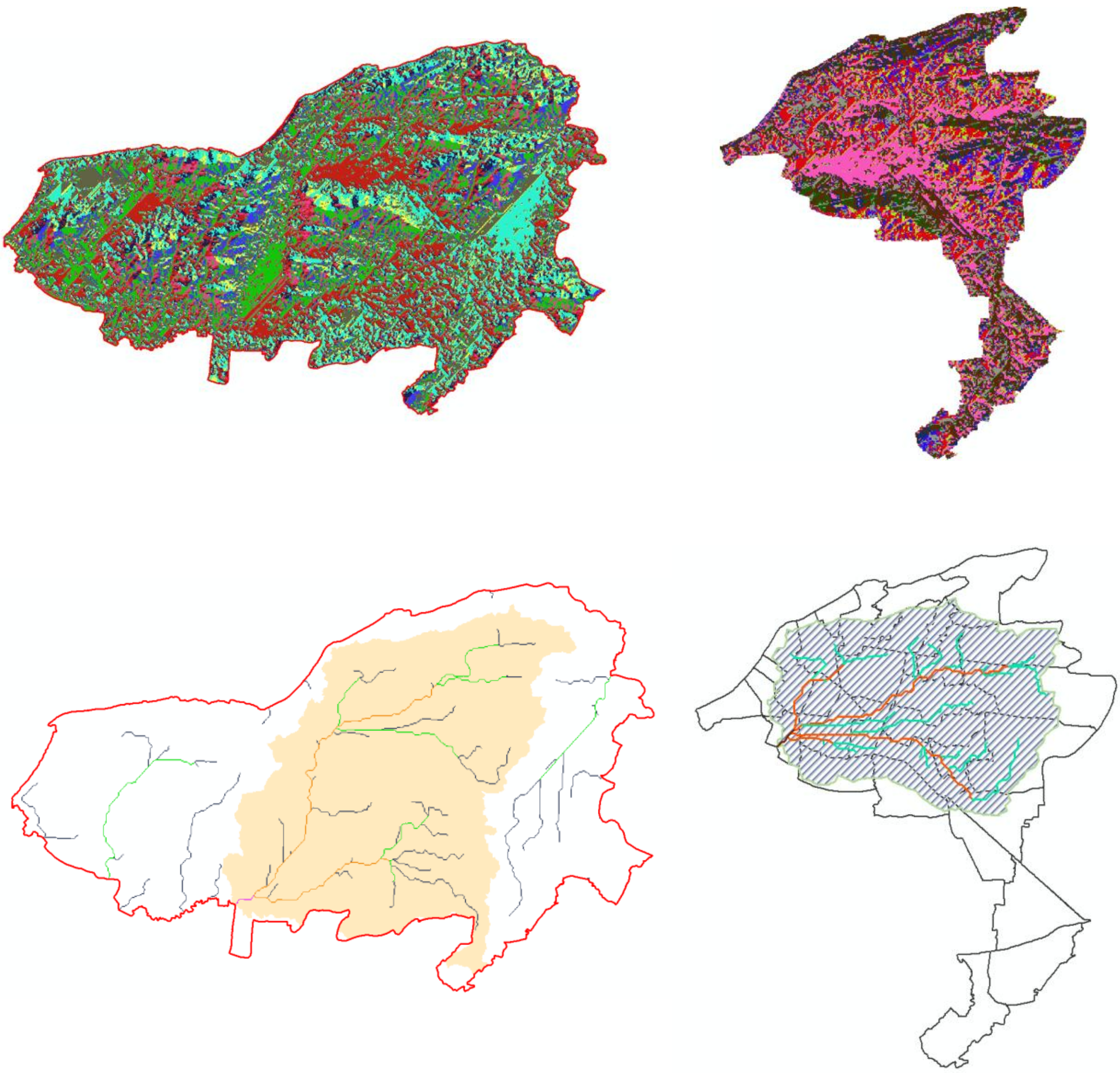


Fig: - 4.2 WATERSHED DELINEATION MAP

The **Pour Point Method** for watershed delineation provides key benefits for simulating drainage in urban environments. It allows for the precise determination of drainage boundaries and flow paths, which are critical for understanding water dynamics in densely built areas. By targeting specific pour points, such as stormwater outlets or confluence points, this method accurately identifies contributing areas and water flow patterns. This precision is invaluable for modeling urban drainage systems, identifying flood-prone regions, and developing effective stormwater management solutions. Moreover, its seamless integration with GIS tools ensures high data accuracy and facilitates advanced hydrological simulations to address urban drainage challenges effectively.

4.3 GENERATION OF INTENSITY-DURATION-FREQUENCY CURVE

4.3.1. Gathering Rainfall Data

Accurate and extensive rainfall data forms the foundation of an IDF curve.

- **Sources of Data:**
  Obtain rainfall records from reliable meteorological organizations (e.g IMD) or weather monitoring systems. Supplement data using satellite estimations or automated weather stations, if necessary.
- **Annual Maximum Rainfall:**
  Identify and record the highest annual rainfall amounts for various durations (e.g., 15 minutes, 1 hour, 6 hours) to capture the most intense events for analysis.
- **Time Span of Data:**
  Use datasets spanning 20–30 years or more to ensure statistical validity. Extended timeframes improve predictions for rare rainfall events.

4.3.2. Preparing the Data

Preparing the collected data is crucial for accurate analysis.

- **Structuring the Data:**
  Organize rainfall data into a table where each row corresponds to a year and each column represents a specific duration. Address any missing values by interpolating or referencing nearby stations with similar climatic patterns.
- **Statistical Analysis:**
  Calculate key statistics for each duration, including:
  - **Mean ($\bar{X}$)**: The average annual rainfall.
  - **Standard Deviation (S)**: The variability of rainfall values.
  - **Range**: Minimum and maximum rainfall amounts.

4.3.3. Ranking Data and Calculating Return Periods

Ranking helps to estimate the probability of rainfall events.

- **Sorting Data:**
  Arrange the annual maximum rainfall values in descending order for each duration, starting with the highest.
- **Assigning Ranks:**
  Rank the sorted values, assigning a rank of 1 to the largest value, 2 to the next, and so forth.
- **Determining Return Periods:**
  Use the formula: T = $\frac{n+1}{m}$

  Where T is the return period, n is the total number of years in the dataset, and m is the rank.

4.3.4. Applying a Gumbel Distribution

Extreme rainfall events are statistically analyzed using probability distributions.

- **Rationale for Gumbel Distribution:**
  The Gumbel distribution effectively models rare, high-intensity rainfall events and simplifies extrapolation for extreme scenarios.
- **Computing the Reduced Variate (Y_T):**
  Transform return periods into a dimensionless scale using: $Y_T = -\ln(-\ln(1 - \frac{1}{T}))$
- **Estimating Distribution Parameters:**
  Calculate the location (β) and scale (α) parameters:
  - **Scale Parameter (α):** Reflects the range of data: α = $\frac{S\sqrt{6}}{\pi}$
  - **Location Parameter (β\beta):** Centers the distribution: β = $\bar{X} - 0.5772\,.\alpha$
- **Rainfall Depth (X_T):**
  Derive rainfall depths for each return period using: $X_T = \beta + \alpha\,.Y_T$

4.3.5. Converting Depth to Intensity

Rainfall depths must be converted to intensities for practical use.

- **Conversion Formula:** $I_T = \frac{X_T}{D}$

  Where I_T is rainfall intensity (mm/hr), $X_T$is rainfall depth, and D is the duration in hours.

4.3.6. Plotting IDF Curves

Visual representation simplifies understanding and application.

- **Setting Axes:**
  - The **X-axis** represents return periods (T) on a logarithmic or semi-logarithmic scale.
  - The **Y-axis** displays rainfall intensities (I_T) in mm/hr.
- **Plotting for Durations:**
  Plot intensity values against return periods for each duration. The resulting graph displays a family of curves, each corresponding to a specific storm duration.
- **Annotating the Graph:**
  Clearly label the curves by duration (e.g., 2Y – 120min, 10Y – 120min, & 25Y – 120min) and use a legend for clarity.

In this way, IDF curve will be derived for my study area which required as an input data in alternative block method for generation of real-time design storm data as an time series value for any hydrological model.

4.4 GENERATING TIME-SERIES BY ALTERNATIVE BLOCK METHOD

The **Alternative Block Method (ABM)** is a structured approach employed to generate synthetic rainfall time series that are used in hydrological modeling. This method helps in creating realistic temporal patterns of rainfall intensities, ensuring that peak rainfall events and their distribution align with natural storm behavior. Below are the detailed and expanded steps to generate a time series using ABM:

1. Collect Input Data

Before starting the time series generation process, it is essential to gather the required input data:

- **Design Rainfall Depths:**
  The first step is to obtain the total rainfall depths for a given storm event. These depths are typically provided for different return periods (e.g., 2-year, 10-year and 25-year) and durations (e.g., 2-hour) from an **Intensity-Duration-Frequency (IDF)** curve. The IDF curve represents the relationship between the storm's intensity, duration, and frequency, which is crucial for understanding the expected rainfall behavior in a region.
- **Time Intervals:**
  The next step involves deciding on the time interval or time step for the time series. Common choices include intervals of 15 minutes, depending on the level of detail required for the model. The total storm duration is then divided into these intervals, ensuring each time step reflects the temporal distribution of rainfall for the entire events

2. Determine Rainfall Intensities

Once the input data is collected, the next step is to convert the total rainfall depth into intensities that are applied over the storm duration:

- **Convert Depth to Intensity:**
  To calculate the rainfall intensity, the total rainfall depth (D) is divided by the storm duration (T). This gives the average rainfall intensity over the storm's duration, expressed in millimeters per hour (mm/hr). The formula is:

$$I = \frac{D}{T}$$

where I represent the rainfall intensity, D is the rainfall depth, and T is the total duration of the storm in hours. This calculation ensures that the total rainfall depth is appropriately distributed over the entire storm duration.

- **Define Temporal Distribution Ratios:**
  After obtaining the rainfall intensities, the next task is to define the temporal distribution of rainfall. This involves breaking the total rainfall depth into smaller blocks, each corresponding to a specific fraction of the total storm intensity. Predefined temporal distribution ratios, often derived from historical storm data or hydrological guidelines, help determine how rainfall intensities are distributed over time. These ratios account for the natural variations in rainfall, ensuring that the time series has a realistic pattern.

3. Identify Peak Intensity

The peak rainfall intensity is one of the most critical aspects of a rainfall time series, as it often influences the hydrological response (such as runoff or flooding). Determining its position in the time series is crucial:

- **Positioning the Peak:**
  In the case of symmetrical storms, the peak intensity is typically placed at the midpoint of the storm duration. This positioning reflects the natural progression of storms, where the heaviest rainfall often occurs in the middle.
  However, for storms that exhibit asymmetrical patterns (e.g., quick onset or tailing off), the peak intensity may be shifted toward the start or end of the time series to more accurately represent the storm's characteristics.

4. Arrange Rainfall Blocks

The next step involves organizing the rainfall blocks, each representing a specific intensity, around the identified peak:

- **Alternative Block Placement:**
  The largest block, representing the peak intensity, is placed at the center of the time series (or at a specified location for asymmetrical storms). Once the peak is positioned, the next-largest blocks are placed alternately before and after the peak, with each subsequent block decreasing in intensity. This alternating pattern helps

create a realistic rainfall profile, where the rainfall intensity gradually decreases from the peak in both directions.

By repeating this process until all blocks are placed, the final time series will reflect a storm event with varying rainfall intensities that replicate natural storm behavior.

5. Verify Total Rainfall

It is essential to verify that the total rainfall in the generated time series matches the design rainfall depth to ensure the time series is accurate:

- **Check the Sum of Blocks:**

  The total rainfall in the time series can be calculated by summing the product of intensity (I_i) for each block and the time step (Δt). This gives the total rainfall for the storm event, and it should match the expected design rainfall depth.

  Total Rainfall = $\sum_{i=1}^{n} I_i \,.\, \Delta t$

  where I_i is the intensity of block i, and Δt is the time interval between blocks

6. Create the Time Series

After arranging the rainfall blocks and verifying the total rainfall, the final step is to create the time series:

- **Plotting the Time Series:**

  The time series is constructed by plotting the rainfall intensity against time. The resulting curve should show a smooth progression of rainfall, with the peak intensity at the designated position and gradually decreasing intensities before and after the peak. This curve visually represents the storm event and serves as the input for further hydrological modeling.

7. Use in Hydrological Modeling

The time series generated using the ABM can now be used for hydrological analysis:

- **Input for Simulation:**

  The generated time series is input into hydrological modeling software, such as SWMM (Storm Water Management Model). These models simulate runoff, drainage, and flood response based on the synthetic rainfall data.

- **Analyze Results:**

  Once the simulations are run, the results can be analyzed to understand the system's performance. Key metrics such as peak discharge, runoff volume, and flood risks are assessed to evaluate how well the drainage system or watershed can handle the modeled storm event.

4.5 SELECTING FLOOD-PRONE AREAS OF BHARALU BASIN FOR SIMULATION

Table: - 4.1 FLOOD PRONE WARD NO

S.No	Location	Ward Numbers
1	Geetanagar / Hatigaon Chariali upto Narengi	37, 42
2	G.N.B Road from Guwahati Club to Noonmati (Except New Guwahati Area)	33, 31
3	R.G. Baruah Road	39, 38, 37, 54, 49
4	Maligaon / Durgasarobar	9, 10
5	Guwahati College approach road	36, 53
6	Nabagraha Road and nearby areas	33, 34
7	Along the Kanwachal Road (southern part)	35, 23, 34
8	Nabin Nagar / Anil Nagar / Ambikagiri Nagar / Tarun Nagar / Lachit Nagar upto Bhangagarh	39
9	Srimantapur	28
10	Christianbasti area of G.S Road	40
11	Rukminigaon, Mathura Nagar, low-lying areas in Beltola	48, 49, 41
12	Some areas on the A.T. Road	18, 16, 31
13	Santipur – Bharalumukh	14
14	Fatasil Ambari	20
15	B.Baruah Road	36
16	Hedayatpur	33, 36, 35
17	Lamb Road, Ambari	32, 31
18	Gandhibasti area	36, 54
19	B.K Kakoti Road	29, 30
20	Kachari Garigaon	1

The areas highlighted in the table above are routinely impacted by stormwater, especially during the monsoon season, when the existing drainage infrastructure is often unable to cope with the high-intensity rainfall that exceeds its designed capacity. To evaluate the level of strain on these systems, a sewerage analysis was performed using the SWMM (1-D) model. This analysis was conducted to assess the ability of the drainage systems to function under pressure during rainfall events. The study specifically focused on the areas marked in red, corresponding to the respective ward numbers. The analysis was performed for multiple return periods (2 years, 10 years, and 25 years), with a 120-minute duration and 15-minute intervals, to assess the drainage systems' performance in managing different rainfall intensities and their efficiency in handling stormwater runoff.

4.6 STORM WATER MANAGEMENT MODEL (SWMM)

The **Storm Water Management Model (SWMM)** is an advanced computational tool used to simulate rainfall-runoff dynamics, based on the principles of mass, momentum, and energy conservation. Renowned for its adaptability, SWMM is extensively utilized for designing, analyzing, and planning drainage systems, as well as for evaluating the quality and quantity of runoff in urban settings (Rossman, 2010). Its ability to model the intricate interactions between precipitation, land surfaces, and drainage infrastructure makes it an invaluable resource for engineers and hydrologists alike.

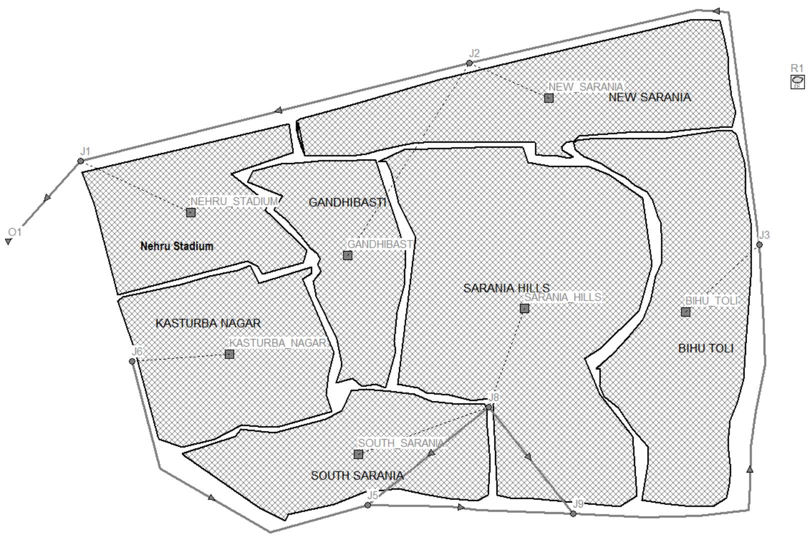
A key strength of SWMM is its capability to accurately predict both runoff quantity and quality within individual catchments and through the network of interconnected pipes and channels over a simulation period. Compared to other hydrological models, SWMM excels in capturing the timing and intensity of peak runoff events, with its results often closely mirroring observed data. This precision enhances its reliability and effectiveness in hydrological analyses.

In this study, each catchment area—comprising impervious surfaces like roads and pavements, as well as pervious areas like parks and green spaces—was modeled as a nonlinear reservoir. The model computes net rainfall and determines how excess runoff flows between catchments. To simulate changes in runoff over time, SWMM employs a combination of the continuity equation and Manning's equation, ensuring accurate representation of flow dynamics.

The infiltration process, essential for understanding water movement into the soil, is modeled using the **Green-Ampt method**, which is adapted to the unique soil and climatic conditions of the study area. For hydraulic calculations within the drainage network, the **Dynamic Wave method** is applied, offering a robust approach to simulating unsteady flow conditions, including backwater effects, flow reversals, and surcharging in the sewer system.

Globally, the **EPA's Storm Water Management Model (SWMM)** is widely recognized for its application in urban and non-urban areas. It is extensively used for planning, analyzing, and designing systems to manage stormwater runoff, combined sewer overflows, and sanitary sewer networks. Its versatility extends to rural and semi-urban drainage challenges. SWMM tracks various hydrological parameters, including runoff volume, flow rate, depth, and water quality, across drainage systems during simulations composed of multiple time steps. This temporal resolution provides a detailed understanding of stormwater behavior and system performance.

With its comprehensive algorithms and adaptable structure, SWMM remains at the forefront of urban hydrology modeling. It serves as an essential tool for tackling modern water management challenges, supporting the design of resilient infrastructure and informed decision-making in stormwater management.



Above fig [] is the project of ward no 36 of GMC where the catchment is divided into 7 sub-catchments in SWMM window.

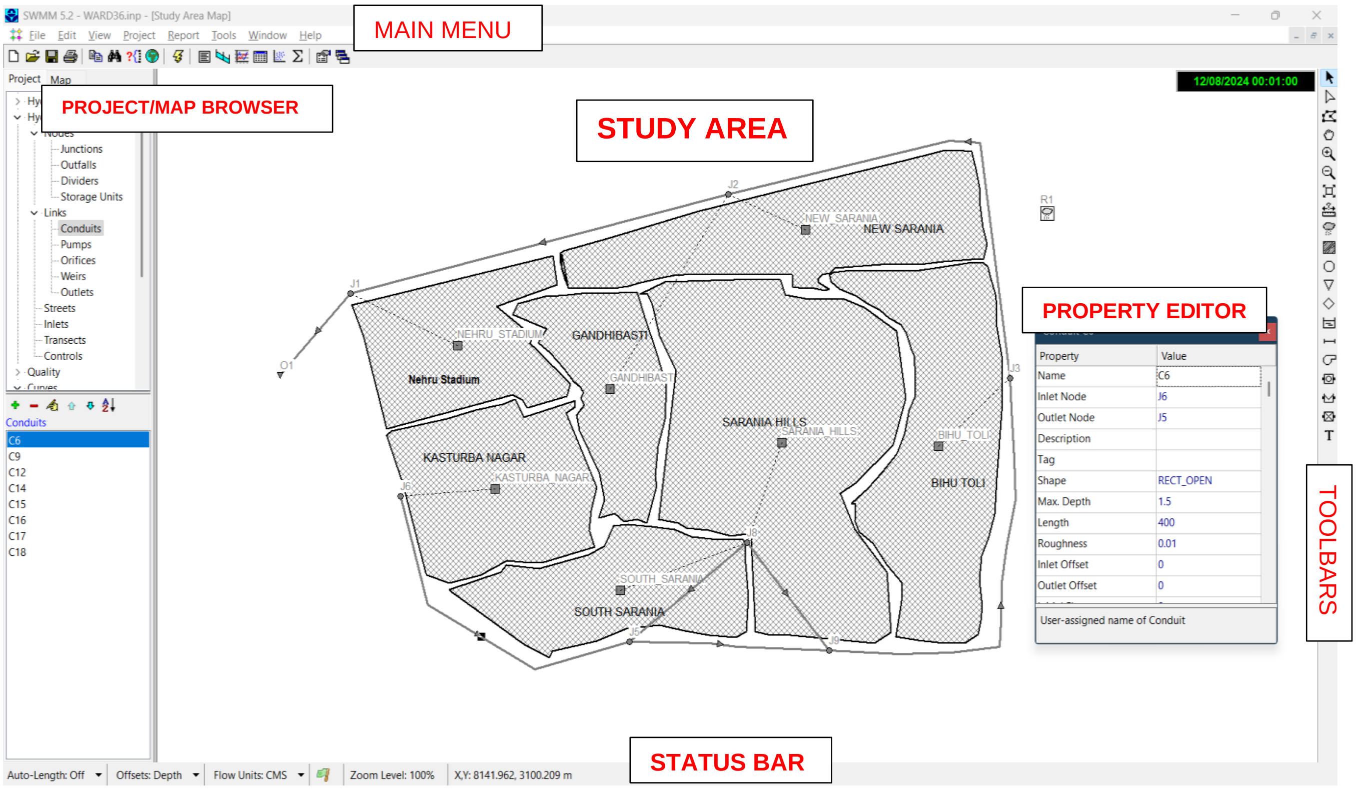
Following methods which were adopted for performing simulation is given as further topics

4.6.1 SWMM'S MAIN WINDOW

Here, it covers the key components of SWMM's workspace. It explains the main menu bar, toolbars, and status bar, along with the three primary windows—the ***Study Area Map****, the* ***Browser****, and the* ***Property Editor****. Additionally, it provides guidance on configuring program preferences.*

4.6.1.1 Overview

The main window of EPA SWMM is shown below and includes several key user interface components: the **Main Menu**, multiple **Toolbars**, a **Status Bar**, the **Study Area Map** window, the **Browser** panel, and the **Property Editor** window. Detailed explanations of each of these elements are provided in the following sections.



4.6.1.2 Main Menu

The Main Menu is positioned at the top of the EPA SWMM main window and provides access to various menus for managing the program. These menus include:

- File Menu
- Edit Menu
- View Menu
- Project Menu
- Report Menu
- Tools Menu
- Window Menu
- Help Menu

File Menu

The File Menu offers commands for managing data files and printing tasks:

Command	Description
New	Creates a new SWMM project.
Open	Opens an existing project.
Reopen	Reopens a recently accessed project.
Save	Saves the current project.
Save As	Saves the current project with a new name.
Export	Exports the study area map in various formats, saves current results as a Hot Start file, or exports Status/Summary reports.
Combine	Merges two Routing Interface files.
Page Setup	Configures page margins and orientation for printing.
Print Preview	Displays a preview of the current view (map, report, graph, or table) before printing.
Print	Prints the currently active view.
Exit	Closes the EPA SWMM program.

Edit Menu

The Edit Menu provides various options for editing and copying elements:

Command	Description
Copy To	Copies the active view (map, report, graph, or table) to the clipboard or saves it to a file.
Select Object	Allows the selection of an object on the map.
Select Vertex	Enables selection of a vertex from a subcatchment or link.
Select Region	Lets users define a region on the map to select multiple objects.
Select All	Selects all objects on the map or all cells in a table when a tabular report is active.
Find Object	Searches for and locates a specific object on the map by name.
Edit Object	Opens the properties of the selected object for editing.
Delete Object	Removes the currently selected object.
Group Edit	Allows editing of a property for multiple objects within a selected map region.
Group Delete	Deletes multiple objects within a selected area on the map.

View Menu

The View Menu offers commands for navigating and customizing the Study Area Map:

Command	Description
Dimensions	Sets the reference coordinates and measurement units for the map.
Backdrop	Adds, adjusts, and displays a background image behind the map.
Pan	Moves across different areas of the map.
Zoom In	Magnifies the map view.
Zoom Out	Reduces the map view.
Full Extent	Resets and redraws the map to its full extent.
Query	Highlights map objects that meet specified conditions.
Overview	Shows or hides the Overview Map for better navigation.
Objects	Controls the visibility of different object categories on the map.
Legends	Manages the display of map legends.
Toolbars	Shows or hides various toolbars in the workspace.

Project Menu

The Project Menu offers commands for managing and analyzing the current project:

Command	Description
Summary	Displays a count of each object type within the project.
Details	Provides a comprehensive list of all project data.
Defaults	Allows editing of the project's default settings.
Calibration Data	Links calibration data files to the project.
Add a New Object	Inserts a new object into the project.
Run Simulation	Initiates a simulation run for the project.

Report Menu

The Report Menu includes commands for presenting analysis results in various formats:

Command	Description
Status	Shows a status report of the latest simulation run.
Summary	Presents summary results in a table format.
Graph	Displays simulation outcomes as graphs.
Table	Shows simulation results in a table format.
Statistics	Provides a statistical breakdown of the simulation results.
Customize	Adjusts the visual style of the currently active graph.

Tools Menu

The Tools Menu provides options for setting program preferences, customizing the map display, and managing external tools:

Command	Description
Program Preferences	Configures program settings like font size, deletion confirmations, and decimal precision.
Map Display Options	Adjusts map visuals, including object size, labels, flow direction arrows, and background color.
Configure Tools	Adds, removes, or edits external add-in tools.

Window Menu

The Window Menu offers options for organizing and selecting open windows within the SWMM workspace:

Command	Description
Cascade	Arranges the windows in a cascading layout, with the study area map occupying the entire display.
Tile	Minimizes the study area map and arranges the remaining windows vertically within the display area.
Close All	Closes all open windows except for the study area map.
Window List	Displays a list of all open windows. The currently selected window is marked with a check.

Help Menu

The **Help Menu** provides access to various resources for assistance with using EPA SWMM:

Command	Description
Help Topics	Opens the Table of Contents for the Help system.
How Do I	Displays a list of topics for common tasks and operations.
Measurement Units	Shows the units of measurement used for all SWMM parameters.
Error Messages	Provides explanations for all error messages encountered in the program.
Tutorial	Offers a brief tutorial to help users get started with EPA SWMM.
About	Displays information about the version of EPA SWMM currently in use.

4.6.1.3 Toolbars

Toolbars provide shortcuts to commonly used operations. There are three such toolbars:

- Standard Toolbar
- Map Toolbar
- Object Toolbar

Individual toolbars can be made visible or invisible by selecting **View** >> **Toolbars** from the Main Menu.

The **Standard Toolbar** contains buttons for the following commonly used commands:

Creates a new project (**File** >> **New**)

Opens an existing project (**File** >> **Open**) Saves the current project (**File** >> **Save**)

Prints the currently active window (**File** >> **Print**)

Copies selection to the clipboard or to a file (**Edit** >> **Copy To**)

Finds a specific object on the Study Area Map (**Edit** >> **Find Object**) Makes a visual query of the study area map (**View** >> **Query**)

Toggles the display of the Overview Map (**View** >> **Overview**) Runs a simulation (**Project** >> **Run Simulation**)

Displays a run's Status or Summary reports (**Report** >> **Status** and **Report** >> **Summary** appear in a dropdown menu)

Creates a profile plot of simulation results (**Report** >> **Graph** >> **Profile**)

Creates a time series plot of simulation results (**Report** >> **Graph** >> **Time Series**)

Creates a time series table of simulation results (**Report** >> **Table**)

Creates a scatter plot of simulation results (**Report** >> **Graph** >> **Scatter**)

Σ Performs a statistical analysis of simulation results (**Report** >> **Statistics**)

Modifies display options for the currently active view (**Tools** >> **Map Display Options** or **Report** >> **Customize**)

Arranges windows in cascaded style, with the study area map filling the entire display area (**Window** >> **Cascade**)

The **Map Toolbar** contains the following buttons for viewing the study area map:

Selects an object on the map (**Edit** >> **Select Object**)

Selects link or subcatchment vertex points (**Edit** >> **Select Vertex**)

Selects a region on the map (**Edit** >> **Select Region**)

Pans across the map (**View** >> **Pan**)

Zooms in on the map (**View** >> **Zoom In**)

Zooms out on the map (**View** >> **Zoom Out**)

Draws map at full extent (**View** >> **Full Extent**)

Measures a length or area on the map

The **Object Toolbar** contains buttons for adding visual objects to a project via the study area map.

Adds a rain gage to the map.

Adds a subcatchment to the map

Adds a junction node to the map

Adds an outfall node to the map

Adds a flow divider node to the map

Adds a storage unit node to the map

Adds a conduit link to the map

Adds a pump link to the map

Adds an orifice link to the map

Adds a weir link to the map

Adds an outlet link to the map

T Adds a text label to the map

4.6.1.4 Status Bar

The Status Bar appears at the bottom of SWMM's Main Window and is divided into six sections:

Auto-Length

Indicates whether the automatic calculation of conduit lengths and subcatchment areas is enabled or disabled. This setting can be modified by clicking the drop-down arrow.

Offsets

Shows whether the positions of links relative to the invert of their connecting nodes are expressed as a **Depth** above the node invert or as the **Elevation** of the offset. You can switch this option using the drop-down arrow. If changed, a dialog box will prompt whether to update all existing offsets in the project (i.e., convert Depth offsets to Elevation offsets or vice versa, depending on the chosen option).

Flow Units

Displays the current flow units being used. You can change the flow units by selecting a new option from the drop-down menu. If a US flow unit is selected, all other quantities will be in US units, while choosing a metric flow unit will convert all quantities to metric units. Note that previously entered data will not automatically adjust when the unit system is changed.

Run Status

- results are not available because no simulation has been run yet. results are up to date.
- results are out of date because project data have changed.
- results are not available because the last simulation had errors.

Zoom Level

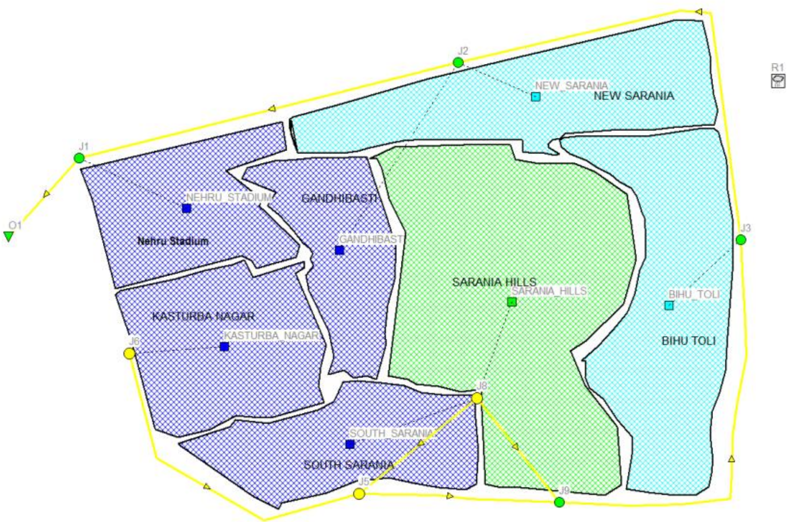
Displays the current zoom level for the map (100% is full-scale).

XY Location

Displays the map coordinates of the current position of the mouse pointer.

4.6.1.5 Study Area Map

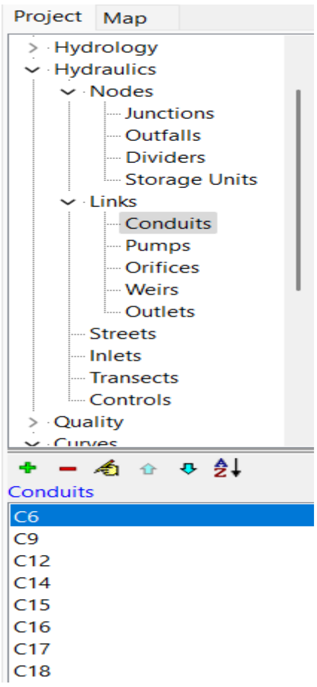
The **Study Area Map** offers a flat, schematic representation of the objects that make up a drainage system. Its key features include:



- The placement of objects and the distances between them on the map do not have to reflect their actual physical scale.
- Properties of these objects, such as water quality at nodes or flow velocity in links, can be visually represented using different colours. These colour codes are explained in a **Legend**, which can be customized.
- New objects can be added directly to the map, and existing objects can be selected for editing, deletion, or repositioning.
- A background image (e.g., a street or topographic map) can be placed behind the network map for reference.
- The map allows zooming to any scale and panning across different positions.
- Nodes and links can be displayed in various sizes, with flow direction arrows, object symbols, ID labels, and numerical property values shown.
- The map can be printed, copied to the Windows clipboard, or exported as a DXF file or Windows metafile.

4.6.1.6 Project Browser

The **Project Browser** panel (shown below) is displayed when the **Project** tab on the left side of SWMM's main window is selected. It allows access to all data objects within a project. The vertical size of the list boxes within the browser can be adjusted using the splitter bar beneath the top list box. Additionally, the width of the **Browser** panel can be resized using the splitter bar along its right edge.



The upper list box displays the various categories of data objects available to a SWMM project. The lower list box lists the name of each individual object of the currently selected data category.

The buttons between the two list boxes are used as follows: adds a new object

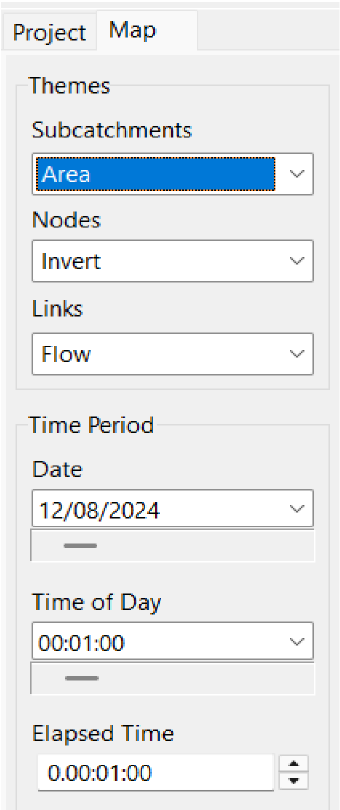
deletes the selected object edits the selected object

moves the selected object up one position moves the selected object down one position sorts the objects in ascending order

Selections made in the Project Browser are coordinated with objects highlighted on the Study Area Map, and vice versa. For example, selecting a conduit in the Browser will cause that conduit to be highlighted on the map, while selecting it on the map will cause it to become the selected object in the Browser.

4.6.1.7 Map Browser

The Map Browser panel (shown below) appears when the Map tab on the left panel of the SWMM's main window is selected. It controls the mapping themes and time periods viewed on the Study Area Map. The width of the Map Browser panel can be adjusted by using the splitter bar located along its right edge. The Map Browser consists of the following three panels that control what results are displayed on the map

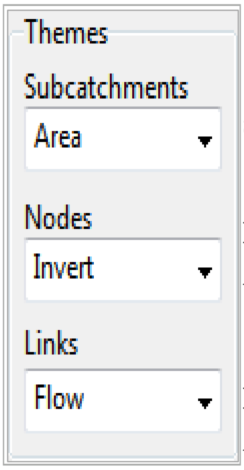


The Themes panel selects a set of variables to view in color-coded fashion on the Map.

The Time Period panel selects which time period of the simulation results are viewed on the Map.

The Animator panel controls the animated display of the Study Area Map and all Profile Plots over time.

The Themes panel of the Map Browser is used to select a thematic variable to view in color- coded fashion on the Study Area Map.

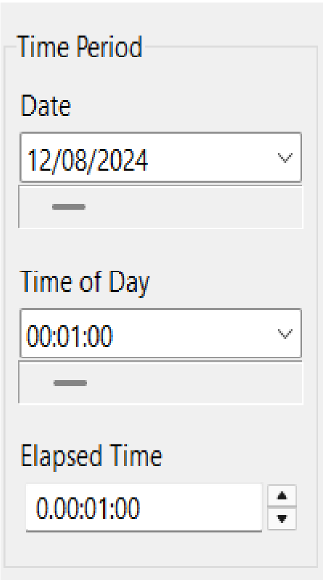


Subcatchments - selects the theme to display for the subcatchment areas shown on the Map.

Nodes - selects the theme to display for the drainage system nodes shown on the Map.

Links - selects the theme to display for the drainage system links shown on the Map.

The Time Period panel of the Map Browser allows is used to select a time period in which to view computed results in thematic fashion on the Study Area Map.

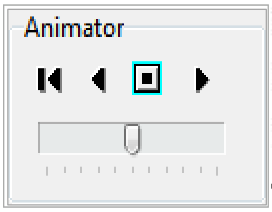


Date - selects the day for which simulation results will be viewed.

Time of Day - selects the time of the current day (in hours:minutes:seconds) for which simulation results will be viewed.

Elapsed Time - selects the elapsed time from the start of the simulation (in days.hours:minutes:seconds) for which results will be viewed.

The Animator panel of the Map Browser contains controls for animating the Study Area Map and all Profile Plots through time i.e., updating map color-coding and hydraulic grade line profile depths as the simulation time clock is automatically moved forward or back. The meaning of the control buttons are as follows:



Returns to the starting period.

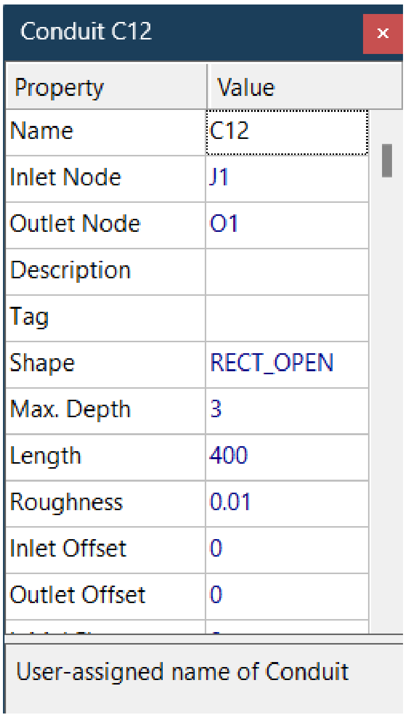
Starts animating backwards in time Stops the animation

Starts animating forwards in time

The slider bar is used to adjust the animation speed.

4.6.1.8 Property Editor

The **Property Editor** (shown to the right) is used to modify the properties of data objects that can be displayed on the **Study Area Map**. It is accessed by selecting an object (either from the map or the **Project Browser**) and double-clicking it, or by clicking the **Edit** button in the **Project Browser**.



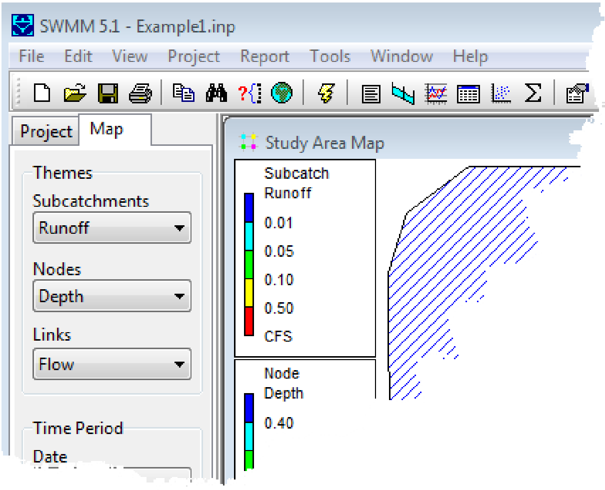
- Key features of the **Property Editor** include:
- The editor is a grid with two columns: one for the property name and the other for its value.
- You can resize the columns by adjusting the header at the top of the editor.
- A hint area at the bottom of the editor provides an expanded description of the property being edited, and its size can be adjusted using the splitter bar above it.
- The **Editor** window can be moved and resized using standard Windows operations.
- Depending on the property, the value field can take different forms:
    - A text box for entering values.
    - A dropdown combo box for selecting a value from a list.
    - A combo box that allows both entering a value and selecting from a list.
    - An ellipsis button that opens a specialized editor.
- The field currently focused on will be highlighted with a focus rectangle.

- Both the mouse and the Up and Down arrow keys can be used to navigate between fields.
- The **Page Up** key selects the previous object of the same type in the **Project Browser**, while **Page Down** selects the next object of the same type.
- To begin editing, either start typing or press **Enter**.
- To confirm edits, press **Enter** or move to another property. To cancel, press **Esc**.
- The **Property Editor** can be hidden by clicking the button in the upper right corner of its title bar.

4.6.2 WORKING WITH THE MAP

4.6.2.1 Selecting a Map Theme

A map theme displays object properties in color-coded fashion on the Study Area Map. The dropdown list boxes on the Map Browser are used for selecting a theme to display for Subcatchments, Nodes and Links.

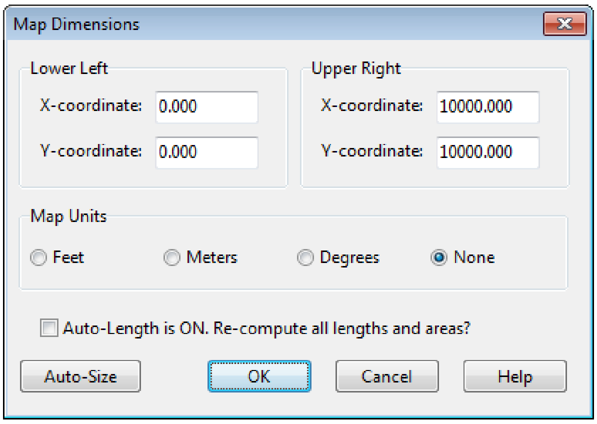


4.6.2.2 Setting the Map's Dimensions

The physical dimensions of the map can be defined so that map coordinates can be properly scaled to the computer's video display. To set the map's dimensions:

1. Select View >> Dimensions from the Main Menu.

2. Enter coordinates for the lower-left and upper-right corners of the map into the Map Dimensions dialog (see below) that appears or click the Auto-Size button to automatically set the dimensions based on the coordinates of the objects currently included in the map.



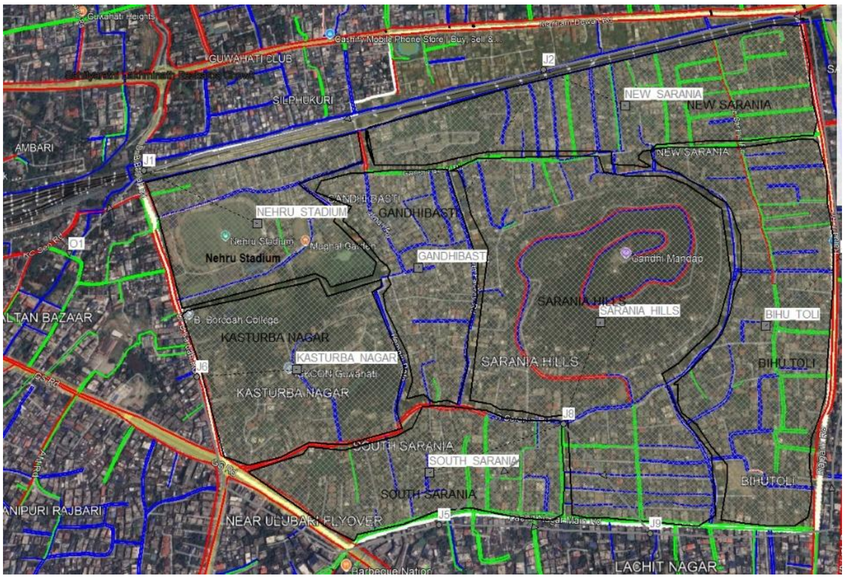
3. Select the distance units to use for these coordinates.

4. If the **Auto-Length** option is in effect, check the “Re-compute all lengths and areas” box if you would like SWMM to re-calculate all conduit lengths and subcatchment areas under the new set of map dimensions.

5. Click the **OK** button to resize the map.

4.6.2.3 Utilizing a Backdrop Image

SWMM can display a backdrop image behind the Study Area Map. The backdrop image might be a street map, utility map, topographic map, site development plan, or any other relevant picture or drawing. For example, using a street map would simplify the process of adding sewer lines to the project since one could essentially digitize the drainage system's nodes and links directly on top of it.



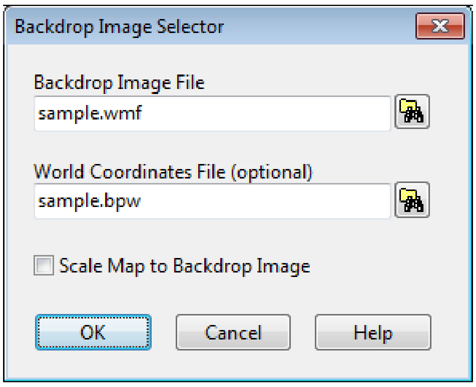
The backdrop image must be a Windows metafile, bitmap, or JPEG image created outside of SWMM. Once imported, its features cannot be edited, although its scale and viewing area will change as the map window is zoomed and panned. For this reason metafiles work better than bitmaps or JPEGs since they will not lose resolution when re-scaled. Most CAD and GIS programs have the ability to save their drawings and maps as metafiles.

Selecting **View** >> **Backdrop** from the Main Menu will display a sub-menu with the following commands:

- **Load** (loads a backdrop image file into the project)
- **Unload** (unloads the backdrop image from the project)

- **Align** (aligns the drainage system schematic with the backdrop)
- **Resize** (resizes the map dimensions of the backdrop)
- **Watermark** (toggles the backdrop image appearance between normal and lightened)

To load a backdrop image select **View** >> **Backdrop** >> **Load** from the Main Menu. A Backdrop Image Selector dialog form will be displayed. The entries on this form are as follows



Backdrop Image File

Enter the name of the file that contains the image. You can click the button to bring up a standard Windows file selection dialog from which you can search for the image file.

World Coordinates File

If a "world" file exists for the image, enter its name here, or click the button to search for it. A world file contains geo-referencing information for the image and can be created from the software that produced the image file or by using a text editor. It contains six lines with the following information:

Line 1: real world width of a pixel in the horizontal direction.

Line 2: X rotation parameter (not used).

Line 3: Y rotation parameter (not used).

Line 4: negative of the real-world height of a pixel in the vertical direction.

Line 5: real world X coordinate of the upper left corner of the image.

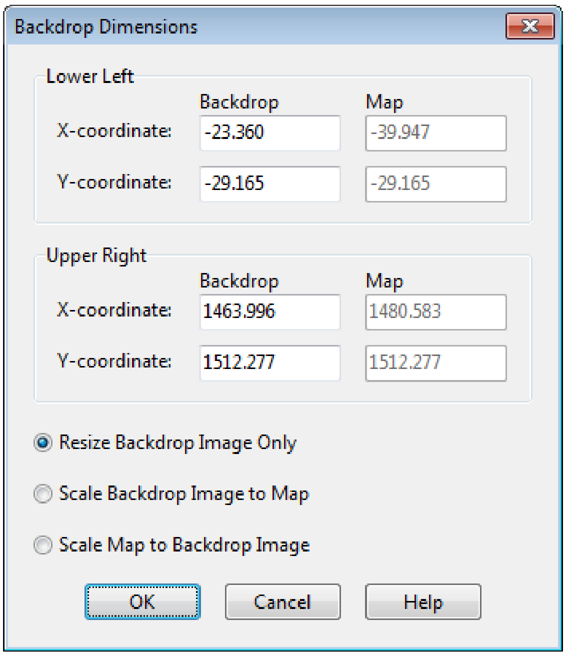
Line 6: real world Y coordinate of the upper left corner of the image.

If no world file is specified, then the backdrop will be scaled to fit into the center of the map display window.

Scale Map to Backdrop Image

This option is only available when a world file has been specified. Selecting it forces the dimensions of the Study Area Map to coincide with those of the backdrop image. In addition, all existing objects on the map will have their coordinates adjusted so that they appear within the new map dimensions yet maintain their relative positions to one another. Selecting this option may then require that the backdrop be re-aligned so that its position relative to the drainage area objects is correct. How to do this is described below.

The backdrop image can be re-positioned relative to the drainage system by selecting **View** >> **Backdrop** >> **Align**. This allows the backdrop image to be moved across the drainage system (by moving the mouse with the left button held down) until one decides that it lines up properly. The backdrop image can also be resized by selecting **View** >> **Backdrop** >> **Resize**. In this case the following Backdrop Dimensions dialog will appear.



The dialog lets you manually enter the X, Y coordinates of the backdrop's lower left and upper right corners. The Study Area Map's dimensions are also displayed for reference. While the dialog is visible you can view map coordinates by moving the mouse over the map window and noting the X, Y values displayed in SWMM's Status Panel (at the bottom of the main window).

Selecting the **Resize Backdrop Image Only** button will resize only the backdrop, and not the Study Area Map, according to the coordinates specified. Selecting the **Scale Backdrop Image to Map** button will position the backdrop image in the center of the Study Area Map and have

it resized to fill the display window without changing its aspect ratio. The map's lower left and upper right coordinates will be placed in the data entry fields for the backdrop coordinates, and these fields will become disabled. Selecting **Scale Map to Backdrop Image** makes the dimensions of the map coincide with the dimensions being set for the backdrop image. Note that this option will change the coordinates of all objects currently on the map so that their positions relative to one another remain unchanged. Selecting this option may then require that the backdrop be re-aligned so that its position relative to the drainage area objects is correct.
The name of the backdrop image file and its map dimensions are saved along with the rest of a project’s data whenever the project is saved to file.
For best results in using a backdrop image:

4.6.2.4 Measuring Distances

To measure a distance or area on the Study Area Map:

- Use a metafile, not a bitmap.
- If the image is loaded before any objects are added to the project, then scale the map to it.

1. Click on the Map Toolbar.
2. Left-click on the map where you wish to begin measuring from.
3. Move the mouse over the distance being measured, left-clicking at each intermediate location where the measured path changes direction.
4. Right-click the mouse or press <**Enter**> to complete the measurement.
5. The distance measured in project units (feet or meters) will be displayed in a dialog box. If the last point on the measured path coincides with the first point, then the area of the enclosed polygon will also be displayed.

4.4.2.5 Zooming the Map

To Zoom In on the Study Area Map:
1. Select **View** >> **Zoom In** from the Main Menu or click on the Map Toolbar.
2. To zoom in 100% (i.e., 2X), move the mouse to the center of the zoom area and click the left button.

3. To perform a custom zoom, move the mouse to the upper left corner of the zoom area and with the left button pressed down, draw a rectangular outline around the zoom area. Then release the left button.

To Zoom Out on the Study Area Map:

1. Select **View** >> **Zoom Out** from the Main Menu or click on the Map Toolbar.

2. The map will be returned to the view in effect at the previous zoom level.

4.6.2.6 Panning the Map

To pan across the Study Area Map window:

1. Select **View** >> **Pan** from the Main Menu or click on the Map Toolbar.

2. With the left button held down over any point on the map, drag the mouse in the direction you wish to pan in.

3. Release the mouse button to complete the pan.

To pan using the Overview Map:

1. If not already visible, bring up the Overview Map by selecting **View** >> **Overview Map** from the Main Menu or click the button on the Standard Toolbar.

2. If the Study Area Map has been zoomed in, an outline of the current viewing area will appear on the Overview Map. Position the mouse within this outline on the Overview Map.

3. With the left button held down, drag the outline to a new position.

4. Release the mouse button and the Study Area Map will be panned to an area corresponding to the outline on the Overview Map.

4.6.2.7 Viewing at Full Extent

To view the Study Area Map at full extent, either:

- select **View** >> **Full Extent** from the Main Menu, or
- press on the Map Toolbar.

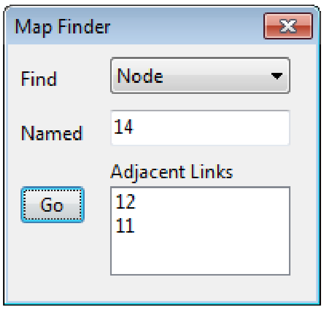
4.6.2.8 Finding an Object

To find an object on the Study Area Map whose name is known:

1. Select **View** >> **Find Object** from the Main Menu or click on the Standard Toolbar.

2. In the Map Finder dialog that appears, select the type of object to find and enter its name.

3. Click the **Go** button.

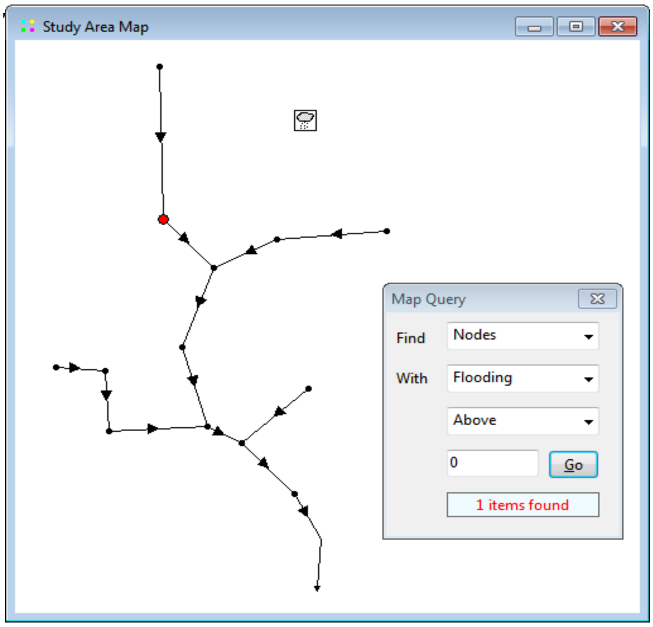


If the object exists, it will be highlighted on the map and in the Data Browser. If the map is currently zoomed in and the object falls outside the current map boundaries, the map will be panned so that the object comes into view.

4.6.2.9 Submitting a Map Query

A Map Query identifies objects on the study area map that meet a specific criterion (e.g., nodes which flood, links with velocity below 2 ft/sec, etc.). It can also identify which subcatchments have LID controls and which nodes have external inflows. To submit a map query:

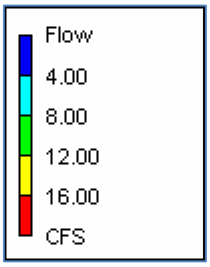
1. Select a time period in which to query the map from the Map Browser.
2. Select View >> Query or click on the Standard Toolbar.
3. Fill in the following information in the Query dialog that appears:
   - Select whether to search for Subcatchments, Nodes, Links, LID Subcatchments or Inflow Nodes.
   - Select a parameter to query or the type of LID or inflow to locate.
   - Select the appropriate operator: Above, Below, or Equals.
   - Enter a value to compare against.
4. Click the Go button. The number of objects that meet the criterion will be displayed in the Query dialog and each such object will be highlighted on the Study Area Map.
5. As a new time period is selected in the Browser, the query results are automatically updated.
6. You can submit another query using the dialog box or close it by clicking the button in the upper right corner.



After the Query box is closed the map will revert back to its original display.

4.6.2.10 Using the Map Legends

Map Legends associate a color with a range of values for the current theme being viewed. Separate legends exist for Subcatchments, Nodes, and Links. A Date/Time Legend is also available for displaying the date and clock time of the simulation period being viewed on the map.



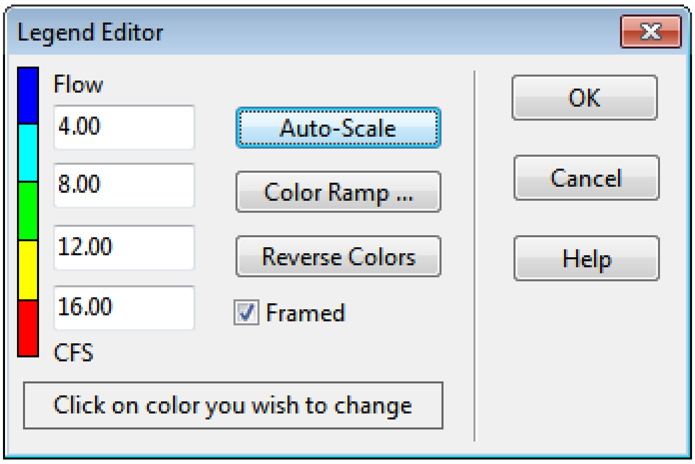
To display or hide a map legend:

1. Select View >> Legends from the Main Menu or right-click on the map and select Legends from the pop-up menu that appears
2. Click on the type of legend whose display should be toggled on or off.

A visible legend can also be hidden by double clicking on it.

To move a legend to another locations, press the left mouse button over the legend, drag the legend to its new location with the button held down, and then release the button.

To edit a legend, either select **View** >> **Legends** >> **Modify** from the Main Menu or right-click on the legend if it is visible. Then use the Legend Editor dialog that appears to modify the legend's colors and intervals.



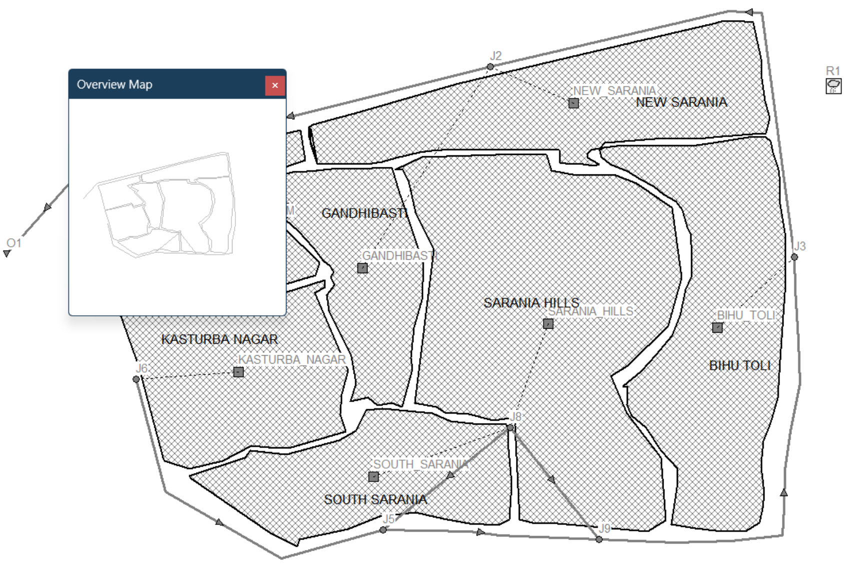
The Legend Editor is used to set numerical ranges to which different colors are assigned for viewing a particular parameter on the network map. It works as follows:

- Numerical values, in increasing order, are entered in the edit boxes to define the ranges. Not all four boxes need to have values.
- To change a color, click on its color band in the Editor and then select a new color from the Color Dialog that will appear.
- Click the Auto-Scale button to automatically assign ranges based on the minimum and maximum values attained by the parameter in question at the current time period.
- The Color Ramp button is used to select from a list of built-in color schemes.
- The Reverse Colors button reverses the ordering of the current set of colors (the color in the lowest range becomes that of the highest range and so on).
- Check Framed if you want a frame drawn around the legend.

Changes made to a legend are saved with the project's settings and remain in effect when the project is re-opened in a subsequent session.

4.6.2.11 Using the Overview Map

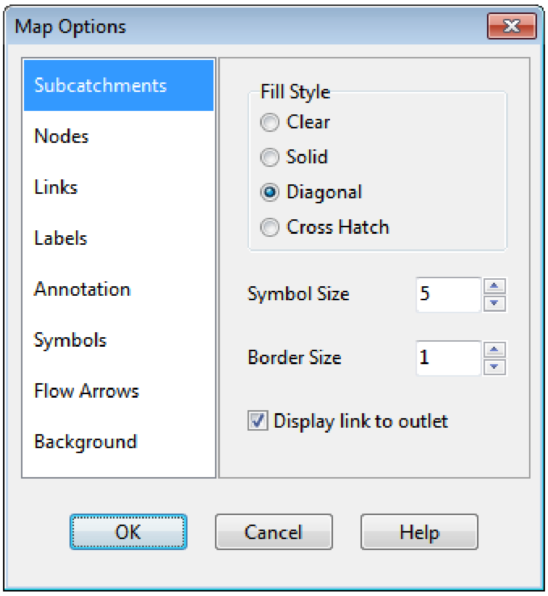
The Overview Map, as pictured below, allows one to see where in terms of the overall system the main Study Area Map is currently focused. This zoom area is depicted by the rectangular outline displayed on the Overview Map. As you drag this rectangle to another position the view within the main map will be redrawn accordingly. The Overview Map can be toggled on and off by selecting View >> Overview Map from the Main Menu or by clicking on the Standard Toolbar. The Overview Map window can also be dragged to any position as well as be re-sized.



4.6.2.12 Setting Map Display Options

The Map Options dialog (shown below) is used to change the appearance of the Study Area Map. There are several ways to invoke it:

- select Tools >> Map Display Options from the Main Menu or,
- click the Options button on the Standard Toolbar when the Study Area Map window has the focus or,
- right-click on any empty portion of the map and select Options from the popup menu that appears.



The dialog contains a separate page, selected from the panel on the left side of the form, for each of the following display option categories:

- Subcatchments (controls fill style, symbol size, and outline thickness of subcatchment areas)
- Nodes (controls size of nodes and making size be proportional to value)
- Links (controls thickness of links and making thickness be proportional to value)
- Labels (turns display of map labels on/off)
- Annotation (displays or hides node/link ID labels and parameter values)
- Symbols (turns display of storage unit, pump, and regulator symbols on/off)
- Flow Arrows (selects visibility and style of flow direction arrows)
- Background (changes color of map's background).

Subcatchment Options

The Subcatchments page of the Map Options dialog controls how subcatchment areas are displayed on the study area map.

Option	*Description*
Fill Style	Specifies the fill pattern used for the interior of the subcatchment area.
Symbol Size	Sets the size of the symbol (in pixels) placed at the centroid of a subcatchment area
Border Size	Adjusts the thickness of the border line around the subcatchment; setting it to zero displays only the centroid symbol.
Display Link to Outlet	When enabled, a dashed line connects the subcatchment centroid to its outlet node or outlet subcatchment.

Node Options

The Nodes page of the Map Options dialog controls how nodes are displayed on the study area map.

Option	Description
Node Size	Determines the diameter of nodes, measured in pixels.
Proportional to Value	Allows node size to scale according to the value of the displayed parameter.
Display Border	Adds a border around each node, recommended for better visibility on light backgrounds.

Link Options

The Links page of the Map Options dialog controls how links are displayed on the map.

Option	*Description*
Link Size	Adjusts the thickness of links displayed on the map, measured in pixels.
Proportional to Value	Enables link thickness to scale based on the magnitude of the viewed parameter.
Display Border	Toggles a black border around each link for better visual distinction.

Label Options

The Labels page of the Map Options dialog controls how user-created map labels are displayed on the study area map.

Option	Description
Use Transparent Text	Enable to display labels with a transparent background; otherwise, an opaque background will be applied.
At Zoom Of	Specifies the minimum zoom level for label visibility; labels will not be shown at zoom levels smaller than this.

Annotation Options

The Annotation page of the Map Options dialog form determines what kind of annotation is provided alongside of the objects on the study area map.

Option	Description
Rain Gage IDs	Enable to display the ID names of rain gauges.
Subcatch IDs	Enable to show the ID names of subcatchments.
Node IDs	Enable to display the ID names of nodes.
Link IDs	Enable to show the ID names of links.
Subcatch Values	Enable to display the current values of subcatchment variables
Node Values	Enable to display the current values of node variables.
Link Values	Enable to show the current values of link variables.
Use Transparent Text	Enable to display text with a transparent background; otherwise, an opaque background is used.
Font Size	Adjust the font size for annotations.
At Zoom Of	Determines the minimum zoom level for displaying annotations; annotations will not appear at lower zoom levels.

Symbol Options

The Symbols page of the Map Options dialog determines which types of objects are represented with special symbols on the map.

Option	Description
Display Node Symbols	When enabled, unique symbols will represent nodes.
Display Link Symbols	When enabled, distinctive symbols will represent links.
At Zoom Of	Determines the minimum zoom level at which symbols will appear; they will not be displayed at lower zoom levels.

Flow Arrow Options

The Flow Arrows page of the Map Options dialog controls how flow-direction arrows are displayed on the map.

Option	Description
Arrow Style	Specifies the arrow's shape or style (choose "None" to hide arrows entirely).
Arrow Size	Adjusts the dimensions of the arrows.
At Zoom Of	Defines the minimum zoom level required to display arrows; they remain hidden at smaller zoom levels.

Background Options

The Background page of the Map Options dialog offers a selection of colors used to paint the map’s background with.

4.6.2.13 Exporting the Map

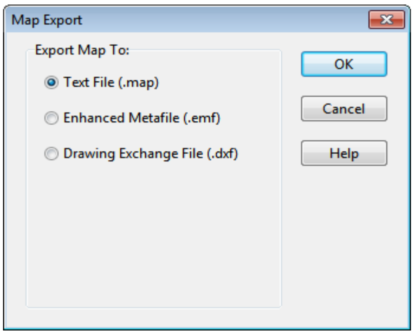
The full extent view of the study area map can be saved to file using either:

- Autodesk's DXF (Drawing Exchange Format) format,
- the Windows enhanced metafile (EMF) format,
- EPA SWMM's own ASCII text (.map) format.

The DXF format is readable by many Computers Aided Design (CAD) programs. Metafiles can be inserted into word processing documents and loaded into drawing programs for re-scaling and editing. Both formats are vector-based and will not lose resolution when they are displayed at different scales.

To export the map to a DXF, metafile, or text file:

1. Select **File** >> **Export** >> **Map**.
2. In the Map Export dialog that appears select the format that you want the map saved in.



If you select DXF format, you have a choice of how nodes will be represented in the DXF file. They can be drawn as filled circles, as open circles, or as filled squares. Not all DXF readers can recognize the format used in the DXF file to draw a filled circle. Also note that map annotation, such as node and link ID labels will not be exported, but map label objects will be. After choosing a format, click **OK** and enter a name for the file in the Save As dialog that appears.

In this manner, simulation techniques are systematically applied across all designated wards to comprehensively analyze the performance of drainage systems. This approach ensures a detailed evaluation of the system's capacity to manage stormwater runoff under varying hydrological conditions, enabling the identification of vulnerabilities and areas requiring intervention.

4.6.3 RUNNING A SIMULATION MODEL

Once the study area is properly defined, its runoff response, flow routing, and water quality behavior can be simulated. This section outlines how to configure analysis options, execute the simulation, and address common issues that may arise.

4.6.3.1 Setting Simulation Options

SWMM provides various options to control how a stormwater drainage system is simulated. To configure these options:

1. Open the **Options** category in the Project Browser.
2. Choose one of the following option categories to edit:
   a. **General Options**
   b. **Date Options**
   c. **Time Step Options**
   d. **Dynamic Wave Routing Options**
   e. **Interface File Options**
   f. **Reporting Options**

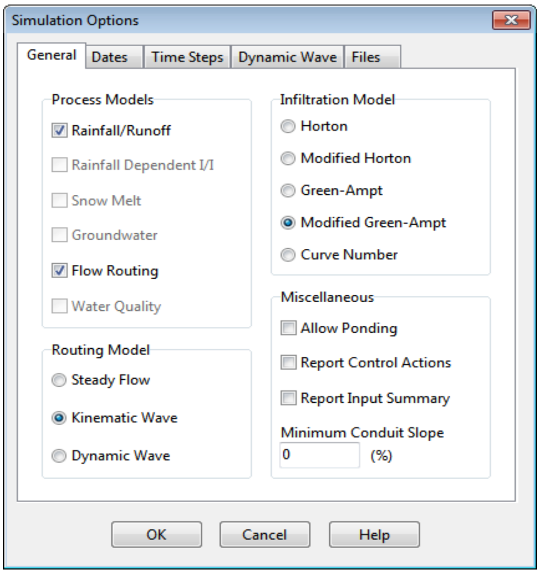
Use the **Edit** button in the Browser panel or navigate to **Edit >> Edit Object** to open the appropriate editor for the selected option category. The **Simulation Options** dialog is used for the first five categories, while the **Reporting Options** dialog is used for the last one.
The **Simulation Options** dialog includes separate tabbed pages for each of the first five categories. Each page is detailed further below.

4.6.3.2 General Options

The **General** tab in the Simulation Options dialog lets you define the following settings:

Process Models

This section allows you to select the process models SWMM will apply to the project. For instance, if a project includes Aquifer and Groundwater elements, the simulation can be run with groundwater computations enabled and then rerun with them disabled to evaluate their impact on site hydrology. If no elements exist to model a specific process (e.g., no Aquifers are defined), the corresponding option will be disabled (e.g., the Groundwater checkbox will appear unchecked and inactive).



Infiltration Model

This setting determines how rainfall infiltration into the upper soil zone of subcatchments is simulated. The available models are:

- **Horton**
- **Modified Horton**
- **Green-Ampt**
- **Modified Green-Ampt**
- **Curve Number**

A brief overview of each model is provided which switching between models requires re-entering infiltration parameters for each subcatchment, except when switching between the two Horton models or the two Green-Ampt models.

Routing Model

This option determines which method is used to route flows through the conveyance system. The choices are:

- Steady Flow
- Kinematic Wave
- Dynamic Wave

Here, Dynamic wave is considered for simulation of drainage system.

Report Input Summary

Enable this option to include a summary of the project's input data in the simulation's Status Report.

Minimum Conduit Slope

Specifies the minimum allowable slope for a conduit (in %). If left blank or set to zero (default), no minimum slope is enforced. However, SWMM applies a default minimum elevation drop of 0.001 ft (0.00035 m) when calculating conduit slopes.

4.6.3.3 Date Options

The **Dates** tab in the Simulation Options dialog specifies the simulation's start and end dates/times.

- **Start Analysis On**
  Enter the simulation's starting date (MM/DD/YYYY) and time.

- **Start Reporting On**
  Specify the date and time when reporting of simulation results begins. If a date earlier than the start date is entered, it defaults to the start date.

- **End Analysis On**
  Define the date and time when the simulation concludes.

- **Start Sweeping On**
  Specify the day of the year (MM/DD) when street sweeping operations start. The default is January 1.
- **End Sweeping On**
  Enter the day of the year (MM/DD) when street sweeping operations stop. The default is December 31.
- **Antecedent Dry Days**
  Define the number of rain-free days prior to the simulation's start. This value is used to calculate the initial pollutant buildup on subcatchment surfaces.

4.6.3.4 Time Step Options

The **Time Steps** tab in the Simulation Options dialog defines the time intervals used for runoff calculations, flow routing, and results reporting. Time steps are specified in days and hours: minutes: seconds, except for flow routing, which uses decimal seconds.

- **Reporting Time Step**
  Set the time interval for reporting computed results.
- **Runoff - Wet Weather Time Step**
  Specify the time step used to calculate runoff during rainfall, when surface water is ponded, or when LID controls are infiltrating or evaporating runoff.
- **Runoff - Dry Weather Time Step**
  Set the time step for runoff calculations during dry weather, which primarily includes pollutant buildup. This value must be greater than or equal to the Wet Weather time step.
- **Routing Time Step**
  Define the time step in decimal seconds for routing flows and water quality constituents through the conveyance system. Dynamic Wave routing requires a much smaller time step than other flow routing methods.
- **Steady Flow Periods**
  Configure options to identify and manage periods when the system hydraulics remain unchanged. A steady flow period is detected under specific conditions.

Enabling the **Skip Steady Flow Periods** option allows SWMM to continue using the most recent flow calculations for the conveyance system whenever the specified criteria are met, instead of recalculating the flow solution. While this can help reduce simulation run times, it may lead to decreased accuracy.

4.6.3.5 Dynamic Wave Options

The **Dynamic Wave** tab in the Simulation Options dialog defines various parameters for dynamic wave flow routing computations. These settings do not affect other flow routing methods.

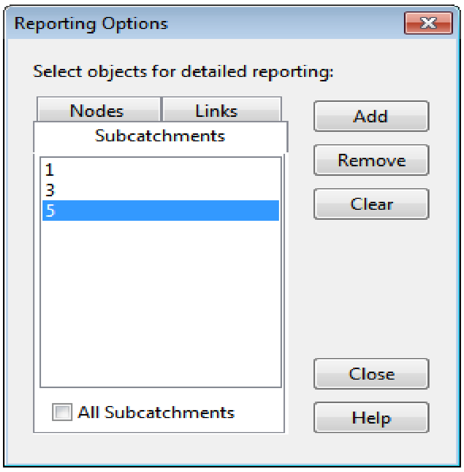
- **Inertial Terms**
  Specifies how inertial terms in the St. Venant momentum equation are handled:
  - **KEEP**: Maintains these terms at their full value in all conditions.
  - **DAMPEN**: Reduces the terms as flow nears critical and eliminates them in supercritical flow.
  - **IGNORE**: Removes the terms entirely, resulting in a Diffusion Wave solution.
- **Define Supercritical Flow By**
  Determines the criteria for supercritical flow in a conduit. Choices are:
  - Water surface slope only (i.e., water surface slope > conduit slope)
  - Froude number only (i.e., Froude number > 1.0)
  - Both water surface slope and Froude number (recommended choice, checks either condition).
- **Force Main Equation**
  Selects the equation for calculating friction losses during pressurized flow in conduits with a Circular Force Main cross-section. Available options are:
  - Hazen-Williams equation
  - Darcy-Weisbach equation
- **Use Variable Time Steps**
  Enables the use of an internally computed variable time step for each routing period. You can apply an adjustment (safety) factor, typically 75%, to ensure compliance with the Courant condition in each conduit. The computed time step won't be smaller than the **Minimum Variable Time Step** or greater than the **fixed time step** defined on the **Time Steps** page.
- **Minimum Variable Time Step**
  Defines the smallest time step allowed when using variable time steps. The default is 0.5 seconds. Smaller values may improve solution accuracy but can increase simulation time.

- **Time Step for Conduit Lengthening**
  Sets the time step in seconds used to artificially lengthen conduits to satisfy the Courant stability criterion under full-flow conditions. Reducing this value reduces the need for conduit lengthening, while a value of zero disables lengthening.
- **Minimum Nodal Surface Area**
  Defines the minimum surface area at nodes used for computing water depth changes. The default is 12.566 ft^2 (1.167 m^2), equivalent to a 4-ft diameter manhole.
- **Maximum Trials per Time Step**
  Sets the maximum number of trials SWMM will attempt to reach convergence when updating hydraulic heads at the nodes. The default is 8.
- **Head Convergence Tolerance**
  Specifies the tolerance for head convergence, below which the flow solution for a time step is considered converged. The default is 0.005 ft (0.0015 m).
- **Number of Threads**
  Selects the number of parallel computing threads to use on multi-core processors. The default is 1.

Clicking **Apply Defaults** resets all Dynamic Wave options to their default values.

4.6.3.6 Setting Reporting Options

The **Reporting Options** dialog is used to choose which subcatchments, nodes, and links will have detailed time series results saved for review after the simulation. By default, all objects will have detailed results stored for them in new projects. To open the dialog, select the **Reporting** category from the Project Browser and click the **Edit** button (or use **Edit >> Edit Object** from the main menu).



The dialog has three tabs—one for subcatchments, one for nodes, and one for links. It is a stay-on-top form, meaning you can select items directly from the Study Area Map or Project Browser while the dialog remains open.

To add an object to the reporting set:

- Select the appropriate tab (Subcatchments, Nodes, or Links).
- Uncheck the "All" box if it is checked.
- Choose the specific object from either the Study Area Map or the Project Browser list.
- Click the **Add** button.
- Repeat for any additional objects.

To remove an object from the reporting set:

1. Select the item from the list in the dialog.
2. Click the **Remove** button to delete it.

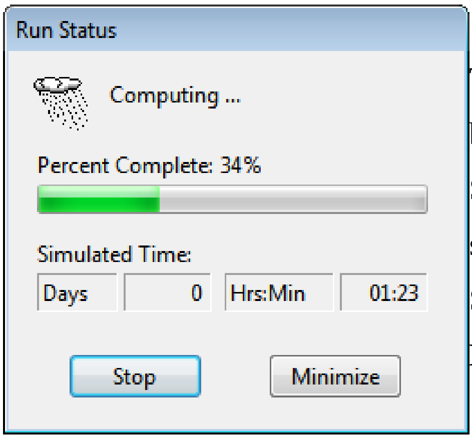
To clear all items from the reporting set for a category, select the corresponding tab and click the **Clear** button.

To include all objects from a category in the reporting set, check the "All" box for that category (Subcatchments, Nodes, or Links). This will override any individually selected items.

Click the **Close** button to exit the dialog.

4.6.3.7 Starting a Simulation

To begin a simulation, either select **Project >> Run Simulation** from the Main Menu or click the **Run Simulation** button on the Standard Toolbar. A **Run Status** window will open, showing the simulation's progress.



To stop a run before its normal termination, click the **Stop** button on the Run Status window or press the <**Esc**> key. Simulation results up until the time when the run was stopped will be available for viewing. To minimize the SWMM program while a simulation is running, click the **Minimize** button on the Run Status window.

If the analysis runs successfully the icon will appear in the Run Status section of the Status Bar at the bottom of SWMM's main window. Any error or warning messages will appear in a Status Report window. If you modify the project after a successful run has been made, the status flag changes to indicating that the current computed results no longer apply to the modified project.

4.6.3.8 Troubleshooting Results

If a simulation ends prematurely, the **Run Status** dialog will indicate an unsuccessful run and direct the user to the **Status Report** for further details. The report will include an error message, code, and description of the issue (e.g., **ERROR 138: Node TG040 has initial depth greater than maximum depth**). Refer to Appendix E for a list of SWMM error messages. Even if the simulation finishes successfully, it's important to verify that the results are reasonable. Common causes for premature run failures or questionable results include:

Unknown ID Error Message

This error appears when an object references another object that is undefined. For example, a subcatchment might reference an outlet node, but no such node exists. Similar issues can arise with incorrect references to Curves, Time Series, Time Patterns, Aquifers, Snow Packs, Transects, Pollutants, or Land Uses.

File Errors

File errors can occur for several reasons:

- A file cannot be found on the user's computer.
- A file is in the wrong format.
- A file cannot be written due to lack of write permissions in the directory where the file is being stored.

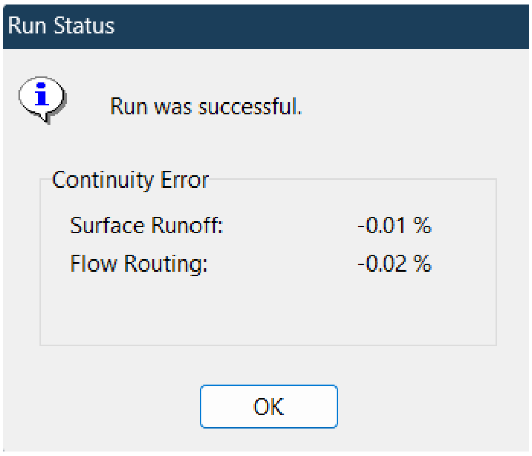
Drainage System Layout Errors

A valid drainage system layout must meet these conditions:

- An outfall node can only have one conduit link connected.
- A flow divider node must have exactly two outflow links.
- A node cannot have more than one dummy link connected.
- Under Kinematic Wave routing, a junction node can only have one outflow link, and a regulator link cannot be the outflow link for a non-storage node.
- Under Dynamic Wave routing, there must be at least one outfall node in the network. An error message will be generated if any of these rules are violated.

Excessive Continuity Errors

When a simulation completes successfully, the **Run Status** window will display mass continuity errors for runoff, flow routing, and pollutant routing. These errors indicate the percentage difference between the initial storage plus total inflow and the final storage plus total outflow for the entire drainage system. If the errors exceed a reasonable threshold, such as 10 percent, the validity of the results should be questioned. Common causes of excessive continuity errors include overly long computational time steps or conduits that are too short.



In addition to the overall system continuity error, the **Status Report** generated by a simulation will highlight the nodes in the drainage network with the largest flow continuity errors. If a node's error is excessive, it's important to assess whether that node is critical to the simulation's objectives. If it is, further investigation is needed to identify ways to reduce the error.

4.6.4 VIEWING SIMULATION SUMMARY FOR ANALYSIS

4.6.4.1 Viewing a Status Report

A **Status Report** is generated after each simulation and provides the following details:

- A summary of the main **Simulation Options** applied during the run.
- A list of any errors encountered during the simulation.
- A summary of the project's input data (if enabled in the Simulation Options).
- A summary of data from each rainfall file used in the simulation.
- A description of control rule actions taken during the run (if enabled in the Simulation Options).
- System-wide mass continuity errors for:
  - Runoff quantity and quality
  - Groundwater flow
  - Conveyance system flow and water quality
- The nodes with the highest individual flow continuity errors.
- The conduits most frequently influencing the time step for flow routing (only when the **Variable Time Step** option is active).
- The links with the highest **Flow Instability Index** values.

Viewing the Status Report

To access the Status Report:

- Select **Report** >> **Status** from the Main Menu.
- Alternatively, click the **Report** button on the Standard Toolbar and choose **Status Report** from the drop-down menu.

Copying and Saving the Report

- To copy selected text from the report to a file or the clipboard, highlight the desired text using the mouse, then choose **Edit** >> **Copy To** from the Main Menu or press the **Copy** button on the Standard Toolbar.
- To save the entire **Status Report** and **Summary Report** (covered next), select **File** >> **Export** >> **Status/Summary Report** from the Main Menu.

4.6.4.2 Viewing Summary Results

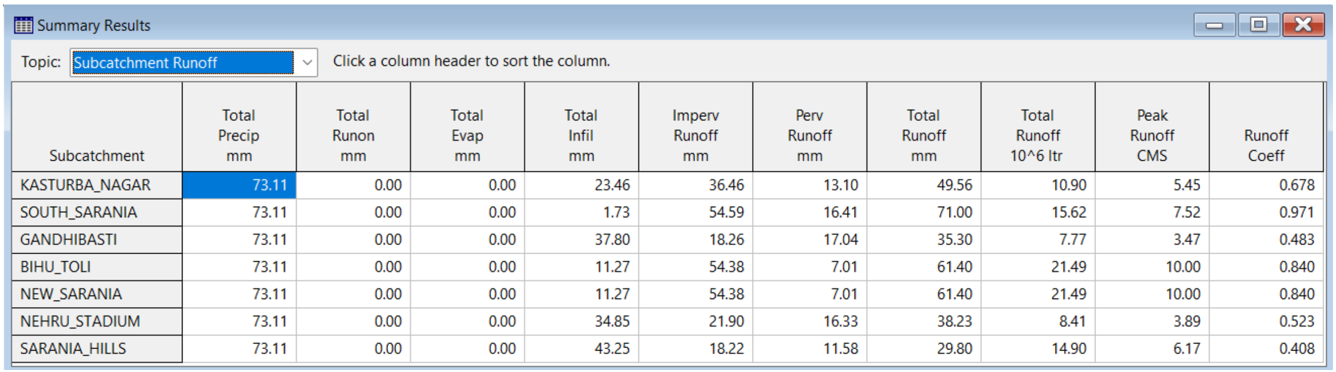
SWMM provides a **Summary Results** report that displays summarized data for each subcatchment, node, and link in the project. These results are organized into a selectable set of tables.

Accessing Summary Results

To view the summary results tables:

- Select **Report** >> **Summary** from the Main Menu.
- Alternatively, click the **Summary Results** button on the toolbar and choose **Summary Results** from the drop-down menu.

The **Summary Results** window presents an intuitive interface for navigating through the available summary data tables.



Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
KASTURBA_NAGAR	73.11	0.00	0.00	23.46	36.46	13.10	49.56	10.90	5.45	0.678
SOUTH_SARANIA	73.11	0.00	0.00	1.73	54.59	16.41	71.00	15.62	7.52	0.971
GANDHIBASTI	73.11	0.00	0.00	37.80	18.26	17.04	35.30	7.77	3.47	0.483
BIHU_TOLI	73.11	0.00	0.00	11.27	54.38	7.01	61.40	21.49	10.00	0.840
NEW_SARANIA	73.11	0.00	0.00	11.27	54.38	7.01	61.40	21.49	10.00	0.840
NEHRU_STADIUM	73.11	0.00	0.00	34.85	21.90	16.33	38.23	8.41	3.89	0.523
SARANIA_HILLS	73.11	0.00	0.00	43.25	18.22	11.58	29.80	14.90	6.17	0.408

The drop-down box at the upper left allows you to choose the type of results to view. The selection of tables and the results they display are as follows:

Table	Columns
Subcatchment Runoff	Total precipitation (in or mm); Total run-on from other subcatchments (in or mm); Total evaporation (in or mm); Total infiltration (in or mm); Total runoff depth (in or mm); Total runoff volume (million gallons or million liters); Peak runoff (flow units); Runoff coefficient (ratio of total runoff to total precipitation).
LID Performance	Total inflow volume Total evaporation loss Total infiltration loss Total surface outflow Total underdrain outflow Initial storage volume Final storage volume Flow continuity error (%) *Note: all quantities are expressed as depths (in or mm) over the LID unit's surface area.*
Groundwater Summary	Total surface infiltration (in or mm) Total evaporation (in or mm) Total lower seepage (in or mm) Total lateral outflow (in or mm) Maximum lateral outflow (flow units) Average upper zone moisture content (volume fraction) Average water table elevation (ft or m) Final upper zone moisture content (volume fraction) Final water table elevation (ft or m)
Subcatchment Washoff	Total mass of each pollutant washed off the subcatchment (lbs or kg).
Node Depth	Average water depth (ft or m); Maximum water depth (ft or m); Maximum hydraulic head (HGL) elevation (ft or m); Time of maximum depth; Maximum water depth at reporting times (ft or m).
Node Inflow	Maximum lateral inflow (flow units); Maximum total inflow (flow units); Time of maximum total inflow; Total lateral inflow volume (million gallons or million liters); Total inflow volume (million gallons or million liters); Flow balance error (%). Note: Total inflow consists of lateral inflow plus inflow from connecting links.
Node Surcharge	Hours surcharged; Maximum height of surcharge above node's crown (ft or m); Minimum depth of surcharge below node's top rim (ft or m). Note: surcharging occurs when water rises above the crown of the highest conduit and only those conduits that surcharge are listed.

Node Flooding	Hours flooded; Maximum flooding rate (flow units); Time of maximum flooding; Total flood volume (million gallons or million liters); Peak depth (for dynamic wave routing in ft or m) or peak volume (1000 ft3 or 1000 m3) of ponded surface water. Note: flooding refers to all water that overflows a node, whether it ponds or not, and only those nodes that flood are listed.
Storage Volume	Average volume of water in the facility (1000 ft3 or 1000 m3); Average percent of full storage capacity utilized; Percent of total stored volume lost to evaporation; Percent of total stored volume lost to seepage; Maximum volume of water in the facility (1000 ft3 or 1000 m3); Maximum percent of full storage capacity utilized; Time of maximum water stored; Maximum outflow rate from the facility (flow units).
Outfall Loading	Percent of time that outfall discharges; Average discharge flow (flow units); Maximum discharge flow (flow units); Total volume of flow discharged (million gallons or million liters); Total mass discharged of each pollutant (lbs or kg).
Link Flow	Maximum flow (flow units); Time of maximum flow; Maximum velocity (ft/sec or m/sec) Ratio of maximum flow to full normal flow; Ratio of maximum flow depth to full depth.
Flow Classification	Ratio of adjusted conduit length to actual length; Fraction of all time steps spent in the following flow categories: ▪ dry on both ends ▪ dry on the upstream end ▪ dry on the downstream end ▪ subcritical flow ▪ supercritical flow ▪ critical flow at the upstream end ▪ critical flow at the downstream end Fraction of all time steps flow is limited to normal flow; Fraction of all time steps flow is inlet controlled (for culverts only).
Conduit Surcharge	Hours that conduit is full at: ▪ both ends ▪ upstream end ▪ downstream end Hours that conduit flows above full normal flow; Hours that conduit is capacity limited

	Note: only conduits with one or more non-zero entries are listed and a conduit is considered capacity limited if its upstream end is full and the HGL slope is greater than the conduit slope.
Link Pollutant Loads	Total mass load (in lbs or kg) of each pollutant carried by the link over the entire simulation period.

Clicking the name of an object in the first column of a summary table highlights its location in both the **Project Browser** and the **Study Area Map**. Clicking a column heading sorts the table's entries by that column's values, toggling between ascending and descending order with each click.

To copy table contents to the **Windows Clipboard** or a file:

Choose **Edit >> Copy To** from the Main Menu.

Alternatively, click the **Copy** button on the Standard Toolbar.

To save both the full **Status Report** and all tables from the **Summary Report** to a file, select **File >> Export >> Status/Summary Report** from the Main Menu.

4.6.4.3 Time Series Results

Detailed time series results for variables can be accessed for each reporting time step. These results can be:

- **Viewed on the map**
- **Plotted as graphs**
- **Displayed in tabular format**
- **Statistically analyzed**

Time series data is available only for subcatchments, nodes, and links specifically selected to have detailed results saved during the simulation. By default, all such objects in the project are included unless the **Reporting** option (under the **Options** category in the **Project Browser**) was used to limit the selection.

Table of Time Series Variables Available for Viewing

Subcatchment Variables	Node Variables	Link Variables	System-Wide Variables
Rainfall intensity (in/hr or mm/hr)	Water level (ft or m above the invert elevation of the node)	Flow rate (flow units)	Atmospheric temperature (°F or °C)
Snow accumulation (in or mm)	Hydraulic head (ft or m, as absolute elevation based on the vertical datum)	Average depth of water (ft or m)	Potential evaporation rate (in/day or mm/day)
Evaporation rate (in/day or mm/day)	Volume of stored water, including ponded water (ft^3 or m^3)	Flow velocity (ft/sec or m/sec)	Actual evaporation rate (in/day or mm/day)
Infiltration rate (in/hr or mm/hr)	Lateral inflow (sum of runoff and other external inputs, in flow units)	Water volume (ft^3 or m^3)	Total precipitation (in/hr or mm/hr)
Surface runoff flow (flow units)	Total inflow (sum of lateral and upstream inflows, in flow units)	Fraction of full capacity filled by flow (conduits) or control settings (pumps/regulators)	Snow cover depth (in or mm)
Groundwater inflow to the drainage system	Flooding volume due to overflow beyond node capacity (flow units)	Pollutant concentration in water (mass/liter)	Average losses due to infiltration or evaporation (in/hr or mm/hr)
Groundwater level (ft or m)	Pollutant concentration after treatment applied at the node (mass/liter)		Total runoff volume (flow units)
Soil moisture content in unsaturated zone (%)			Total inflow from dry weather sources (flow units)
Pollutant washoff concentration (mass/liter)			Total groundwater inflow (flow units)
			Total inflow from rainfall-dependent infiltration (flow units)
			Total direct inflow volume (flow units)
			Total external input (flow units)

Subcatchment Variables	Node Variables	Link Variables	System-Wide Variables
			Total external flooding volume (flow units)
			Total discharge through outfalls (flow units)
			Total storage at nodes (ft^3 or m^3)

Here, only rainfall intensity is considered of different interval as a design storm for SWMM model simulation.

4.6.4.4 Viewing Results on the Map

There are multiple methods to view input parameters and simulation results directly on the Study Area Map:

- The map will color the subcatchments, nodes, and links according to their respective Map Legends based on the current settings in the Map Browser. The color coding will update as you select different time periods.
- When the Flyover Map Labeling preference is enabled, hovering the mouse over a map object will show its ID name and the value of the current theme parameter in a hint box.
- ID names and parameter values can be displayed next to subcatchments, nodes, or links by choosing the relevant options in the Annotation page of the Map Options dialog.
- Specific subcatchments, nodes, or links that meet a defined criterion can be identified by submitting a Map Query.
- You can animate the results on the network map, either forward or backward in time, using the controls on the Animator panel in the Map Browser.
- The map can be printed, copied to the clipboard, or saved as a DXF file or Windows metafile.

4.6.4.5 Viewing results with recommended graph

Here, simulation data have been supported by system generated graphs for better clarity of the simulation process.

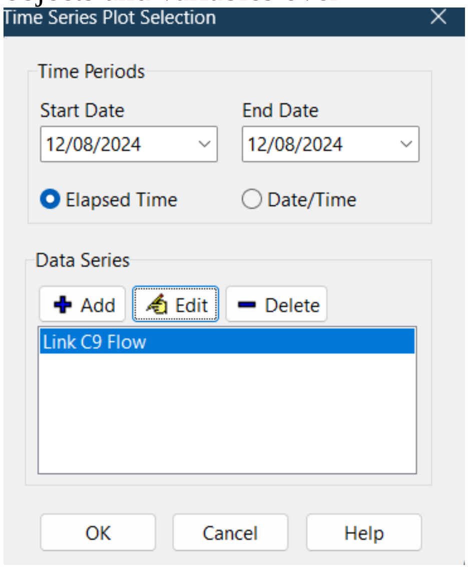
Considered graphs are-

- Time series plot
- Profile Plot
- Scatter Plot

Steps that follow of creating above plots are below –

4.6.4.5.1 Time Series Plots

A Time Series Plot displays the values of specific combinations of objects and variables over time. You can plot up to six time series on a single graph. If only one time series is plotted and the item has calibration data registered for the selected variable, the calibration data will be shown on the graph be plotted along with the simulated.



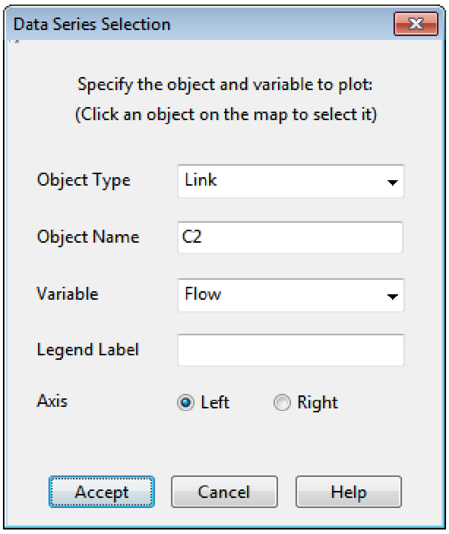
To create a Time Series Plot:

- Go to Report >> Graph >> Time Series in the Main Menu, or click the corresponding icon on the Standard Toolbar.
- The Time Series Plot Selection dialog will open, allowing you to specify the objects and quantities to be plotted.

The Time Series Plot Selection dialog allows you to define the objects and their variables to be graphed in the Time Series Plot. The steps for using the dialog are as follows:

1. Set a Start Date and End Date for the plot (the default is the entire simulation period).
2. Choose to display time as either Elapsed Time or Date/Time values.
3. Add up to six different data series to the plot by clicking the Add button above the data series list.
4. Use the Edit button to modify a selected data series or the Delete button to remove a data series.
5. Use the Up and Down buttons to adjust the order in which the data series are plotted.
6. Click OK to generate the plot.

When you click the **Add** or **Edit** buttons a Data Series Selection dialog will be displayed for selecting a particular object and variable to plot. It contains the following data fields:



Object Type: Specifies the type of object to plot (e.g., Subcatchment, Node, Link, or System).
Object Name: The ID name of the object to be plotted (this field is not available for System variables).
Variable: The variable for which the time series will be plotted (options depend on the object type).
Legend Label: The label to be displayed in the legend for the data series. If left empty, a default label will be generated using the object type, name, variable, and units (e.g., Link C16 Flow (CFS)).
Axis: Indicates whether the data series should be plotted on the left or right vertical axis.
Click the Accept button to add or update the data series in the plot, or click the Cancel button to discard your changes. You will then return to the Time Series Plot Selection dialog, where you can add or modify another data series.

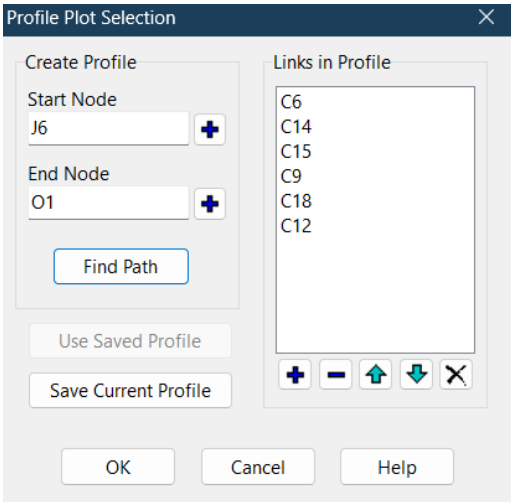
4.6.4.5.2 Profile Plot

A Profile Plot illustrates the changes in simulated water depth along a connected path of drainage system links and nodes at a specific moment in time. Once generated, the plot automatically updates as new time periods are selected using the Map Browser.

Steps to create a Profile Plot:

- Navigate to **Report** >> **Graph** >> **Profile** from the main menu or click the respective icon on the Standard Toolbar.

- The **Profile Plot Selection** dialog box will appear. Use this dialog to define the path for which the profile plot will be created.



The **Profile Plot Selection** dialog allows you to define a connected path of conveyance system links for generating a water depth profile against distance. To set the path using this dialog:

1. Input the ID of the upstream node for the first link in the path into the **Start Node** field. Alternatively, you can select the node directly on the **Study Area Map** and click the adjacent button next to the input field.
2. Enter the ID of the downstream node for the last link in the path into the **End Node** field, or select the node on the map and click the button next to the input field.
3. Click the **Find Path** button to let the program automatically determine the path with the fewest links between the start and end nodes. The identified links will appear in the **Links in Profile** box.
4. To add a new link to the **Links in Profile** list, select the desired link on the **Study Area Map** or in the **Project Browser**, then click the button beneath the list box.
5. You can remove or rearrange items in the **Links in Profile** list using and the available buttons below the list box.
6. Click **OK** to display the profile plot.

Saving the Current Link Set for Future Use:

1. Click the **Save Current Profile** button.
2. Provide a name for the profile when prompted.

Using a Previously Saved Profile:

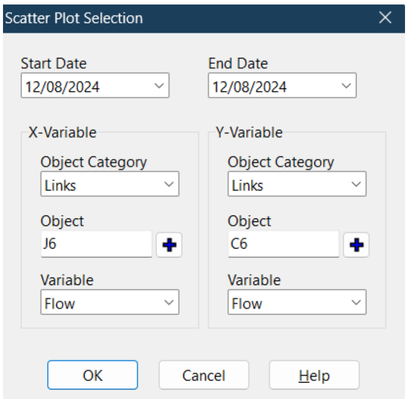
1. Click the **Use Saved Profile** button.
2. Choose a profile from the **Profile Selection** dialog.

Profile plots can also be generated before simulation results are available. This feature helps visualize and verify the vertical configuration of a drainage system. These plots will include a **Refresh** button in the top-left corner, allowing you to update the plot after making changes to any elevation data.

4.6.4.5.3 Scatter Plots

A Scatter Plot illustrates the relationship between two variables, such as the flow rate in a pipe compared to the water depth at a node.

To create a Scatter Plot:



1. Go to Report >> Graph >> Scatter in the main menu or click the corresponding icon on the Standard Toolbar.
2. In the Scatter Plot Selection dialog that appears, choose the time interval and select the pair of objects and their variables to plot.

The Scatter Plot Selection dialog allows you to select the objects and variables to compare in the scatter plot. Follow these steps to use the dialog effectively:

Choose the **Start Date** and **End Date** for the plot (by default, the entire simulation period is selected).

Configure the **X-variable** (plotted on the horizontal axis) by selecting:

a. **Object Category** (Subcatchment, Node, or Link)

b. **Object ID** (enter the ID manually or select the object from the **Study Area Map** or **Project Browser**, then click the button next to the field)

c. The **Variable to Plot** (options vary based on the selected object category)

3. Repeat the same steps to set up the **Y-variable** (plotted on the vertical axis).
4. Click **OK** to generate the scatter plot.

In this way overall simulation is performed from input data to plotting required graphs for existing drainage performance analysis.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 WATERSHED DELINEATION

5.1.1 WATERSHED DELINEATION OF GMC AREA

The watershed delineation process is performed using the pour point method. Initially, the entire Guwahati Municipality Area is delineated in **ArcGIS 10.4**. The analysis includes calculating key hydrological parameters such as **Flow Accumulation**, **Flow Direction**, **Basins** and **Stream Order**. These calculations are essential for visualizing the drainage flow in the area, helping to understand how water moves through the landscape and where it accumulates. This process is vital for effective watershed management, flood control, and urban planning in the region.

Flow Accumulation

Flow accumulation calculates the amount of water that flows into each cell within a Digital Elevation Model (DEM). In simpler terms, it shows where water collects as it moves downhill. Areas with higher flow accumulation values represent regions where water accumulates more, such as streams or rivers, while lower values indicate areas where water is less likely to gather.

Flow Direction

Flow direction determines the path that water will follow as it moves downhill across the landscape. It assigns a direction to each cell in the DEM based on the steepest slope, helping to define the flow pattern of streams and rivers. This process essentially shows the movement of water from one cell to another.

Stream Order

Stream order is a system for classifying streams based on their size and connections within a watershed. A first-order stream is the smallest, and when two first-order streams meet, they form a second-order stream, and so on. Higher-order streams are larger and represent the main channels of a watershed, offering insight into the drainage network's structure and size.

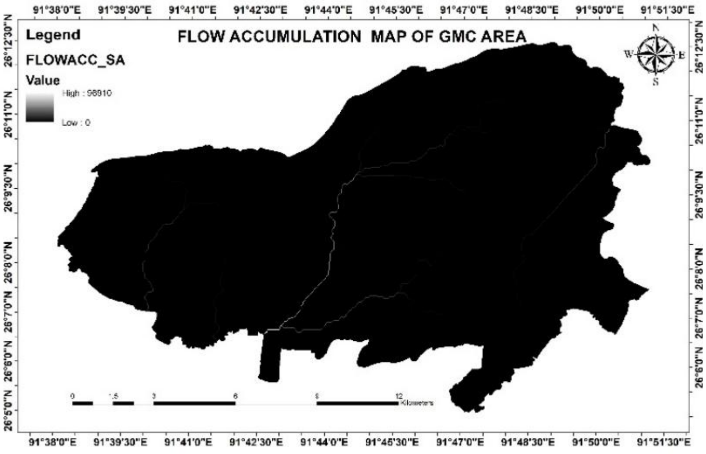


Fig: - 5.1 FLOW ACCUMULATION GMC

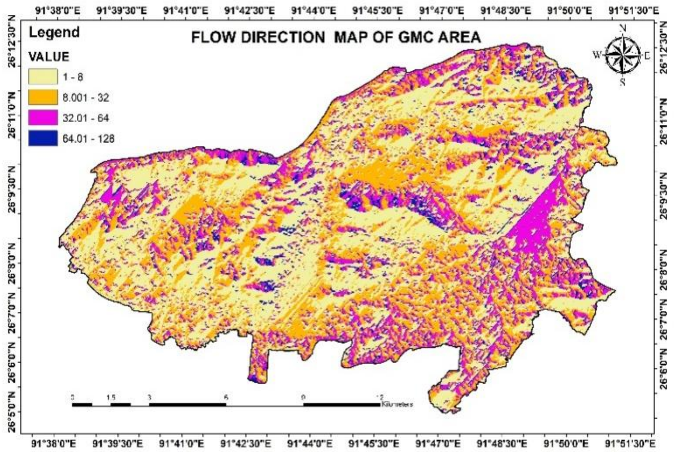


Fig: - 5.2 FLOW DIRECTION GMC

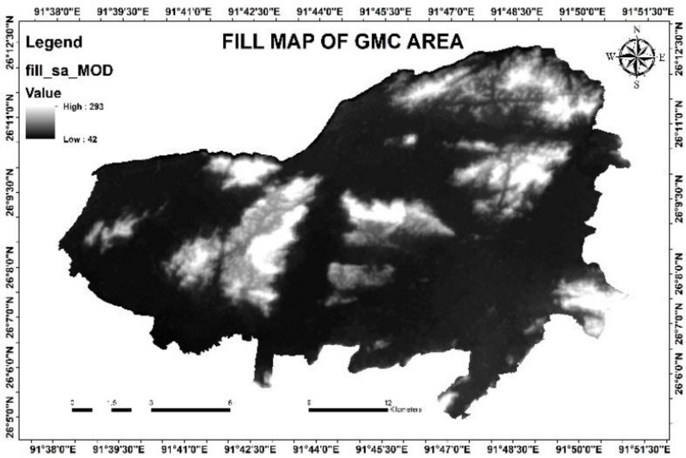


Fig: - 5.3 FILL MAP GMC

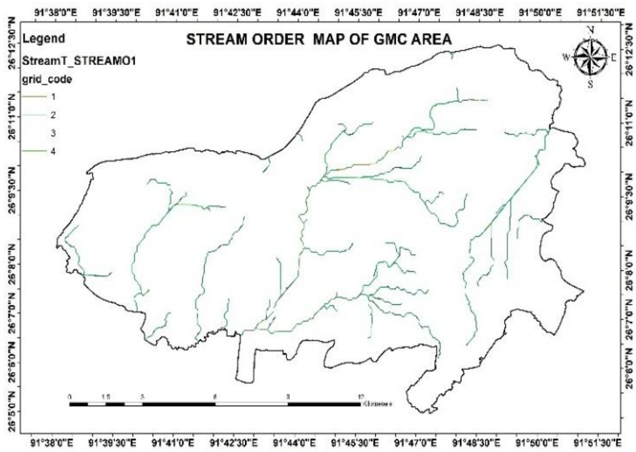
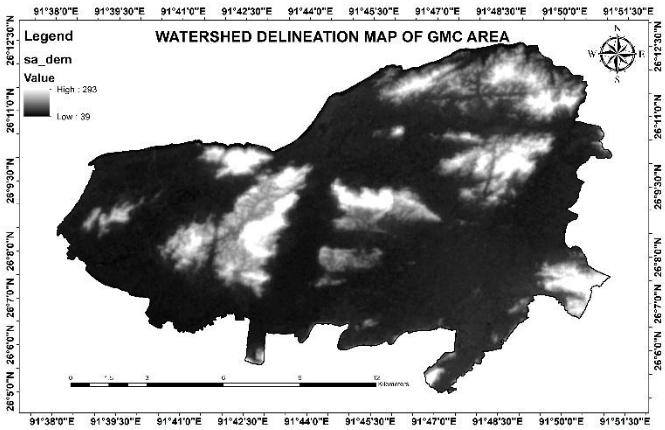


Fig: - 5.4 STREAM ORDER MAP GMC



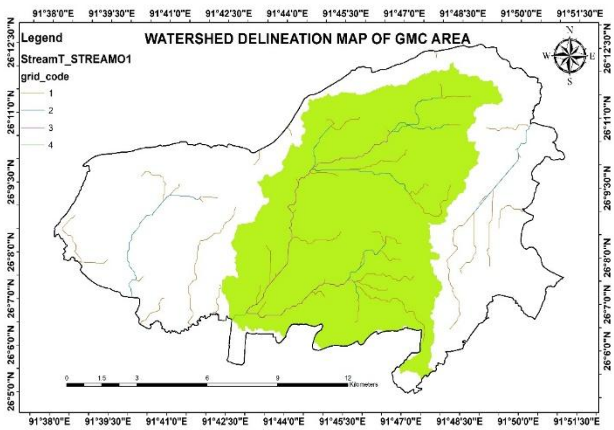


Fig: - 5.5 WATERSHED DELINEATION GMC

The **Flow Accumulation Map** for the **Guwahati Municipality Area (GMC)**, with values ranging from 0 to 96,910, highlights areas where water accumulates, with higher values indicating flood-prone regions like valleys or near rivers. The **Flow Direction Map**, showing values from 1 to 128, reveals the path of water flow across the terrain, helping to understand water movement influenced by natural and man-made features. The **Fill Map** (values 42 to 293) ensures accurate water flow modeling by filling depressions caused by urban infrastructure. The **Digital Elevation Model (DEM)**, with values from 39 to 293, indicates the land's elevation, guiding water flow predictions and drainage system design. Integrating these maps into **SWMM simulations** helps identify areas requiring improved drainage, optimize infrastructure placement, and design an efficient stormwater management system to handle runoff and reduce flooding risks in GMC.

By considering the above parameters, watershed delineation has been done separately for the Bharalu-covered area, where flooding is highly affected, to enable better simulation for the desired Ward Nos., as categorized by ASDMA based on flood vulnerability.

5.1.2 WATERSHED DELINEATION OF BHARALU AREA

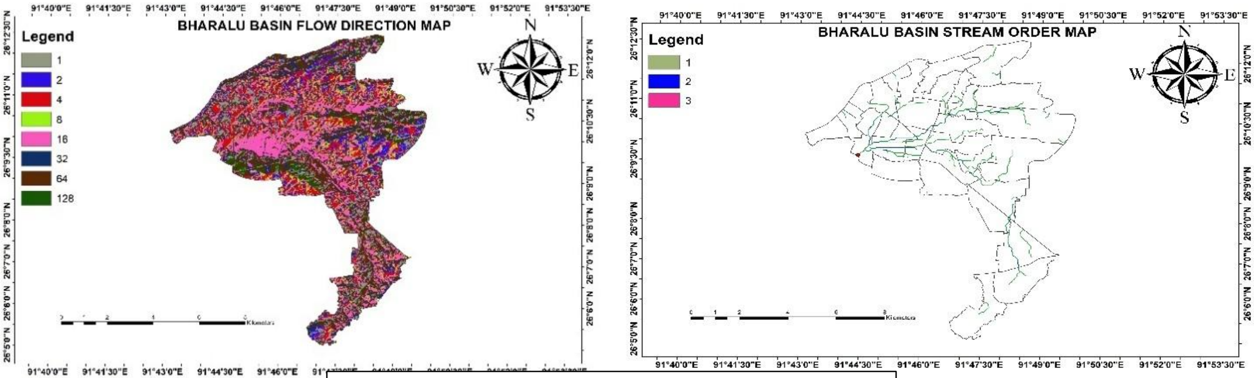


Fig: - 5.6 FLOW DIRECTION BHARALU

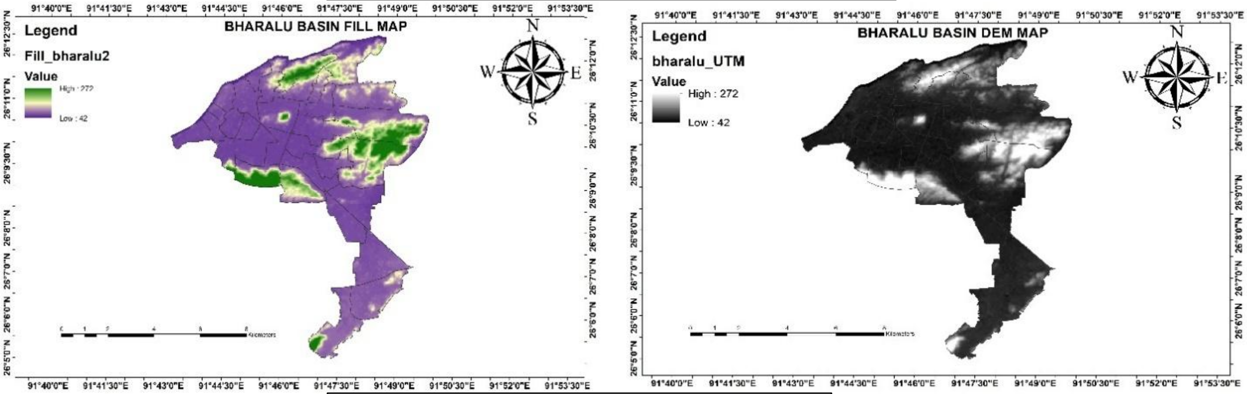


Fig: - 5.7 FILL DIRECTION BHARALU

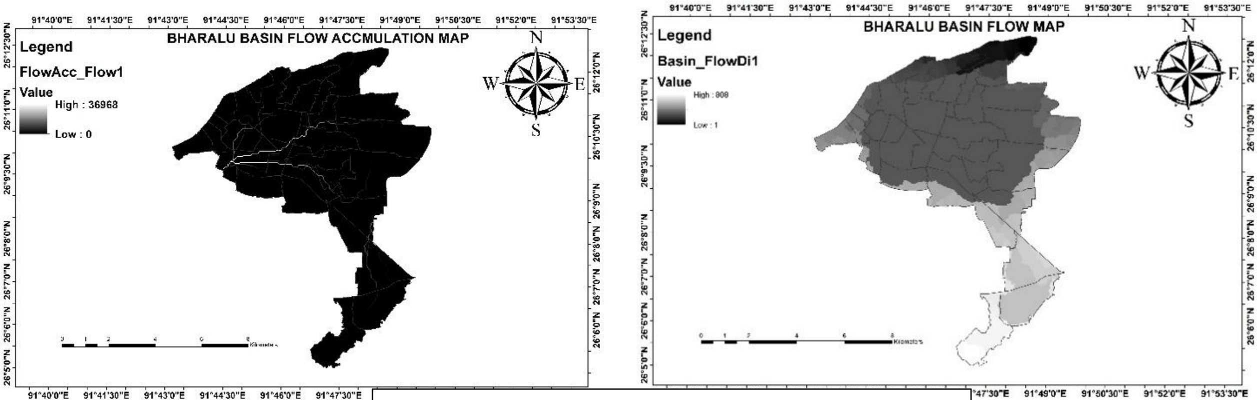


Fig: - 5.8 FLOW ACCUMULATION BHARALU

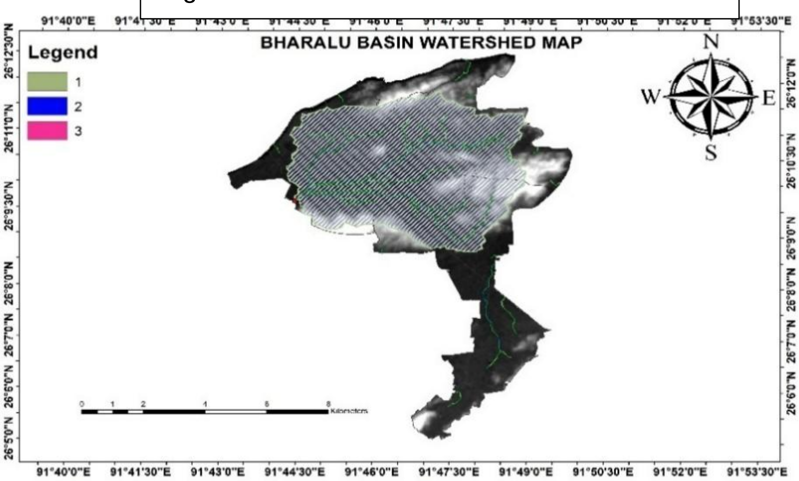


Fig: - 5.9 WATERSHED DELINEATION BHARALU

The **Bharalu Watershed Delineation** involves analyzing parameters like **Basin Flow**, **DEM**, **Flow Accumulation**, **Flow Direction**, and **Basin Fill** to understand the area's drainage patterns and flood risks. The **Basin Flow** range (1-808) highlights areas with varying water flow, indicating regions that may need increased drainage capacity. The **DEM** range (42-272) reveals the terrain's elevation, showing how water will naturally flow and accumulate, with lower areas being prone to flooding. The **Basin Fill** (42-272) accounts for depressions created by human infrastructure, ensuring accurate flow modeling. **Flow Accumulation** (0-36,968) helps identify flood-prone areas where water is likely to gather, while **Flow Direction** (1-128) indicates the paths water will follow across the landscape. These parameters, when integrated into **SWMM** simulations, allow for better flood prediction and drainage system optimization, ensuring that the watershed can manage stormwater efficiently and reduce flooding risks in urban areas like Bharalu. This data-driven approach aids in designing effective flood management strategies and resilient urban drainage systems.

So, from above results its claimed that the **Bharalu Basin** within **Guwahati Municipality Area (GMC)** contributes to **38.15%** of the total flow accumulation in the region, with **36,968** out of **96,910** units of accumulated water. This substantial proportion highlights the basin's natural tendency to collect water, particularly in its lower elevation areas, which amplifies the risk of flooding. The heavy rainfall during the monsoon season exacerbates this issue, often overwhelming existing drainage systems and causing significant flooding. Due to its high flow accumulation, the **Bharalu Basin** is a key area for flood management strategies. Focused planning and infrastructure development are necessary to prevent flooding and improve stormwater management, making flood risk assessment and tailored infrastructure design crucial for addressing the basin's flooding challenges.

5.2 INTENSITY – DURATION – FREQUENCY (IDF) CURVE

5.2.1. GENERATING IDF CURVE FROM RAINFALL DATA

Here, we considered highest peak daily rainfall data for nearly 30 years for calculating return period using Gumbel Method

Table: - 5.1 PEAK RAINFALL DATA

Year	Highest peak daily rainfall (mm)
1993	61.7876
1994	75.1169
1995	70.0319
1996	64.5436
1997	72.2448
1998	103.0041
1999	150.0688
2000	72.7493
2001	64.0783
2002	48.658
2003	42.6778
2004	145.6885
2005	68.5598
2006	66.7396
2007	159.292
2008	77.7763
2009	137.7656
2010	79.8701
2011	78.9996
2012	89.9093
2013	59.8987
2014	140.1792
2015	71.6339
2016	24.7374
2017	38.7031
2018	88.6877
2019	88.7629
2020	86.3847
2021	40.7636
2022	141.6705
2023	69.7529

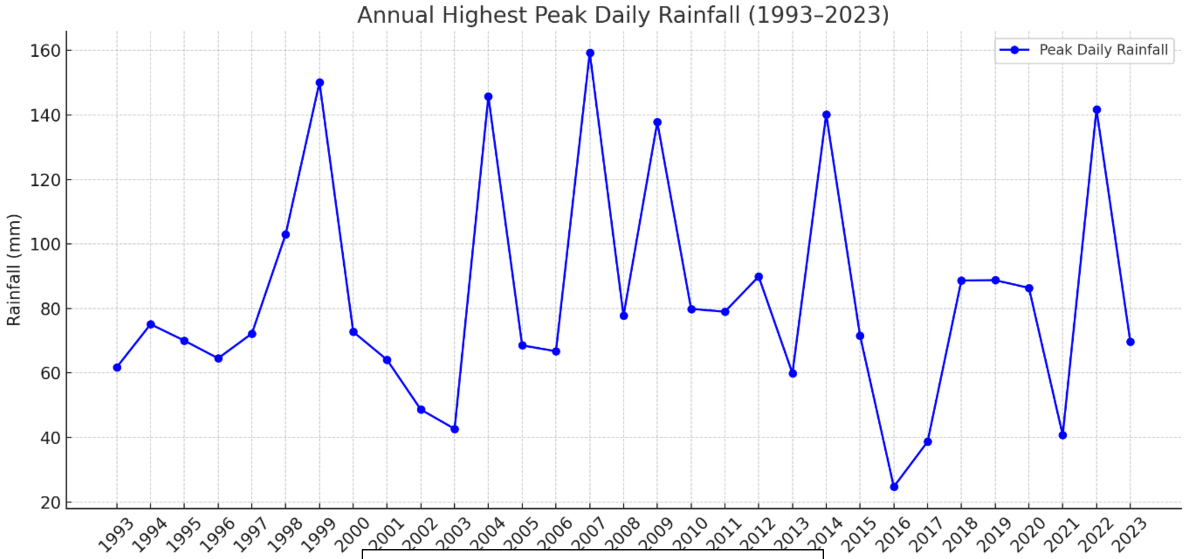


Fig: - 5.10 ANNUAL PEAK GRAPH

The dataset of peak daily rainfall from 1993 to 2023 is useful for creating Intensity-Duration-Frequency (IDF) curves, important for managing water resources in Guwahati. The data shows major rainfall peaks in years like 1999, 2004, 2007, 2014, and 2022, occurring every 5–7 years. This suggests the need to consider longer return periods in IDF analysis to plan for extreme rainfall.

An increasing trend in heavy rainfall events, especially after the late 1990s, may indicate climate changes. However, some years, like 2016 and 2017, had very low rainfall, showing high variability. This variability should be accounted for using statistical models like the Gumbel distribution.

To build accurate IDF curves, frequency analysis should be done on this data. Understanding these rainfall patterns will help design better drainage and flood management systems for Guwahati.

5.2.2 RAINFALL MAGNITUDE CALCULATION OF DIFFERENT DURATION

Table: - 5.2 RAINFALL DATA AS PER RETURN PERIOD

Year	5 min	10 min	15 min	30 min	60 min	120 min	180 min	360 min	720 min	1440 min
1993	9.44	11.9	13.62	17.16	21.62	27.24	31.19	39.29	49.5	62.37
1994	11.48	14.47	16.56	20.86	26.29	33.12	37.91	47.77	60.18	75.83
1995	10.7	13.49	15.44	19.45	24.51	30.88	35.35	44.53	56.11	70.69
1996	9.87	12.43	14.23	17.93	22.59	28.46	32.58	41.04	51.71	65.15
1997	11.04	13.91	15.93	20.07	25.28	31.85	36.46	45.94	57.88	72.93
1998	15.74	19.84	22.71	28.61	36.05	45.42	51.99	65.5	82.53	103.98
1999	22.94	28.9	33.08	41.68	52.52	66.17	75.74	95.43	120.23	151.48
2000	11.12	14.01	16.04	20.21	25.46	32.08	36.72	46.26	58.29	73.44
2001	9.79	12.34	14.13	17.8	22.42	28.25	32.34	40.75	51.34	64.68
2002	7.44	9.37	10.73	13.52	17.03	21.45	24.56	30.94	38.98	49.12
2003	6.52	8.22	9.41	11.85	14.94	18.82	21.54	27.14	34.19	43.08
2004	22.27	28.06	32.12	40.47	50.98	64.24	73.53	92.64	116.72	147.06
2005	10.48	13.2	15.11	19.04	23.99	30.23	34.6	43.6	54.93	69.21
2006	10.2	12.85	14.71	18.54	23.36	29.43	33.68	42.44	53.47	67.37
2007	24.35	30.68	35.12	44.24	55.74	70.23	80.4	101.29	127.62	160.79
2008	11.89	14.98	17.15	21.6	27.22	34.29	39.26	49.46	62.31	78.51
2009	21.06	26.53	30.37	38.27	48.21	60.74	69.53	87.61	110.38	139.07
2010	12.21	15.38	17.61	22.18	27.95	35.22	40.31	50.79	63.99	80.62
2011	12.08	15.21	17.42	21.94	27.65	34.83	39.87	50.24	63.29	79.74
2012	13.74	17.32	19.82	24.97	31.46	39.64	45.38	57.17	72.03	90.76
2013	9.16	11.54	13.21	16.64	20.96	26.41	30.23	38.09	47.99	60.46
2014	21.43	27	30.9	38.94	49.06	61.81	70.75	89.14	112.31	141.5
2015	10.95	13.8	15.79	19.9	25.07	31.58	36.15	45.55	57.39	72.31
2016	3.78	4.76	5.45	6.87	8.66	10.91	12.49	15.73	19.82	24.97
2017	5.92	7.45	8.53	10.75	13.54	17.06	19.53	24.61	31.01	39.07
2018	13.56	17.08	19.55	24.63	31.04	39.1	44.76	56.4	71.06	89.52
2019	13.57	17.09	19.57	24.65	31.06	39.14	44.8	56.44	71.12	89.6
2020	13.2	16.64	19.04	23.99	30.23	38.09	43.6	54.93	69.21	87.2
2021	6.23	7.85	8.99	11.32	14.27	17.97	20.57	25.92	32.66	41.15
2022	21.66	27.28	31.23	39.35	49.58	62.46	71.5	90.09	113.5	143.01
2023	10.66	13.43	15.38	19.37	24.41	30.75	35.21	44.36	55.89	70.41

Above table is calculation of rainfall frequency for generating IDF curve of different return period

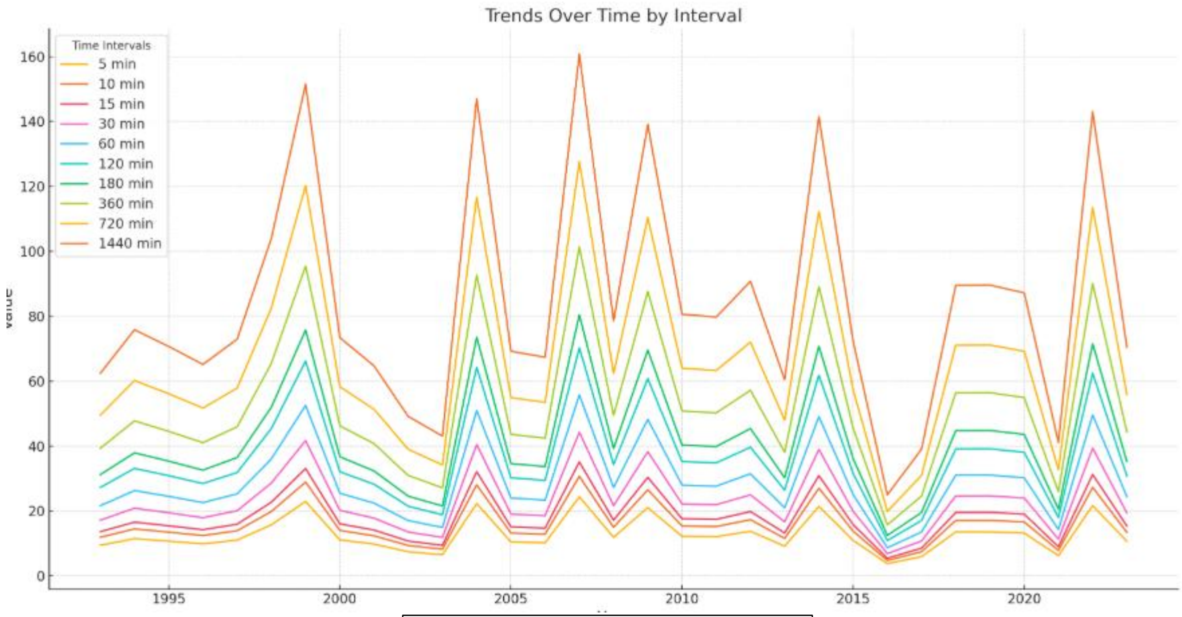


Fig: - 5.11 IDF TREND CHART

The rainfall data from 1993 to 2023 across various durations (5 minutes to 1440 minutes) shows significant variability, which is essential for developing Intensity-Duration-Frequency (IDF) curves using the Gumbel distribution. This analysis helps in understanding extreme rainfall behaviour critical for effective flood and drainage management.

Years like 1999, 2004, 2007, 2014, and 2022 recorded extremely high rainfall values across all durations, indicating the occurrence of severe weather events. These extreme values must be modelled using the Gumbel distribution, which focuses on predicting rare, high-intensity rainfall events.

In contrast, years such as 2016 and 2017 showed significantly lower rainfall, reflecting substantial year-to-year variability. This variability is crucial in fitting statistical models like the Gumbel distribution to accurately capture both high and low extremes in rainfall data.

Rainfall intensity consistently increases with longer durations, following expected accumulation patterns over time. This behaviour supports the use of the Gumbel distribution for modelling maximum rainfall events and predicting rainfall for different return periods.

Overall, the increasing trend of extreme rainfall in the post-2000 period suggests the potential influence of climate variability. Applying **the Gumbel distribution** will help estimate return periods and design more resilient urban drainage systems, accounting for both extreme and moderate rainfall events.

5.3 GUMBEL DISTRIBUTION APPROACH FOR IDF GENERATION

The Gumbel distribution method is applied as described in Chapter 4: Methodology.

Sn	**1.1363**	**1.1363**	**1.1363**	**1.1363**	**1.1363**	**1.1363**
Yn	**0.5424**	**0.5424**	**0.5424**	**0.5424**	**0.5424**	**0.5424**

Here, above data is calculated for different period as **2, 10, 25, 50, 75 and 100** years respectively.

After, applying Gumbel distribution formulas mentioned in Methodology Chapter, Y_n and S_n values are calculated.

Return period T	**2 years**	**10 years**	**25 years**	**50 years**	**75 years**	**100 years**
Yn= $-\ln(\ln\frac{T}{T-1})$	**0.37**	**2.25**	**3.2**	**3.9**	**4.31**	**4.6**
Kt (frequency factor)	**-0.15**	**1.5**	**2.34**	**2.96**	**3.32**	**3.57**

Now by applying, $\mathbf{X_t = Mean + S.D * K_t}$

Required IDF graph is generated

Table: - 5.3 IDF DATA

TIME (hr)	Time (min)	Mean	S.D.
0.08	5	12.73	5.4
0.17	10	16.03	6.8
0.25	15	18.35	7.78
0.5	30	23.12	9.81
1	60	29.13	12.35
2	120	36.71	15.57
3	180	42.02	17.82
6	360	52.94	22.45
12	720	66.7	28.29
24	1440	84.03	35.64

Above table shows Mean and S.D values of different duration for calculation IDF curve of different Return Periods

Time (min)	RETURN PERIOD Rainfall (mm)	2 years Rainfall (mm/hr)	Rainfall (mm)	10 years Rainfall (mm/hr)
5	11.89	142.79	20.85	250.26
10	14.98	89.9	26.25	157.57
15	17.15	68.58	30.04	120.18
30	21.6	43.2	37.87	75.73
60	27.22	27.22	47.69	47.69
120	34.3	17.15	60.11	30.06
180	39.26	13.09	68.81	22.94
360	49.46	8.24	86.69	14.45
720	62.32	5.19	109.22	9.1
1440	78.51	3.27	137.6	5.73

Table: - 5.4 IDF DATA OF 2 & 10 RETURN PERIOD

Above table shows the IDF curve for 2 years and 10 years return period of different duration.

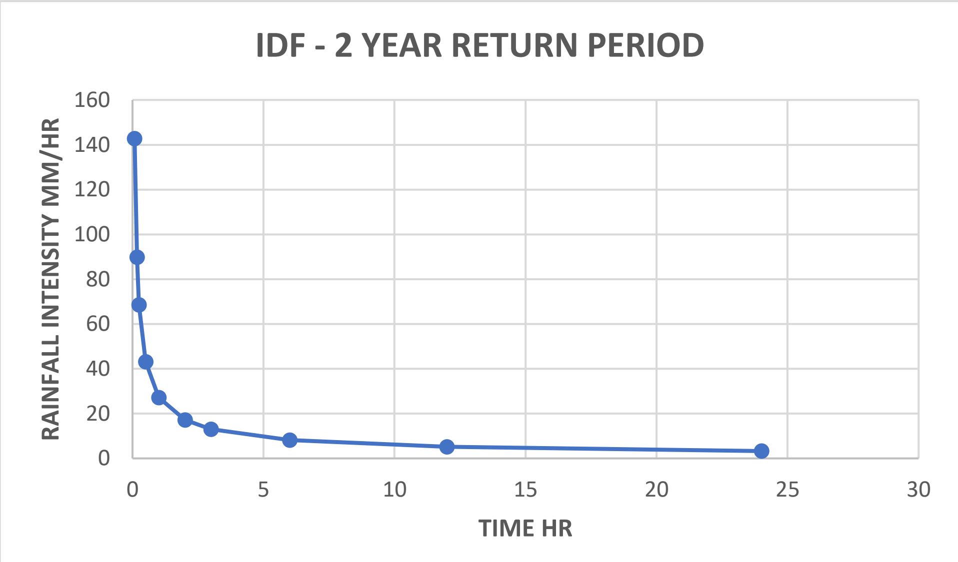


Fig: - 5.12 IDF – 2 YR RETURN PERIOD

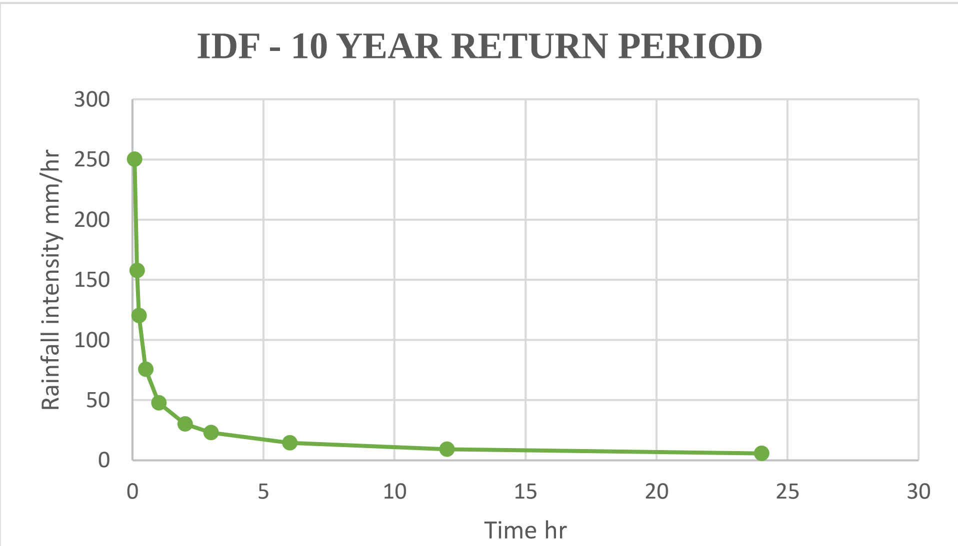


Fig: - 5.13 IDF – 10 YR RETURN PERIOD

Time (min)	RETURN PERIOD Rainfall (mm)	25 years Rainfall (mm/hr)	Rainfall (mm)	50 years Rainfall (mm/hr)
5	25.35	304.35	28.7	344.48
10	31.93	191.63	36.13	216.89
15	36.54	146.14	41.35	165.41
30	46.05	92.1	52.12	104.25
60	58	58	65.64	65.64
120	73.11	36.55	82.74	41.37
180	83.67	27.89	94.71	31.57
360	105.43	17.57	119.33	19.89
720	132.83	11.07	150.34	12.53
1440	167.34	6.97	189.4	7.89

Table: - 5.5 IDF DATA OF 25 & 50 RETURN PERIOD

Above table shows the IDF curve for 25 years and 50 years return period of different duration.

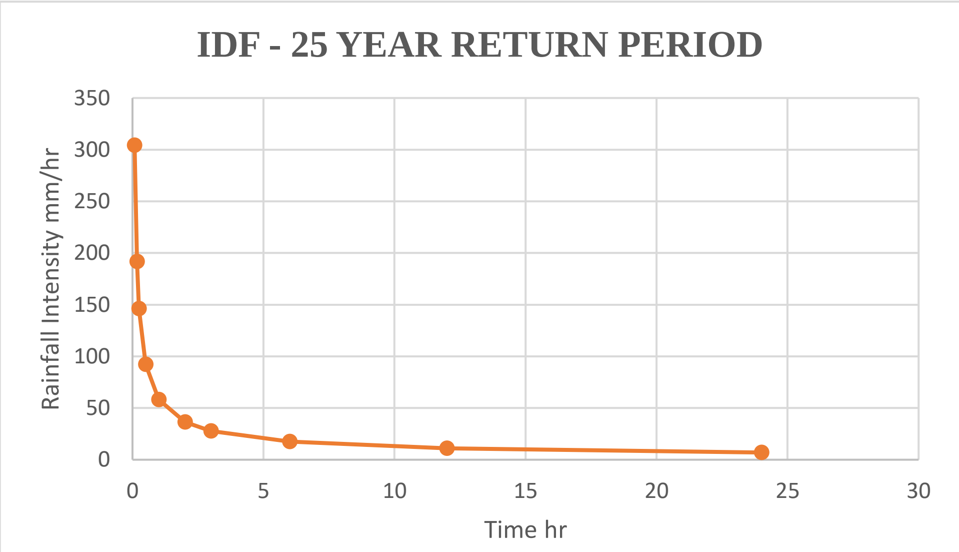


Fig: - 5.14 IDF – 25 YR RETURN PERIOD

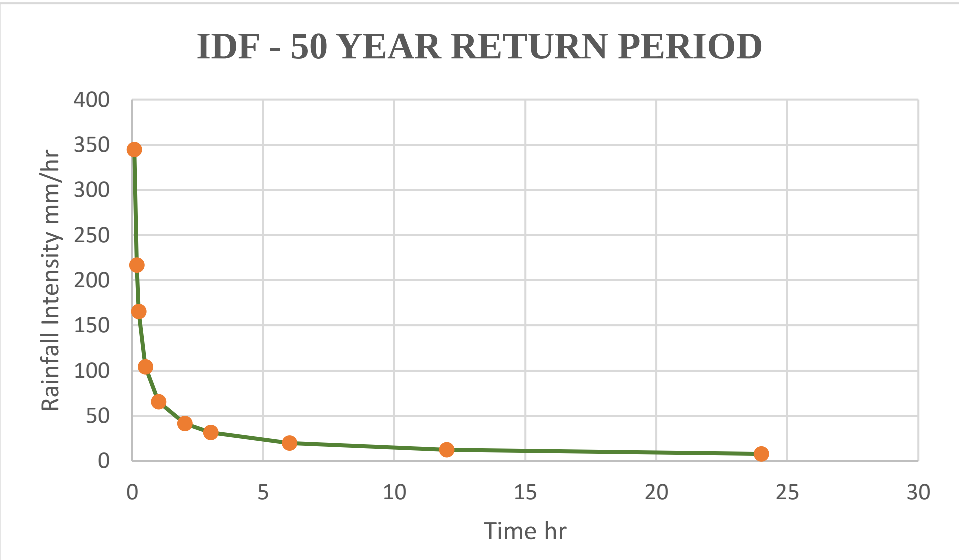


Fig: - 5.15 IDF – 50 YR RETURN PERIOD

RETURN PERIOD	75 years		100 years
Time (min)	Rainfall (mm/hr)	Rainfall (mm)	Rainfall (mm/hr)
5	367.81	32.01	384.32
10	231.58	40.31	241.97
15	176.61	46.13	184.53
30	111.31	58.15	116.3
60	70.09	73.23	73.23
120	44.17	92.31	46.16
180	33.71	105.66	35.22
360	21.23	133.12	22.19
720	13.38	167.72	13.98
1440	8.43	211.3	8.8

Table: - 5.6 IDF DATA OF 75 & 100 RETURN PERIOD

Above table shows the IDF curve for 75 years and 100 years return period of different duration.

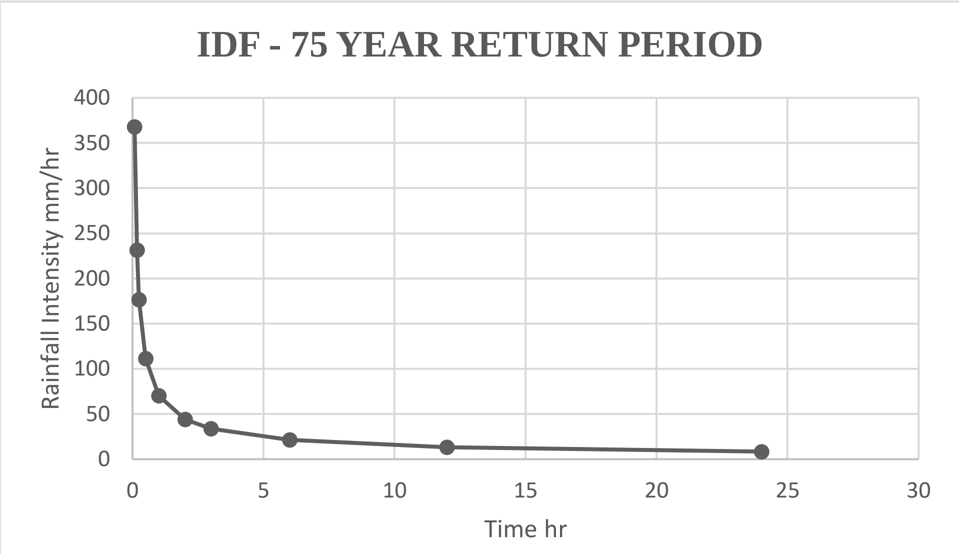


Fig: - 5.16 IDF – 75 YR RETURN PERIOD

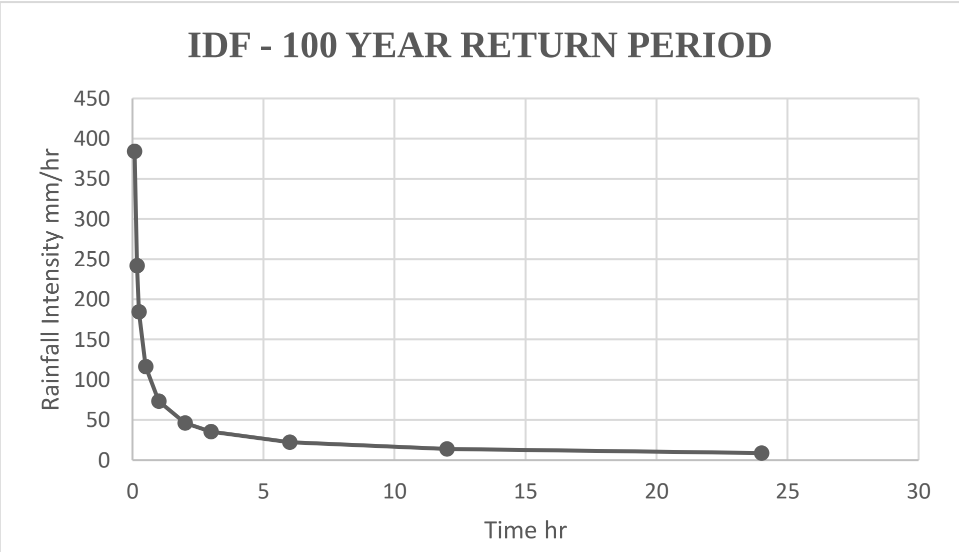


Fig: - 5.17 IDF – 100 YR RETURN PERIOD

Considering the overall rainfall intensity for different return periods and varying durations, the IDF curve is generated as shown in Fig. [].

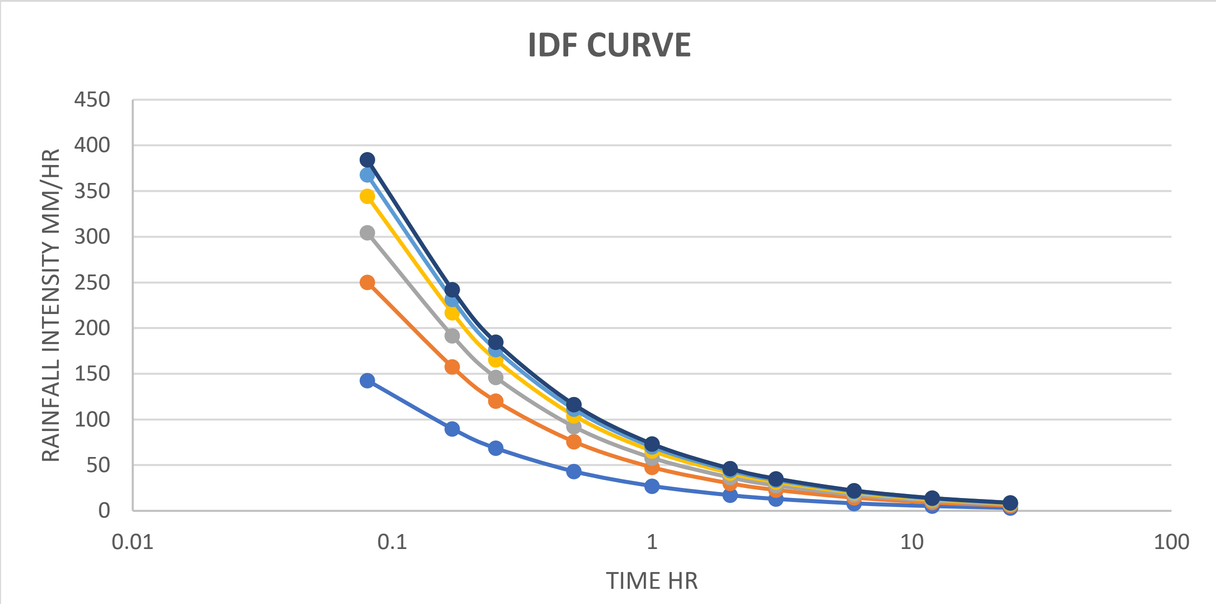


Fig: - 5.18 IDF CURVE

The provided table and graph, reveals key insights for constructing Intensity-Duration-Frequency (IDF) curves. Rainfall intensity (mm/hr) shows an inverse relationship with duration, decreasing as the duration increases, while total rainfall (mm) rises. For instance, at a 2-year return period, intensity drops from **142.79 mm/hr** for 5 minutes to **3.27 mm/hr** for 24 hours. Conversely, intensity increases with higher return periods, reflecting the severity of rare, extreme rainfall events, such as a rise from **142.79 mm/hr** (2 years) to **384.32 mm/hr** (100 years) for a 5-minute duration. The data demonstrates consistent hydrological trends, making it suitable for developing IDF curves, which are crucial for flood risk management, urban drainage design, and hydrological studies.

5.4 GENERATING TIME SERIES BY ABM

Rainfall depth data from the IDF curve for various return periods has been utilized to create an IDF curve through the **Alternative Block Method**, which organizes rainfall intensity data to simulate critical storm scenarios, resulting in a synthetic rainfall hyetograph. This refined data is incorporated into the **time series bar** within the **SWMM (Storm Water Management Model)** to simulate rainfall events. The simulation supports **drainage system design and analysis**, **flood risk assessment**, and **preparation for extreme weather events**, ensuring effective urban drainage and flood management by accurately representing peak storm intensities.

ALTERNATING BLOCK DESIGN STORM HYETOGRAPH

PFDS Data Matrix

Duration		Return Period (ye				
various	minutes	1	2	5	10	25
5-min:	5		11.89		20.85	25.35
10-min:	10		14.98		26.25	31.93
15-min:	15		17.15		30.04	36.54
30-min:	30		21.6		37.87	46.05
60-min:	60		27.22		47.69	58
2-hr:	120		34.3		60.11	73.11
3-hr:	180		39.26		68.81	83.67
6-hr:	360		49.46		86.69	105.43
12-hr:	720		62.36		109.22	132.83
24-hr:	1440		78.51		137.6	167.34
2-day:	2880					
3-day:	4320					
4-day:	5760					
7-day:	10080					
10-day:	14400					
20-day:	28800					
30-day:	43200					
45-day:	64800					
60-day:	86400					

Here, in above figure its shows that rainfall depth is present in 2, 10 and 25 years return period column in ABM excel template.

Then required return period time series in input on the template and recommended hyetograph is generated along with time series for SWMM

Here time series for 2-year return period of 120 min duration with 15min intervals

Duration and Time Step

Storm duration should be 5 to 10 times larger than the time of concentration	Hyetograph time step should be 5 to 10 times smaller than the time lag
Storm Duration (minute)	Hyetograph Time Step (minute)
120	15

Return Period

Return period is typically based on local cod
Return Period (year)
2

Final time series	Re-ordered interpolated ***incremental*** depths	Re-ordered interpolated ***cumulative*** depths
Time (minute)	Depth (mm)	Depth (mm)
0	-	0.00
15	1.770	1.770
30	1.770	3.540
45	2.810	6.350
60	4.450	10.800
75	17.150	27.950
90	2.810	30.760
105	1.770	32.530
120	1.770	34.300

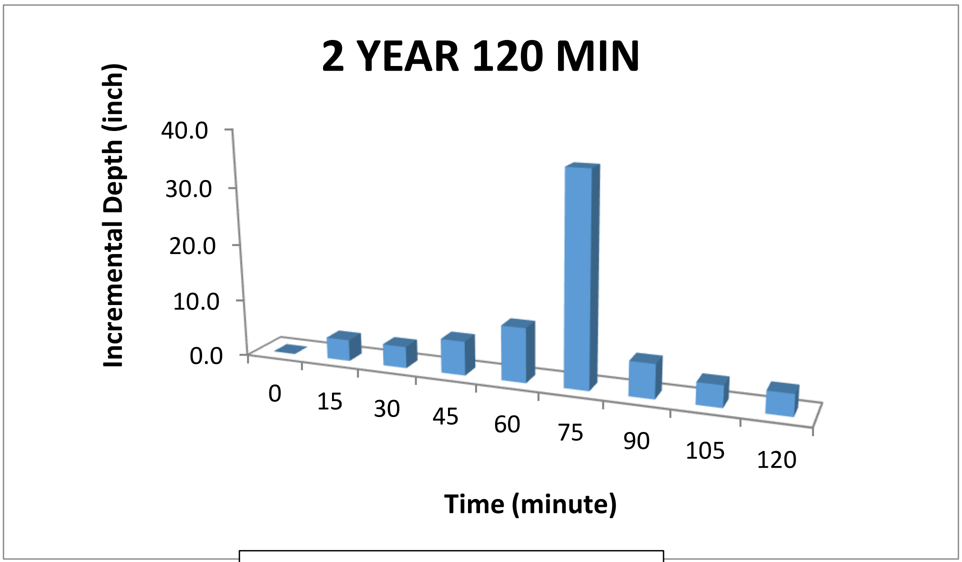


Fig: - 5.19 2 YR HYETOGRAPH

Similarly, 10-year and 25-year time series are generated along with hyetograph for visualization.

Duration and Time Step	
Storm duration should be 5 to 10 times larger than the time of concentration	Hyetograph time step should be 5 to 10 times smaller than the time lag
Storm Duration (minute)	Hyetograph Time Step (minute)
120	15
Return Period	
Return period is typically based on local cod	
Return Period (year)	
10	

Final time series	Re-ordered interpolated ***incremental*** depths	Re-ordered interpolated ***cumulative*** depths
Time (minute)	Depth (mm)	Depth (mm)
0	-	0.00
15	3.105	3.105
30	3.105	6.210
45	4.910	11.120
60	7.830	18.950
75	30.040	48.990
90	4.910	53.900
105	3.105	57.005
120	3.105	60.110

Duration and Time Step	
Storm duration should be 5 to 10 times larger than the time of concentration	Hyetograph time step should be 5 to 10 times smaller than the time lag
Storm Duration (minute)	Hyetograph Time Step (minute)
120	15
Return Period	
Return period is typically based on local cod	
Return Period (year)	
25	

Final time series	Re-ordered interpolated ***incremental*** depths	Re-ordered interpolated ***cumulative*** depths
Time (minute)	Depth (mm)	Depth (mm)
0	-	0.00
15	3.777	3.777
30	3.778	7.555
45	5.975	13.530
60	9.510	23.040
75	36.540	59.580
90	5.975	65.555
105	3.778	69.333
120	3.778	73.110

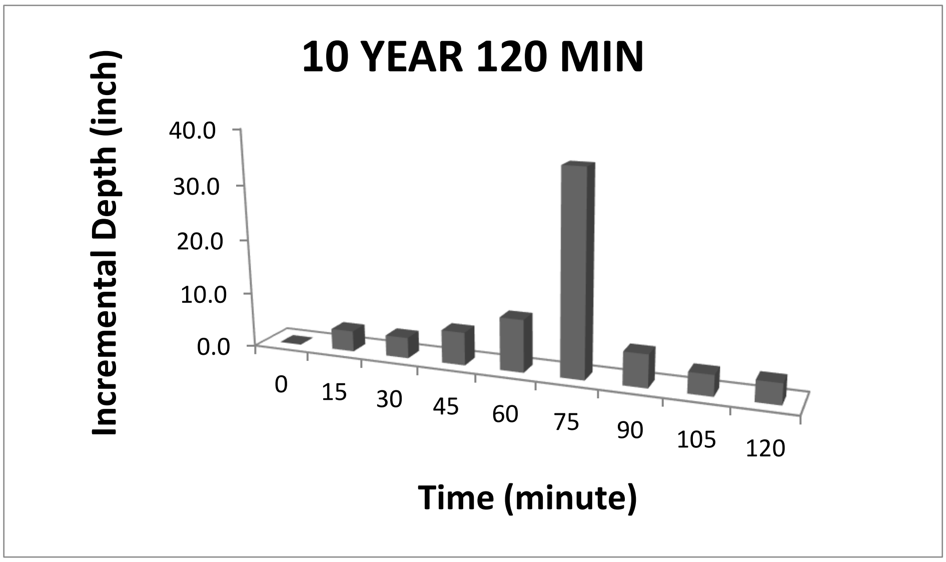


Fig: - 5.20 10 YR HYETOGRAPH

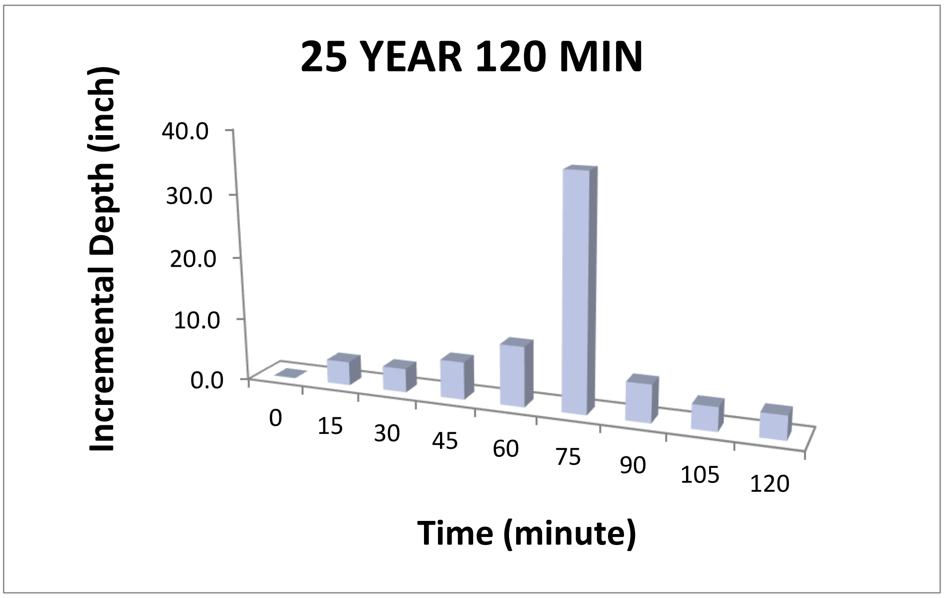
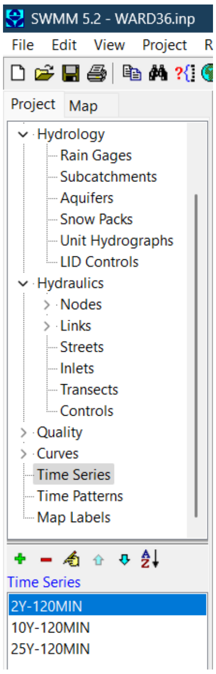


Fig: - 5.21 25 YR HYETOGRAPH



The above-mentioned time series will be imported into the SWMM software for real-time simulation of different return periods to analyze drainage system stress resistance as shown in figure [5.21] of property window

5.5 SIMULATION OF STUDY AREA AS PER ASDMA

As mentioned in *Chapter 4 – Methodology at 4.5 Clause.*

5.5.1 SIMULATION OF EXISTING DRAINAGE

5.5.1.1 WARD 36 SIMULATION

Here, Ward 36 is considered for drainage simulation of different time series with their existing drainage specifications as per GMC data.

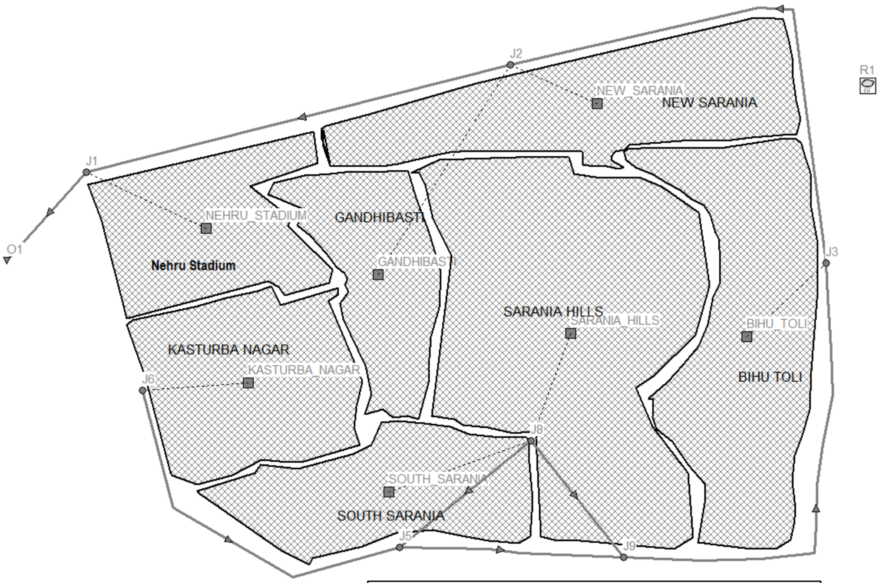


Fig: - 5.22 WARD 36 INTERFACE

5.5.1.2 SUMMARY REPORTS OF WARD 36 FOR 2-YEAR 120 MIN TIME SERIES

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
KASTURBA_NAGAR	34.30	0.00	0.00	15.59	17.05	1.56	18.61	4.10	2.08	0.543
SOUTH_SARANIA	34.30	0.00	0.00	1.59	25.49	6.91	32.39	7.13	3.08	0.944
GANDHIBASTI	34.30	0.00	0.00	23.97	8.55	1.76	10.31	2.27	1.22	0.301
BIHU_TOLI	34.30	0.00	0.00	7.67	25.30	0.90	26.20	9.17	3.76	0.764
NEW_SARANIA	34.30	0.00	0.00	7.67	25.30	0.90	26.20	9.17	3.76	0.764
NEHRU_STADIUM	34.30	0.00	0.00	22.29	10.26	1.72	11.98	2.64	1.41	0.349
SARANIA_HILLS	34.30	0.00	0.00	24.82	8.52	0.90	9.42	4.71	2.30	0.275

Topic: Node Depth — Click a column header to sort the column.

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Day of Maximum Depth	Hour of Maximum Depth	Maximum Reported Depth Meters
J1	JUNCTION	0.19	1.05	69.05	0	01:31	1.04
J2	JUNCTION	0.16	0.87	72.87	0	01:30	0.87
J3	JUNCTION	0.30	1.68	74.68	0	01:31	1.68
J5	JUNCTION	0.25	1.50	76.50	0	01:27	1.50
J6	JUNCTION	0.06	0.40	77.40	0	01:30	0.40
J8	JUNCTION	0.12	0.83	80.83	0	01:30	0.82
J9	JUNCTION	0.22	1.31	75.31	0	01:31	1.31
O1	OUTFALL	0.19	1.03	66.03	0	01:32	1.03

Topic: Node Flooding Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J5	0.13	1.389	0	01:30	0.415	0.000

Topic: Outfall Loading Click a column header to sort the column.

Outfall Node	Flow Frequency %	Avgerage Flow CMS	Maximum Flow CMS	Total Volume 10^6 ltr
O1	95.01	1.880	15.338	38.643

Topic: Conduit Surcharge Click a column header to sort the column.

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Downstream Full	Hours Above Normal Flow	Hours Capacity Limited
C9	0.01	0.01	0.01	0.13	0.01
C14	0.01	0.01	0.01	0.24	0.01

Here, above table is summary of drainage performance where J5 junction faces node flooding leading to overland flood nearby areas and conduit C9 and C14 gets affected in 01:30 (HH/MM) duration

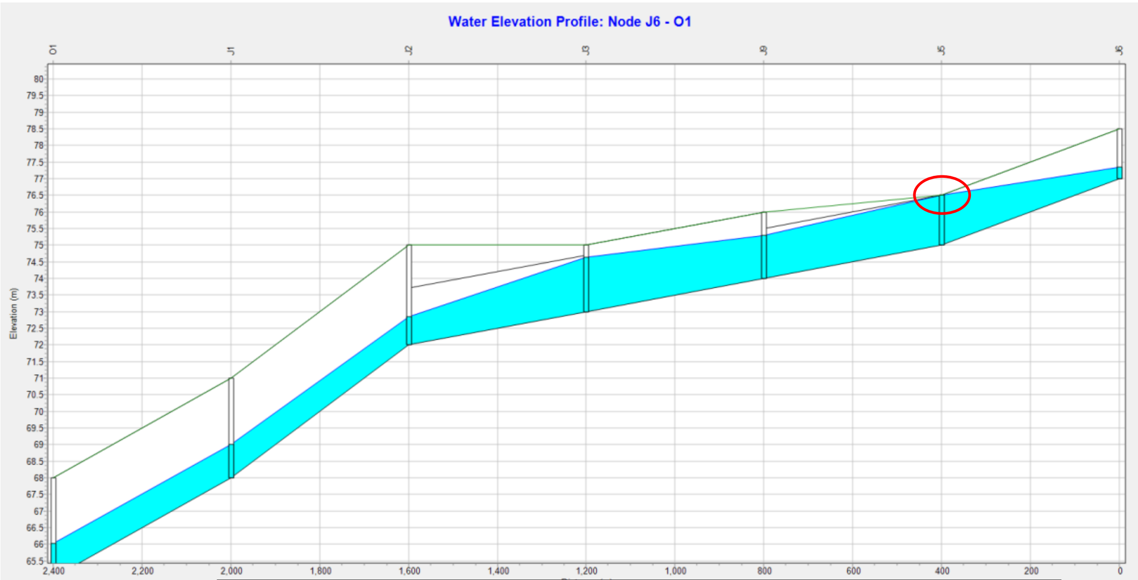


Fig: - 5.23 WATER ELEVATION PROFILE 2-YR RETURN PERIOD

Above figure is the Water Elevation Profile: Node J6 – O1 whereas J5 gets affected in mentioned time by cumulative rainfall depth of 30.760mm

5.5.1.3 SUMMARY REPORTS OF WARD 36 FOR 10-YEAR 120 MIN TIME SERIES

Topic: Subcatchment Runoff   Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
KASTURBA_NAGAR	60.11	0.00	0.00	21.63	29.96	8.42	38.38	8.44	4.25	0.639
SOUTH_SARANIA	60.11	0.00	0.00	1.69	44.84	13.21	58.05	12.77	6.00	0.966
GANDHIBASTI	60.11	0.00	0.00	34.49	15.01	10.60	25.60	5.63	2.64	0.426
BIHU_TOLI	60.11	0.00	0.00	10.44	44.64	4.59	49.22	17.23	7.80	0.819
NEW_SARANIA	60.11	0.00	0.00	10.44	44.64	4.59	49.22	17.23	7.80	0.819
NEHRU_STADIUM	60.11	0.00	0.00	31.87	18.00	10.21	28.22	6.21	2.98	0.469
SARANIA_HILLS	60.11	0.00	0.00	38.40	14.97	6.68	21.66	10.83	4.77	0.360

Topic: Node Depth   Click a column header to sort the column.

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Day of Maximum Depth	Hour of Maximum Depth	Maximum Reported Depth Meters
J1	JUNCTION	0.28	1.43	69.43	0	01:30	1.43
J2	JUNCTION	0.24	1.16	73.16	0	01:30	1.15
J3	JUNCTION	0.45	2.00	75.00	0	01:23	2.00
J5	JUNCTION	0.37	1.50	76.50	0	01:20	1.50
J6	JUNCTION	0.10	0.67	77.67	0	01:30	0.67
J8	JUNCTION	0.20	1.50	81.50	0	01:29	1.50
J9	JUNCTION	0.34	1.69	75.69	0	01:29	1.69
O1	OUTFALL	0.28	1.42	66.42	0	01:31	1.42

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J3	0.27	5.229	0	01:30	2.934	0.000
J5	0.46	6.179	0	01:28	5.050	0.000
J8	0.04	1.276	0	01:30	0.133	0.000

Topic: Outfall Loading   Click a column header to sort the column.

Outfall Node	Flow Frequency %	Avgerage Flow CMS	Maximum Flow CMS	Total Volume 10^6 ltr
O1	95.19	3.405	23.466	70.130

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Downstream Full	Hours Above Normal Flow	Hours Capacity Limited
C9	0.01	0.39	0.01	0.47	0.01
C14	0.01	0.01	0.20	0.37	0.01
C16	0.04	0.04	0.19	0.05	0.01
C17	0.01	0.04	0.01	0.09	0.01

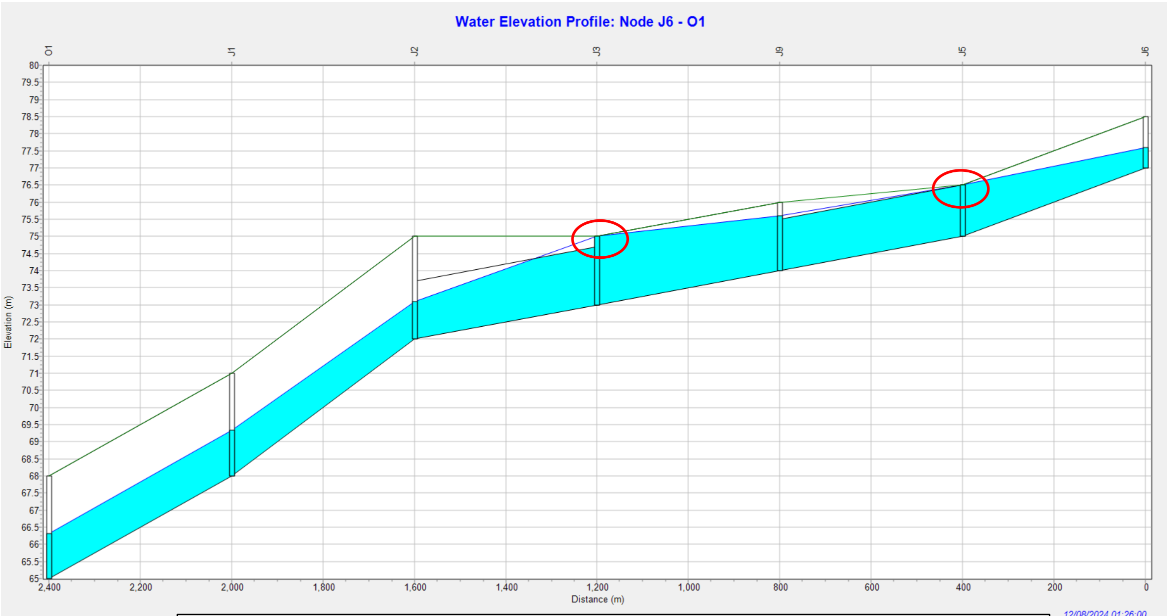


Fig: - 5.24 WATER ELEVATION PROFILE 10-YR RETURN PERIOD

Here, above table [] is summary of drainage performance where J3, J5 and J8 junction faces node flooding leading to overland flood nearby areas and conduit C9, C14, C16 and C17 gets affected in 01:28 and 01:30 respectively. (HH/MM) duration

And from above Water elevation plots NODE J3, NODE J5 AND J8 gets affected leads to flooding.

5.5.1.4 SUMMARY REPORTS OF WARD 36 FOR 25-YEAR 120 MIN TIME SERIES

Topic: Subcatchment Runoff — Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Imperv Runoff mm	Perv Runoff mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
KASTURBA_NAGAR	73.11	0.00	0.00	23.46	36.46	13.10	49.56	10.90	5.45	0.678
SOUTH_SARANIA	73.11	0.00	0.00	1.73	54.59	16.41	71.00	15.62	7.52	0.971
GANDHIBASTI	73.11	0.00	0.00	37.80	18.26	17.04	35.30	7.77	3.47	0.483
BIHU_TOLI	73.11	0.00	0.00	11.27	54.38	7.01	61.40	21.49	10.00	0.840
NEW_SARANIA	73.11	0.00	0.00	11.27	54.38	7.01	61.40	21.49	10.00	0.840
NEHRU_STADIUM	73.11	0.00	0.00	34.85	21.90	16.33	38.23	8.41	3.89	0.523
SARANIA_HILLS	73.11	0.00	0.00	43.25	18.22	11.58	29.80	14.90	6.17	0.408

Topic: Node Depth — Click a column header to sort the column.

Node	Type	Average Depth Meters	Maximum Depth Meters	Maximum HGL Meters	Day of Maximum Depth	Hour of Maximum Depth	Maximum Reported Depth Meters
J1	JUNCTION	0.32	1.60	69.60	0	01:30	1.60
J2	JUNCTION	0.27	1.28	73.28	0	01:30	1.27
J3	JUNCTION	0.51	2.00	75.00	0	01:21	2.00
J5	JUNCTION	0.43	1.50	76.50	0	01:18	1.50
J6	JUNCTION	0.12	0.81	77.81	0	01:30	0.80
J8	JUNCTION	0.24	1.50	81.50	0	01:23	1.50
J9	JUNCTION	0.39	1.68	75.68	0	01:24	1.68
O1	OUTFALL	0.32	1.59	66.59	0	01:31	1.59

Topic: Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J3	0.39	7.349	0	01:30	5.584	0.000
J5	0.59	7.200	0	01:30	7.653	0.000
J8	0.18	4.217	0	01:30	1.586	0.000

Topic: Outfall Loading — Click a column header to sort the column.

Outfall Node	Flow Frequency %	Avgerage Flow CMS	Maximum Flow CMS	Total Volume 10^6 ltr
O1	95.29	4.155	27.197	85.658

Topic: Conduit Surcharge — Click a column header to sort the column.

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours Downstream Full	Hours Above Normal Flow	Hours Capacity Limited
C9	0.01	0.51	0.01	0.58	0.01
C14	0.01	0.01	0.28	0.45	0.01
C16	0.18	0.18	0.28	0.03	0.01
C17	0.01	0.18	0.01	0.07	0.01

Here, above table [] is summary of drainage performance where J3, J5 and J8 junction faces node flooding leading to overland flood nearby areas and conduit C9, C14, C16 and C17 gets affected in 01:30 simultaneously (HH/MM) duration

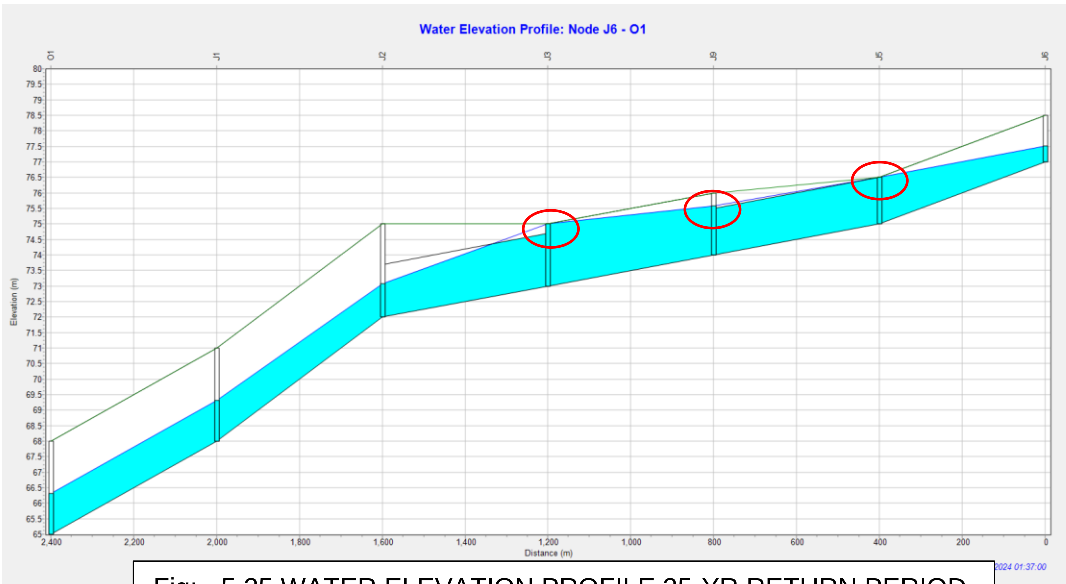


Fig: - 5.25 WATER ELEVATION PROFILE 25-YR RETURN PERIOD

And from above Water elevation plots NODE J3, NODE J5 AND J8 gets affected leads to flooding.

Above SWMM simulation reveals varying levels of impact on specific nodes and conduits across different return periods. During the 2-year return period, only node J5 is affected, with a recorded volume of **0.415 × 10^6 liters**. As the return period extends to 10 years, nodes J3, J5, and J8 show increased impacts, with volumes reaching **2.934 × 10^6 liters, 5.050 × 10^6 liters**, and **0.133 × 10^6 liters**, respectively. At the 25-year return period, the impacts intensify further, with J3, J5, and J8 experiencing volumes of **5.584 × 10^6 liters, 7.653 × 10^6 liters, and 1.586 × 10^6 liters,** respectively where trend graph is shown for existing drainage specifications fig []

As the return period increases, the stormwater impact grows more severe, underscoring the challenges posed by rarer and more intense storm events. Node J5 consistently faces the greatest impact, making it a critical component of the system that requires prioritized flood management interventions.

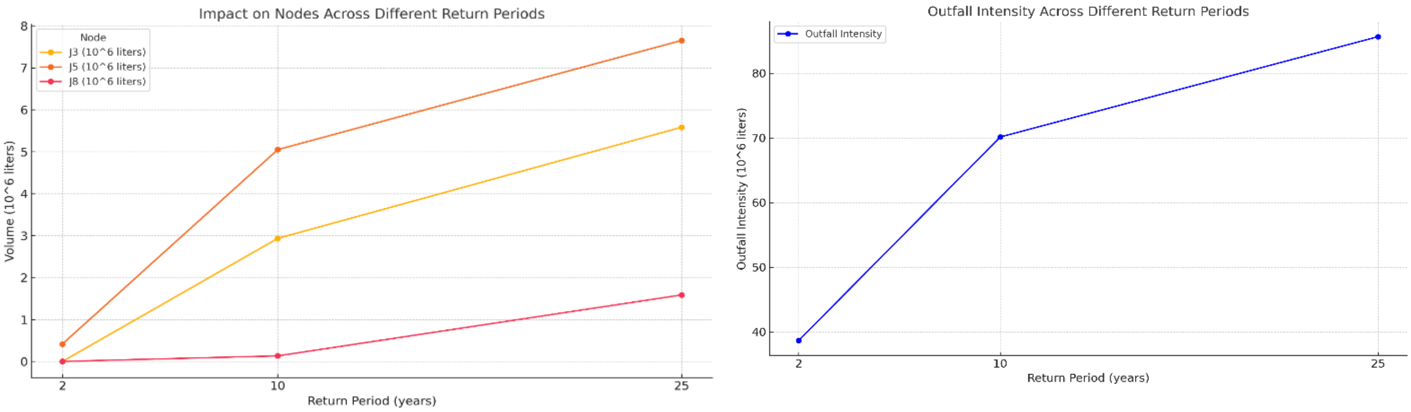


Fig: - 5.26 IMPACT ON NODES, OUTFALL INTENSITY VS RETURN PERIODS

Outfall Intensity Summary

Outfall intensity increases significantly with longer return periods:

- 2-year event: 38.643 × 10^6 litres
- 10-year event: 70.130 × 10^6 litres
- 25-year event: 85.658 × 10^6 litres

This highlights above fig [] the growing strain on drainage systems during intense and infrequent storms, emphasizing the need for improved management and mitigation strategies.

CHAPTER 6
CONCLUSIONS

The SWMM simulation for Ward No. 36 in Guwahati reveals an increasing challenge for the drainage system, which is struggling to cope with heavy rainfall events. Although storms are becoming less frequent, they are growing in intensity, leading to larger volumes of water. This exerts significant pressure on the existing drainage infrastructure, which wasn't designed to manage such high volumes of water.

Node J5 is one of the most affected areas, with stormwater reaching up to 7.653 million litres during severe storms, highlighting the urgent need for attention in this area.

The drainage system's outfall also demonstrates this issue: in a smaller 2-year storm, water flow measures around 38.643 million litres, but in a stronger 25-year storm, the flow increases sharply to 85.658 million litres. This shows how vulnerable the system is to more extreme, less frequent weather events.

To address these problems, it is crucial to enhance the drainage system. One solution would be to deepen the current drains to accommodate greater volumes of stormwater. Additionally, introducing more green spaces to absorb rainwater and ensuring consistent maintenance of the drainage system can help reduce flooding risks and improve resilience against future storms.

FUTURE SCOPE

1. If possible, LID (Low Impact Development) will be done for study surface runoff issue in urban area
2. Remaining Flood affected Ward Area will be simulated

CHAPTER 7

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