

STORM WATER & DRAINAGE ANALYSIS IN BALLY, HOWRAH

*At thesis submitted towards partial fulfillment of the
requirements for the degree of*

MASTER OF ENGINEERING

*In **Water Resources and Hydraulic Engineering***

Course affiliated to Faculty Council of Engineering & Technology

Jadavpur University

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2024

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ACKNOWLEDGEMENT

I express my sincere gratitude to my supervisor **Dr. Rajib Das**, Assistant Professor of School of Water Resources Engineering, Jadavpur University under whose supervision and guidance this work has been carried out. It would have been impossible to carry out this thesis work with confidence without his whole hearted involvement, advice, support and constant encouragement throughout. He has not only helped me in my thesis work but also has given valuable advice to proceed further in my life.

I would also express my sincere gratitude to **Prof. (Dr.) Asis Majumder** and **Prof. (Dr). Pankaj Kumar Roy** of School of Water Resources Engineering, Jadavpur University, **Dr. Subhasish Das**, Associate Professor, School of Water Resources Engineering, Jadavpur University, **Dr. Gaurab Banerjee**, Assistant Professor, School of Water Resources Engineering, Jadavpur University for their valuable suggestions.

I sincerely thank all the staffs and my batch mates of School of Water Resources Engineering of Jadavpur University for their help and support.

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ABSTRACT

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

So, the study focuses on the assessment of drainage system in Howrah, ward number four under borough number one of Howrah Municipal Corporation as a case study using Sewer GEMS and Google Earth Software. Based on primary and secondary data collected and Howrah Municipal Corporation map, the problems in this area are categorized as mainly construction, management and design problem. The method used to investigate problem in the existing drainage network of the above mentioned area is field data collection and site visit. By using Google Earth Software, catchment area Howrah has been defined.

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

Key words: Urbanization, Management, GIS, SewerGEMS, CAD

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CHAPTER-1

1. Introduction

1.1 General Background

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

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

1.2 Effect of Urbanization on Storm Runoff

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

Urban drainage system handle with the aim of minimizing the problems caused to human life and environment. Nowadays, as a consequence of urbanization and climate change, urban water managers have to rethink the ways in which water is managed today, taking into account economic, environmental and social factors. The concept of storm water is strongly related to urban areas where conveyance system exists. Despite flooding, storm water also is interesting regarding the urban water balance. The expansion of impervious land-cover implies both larger storm water runoff volumes and peak flows and consequently reduces other components of the hydrologic cycle.

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

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

1.3Background of Drainage Structures of the Study Area

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

1.4Statement of the Problem

Lack of Urban Storm Drainage (USWD) Management and sewer drainage is one of the most common sources of complaint from residents in many of Howrah's urban

Centers,

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

1.5 Significance of the study

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

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

CHAPTER-2

2. General Concept

2.1 Historical Perspective of Urban Drainage

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

2.2 Literature study

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

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

D'Asaro and Grillone (2010) described in detail the Curve Number (CN) procedure, which is largely and worldwide used for this easy application, allows to

Estimate the volume of direct runoff for a given rainfall event using a single parameter, CN, representing the storage of the basin in filtration and depending on the type of soil, land cover and land use.

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

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

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

Bhadiyadra *et al.* (2015) conducted a study on Surat City on the issue of storm water drainage. The research showed that the problem of storm water flowing back in river Tapti under high flood conditions is the major problem of storm water drainage when drainage outlets for Seurat city are closed. It indicates that Seurat City's storm water drainage system during flooding is not very effective in some of Seurat City's low-lying areas. In this case study, the feasible solution to this problem was achieved bydesigningsomegeneralaswellassystematicdrainagesolutionaswellasasuitable design of the desired working objective storm water drainage system. In this situation, if storm water logging from drains takes place, it will lead to road traffic, inflection, and obstruction to the general public's routine life, etc. Earlier the problem pumping systems were used during storm water backflow to remove excess storm water from SuratCity'slowlyingarea.Butthepumpingsystemwasnotenoughtopumplarge

Quantities of water from any location, and it were also very expensive to buy or hire both. Therefore, the current pumping system needed some improvements that resulted in a permanent solution to the storm water backflow needs a permanent solution, better storm water drainage facilities in any urban area that leads to better transportation facilities. On the other hand, existing storm water drainage system is needed to solve this problem. For example, instead of supplying a high-capacity pump in low-lying areas, this water is diverted to the bank of the river and then at this location we can provide a moderate capacity pump that continually pumps storm water at the bank of the river.

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

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

Kyiet *et al.* (2017) analyzed the existing drain condition and to propose the appropriate drain size and effective drainage system of Yangon city area. Increased frequency and intensity of heavy storm events predicted by climate changes effect will amplify the impact of urbanization on storm water runoff. Safe and dependable storm water drainage system is a long term ambition of society. The study area is situated in the south-western part of Yangon city area. The total study area is about 5.6 sq. km. At present, the study area receives the runoff from the largest catchment of Stanching Township. Due to the tidal effect of Yangon River and Hlaing River, insufficient drainage capacity and increase in surface runoff causes that lead to flooding in the study area. Here the modified rational method was used to estimate design flood for 10yr, 50yr and 100yr, respectively. After that, Manning's formula was used to estimate proposed drain size. Ten year average recurrence interval was used as design flood for conveyance structure and 50 year for culvert design. At first

the existing drain capacity were checked by using 10 yrs design flood and it was founded that almost existing all drain size so small and not enough to carry design discharge. So, new dimension of drain size were proposed using Manning's formula by fixing existing bed slope. Yangon River is influenced significantly by the tide and the tidal effect is one of the main factors for flooding. To simulate the rainfall-runoff process, SWMM was used for checking estimation of proposed drain capacity. It was observed that almost all the major drain and minor drain cannot carry the peak discharge of 10year return period.

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

CHAPTER 3

3.1 Objectives

3.1.1 General Objective

- To contribute efforts that aim at improving the storm water and sewer drainage problem of an Urban Local body. Here, Bally Municipality in Howrah District, West Bengal has been considered for case study

3.1.2 Specific Objectives

- To assess the . the problem of optimal storm drainage design for different rainfall conditions
- To assess the hydraulic performance of drainage systems of Bally Municipality area.
- To find out the possibility of separate and combined system for the project area

3.2 Scope of the Study

For the purposed of the study a sample catchment in the Bally area is considered. Different storm frequencies has been used for the design purpose. This study focuses specifically on evaluating, proper designing the drainage system for implementing, operating and maintaining the storm water flooding problem in the study area. The study focusses on hydraulic aspects of the network under consideration.

CHAPTER -4

4.1 METHODOLOGY

1. Data Collection and Preliminary Assessment:

- Topographical survey data obtained through DGPS and Total station survey has been considered for the study. The elevation data are based on standard benchmark used by the municipality. The data is obtained from the municipality.
- Conduct a preliminary assessment of the study area to identify key hydraulic physical constraints, such as terrain elevation, space availability, flood-prone areas.

2. Model Development:

- Set up a hydraulic model of the sewer network using SewerGEMS. This involves defining the network topology, including pipes, manholes, junctions, and boundary conditions.
- Assign properties to the sewer elements, such as pipe diameter, material, roughness coefficient, slope, and initial flow conditions for different storm scenario.
- Assess sanitary load for the network based on the population data.
- .Design the

3. Flow Analysis:

- SewerGEMS is used to simulate the hydraulic behavior of the sewer network under various operating conditions, such as dry weather flow, wet weather flow.
- Evaluate flow velocities, pipe slopes throughout the network to identify areas of concern, such as flow bottlenecks, surcharge points, and overflows.

4. Capacity Assessment:

- Assess the capacity of the sewer network to convey wastewater flows from upstream to downstream nodes without exceeding design criteria or causing hydraulic overloading.
- Identify critical points in the network where hydraulic capacity limits are likely to be exceeded during peak flow conditions, such as during storm events or periods of high wastewater demand.

5. System Design and Optimization:

- Optimize the design of the sewer network to meet the required hydraulic performance objectives, .
- Use SewerGEMS to explore alternative design scenarios, such as adjusting pipe sizes, realigning pipe routes, optimizing hydraulic gradients, and incorporating storage facilities or flow control devices.

6. Documentation and Reporting:

- Document the analysis and design process, including model inputs, assumptions, methodologies, and results.
- Prepare comprehensive reports, drawings, and presentations summarizing the findings of the sewer network analysis and design, including recommendations for system improvements, upgrades, and future monitoring.

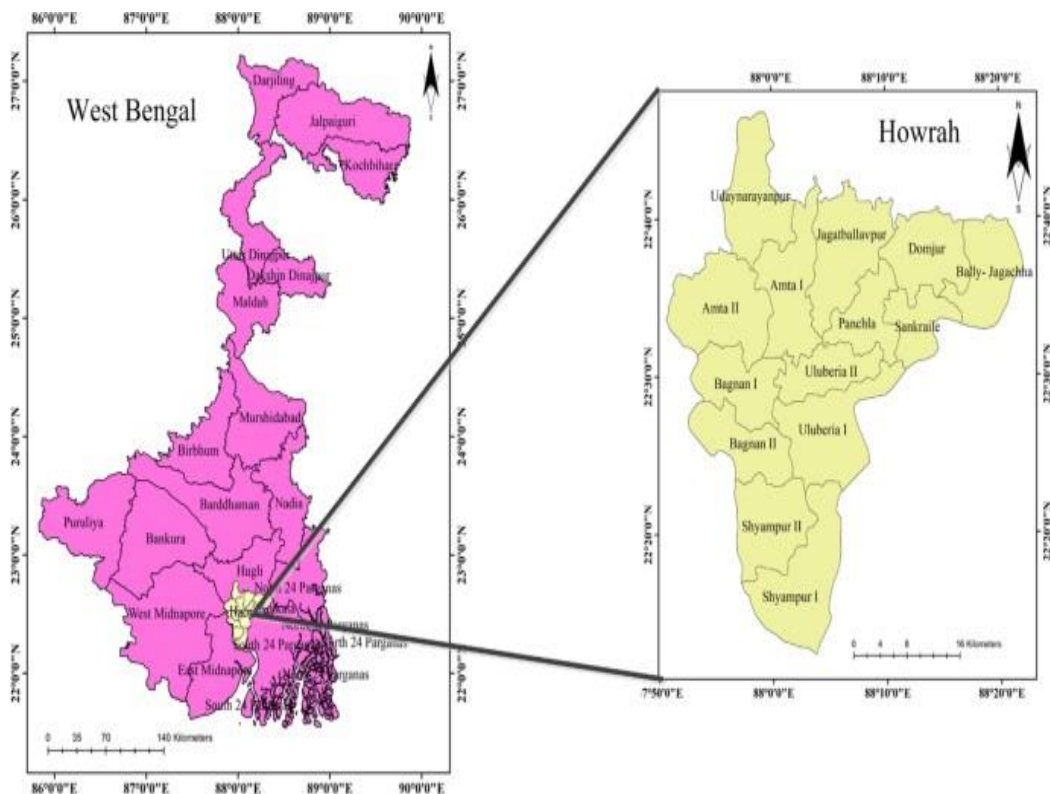
4.2 Possible outcome of thesis

- **Hydraulic Performance Optimization:** Ensure that the sewer network is designed to effectively convey wastewater without causing overflows or surcharging during peak flow conditions. This involves analyzing flow rates, velocities, and pressure heads to identify potential bottlenecks and optimize pipe sizes, slopes, and alignments for efficient flow distribution.
- **Capacity Assessment:** Evaluate the capacity of the sewer network to accommodate current and future wastewater loads. This includes assessing the system's ability to handle population growth, urban expansion, and changes in land use patterns. Use SewerGEMS to simulate various scenarios and predict future demand requirements, allowing for proactive infrastructure planning and capacity upgrades.
- **Flood Risk Mitigation:** Minimize the risk of urban flooding by designing the sewer network to effectively manage storm water runoff and prevent inundation of streets, properties, and critical infrastructure. Utilize SewerGEMS to model rainfall-runoff processes, analyze surface drainage patterns,.

CHAPTER -5

5.1 Study Area

Bally Municipality is located at 22.65°N 88.34°E and also the northernmost part of Howrah city. Bally is a small city located in the metropolitan area of Kolkata, West Bengal, India. It is a modern urban area, with great modern social services like schools, medical centers, shopping centers, etc. There are some very prestigious districts in the city, with quite expensive real estate and very high living standards.



333399

Figure 5.1.1: location of study area



Figure 5.1.2: whole BALLY Area by Google Earth Platform

5.2 Natural Drainage in the Project Area

5.2.1 Drainage Outfall

The major drainage outfall channels in the project area are

- Hoogli River Along the Eastern Boundary
- Bally Khal along the Northern and North-Eastern Boundary
- Branch II of Howrah Drainage Canal
- Nayanjuli Khal
- Mahanala, a major drain in Liluah area, started near Devi Mandir lane and it ran down via Mirpara Road to Tripura Road, then Gadadhar Bhatta Road to Netaji Subhas Road and finally it disposed the entire water from 63, 64 and 65 to HDC Branch - III

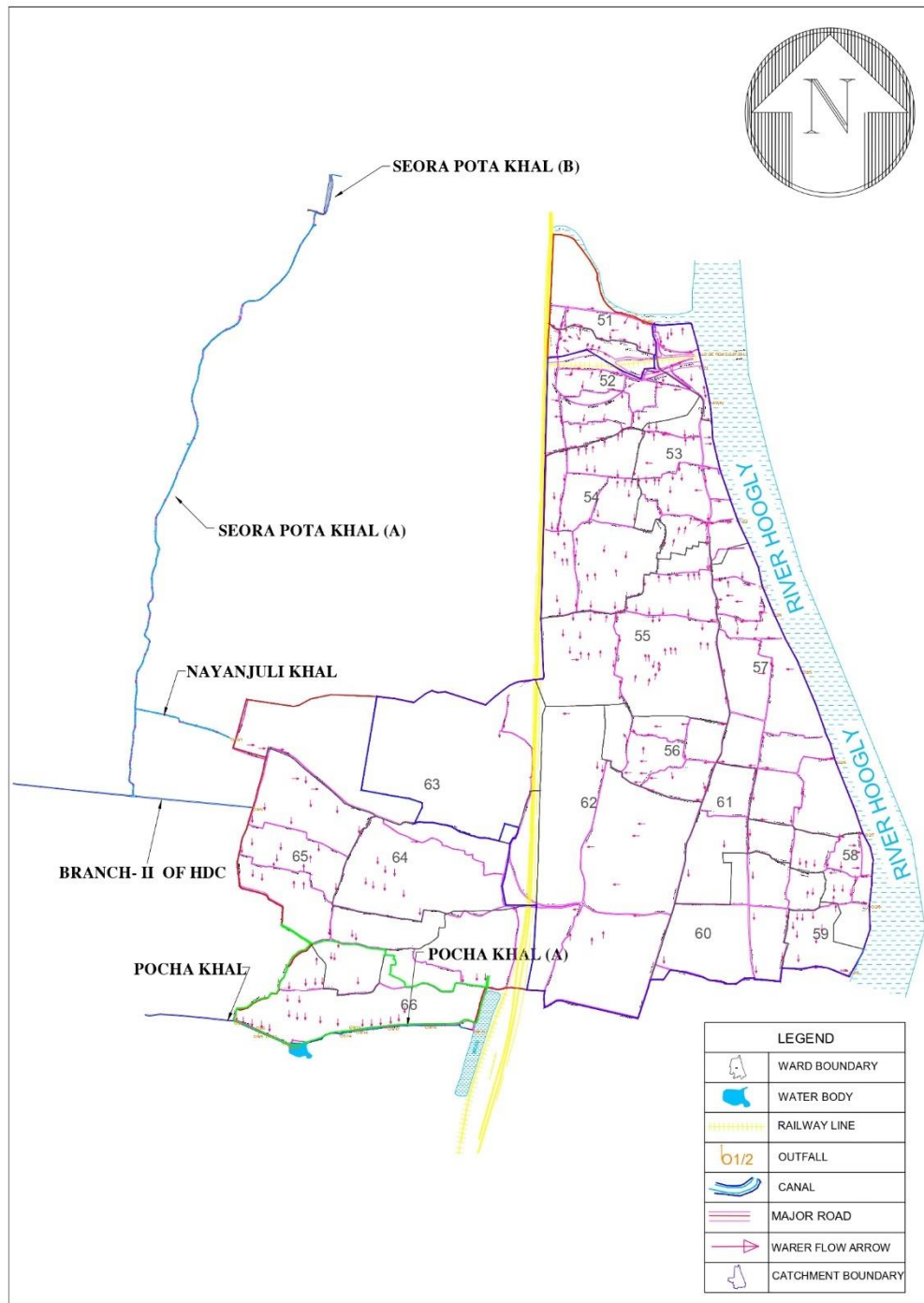


Figure 5.2.1: Drainage Channels in the Project Area

5.2.2 Storm and Sewer Drain

- A storm drain is that portion of the roadway drainage system that receives runoff from inlets to some point where it can be discharged into a ditch, channel, stream, pond, lake or pipe. Storm drains shall be designed using the following criteria where applicable:
- A storm drain, storm sewer, surface water drain/sewer or storm water drains designed to drain excess rain and ground water from impervious surfaces such as paved streets, car parks, parking lots footpaths, sidewalks, and roofs. Storm drains vary in design from small residential dry wells to large municipal systems.
- The Drains in the project Area are mainly covered surface drains. Depending on the road width the drain can be summarised as follows

Area	Length (km) of Drain for Road width		Total Length (km)
	< 3 m	> 3m	
Bally Area	92.69	67.87	160.56

Table 5.2.1: Road-width wise Drain Lengths in Project Area

- It is observed that in the project area, 75% drains are covered but in majority of the cases, the condition of the covers are not good.
- Roads are categorized as Black-Top Road (BT Road), Kachha Road, Concrete Road, brick road and Pucca road.
- Existing drainage facilities not to be included in the proposed drainage system shall be removed completely if they conflict with any element of the proposed construction.

5.3 Design Consideration

All the designs will generally conform to the latest 'Manual on Storm Water Drainage Systems – 2019' (Published by *Central Public Health and Environmental Engineering Organization*, CPHEEO, Govt. of India), modified suitably to account for project specific needs. Important factors relevant to the design as adopted are discussed in this section and are proposed to be adopted for the study.

5.3.1 Storm Water

Storm water, originates during precipitation events and snow/ice melts. Storm water can soak into the soil (infiltrate), be held on the surface and evaporate, or runoff and end up in nearby streams, rivers, or other water bodies (surface water). In natural landscapes such as forests, the soil absorbs much of the storm water and plants help

hold storm water close to where it falls. In developed environments, unmanaged storm water can create two major issues: one related to the volume and timing of runoff water (flooding) and the other related to potential contaminants that the water is carrying (water pollution). Storm water is also an important resource as the world's human population demand exceeds the availability of readily available water. Techniques of storm water harvesting with point source water management and purification can potentially make urban environments self-sustaining in terms of water. In urban areas storm water is generated by rain runoff from roofs, roads, driveways, footpaths and other impervious or hard surfaces. Unlike Sewage, storm water is generally not treated before being discharged to waterways and the sea. Poorly managed storm water can cause problems on and off site through erosion and the transportation of nutrients, chemical pollutants, litter and sediments to waterways, Well-managed Storm water can replace imported water for uses where high quality water is not required, such as garden watering.

5.3.2 Storm Runoff

Storm drainage disposal involves the conversion of rainfall into runoff and remove the precipitation to the receiving waters avoiding stagnation and inundation. The design principles primarily involve the translation of rainfall into runoff mostly by gravity. The computations of discharges are carried out by various methods suggested by various investigators. The discharge depends on the quantity of rainfall minus the evaporation losses, percolation losses and the amount of rain captured by the soil and other absorbents before it reaches the storm water drain.

5.3.3 Computation of runoff by rational method

The runoff will be calculated using the expression in Equation:

$$Q = 10 C i A$$

Where,

Q = Runoff (m^3/hr)

C = Coefficient of runoff

i = Intensity of rainfall (mm/hr)

A = Area of catchments of the particular drain/sewer (*hectares*)

The coefficient of runoff “ C ” will be selected on basis of the weighted average of percentage imperviousness of the drainage basin. CPHEEO Manual and other references provide values of imperviousness to be adopted for grass cover, undeveloped, residential, and industrial and commercially developed areas.

Coefficient of runoff (C): This is dependent on land use pattern and various terrain factors like nature of the surface, surface slope, initial soil conditions (before the storm starts) etc.. Considering the water tight bitumen surface for the at-grade road and the elevated expressway, runoff coefficient is considered as 0.9

(Refer Table 6.1, IRC:SP: 50, 2013)

5.3.4 Rainfall

The rainfall occurs in the locality during South West monsoon i.e., from June to September. However, the late withdrawal of monsoon even after second week of October has also been observed. During the period from the middle of April to the middle of May, the area witnesses several thunderstorms known as Norwester or Kal Baishakhi, which includes hails, severe storms and intense rainfalls over a short period. Data collected at Alipore Meteorological Station, RMC Kolkata in project area is used in the analysis

5.3.5 Rainfall Intensity & Return Period

The rainfall intensity adopted for CMPO master Plan was for once in 2 months or 6 times a year. Accordingly the drainage works in Howrah basin was developed after 1965.

This above intensity was reaffirmed in JNNURM report (DPR for Improvement in Howrah city and Its Vicinity) was prepared in 2007, by a consortium of different Government agencies led by KMDA and comprising HMC, HIT and IWD. This report is approved by CPHEEO, Govt. of India, clearly mentioned in Section 4.1 *“De-silting and re-excavation of Existing Canal / Channels in accordance with the hydraulic design to accommodate 2 months frequency storm.”* Accordingly the hydraulic design of proposed works, capacity of pumping stations and Howrah Drainage Channel has been calculated. The subsequent drainage development works in Howrah city were carried out based on approved JNNURM report.

A peek into the national guideline for this matter reveals that in 2007 (when JNNURM DPR was approved), there were no separate Guideline for drainage design. The CPHEEO Manual on sewerage and sewage treatment was the only available guideline for storm frequency of urban drainage. This guideline Recommended adoption of following storm frequencies

- a) Residential areas
 - i) Peripheral areas twice a year
 - ii) Central and comparatively high priced areas once a year
- b) Commercial and high priced areas once in 2 years

These values remained unchanged in the revised version of CPHEEO Manual on sewerage and sewage treatment, published in 2013 (Refer Section 3.9.3.2, Part A). In the year 2019, a separate manual for design of STORM WATER DRAINAGE SYSTEM was published jointly by Ministry of Housing and Urban Affairs (MOHUA) and CPHEEO of Govt. of India. This manual has the following

recommendation for the storm frequencies for design of drainage system.

Table 4.1: Recommended Design Return Period for various types of urban catchments

S. No.	Urban Catchment	Return Period	
		Class I Cities**	Other cities***
1.	Central Business and commercial	Once in 5 years	Once in 2 years
2.	Industrial	Once in 5 years	Once in 2 years
3.	Urban Residential	Once in 5 years	Once in 2 years
4.	Airports and other critical infrastructure*	Once in 100 years	Once in 50 years

*Critical infrastructure includes Railway Stations, Power stations, etc.

** Class I Cities are cities having population 1 Lakh and above

*** Other cities are cities having population less than 1 lakh

Table 5.3.1: Recommendation design return period

So following the CPHEEO manual for Drainage Design (As per Table 4.1 above), according to the present population of project area (HMC area), the adopted storm frequency shall be once in 5 years.

Impact of Changing the Storm Frequency

It has been already mentioned in the inception report that in absence of any other reliable meteorological stations, Alipore IMD will be considered for analysis of rainfall data. The IDF curves developed using Alipore IMD data during preparation of Sewerage & Drainage Master Plan of Kolkata Municipal Corporation, for different storm frequencies are as follows (Refer Annex 4 of the S&D Master Plan of Kolkata Municipal Corporation)

For Alipore

- 1 month storm frequency : $y = 371.27 x^{-0.7683}$
- 2 months storm frequency : $y = 496.06 x^{-0.7662}$
- 3 months storm frequency : $y = 496.80 x^{-0.7323}$
- 6 months storm frequency : $y = 646.66 x^{-0.7518}$
- 1 year storm frequency : $y = 765.73 x^{-0.7346}$
- 2 years storm frequency : $y = 772.15 x^{-0.6880}$

Here y = intensity of storm in mm/hr and x = duration of rainfall in minutes.

Considering topography of project area, the average Time of concentrations for most of the drains will be 40- 70 minutes. A comparison of runoff generated for above frequencies gives following values.

Intensity (mm/hr)	for Storm	% Increase wrt
-------------------	-----------	----------------

Duration (min)	Frequency				2 months frequency		
	2 month	6 months	1 year	2 year	6 months	1 year	2 year
40	29.38	40.39	50.96	61.02	137%	173%	208%
50	24.76	34.15	43.25	52.34	138%	175%	211%
60	21.53	29.78	37.83	46.17	138%	176%	214%
70	19.13	26.52	33.78	41.52	139%	177%	217%

Table 5.3.2: Intensity (mm/hr) for Storm Frequency

It clearly shows that even if the earlier standard of once in 1 year for central and high priced areas are adopted, the corresponding rainfall intensity will be on an average 170% higher, while adopting a 2 year storm frequency will increase the rainfall intensities by 200% on an average.

Moreover, the earlier designs are all done with an imperviousness factor of 70%. Considering the present level of built up area, it should be rational to adopt a factor of 85-95% imperviousness for majority of the residential areas.

So the resultant increase in generated runoff will increase be around 205% for storm frequency of once a year and 242% for a frequency of once in 2 years.

As most of the existing drains have rectangular section and increasing the depth is very difficult considering the fixed outlet conditions (in the canals), the hydraulic capacity can only be increased by increasing the width of the drain. It is observed, that keeping depth unaltered, following are the typical increase width required for increasing the capacity by 170%, which corresponds to a storm frequency of once a year.

Typical Original Drain Section		Increased width for 170% higher capacity	
Width (m)	Hydraulic Depth (m)	Modified width (m)	% increase in width
0.25	0.30	0.36	1.45
0.30	0.50	0.43	1.43
0.40	0.60	0.58	1.44
0.75	0.60	1.10	1.47
0.75	0.90	1.08	1.44
1.00	1.20	1.44	1.44
1.00	0.60	1.49	1.49

Table 5.3.3: Drainage details

5.3.6 Storm Duration

Storm duration will be selected based on the Time of Concentration (T_c) of the drainage basin. As per CPHEEO Manual, the time of concentration will be calculated as sum of (i) inlet time and (ii) time of flow in storm drain to the outlet.

5.3.7 Time of Concentration

After the rain reaches the ground it is intercepted by the topography of the ground, friction offered by the ground for the flow from hydraulically most distant point to reach the drain

which is normally known as the “Time of Inlet (T_i).” The precipitation after reaching the drain travels in the drain catching the intermediate precipitation before it finally discharges into receiving water and this is known as “Time of Flow (T_f)”. The total time for the storm to reach at a given point on the drain is known as “Time of Concentration ($T_c = T_i + T_f$)”. Thus the time of concentration is the time required for the rain water to flow over the ground surface from the hydraulically farthest point in the drainage basin and reach the point under consideration (point of entry in the drain).

Thus, the **Time of Concentration (T_c)** for a given storm water drain generally consists of two parts –Time of concentration is made up of inlet time, the period required to establish run-off and for water to flow from the most distant point in the drainage area to the drain, and time of flow in the drain. The latter is readily estimated by hydraulic computations. Inlet time is sometimes the most important factor in determining the probable run-off particularly in small districts or in fairly large districts with steep slopes. In towns it is seldom less than 3 or more than 20 minutes. Normally intense rains last not more than 20 min after which they weaken and restart after lapse of 60 min. CPHEEO Manual recommends to design the system for 12 mm/hr to 20 mm/hr which is normally suited for tropical conditions. Thus when the system is designed for 20 mm/hr, many a times the system will be able to carry 60 mm/hr intensities. This is however an indication in favour of adequacy of the drains provided the drains are free from obstructions and silt loads. Estimation of time of concentration of the storm is necessary for the calculation of quantum of flow. It depends on the characteristics of the catchments.

5.3.7.1 Time of flow in the drain or the channel flow time (T_f)

This may be obtained by dividing the length of the drain by the flow velocity in the drain.

i.e. $T_f = \text{length of the proposed drain}$

5.3.7.2 Flow velocity in the proposed drain

Thus, the total time of concentration (T_c) at a given point in the drain, can be easily obtained

As $T_c = T_i + T_f$

5.3.7.3 Kirpich Equation

(Ref. ‘Engineering Hydrology’ Auth. K. Subramanya (4E) Page. No. 298)

$$t_c = 0.01947 L^{0.77} S^{-0.385}$$

Where, t_c = Time of Concentration

L = maximum length of travel of water in basin

S = slope of catchments = (diff of maximum level and out fall level/length)

For smaller sewers, the following minimum slopes have been recommended.

5.3.8 Coefficient of Runoff

The coefficient of runoff will be adopted as prescribed by the CPEEHO manual (Table 4.2, Page No. 53) depending on the Land Use Pattern of the catchments. Runoff entirely depends on the basin characteristics and covers the following broad parameters.

- **Area:** Area affecting the runoff is more important. This is determined by survey or by computing (approx.) from available survey sheets.
- **Shape:** The shape has same effect as runoff. Ex: - long narrow watersheds give generally low peak flows than fan shaped shapes.
- **Slope:** Slope has a major factor in contributing to runoff. Steep slopes contribute quick runoff & more flow.
- **Land Use:** Land use studies give valuable back ground for fixing runoff coefficients for the storm.
- **Soil & Geology:** The type of surface soil has an important bearing on the calculation for runoff.
- **Storage:** Intercepting & depression storage in the basin are another important consideration for runoff. They include the interception due to Storage, Vegetation, Land expressions and Rain Water Harvesting Practices etc.

Basin Characteristics such as imperviousness, orientation, humidity, temperature, infiltration, gales at the time of the storm also have an impact on the storm. However, it is very difficult to incorporate these effects in the runoff calculations.

Computation of Runoff coefficient

The computation of the runoff coefficient depends on the following basic data

- The time–intensity rainfall curve to be used as a basis of design, i.e., time of concentration
- The probable future condition of the drainage area i.e., the percentage of imperviousness surface which may be expected when the district shall have been developed to the extent assumed.
- The runoff coefficient i.e., the proportion of the rainfall which will run off over the surface of the ground.
- The probable time required for water to flow over the surface of the ground to the first inlet, called the “inlet time” or “time of entrance”.
- The area tributary to the drain at the point at which the size is to be determined.
- The time required for water to flow in the sewer from the first inlet to the above mentioned point, which added to the inlet time, gives the Time of Concentration.

5.3.8.1 Horner’s Coefficient:

Considering all the above factors, Horner conducted tests over many catchments in US and arrived at certain coefficients which fairly tallied with real gauged values over many basins. These coefficients are extensively used for adaptation in the rational method.

For the present study considering the land use pattern of the Bally area , a fixed runoff coefficient of 0.9 is considered.

5.3.9 Drain sections

Drainage sections have been determined by calculating the hydraulic capacity and maintaining the velocity.

Manning's Formula shall be used for designing the Storm collection system

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

and the design hydraulic capacity of the section has been calculated from

$$Q = A \times V$$

Where, V = Velocity of flow in m/s

n = Manning's coefficient of roughness

R = Hydraulic radius in m (A/P)

S = Slope of hydraulic gradient

Q = Discharge in m³/s

A = Flow area in m²

As per CPHEEO manual (Table 5.1 , Page No.109), the Manning's coefficient of roughness will be adopted for the designs of various drains and conduits.

The bed slopes are in general provided to ensure a self cleansing velocity (> 0.6 m/s).

The maximum velocity is kept under 3.0 m/s.

In general a free board of 300 mm is provided at starting of all the drains. The free board increases further downstream depending on the ground profile. In a number of stretches the drain is laid at a slope opposite to the natural gradient of the road profile, thereby increasing the depth substantially

Coefficient of roughness

Coefficient of roughness plays an important role in offering resistance for the liquid to flow on its surface. This widely depends on the Reynolds's Number.

Manning's Coefficient of Rugosity (n)

Roughness coefficient as suggested in CPHEEO Manual to be used in Manning's formula are furnished below.

Coefficient of Roughness (n) in Manning's Formulae

Type of Material		Manning's n
Masonry	(a) Neat Cement Plaster	0.018
	(b) Sand & Cement Plaster	0.015
	(c) Concrete, Steel troweled	0.014
	(d) Concrete, Wood troweled	0.015
	(e) Brick in good condition	0.015
	(f) Brick in Bad Condition	0.017
	(g) Masonry in bad condition	0.02
Stone Work	(a) smooth, dressed ashlar	0.015
	(b) rubble set in cement	0.017
	(c) fine, well packed gravel	0.02
Earth	(a) Regular Surface in good condition	0.02

Table 5.3.8.1 Coefficient of Roughness (n) in Manning's Formulae

5.3.10 Minimum and Maximum Velocity

Minimum i.e. self-cleansing velocity should be achieved at least at normal storms to convey wastewater or storm water without long-term deposition of solid material. . A common design criterion is to maintain a value of 0.80 m/sec when the pipe is running full. However, a velocity as low as 0.60 m/sec may be allowed to transport sand/silt particles etc. Hence, the minimum velocity targeted during design is 0.8 m/s at design peak flow and 0.6 m/s for present peak flow in accordance with the recommendations of the CPHEEO manual referred to Table 5.2.

In case of a combined sewer system, often it is not possible to maintain the self-cleansing velocity, particularly those in upper stretches of the system during dry weather flow condition. This is an inherent weakness of combined system of drainage. However, it is expected that the silt deposited will be flushed out during peak flows. Where it is not possible to maintain self cleansing velocity during the time of peak flows necessary provisions of flushing arrangements is required.

From the design of sewers, it may be observed that for sewers running partially full for a given flow and slope, velocity gets little influenced by pipe diameter.

5.3.11 Computation of Area of Drainage Basin

The area contributing runoff to each drain is computed from the contour maps of the duly identifying the ridges and valleys. The area is computed in hectares as already indicated. The area of the drainage basin is divided into suitable segments of 50 hectares or less as required. The sizes of drains are to be computed accordingly

5.3.12 Design Period

The design period for sewerage and drainage schemes are so planned to meet the requirements that the systems operate for many years after their completion. The project horizon of this Master Plan is considered as year 2056 and different components of the systems have been sized and designed with the following life cycles.

5.4 Population Projections

For a considerable period of time Bally Municipality was part of the Howrah Municipal Corporation. So it will be more logical to consider the two Urban local bodies together for the purpose of population analysis.

As per Census data, the coverage of Howrah Municipality keeps changing from 1961. The district census handbook, 1971 mentioned total area of Howrah municipality as 61.5 sq km and specified that Bally municipality has been counted as a component of the Howrah Municipality. In fact it is specified that this area includes that Malipachghaa, Golabari, Howrah ,Bantra, Shibpur, Jagashha PS and two mouzas of JL no 39 and 40 of Sankrail PS. Subsequently in 1981, the Bally municipality was considered as a separate Municipality of Area 11.81 sq km and Howrah was mentioned as Municipal corporation, covering an area of 51. 74 sq km (Ref. : Page -110, Census of India, 1981, Series 23, WB, page II-A, General Population Tables). Through Howrah Municipal Corporation Act of 1980; it became a Municipal Corporation, in 1984 and wards 45 to 50 were added to the then Howrah Municipality. So, it is not clear how the area remains same in 1981 census tables and thereafter. One possibility is that the census enumeration in 1981 has already considered the area of these wards. So, for avoiding the confusion the populations of only from 1981 is considered for population projection purpose. Similarly for Bally also, the population data is considered from 1981.

Year	Howrah		Bally	
	Area (in km ²)	Population	Area (in km ²)	Population
1961	28.83	512,598	11.68	29,737
1971	61.50	737,877	11.68	38,892
1981	51.74	744,429	11.81	147,735
1991	51.74	950,435	11.81	184,474
2001	51.74	1,007,532	11.81	260,906
2011	51.74	1,077,075	11.81	293,373

**Table 5.4.1: Historical population data
(as obtained from Census Handbook of Govt. of India)**

The following methods are considered for the analysis:

- 1) Arithmetic Increase Method
- 2) Incremental increase method
- 3) Graphical Method

4) Logistic Curve Method

As decided during the Technical committee meeting that for the preparation of Master Plan and DPR, the design horizon shall be 2056 (2023 tender inviting, 3 yrs construction period, 30 years design period for civil works). The intermediate design horizon shall be 2041.

The results obtained from the four methods can be compared as follows

	HOWRAH		BALLY	
	2041	2056	2041	2056
Arithmetic average	1,409,721	1,576,044	439,011	511,830
incremental increase	700,951	731,679	295,121	485,397
Graphical method	1,898,919	3,748,050	389,545	452,930
Logistic Curve	1,415,546	1,736,063	307,030	307,271

Table 5.4.2: Population data

In case of Howrah, The incremental increase method gives a sharp decrease in Population, hence not considered. The value for 2056 predicted by Graphical method, gives a too high value. The values predicted by Arithmetic Method and Logistic method are close. The logistic method has considered a population less than the present population. So the logistics method is discarded in this case. The results obtained from the Arithmetic increase method are adopted as the projected population (Designed Population).

In case of Bally, the arithmetic method gives a sharp increase. In case of the incremental increase method and Graphical method gives similar values. There is unrealistic low change in population for the logistic curve method. So the value obtained from Graphical method is adopted as the projected population (Designed Population).

Storm Water Inlets

TYPE OF INLET SYSTEM CONSIDERED

These are devices to admit surface runoff to the sewers. The water inlets will be provided at appropriate intervals. The following type of the inlet will be considered in the system.

- Curb Inlets
- Gutter Inlets
- Combination Inlets

Each inlet being either depressed or flushed upon their elevation with reference to the pavement surface. Under the present study gully pits, catch pits and inspection pits for the mentioned purposes have been considered

Storm water inlets are proposed to be of brick structure with cast iron or polyelastomer grating. The connecting pipe from the street inlet to the main street sewer are considered to be of uPVC with size not be less than 200mm. Spacing of inlets depends upon various factors viz. condition of road surface, size and type of inlet and rainfall pattern.

Maximum spacing of inlet appurtenances recommended are as follows:

- Road width less than 3.5 m – 20 m at one side of road
- Road width greater than 3.5 m – 20 m at both sides of road

Manhole

Manholes are to be built at every change of alignment, gradient or diameter, at the head of all sewers and branches, at every junction of two or more sewers and at regular intervals for ease of maintenance of sewers. Spacing of manholes considered for a straight reach is as follows :

- Road width less than 3.5 m – 20 m
- Road width greater than 3.5 m – 30 m

Spacing may be increased on straight runs for large diameter man-entry sewers i.e. 900 mm and above.

5.5 Flooding

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

Types of Flood

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

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

collapse of debris dams also can cause flash floods.

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

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

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

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

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

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

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

water quality and risk of epidemics.

River Flood: During an extended period of rainfall and an extended area, major rivers may overflow their banks. Water can cover vast areas. Downstream areas may be affected, even though they themselves have not received much rain. The process is relatively slow with big rivers. In many ways, rain water enters the river. Some rain will fall directly into the river, but that alone will not cause the river to rise high. When the soil is saturated or hard, it will

Thus, in this one very large river, all the rain that fell in a large area (catchment area) comes together. It takes time for all the rainwater to reach the river when there is plenty of rain over a long period of time. While the water level rises slowly, officials may decide to evacuate individuals before the river overflows. The flooded area can be huge. Cattle would normally graze villages surrounded by large stretches of water. Whole communities can isolate themselves from the rest of the world as roads are blocked and communities are down. When a dike or dam breaks and a lot of water is suddenly released, a flash flood speed can be compared to the speed of the water at the breach. The speed will be reduced as a larger area becomes covered. Before slowly rising, the water spreads out to the lower lying areas as much as possible. For the people living near it, a breach is very dangerous. The water's strength can carry away cars, trees, and even houses, causing loss of life.

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

5.5.1 Causes of Flooding

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

the detailed behavior of the precipitation and by the nature of situation in which the event is likely to occur.

5.5.2 Effects of Flooding

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

CHAPTER-6

6.1 Sewer GEMS

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

With Bentley Sewer GEMS, the following can be done-

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

6.2 Laying Out Nodes and Links

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

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

The term links refers to any of the available line elements:

- Pressure Pipe
- Conduits
- Channels

- Gutters

6.3 Uses of Sewer GEMS

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

6.4 Data required for Design in sSewerGEMS

1) Catchment Area Data

- **Catchment Boundaries:** Delineation of the area contributing runoff to each Catch basin or manhole.

For the present study catchment area division for different nodes/manholes of Thiessen Polygon method and then further modified on the basis of the road levels. The Thiessen polygon method, also known as the Voronoi polygon method, is a technique used in hydrology and meteorology to estimate the spatial distribution of a variable such as precipitation or temperature over a region. This method divides a geographical area into a number of polygons, each associated with a specific data point, such as a weather station. This is constructed by constructing perpendicular bisectors of the lines between neighboring data points. Each polygon contains all the locations that are closer to its associated data point than to any other data point.



- **Area:** The size of each catchment. The sizes are measured from SewerGEMS directly. The total area of 54 ha (0.54 sq km) is divided into 54 sub catchments.
- **Runoff Coefficient (C):** A factor representing the fraction of rainfall that becomes runoff, dependent on land use, soil type, and surface condition. As mentioned earlier here a constant runoff coefficient of 0.9 is considered.
- **Time of Concentration:** The time it takes for runoff to travel from the furthest point in the catchment to the outlet. For all the inlets a constant time of concentration of 10 minute is considered

2) Rainfall Data

- **Rainfall Intensity-Duration-Frequency (IDF) Curves:** Data representing the relationship between rainfall intensity, duration, and frequency for the area of interest. Here the data for IDF curves

- Design Storm: Selection of appropriate design storm events (e.g., 2-year, 10-year, 100-year storms) based on local regulations and project requirements.

3) Land Use and Surface Characteristics

- Land Use Data: Information on the type and extent of different land uses within each catchment (e.g., residential, commercial, industrial).
- Surface Characteristics: Details about the impervious surfaces, soil types, and vegetation cover.

A GIS based land use map available from Howrah is used for assessing the built up area in the area under consideration. Specific Land use map for Bally is not available.

4) Topographic Data

- Digital Elevation Model (DEM): Elevation data to determine the natural flow paths and slopes.
- Contours: Topographic contours to assist in defining catchment boundaries and flow directions.

A contour file is prepared based on the available elevation data from the topographic survey. The contour file is prepared using AutoCAD civil 3D software.

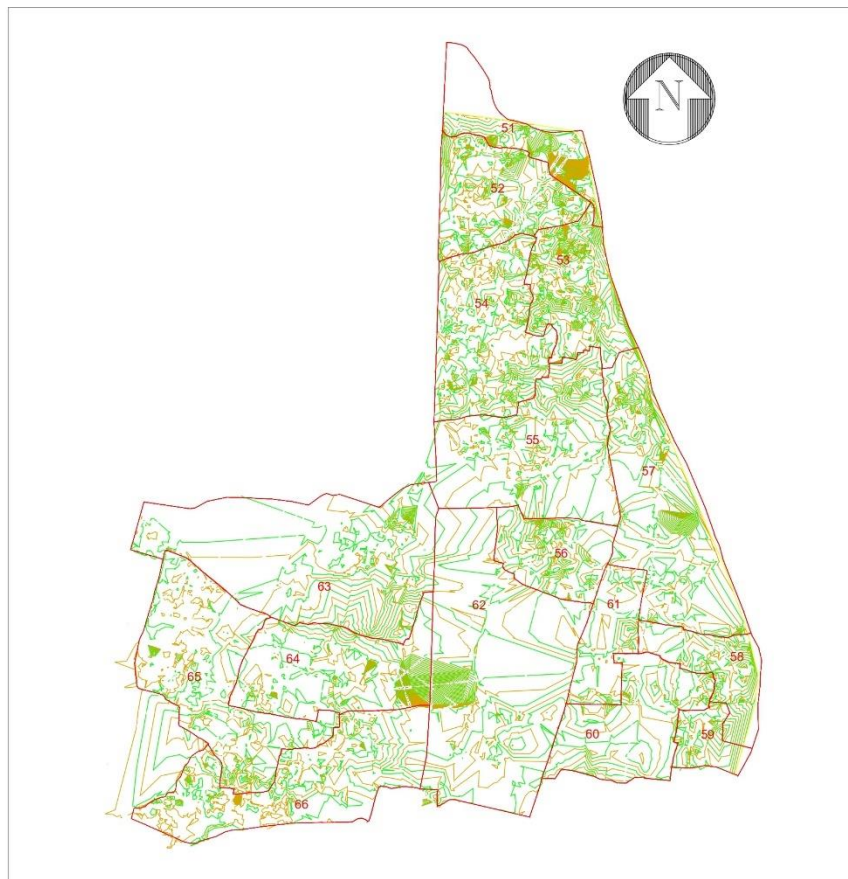


Figure 6.4.1: Contour Map of Bally

5) Existing Infrastructure Data

- Existing Sewer Network: Details of the current storm sewer system, including pipe sizes, lengths, materials, and conditions.
- Manholes and Inlets: Locations, elevations, and dimensions of existing manholes and inlets.

Here only the alignment of the existing drainage networks are considered.

6) Proposed System Data

- Proposed Sewer Network Layout: The planned layout of the storm sewer network, including proposed pipes, manholes, and inlets.
- Pipe Data: Proposed pipe sizes, materials, lengths, slopes, and other specifications. For the design here RCC circular pipes are considered.
- Manhole and Inlet Data: Proposed locations, elevations, and dimensions. Circular manholes and rectangular catch basin/ inlets are considered for this study.

7) Hydraulic Structures

- Outfalls: Locations and characteristics of discharge points where stormwater leaves the system.
In the present study two outfalls are there in the networks selected. Both the outfalls are considered as free flow condition.
- Control Structures: Details of any planned control structures such as weirs, orifices, or detention basins.
- Pumps: Specifications for any pumping stations required in the design.

8) Hydrologic Data

- Hydrologic Parameters: Parameters needed for runoff calculation methods used, such as curve number (CN) for SCS/NRCS methods or initial abstraction.
- Base Flow Data: Information on any base flow contributions to the system from groundwater or other sources.

Here the runoff calculation is done using Rational method

9) Geotechnical Data

- Soil Infiltration Rates: Infiltration rates for different soil types within the catchment areas.
- Groundwater Levels: Information on the local groundwater table and its potential impact on the storm sewer system.

For the present study these data are not used.

10) Regulatory and Design Criteria

- Local Design Standards: Compliance with local design criteria and regulations for storm sewer systems.

- Safety Factors and Design Margins: Incorporation of safety factors and design margins as required by local authorities.

These parameters are not considered in the present study

6.5 Selecting the Solver:

SewerGEMS has the option of several solvers, each designed to address specific types of hydraulic and hydrologic modeling challenges in sewer and stormwater systems

- a) **GVF-Convex Solver** :The GVF-Convex (Gradually Varied Flow Convex) solver is designed for steady-state analysis, focusing on peak flow conditions. It uses the convex routing method for gradually varied flow.

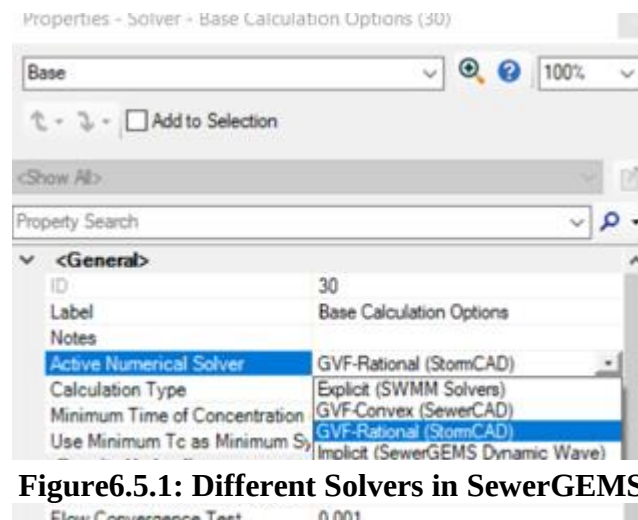


Figure 6.5.1: Different Solvers in SewerGEMS

- b) **GVF-Rational Solver**: The GVF-Rational solver is based on the Rational Method for peak flow estimation and routing in storm sewer systems
- c) **SWMM Solver**: The SWMM (Storm Water Management Model) solver is a dynamic wave solver that can handle unsteady flow conditions. It simulates the movement of water through both the surface and subsurface components of a drainage system
- d) **GVF Implicit Solver**: This Uses a four-point implicit finite difference solver to find the numerical solutions for the hydrodynamic Saint-Venant equations. This solver is based on the National Weather Service FLDWAV model. The implicit solver tends to be more stable with pumping situations

For the present study – GVF Rational solver is used for Storm network Design while GVF convex solver is used for sanitary sewer design.

The GVF (Generalized Variable Flow) Rational Solver is a hydraulic computation method used for small drainage areas with short travel times. It uses hydraulic analysis and design of storm sewer systems using the Rational Method

- Peak Flow Estimation: Calculates peak discharge using the Rational Method formula
- Flow Routing: Routes peak flows through the sewer network, accounting for changes in flow and

storage.

- Pipe Sizing and Hydraulic Grade Line Computation: Determines appropriate pipe sizes and computes the hydraulic grade line (HGL) and energy grade line (EGL)

The GVF convex Solver in SewerGEMS is designed for analyzing storm and sanitary sewer systems using steady-state flow conditions, combined with the efficiency of the convex method. This solver is specifically designed to handle steady-state flow conditions and is based on the Gradually Varied Flow (GVF) method.

GVF refers to the gradual changes in flow depth and velocity along a channel or pipe.

In sewer systems, GVF analysis considers factors such as channel geometry, flow rates, and boundary conditions to predict hydraulic profiles.

6.6 Design and Analysis Using SewerGEMS

The steps followed for the storm Design are as follows

- a. Model Setup: The basic network was prepared in AutoCAD and then using the ModelBuider toll the network is imported to SewerGEMS. Then the node (Catchbasins) and pipes are renumbered as per the actual drawing. Only the primary network was used for design. The conduits are initialized from Catalogue conduits with minimum diameter.
- b. Defining Catchments: Catchments are defined using Theissen polygon method as described earlier by replacing the catch basins as manholes. Then it is again reverted back to catch basins and linkage with each catch basin with the manhole was established/
- c. Assign Runoff Coefficient (C): All the catchments were assigned a runoff coefficient of 0.9
- d. Time of Concentration: Considering the small catchment areas, all the catchments are designed with same ToC of 10 min.
- e. Input Rainfall Data: The Rainfall data has been provided as User defined table

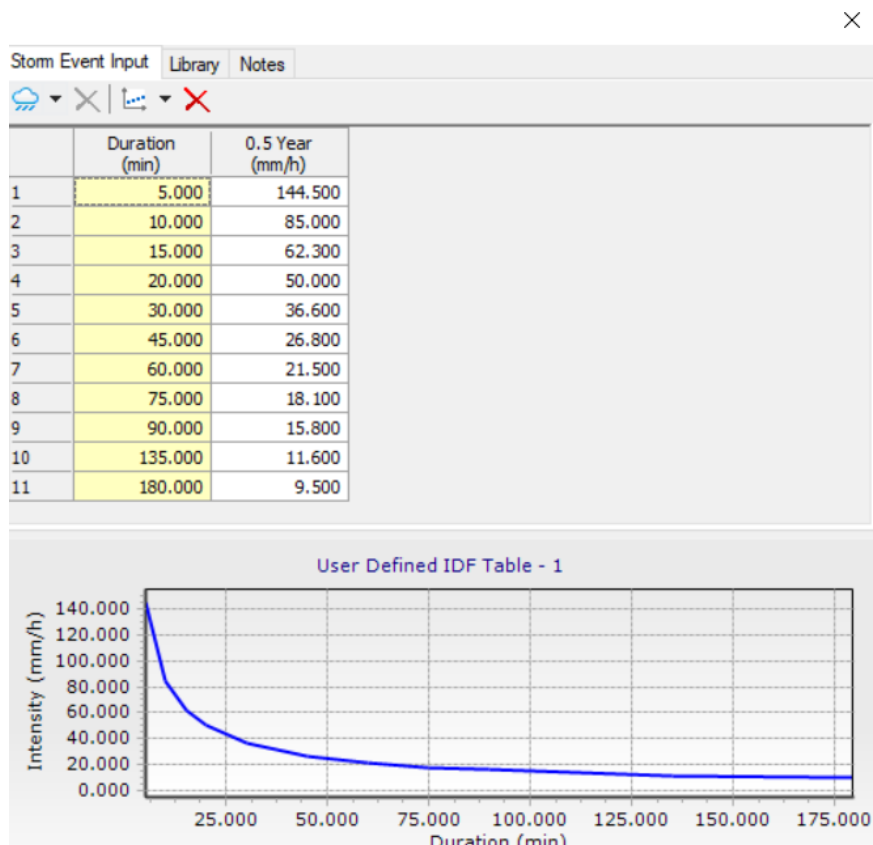


Figure 6.6.1: Input Rainfall Data

f) The solver was configured with suitable options. The time of travel in the pipe is defined. Initial analysis was done in design mode.

The Design constraints were set as follows

1. Slope : Max. 1 in 700, minimum 1 in 300
2. Velocity : Max. 2.0 m/s and minimum 0.60 m/s
3. Cover: Minimum 1 m and maximum 4 m
4. Crown matching at nodes
5. Design is done for 100% flow in sewer.

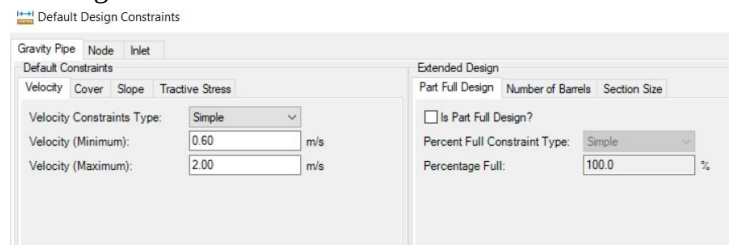


Figure 6.6.2: Design Constraints in Stormnetwork

The Solver in totality is presented below.

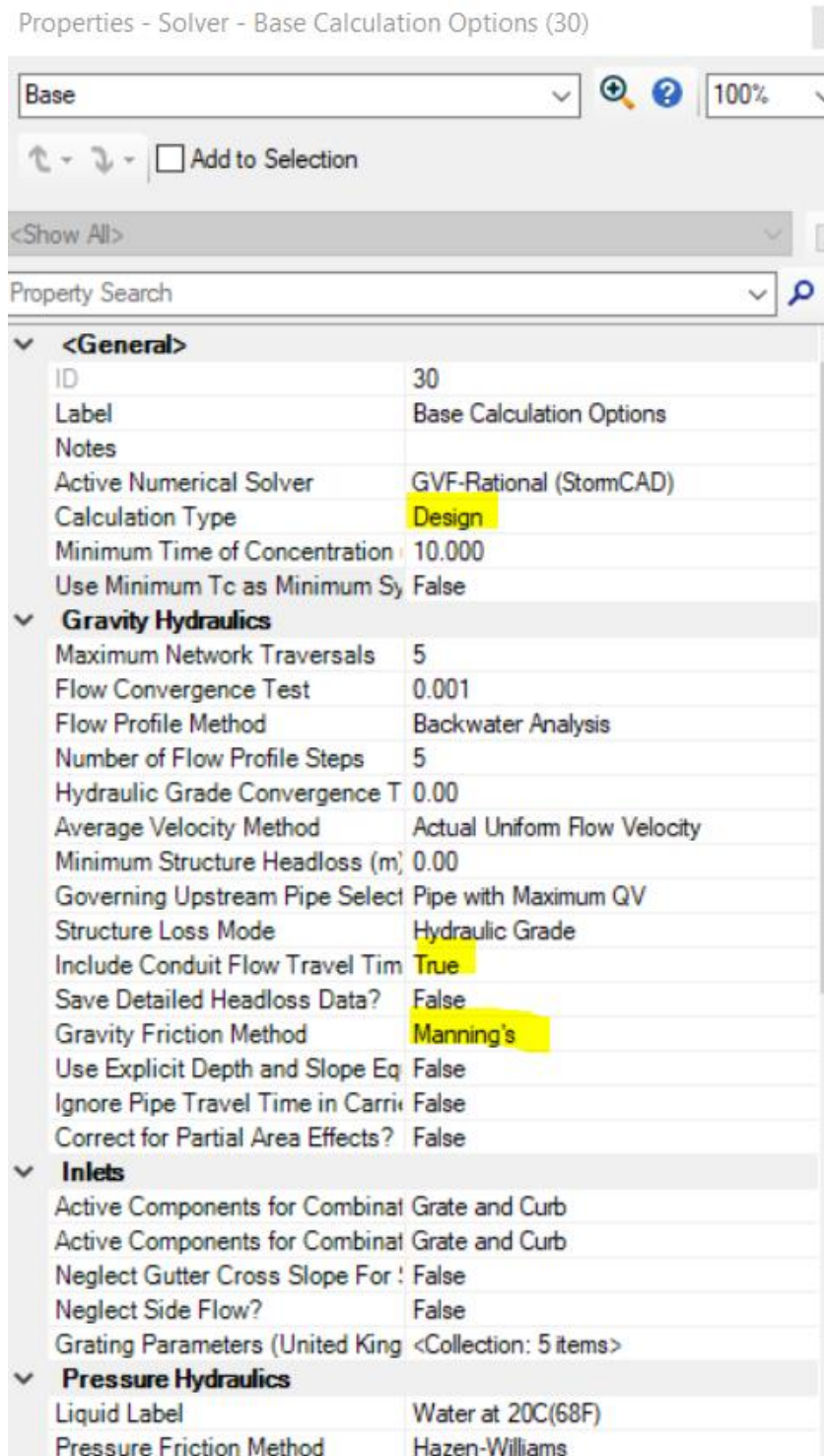


Figure 1.6.3: Solver for the SewerGEMS

In case of sanitary sewer the sanitary load distribution is done using the load builder tool, using population density and per capita wastewater flow (108 lpcd).

CHAPTER-7

In this Section the results of designing the network for the following design conditions and scenario are presented and the results are discussed.

- Design of the considered network for a storm frequency of 6 month or 1 year
- Design the considered network for sanitary load only
- Possibility of using the proposed network as combined sewer.

The design network is covering 54 ha in wards 51 and 52 of Bally Municipality. The outfalls (marked in red) are located in Bally Khal Area.

7.1 Results

7.1.1 Design and Analysis of Storm Sewers

The model was set up for the storm drainage design as described in the earlier section. The design was based on a set of circular conduits given input as catalogue conduit in sewergems.

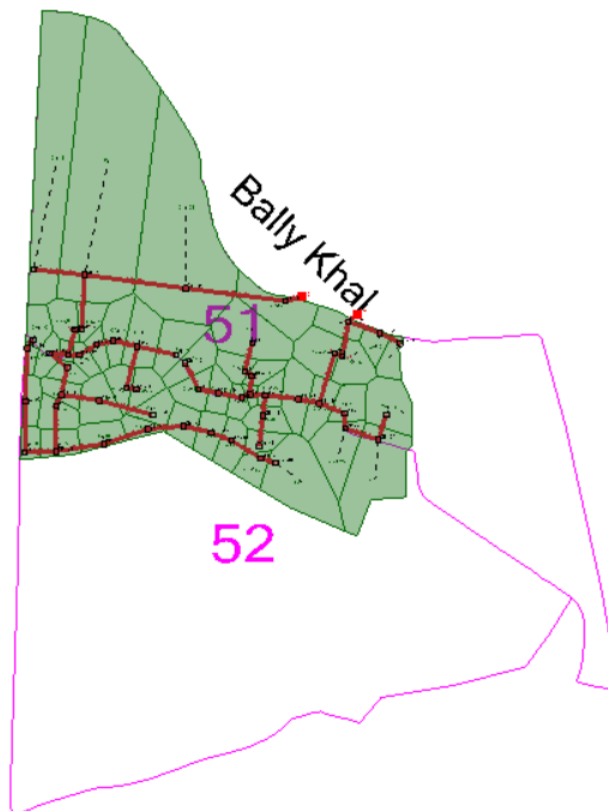


Figure 2.1.1 : Model Set up for the Storm analysis

It is observed that the pipe diameter varies from 300 mm dia to 1500 mm dia. The

pipe inventory can is as follows:

Conduit Description	Length (Concrete) (m)
Circle - 300.0 mm	55.7
Circle - 375.0 mm	230.5
Circle - 450.0 mm	462.8
Circle - 525.0 mm	283.7
Circle - 600.0 mm	94.1
Circle - 750.0 mm	645.4
Circle - 900.0 mm	243.9
Circle - 1,200.0 mm	586.2
Circle - 1,350.0 mm	186.1
Circle - 1,500.0 mm	213.1
Total Length	3,001.50

Table 7.1.1: Pipe inventory from Design with 6 month Storm Frequency

The results are summarized in Table 7.2, 7.3 and 7.4 for the conduit details, node details and the outfall details. It is observed that the design constrains were set to maximum cover of 4 m from ground level but it could not be maintained and the maximum cover is 4.67 m while the minimum cover is 0.7 m

ID	Label	Elevation (Rim) (m)	Elevation (Invert) (m)	Hydraulic Grade Line (In) (m)	Depth (Structure) (m)
915	CB - 1	5.65	0.61	0.83	5.05
916	CB - 2	5.06	0.40	0.69	4.66
918	CB - 3	5.02	-0.56	0.32	5.58
919	CB - 4	4.75	-0.92	0.21	5.67
920	CB - 5	5.25	0.31	1.43	4.94
921	CB - 6	4.47	0.92	1.62	3.55
922	CB - 7	4.61	0.64	1.57	3.97
923	CB - 8	4.66	0.68	1.63	3.98
924	CB - 9	4.25	0.84	1.73	3.41
925	CB - 10	3.96	2.58	2.86	1.38
926	CB - 11	4.45	0.95	1.77	3.50
927	CB - 12	4.24	1.36	1.92	2.88
928	CB - 13	4.01	1.48	2.05	2.53
929	CB - 14	4.00	1.58	2.14	2.42
930	CB - 15	3.47	1.72	2.23	1.75
931	CB - 16	4.02	2.26	2.59	1.76
932	CB - 17	4.18	1.78	2.10	2.41
933	CB - 18	4.03	1.45	1.84	2.58
934	CB - 19	4.12	1.32	1.76	2.79
935	CB - 20	4.50	1.10	1.57	3.40
936	CB - 21	4.34	0.90	1.51	3.44
937	CB - 22	3.25	0.66	1.30	2.59
938	CB - 23	3.90	0.45	1.12	3.45
939	CB - 24	3.64	0.03	0.86	3.61
940	CB - 25	4.42	0.49	1.10	3.93
941	CB - 26	4.51	0.73	1.37	3.78
942	CB - 27	4.74	0.95	1.52	3.79
943	CB - 28	4.90	1.41	1.79	3.49
944	CB - 29	4.47	-0.34	0.53	4.82
945	CB - 30	4.50	-0.29	0.63	4.79
946	CB - 31	4.54	1.17	1.67	3.37
947	CB - 32	4.64	1.22	1.73	3.43
948	CB - 33	4.50	1.47	1.92	3.03
949	CB - 34	4.60	2.28	2.62	2.32
950	CB - 35	4.31	2.41	2.68	1.89
951	CB - 36	5.19	2.48	2.80	2.71
952	CB - 37	5.52	2.27	2.65	3.25
953	CB - 38	5.73	2.14	2.52	3.60
954	CB - 39	4.17	1.38	2.07	2.79
955	CB - 40	4.26	2.13	2.77	2.13
956	CB - 41	4.43	2.41	3.03	2.02

ID	Label	Elevation (Rim) (m)	Elevation (Invert) (m)	Hydraulic Grade Line (In) (m)	Depth (Structure) (m)
957	CB - 42	4.51	2.62	3.24	1.88
958	CB - 43	4.56	2.80	3.38	1.76
959	CB - 44	4.94	2.93	3.48	2.01
960	CB - 45	5.14	3.14	3.61	2.00
961	CB - 46	6.03	3.38	3.86	2.64
962	CB - 47	4.96	1.57	1.81	3.39
963	CB - 48	4.26	1.23	1.54	3.03
964	CB - 49	4.27	2.62	2.87	1.64
965	CB - 50	4.49	2.21	2.61	2.28
966	CB - 51	4.21	1.23	1.92	2.98
967	CB - 52	4.25	1.26	1.97	2.99
968	CB - 53	4.23	1.09	1.83	3.14
969	CB - 54	4.97	-0.31	0.83	5.28

Table 7.1.2: Details of these Catch basins For Storm Sewer

Label	Start Node	Invert (Start) (m)	Stop Node	Invert (Stop) (m)	Length (Scaled) (m)	Size (mm)	Slope (Calculated) (1/S)	Section Type	Manning's n	Velocity (m/s)	Capacity (Full Flow) (m³/s)	Flow / Capacity (Design) (%)
CO-68	CB - 4	-0.92	O-1	-1.02	29.9	1500	300	Circle	0.013	2.54	4.08	75.8
CO-9(1)	CB - 4	-0.92	CB - 54	-0.31	183.2	1500	-300	Circle	0.013	2.54	4.08	75.9
CO-9(2)	CB - 54	-0.31	CB - 5	0.31	186.1	1350	-300	Circle	0.013	2.42	3.08	85.8
CO-11	CB - 5	0.31	CB - 7	0.64	98.9	1200	-300	Circle	0.013	2.08	2.25	60.5
CO-12	CB - 7	0.64	CB - 8	0.68	11.5	1200	-300	Circle	0.013	2.07	2.25	59
CO-13	CB - 8	0.68	CB - 9	0.84	48.2	1200	-300	Circle	0.013	2.06	2.25	57.9
CO-15	CB - 11	0.95	CB - 9	0.84	34.4	1200	300	Circle	0.013	1.89	2.25	41.1
CO-35	CB - 3	-0.56	CB - 29	-0.34	64.1	1200	-300	Circle	0.013	2.15	2.25	69.2
CO-36	CB - 29	-0.34	CB - 30	-0.29	15.4	1200	-300	Circle	0.013	2.13	2.25	66.2
CO-37	CB - 30	-0.29	CB - 24	0.03	95.4	1200	-300	Circle	0.013	2.12	2.25	65
CO-62	CB - 39	1.38	CB - 52	1.26	83	1200	700	Circle	0.013	1.29	1.47	48.7
CO-63	CB - 52	1.26	CB - 51	1.23	22.7	1200	700	Circle	0.013	1.3	1.47	50.3
CO-64	CB - 51	1.23	CB - 53	1.09	51	1200	369.811	Circle	0.013	1.74	2.03	44
CO-65	CB - 53	1.09	CB - 11	0.95	41.4	1200	300	Circle	0.013	1.88	2.25	40.2
CO-66	CB - 3	-0.56	O-2	-0.63	20.3	1200	300	Circle	0.013	2.17	2.25	72.9
CO-10	CB - 5	0.61	CB - 6	0.92	94	900	-300	Circle	0.013	1.79	1.05	72.4
CO-27	CB - 22	0.66	CB - 23	0.45	60.8	900	300	Circle	0.013	1.77	1.05	68.2
CO-28	CB - 23	0.45	CB - 24	0.33	38.8	900	300	Circle	0.013	1.81	1.05	75.5
CO-29	CB - 24	0.33	CB - 25	0.49	50.2	900	-300	Circle	0.013	1.75	1.05	65
CO-16	CB - 9	1.29	CB - 12	1.36	20.5	750	-300	Circle	0.013	1.61	0.64	78.4
CO-17	CB - 12	1.36	CB - 13	1.48	36.6	750	-300	Circle	0.013	1.6	0.64	74.9
CO-18	CB - 13	1.48	CB - 14	1.58	30.8	750	-300	Circle	0.013	1.58	0.64	70.3
CO-19	CB - 14	1.58	CB - 15	1.72	45.2	750	-320.621	Circle	0.013	1.47	0.62	59
CO-26	CB - 21	0.9	CB - 22	0.81	28	750	300	Circle	0.013	1.64	0.64	88.6

Label	Start Node	Invert (Start) (m)	Stop Node	Invert (Stop) (m)	Length (Scaled) (m)	Size (mm)	Slope (Calculated) (1/S)	Section Type	Manning's n	Velocity (m/s)	Capacity (Full Flow) (m³/s)	Flow / Capacity (Design) (%)
CO-30	CB - 25	0.64	CB - 26	0.73	27.3	750	-300	Circle	0.013	1.66	0.64	95.5
CO-31	CB - 26	0.73	CB - 27	0.95	64.1	750	-300	Circle	0.013	1.59	0.64	73.1
CO-47	CB - 39	1.83	CB - 40	2.13	89	750	-300	Circle	0.013	1.65	0.64	92.6
CO-48	CB - 40	2.13	CB - 41	2.41	84.5	750	-300	Circle	0.013	1.64	0.64	87.2
CO-49	CB - 41	2.41	CB - 42	2.62	65.2	750	-300	Circle	0.013	1.63	0.64	84.3
CO-50	CB - 42	2.62	CB - 43	2.8	51.5	750	-300	Circle	0.013	1.6	0.64	76.2
CO-51	CB - 43	2.8	CB - 44	2.93	39.3	750	-300	Circle	0.013	1.56	0.64	66.9
CO-52	CB - 44	2.93	CB - 45	3.14	63.4	750	-300	Circle	0.013	1.5	0.64	56.6
CO-25	CB - 20	1.1	CB - 21	1.05	16.1	600	300	Circle	0.013	1.37	0.35	72.3
CO-38	CB - 21	1.05	CB - 31	1.17	34.5	600	-300	Circle	0.013	1.42	0.35	91
CO-39	CB - 31	1.17	CB - 32	1.22	15.1	600	-300	Circle	0.013	1.39	0.35	78.4
CO-53	CB - 45	3.29	CB - 46	3.38	28.3	600	-300	Circle	0.013	1.41	0.35	87.2
CO-23	CB - 18	1.45	CB - 19	1.32	37.5	525	300	Circle	0.013	1.24	0.25	68.7
CO-24	CB - 19	1.32	CB - 20	1.18	43.2	525	300	Circle	0.013	1.3	0.25	91
CO-40	CB - 33	1.47	CB - 32	1.29	53.3	525	300	Circle	0.013	1.3	0.25	91.8
CO-45	CB - 37	2.27	CB - 38	2.14	92.9	525	700	Circle	0.013	0.83	0.16	80
CO-46	CB - 38	2.14	CB - 39	2.05	56.9	525	700	Circle	0.013	0.85	0.16	91.2
CO-7	CB - 2	0.4	CB - 3	0.19	61.5	450	300	Circle	0.013	1.09	0.16	62.9
CO-20	CB - 15	2.02	CB - 16	2.26	72.4	450	-300	Circle	0.013	1.13	0.16	74.6
CO-33	CB - 27	1.25	CB - 28	1.41	48	450	-300	Circle	0.013	1.18	0.16	94.6
CO-41	CB - 15	2.02	CB - 34	2.28	77.5	450	-300	Circle	0.013	1.15	0.16	80.9
CO-44	CB - 36	2.48	CB - 37	2.34	96.7	450	700	Circle	0.013	0.75	0.11	80.7
CO-56	CB - 48	1.23	CB - 22	1.11	36.9	450	300	Circle	0.013	1.12	0.16	71.3
CO-61	CB - 50	2.21	CB - 51	1.98	69.8	450	300	Circle	0.013	1.18	0.16	99.1
CO-6	CB - 1	0.61	CB - 2	0.47	40.6	375	300	Circle	0.013	0.94	0.1	55.6
CO-22	CB - 17	1.78	CB - 18	1.6	53.1	375	300	Circle	0.013	1.04	0.1	98

Label	Start Node	Invert (Start) (m)	Stop Node	Invert (Stop) (m)	Length (Scaled) (m)	Size (mm)	Slope (Calculated) (1/S)	Section Type	Manning's n	Velocity (m/s)	Capacity (Full Flow) (m³/s)	Flow / Capacity (Design) (%)
CO-42	CB - 34	2.35	CB - 35	2.41	17.3	375	-300	Circle	0.013	0.99	0.1	68.8
CO-43	CB - 10	2.58	CB - 36	2.56	18.5	375	700	Circle	0.013	0.68	0.07	98.9
CO-60	CB - 49	2.62	CB - 50	2.29	101.1	375	300	Circle	0.013	0.98	0.1	67.3
CO-55	CB - 47	1.57	CB - 48	1.38	55.7	300	300	Circle	0.013	0.9	0.06	92.1

Table 7.1.3: Details of the Conduits for Storm Sewer

Label	Elevation (Ground) (m)	Elevation (Invert) (m)	Boundary Condition Type	Hydraulic Grade (m)	Flow (Total Out) (m³/s)
O-2	1.57	-0.63	Free Outfall	0.08	1.62
O-1	1.18	-1.02	Free Outfall	-0.11	3.08

Table 7.1.4: Details of the Outfalls for Storm Sewer

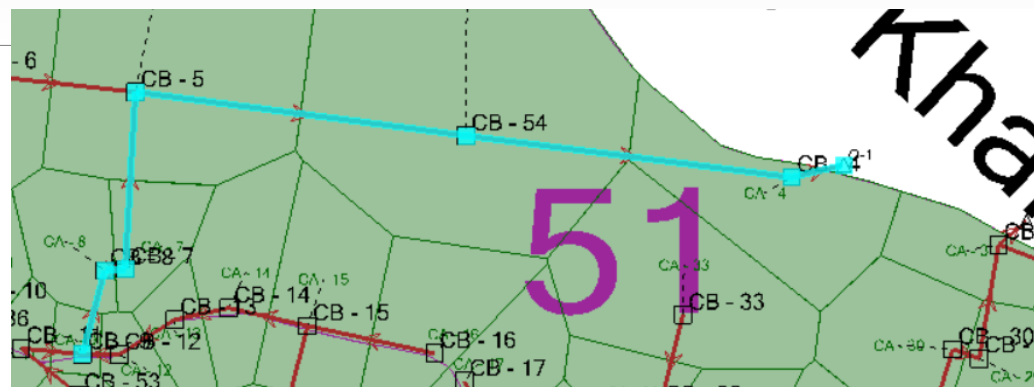
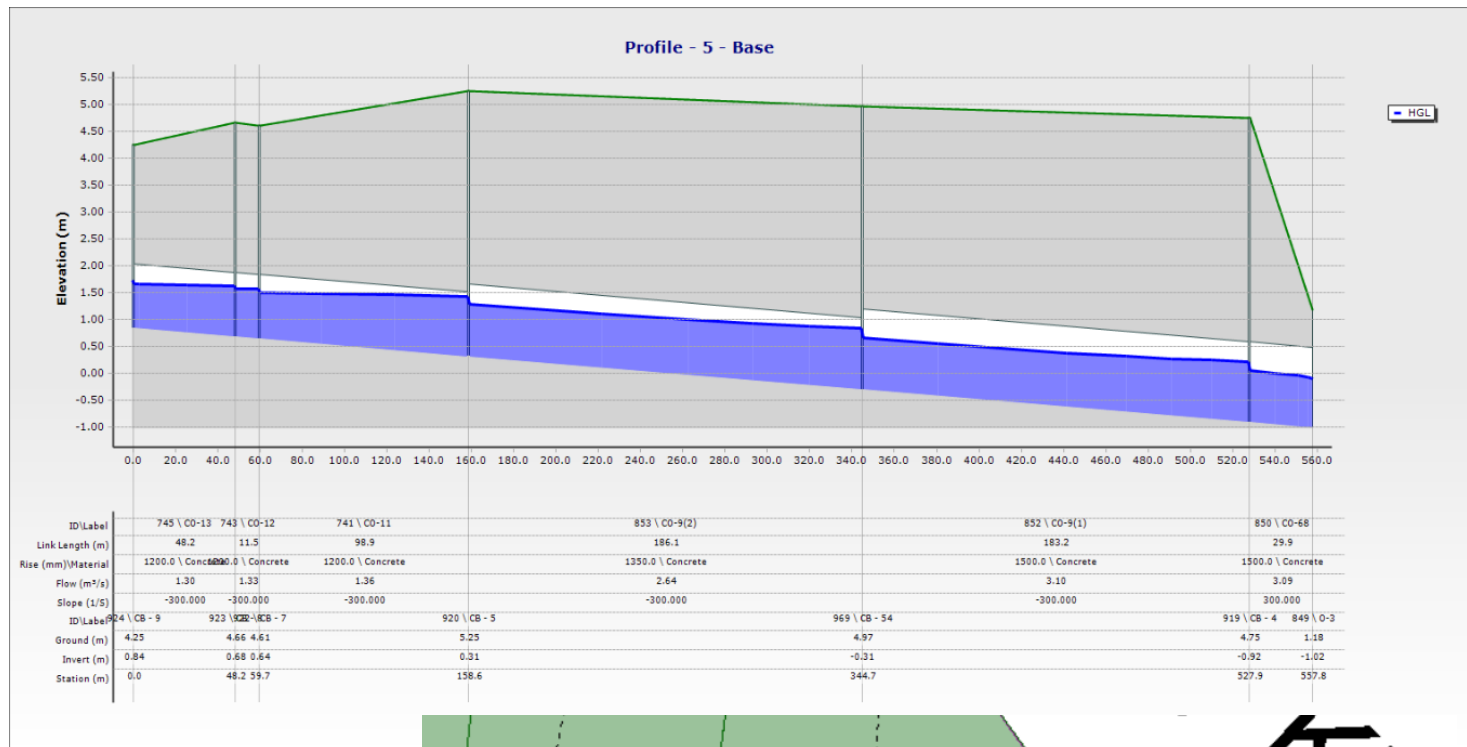


Figure 7.1.2: Longitudinal Profile Near Outfall 1

The above profile for Outfall 1 shows that the hydraulic grade is sufficiently below the ground level. The stretch shown in the longitudinal profile is highlighted in plan in blue.

Similar profile is observed for Outfall 2.

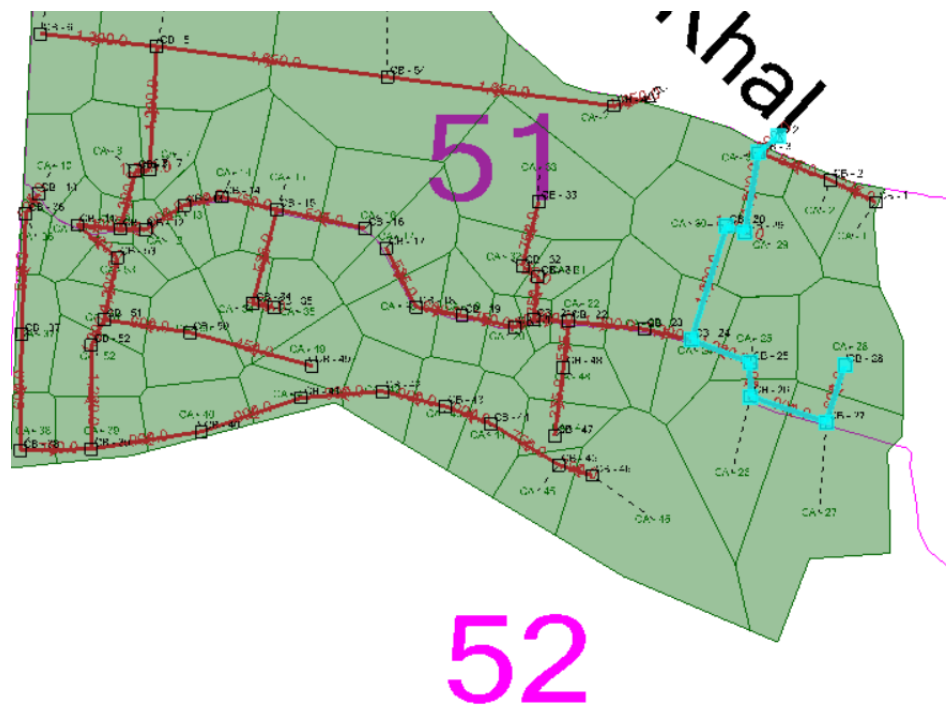
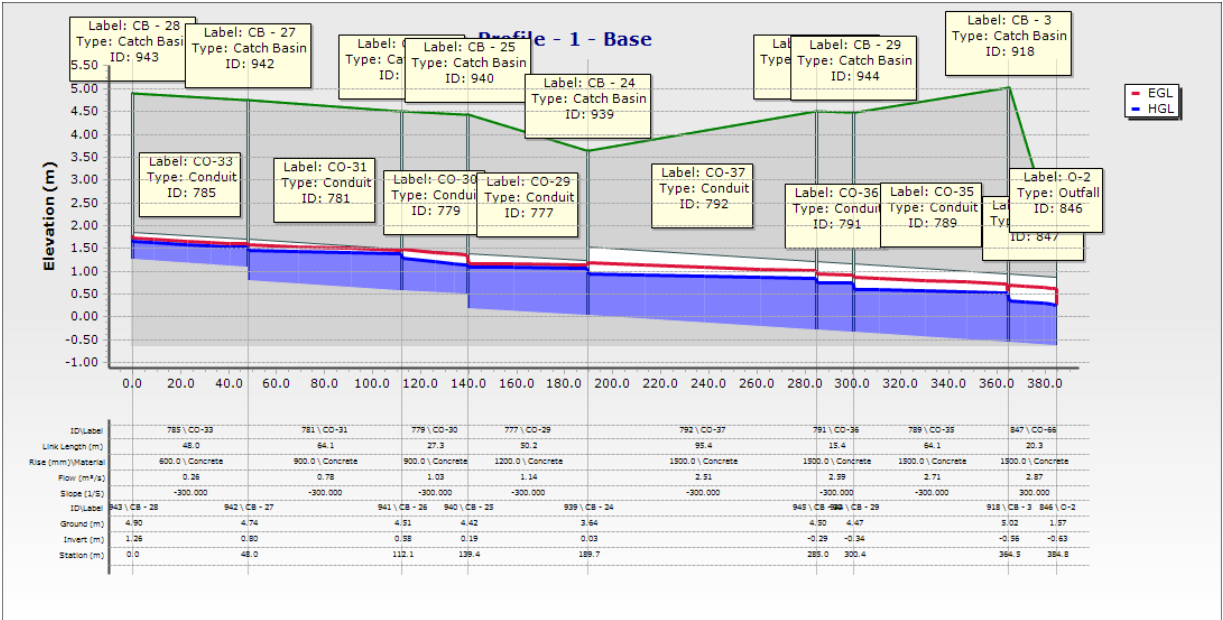


Figure 7.1.3: Longitudinal Profile Near Outfall 2

7.1.2: Design for 1 year Storm Frequency

A design run was done with 1 year storm frequency and it was found that almost all the runoff exceed the capacity . The figure below indicate the sewers (mark in red) whose capacity is lower than the generated runoff.

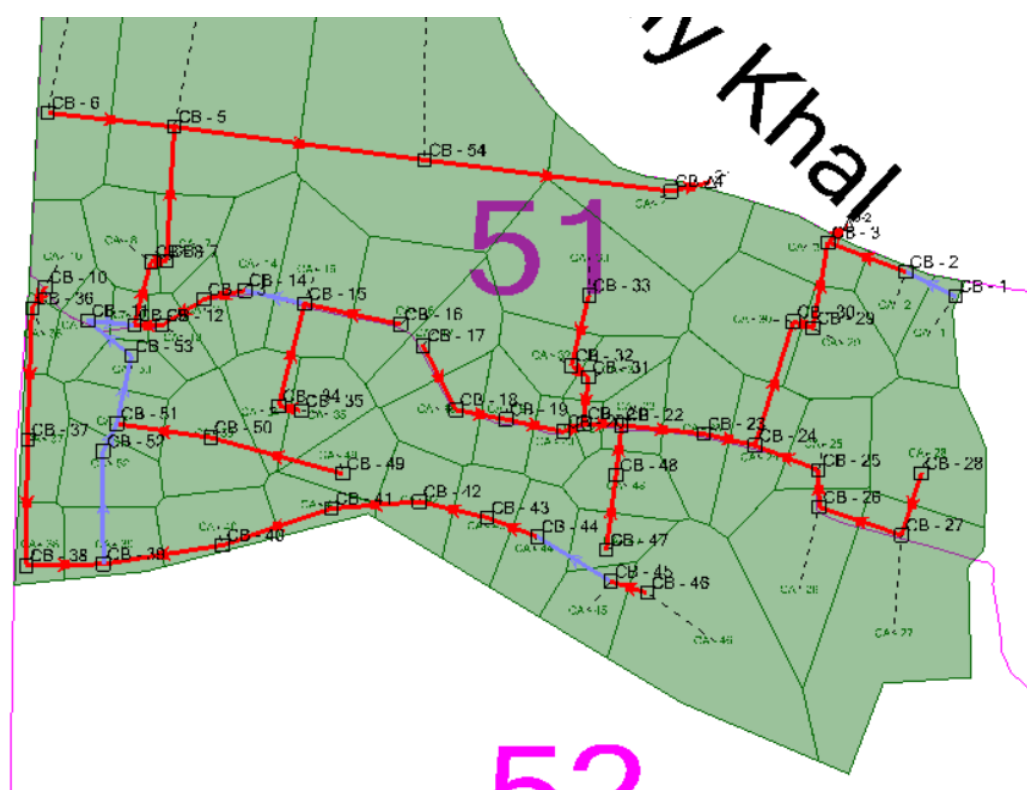


Figure 7.1.4: Incapacitated Sewers with 1 year Storm Frequency

The pipes required can be summarized as below

Conduit Description	Length (Concrete) (m)
Circle - 375.0 mm	96.4
Circle - 450.0 mm	118.3
Circle - 525.0 mm	416.6
Circle - 600.0 mm	248.1
Circle - 750.0 mm	356.1
Circle - 900.0 mm	536.8
Circle - 1,200.0 mm	635
Circle - 1,500.0 mm	195.1
Circle - 1,650.0 mm	399.2
Circle - 375.0 mm	96.4
Total Length	3,001.50

Table 7.1.5: Pipe inventory from Design with 1 year Storm Frequency

7.1.3 Design and Analysis of Sanitary Sewer

The same network was analysed for sanitary load only and the results are summarized in

Conduit Description	Length (Concrete) (m)
Circle - 200.0 mm	772.2
Circle - 250.0 mm	422.9
Circle - 300.0 mm	249.3
Circle - 450.0 mm	804.2
Circle - 600.0 mm	353.7
Circle - 750.0 mm	399.2
Total Length	3,001.50

Table 7.1.6: Pipe inventory from Sanitary Sewer

It is observed that slopes are quite steep for sanitary sewers. However, all the stretches attain self cleansing velocity. The results obtained from design by SewerGEMS are presented in Tables 7.7 and Tables 7.8

ID	Label	Elevation (Rim) (m)	Elevation (Invert) (m)	Hydraulic Grade Line (In) (m)	Depth (Structure) (m)
915	MO -1	5.65	3.75	3.82	1.91
916	MO -2	5.06	3.61	3.73	1.45
918	MO -3	5.02	-0.86	0.36	5.88
919	MO -4	4.75	-1.67	0.02	6.42
920	MO -5	5.25	0.07	1.48	5.18
921	MO -6	4.47	2.27	2.51	2.20
922	MO -7	4.61	0.66	1.63	3.94
923	MO -8	4.66	0.68	1.65	3.98
924	MO -9	4.25	0.75	1.70	3.50
925	MO -10	3.96	2.51	2.60	1.45
926	MO -11	4.45	1.10	1.90	3.35
927	MO -12	4.24	1.41	1.81	2.83
928	MO -13	4.01	1.46	1.86	2.55
929	MO -14	4.00	1.51	1.89	2.49
930	MO -15	3.47	1.72	2.13	1.75
931	MO -16	4.02	2.26	2.37	1.76
932	MO -17	4.18	2.73	2.83	1.45
933	MO -18	4.03	2.43	2.65	1.60
934	MO -19	4.12	2.23	2.61	1.89
935	MO -20	4.50	2.16	2.55	2.34
936	MO -21	4.34	1.59	2.27	2.75
937	MO -22	3.25	1.05	2.05	2.20
938	MO -23	3.90	0.96	1.99	2.94
939	MO -24	3.64	0.61	1.85	3.03
940	MO -25	4.42	1.90	2.76	2.52
941	MO -26	4.51	2.61	3.37	1.90
942	MO -27	4.74	2.98	3.45	1.77
943	MO -28	4.90	3.45	3.58	1.45
944	MO -29	4.47	0.45	1.71	4.02
945	MO -30	4.50	0.47	1.73	4.03
946	MO -31	4.54	2.65	2.89	1.89
947	MO -32	4.64	2.67	2.98	1.97
948	MO -33	4.50	2.90	3.05	1.60
949	MO -34	4.60	2.28	2.64	2.32
950	MO -35	4.31	2.86	2.95	1.45
951	MO -36	5.19	2.48	2.59	2.71
952	MO -37	5.52	2.19	2.50	3.32
953	MO -38	5.73	2.06	2.29	3.67
954	MO -39	4.17	1.38	2.10	2.79
955	MO -40	4.26	2.06	3.05	2.20
956	MO -41	4.43	2.49	3.16	1.94

ID	Label	Elevation (Rim) (m)	Elevation (Invert) (m)	Hydraulic Grade Line (In) (m)	Depth (Structure) (m)
957	MO -42	4.51	2.58	3.25	1.92
958	MO -43	4.56	2.66	3.31	1.90
959	MO -44	4.94	2.94	3.65	2.00
960	MO -45	5.14	3.39	3.79	1.75
961	MO -46	6.03	3.64	3.83	2.39
962	MO -47	4.96	3.15	3.21	1.81
963	MO -48	4.26	1.92	2.28	2.34
964	MO -49	4.27	2.82	2.91	1.45
965	MO -50	4.49	2.52	2.75	1.97
966	MO -51	4.21	1.23	2.01	2.98
967	MO -52	4.25	1.26	2.03	2.99
968	MO -53	4.23	1.16	1.95	3.08
969	MO -54	4.97	-0.20	1.30	5.16

Table 7.1.7: Details of the Manholes for Sanitary Sewers

Label	Start Node	Invert (Start) (m)	Stop Node	Invert (Stop) (m)	Length (Scaled) (m)	Size (mm)	Slope (Calculated) (1/S)	Velocity (m/s)	Flow / Capacity (Design) (%)
CO-68	MO -1	3.75	MO -2	3.61	40.6	200 mm	300.000	0.61	52.4
CO-9(1)	MO -2	3.61	MO -3	3.52	61.5	200 mm	700.000	0.54	41.2
CO-9(2)	MO -3	1.26	MO -29	1.35	64.1	600 mm	700.000	0.60	42.8
CO-11	MO -3	0.04	O-2	-0.03	20.3	600 mm	300.000	0.51	79.5
CO-12	MO -4	-0.47	O-3	-0.57	29.9	750 mm	300.000	0.60	78.7
CO-13	MO -4	0.43	MO -54	0.69	183.2	750 mm	700.000	0.89	84.3
CO-15	MO -5	2.14	MO -6	2.27	94.0	450 mm	700.000	0.60	61.5
CO-35	MO -5	1.11	MO -7	1.25	98.9	600 mm	700.000	0.70	55.6
CO-36	MO -7	1.25	MO -8	1.27	11.5	600 mm	700.000	0.72	63.8
CO-37	MO -8	1.27	MO -9	1.34	48.2	600 mm	700.000	0.90	97.7
CO-62	MO -9	1.57	MO -12	1.60	20.5	450 mm	700.000	0.78	99.7
CO-63	MO -10	2.51	MO -36	2.48	18.5	200 mm	700.000	0.60	95.9
CO-64	MO -11	1.53	MO -9	1.49	34.4	450 mm	700.000	0.60	64.2
CO-65	MO -12	1.60	MO -13	1.66	36.6	450 mm	700.000	0.86	60.2
CO-66	MO -13	1.66	MO -14	1.70	30.8	450 mm	700.000	0.84	56.2
CO-10	MO -14	1.85	MO -15	1.92	45.2	300 mm	627.157	0.52	94.1
CO-27	MO -15	2.02	MO -16	2.26	72.4	200 mm	300.000	0.60	59.1
CO-28	MO -15	2.27	MO -34	2.53	77.5	200 mm	300.000	0.38	41.2
CO-29	MO -17	2.73	MO -18	2.58	53.1	200 mm	344.843	0.40	52.6
CO-16	MO -18	2.53	MO -19	2.43	37.5	250 mm	376.880	0.45	89.2
CO-17	MO -19	2.43	MO -20	2.37	43.2	250 mm	700.000	0.60	47.8
CO-18	MO -20	2.37	MO -21	2.34	16.1	250 mm	499.714	0.68	49.9
CO-19	MO -21	2.04	MO -22	1.95	28.0	300 mm	300.000	0.73	68.1
CO-26	MO -21	2.65	MO -31	2.71	34.5	300 mm	574.232	0.68	42.4
CO-30	MO -22	1.80	MO -23	1.71	60.8	450 mm	700.000	0.64	41.3
CO-31	MO -23	1.71	MO -24	1.66	38.8	450 mm	700.000	0.62	36.2
CO-47	MO -24	2.34	MO -25	2.50	50.2	300 mm	300.000	0.80	97.2
CO-48	MO -25	3.04	MO -26	3.11	27.3	300 mm	394.737	0.65	96.5
CO-49	MO -26	3.11	MO -27	3.21	64.1	300 mm	673.077	0.60	86.5
CO-50	MO -27	3.31	MO -28	3.45	48.0	200 mm	339.958	0.47	19.9
CO-51	MO -29	1.35	MO -30	1.37	15.4	600 mm	700.000	0.60	48.1
CO-52	MO -30	1.37	MO -24	1.51	95.4	600 mm	700.000	0.37	40.3
CO-25	MO -31	2.76	MO -32	2.78	15.1	250 mm	700.000	0.60	43.0
CO-38	MO -32	2.78	MO -33	2.90	53.3	250 mm	442.255	0.77	89.6
CO-39	MO -34	2.83	MO -35	2.86	17.3	200 mm	700.000	0.74	73.5
CO-53	MO -36	2.48	MO -37	2.34	96.7	200 mm	700.000	0.77	92.8
CO-23	MO -37	2.34	MO -38	2.21	92.9	200 mm	700.000	1.05	75.9
CO-24	MO -38	2.16	MO -39	2.02	56.9	250 mm	398.917	0.61	52.4
CO-40	MO -39	2.68	MO -40	2.81	89.0	450 mm	700.000	0.54	41.2
CO-45	MO -39	1.82	MO -52	1.70	83.0	450 mm	700.000	0.60	42.8
CO-46	MO -40	2.81	MO -41	2.94	84.5	450 mm	636.553	0.51	79.5

Label	Start Node	Invert (Start) (m)	Stop Node	Invert (Stop) (m)	Length (Scaled) (m)	Size (mm)	Slope (Calculated) (1/S)	Velocity (m/s)	Flow / Capacity (Design) (%)
CO-7	MO -41	2.94	MO -42	3.03	65.2	450 mm	700.000	0.60	78.7
CO-20	MO -42	3.03	MO -43	3.11	51.5	450 mm	700.000	0.89	84.3
CO-33	MO -43	3.31	MO -44	3.44	39.3	250 mm	300.000	0.60	61.5
CO-41	MO -44	3.44	MO -45	3.58	63.4	250 mm	445.383	0.70	55.6
CO-44	MO -45	3.58	MO -46	3.64	28.3	250 mm	514.706	0.72	63.8
CO-56	MO -47	3.15	MO -48	2.96	55.7	200 mm	300.000	0.90	97.7
CO-61	MO -48	2.17	MO -22	2.05	36.9	200 mm	300.000	0.78	99.7
CO-6	MO -49	2.82	MO -50	2.67	101.1	200 mm	700.000	0.60	95.9
CO-22	MO -50	2.62	MO -51	2.44	69.8	250 mm	378.019	0.60	64.2
CO-42	MO -51	1.67	MO -53	1.59	51.0	450 mm	700.000	0.86	60.2
CO-43	MO -52	1.70	MO -51	1.67	22.7	450 mm	700.000	0.84	56.2
CO-60	MO -53	1.59	MO -11	1.53	41.4	450 mm	700.000	0.52	94.1
CO-55	MO -54	0.69	MO -5	0.96	186.1	750 mm	700.000	0.60	59.1

Table 7.1.8:Details of the for Sanitary Sewers

7.1.4 Design of Combined Sewer

Considering the sanitary load and storm runoff, the analysis is done for the same network as a combined sewer. The storm load is taken for 6 months frequency. It is observed that the maximum sewer diameter remains same as in the case of Storm sewer Alone as shown in Table 7.9.

Conduit Description	Length (Concrete) (m)
Circle - 375.0 mm	586.2
Circle - 450.0 mm	186.1
Circle - 525.0 mm	213.1
Circle - 600.0 mm	159
Circle - 750.0 mm	400.7
Circle - 900.0 mm	130.3
Circle - 1,200.0 mm	332.5
Circle - 1,350.0 mm	633.3
Circle - 1,500.0 mm	360.2
Total Length	3,001.50

Table 7.1.9: Pipe inventory from Combined Sewer

So in an area, where space is a constraint, it may be a good option to select combined System as a method of conveyance.

7.2 Discussion

- It is observed that SewerGEEMS can be used for quick design of the network for both sanitary and storm sewer. The flow / Design capacity ration for the conduits indicate that the designed sections are hydraulically sufficient.
- The design results obtained for higher storm frequency indicates that it is not possible to accommodate the higher storm runoff for 1 year storm frequency with the 6 months storm frequency. To accommodate the higher runoff for 1 year storm frequency, an average increase in diameter is required by 20%. But in an area like Bally, which is an unplanned and old urban development, such increase in the size of the sewers will require substantial road excavation for laying sewers and manholes. Moreover, as 30% of the roads are less than 3 m, providing large diameter pipes may be difficult. So in Bally, using one year storm frequency will not be justifiable, though the recommendation of the CPHEEO manual advocates 2 year storm frequency
- The results obtained Combined system indicate that there is increase in only smaller diameter pipes while the larger diameter pipes obtained for storm sewers are sufficient to accommodate the additional sewer load. So combined sewers can be a good option for this purpose. Also this allows sewers to be laid at a flatter slope and as a result the cost of laying can be reduced.

CHAPTER 8

8.1 Conclusion

The purpose of this study was to:

- Develop a design of the sewer network to effectively convey storm and wastewater without causing overflows or surcharging during peak flow conditions. This involves analyzing flow rates, velocities, and pressure heads to identify potential bottlenecks and optimize pipe sizes, slopes, and alignments for efficient flow distribution.
- Evaluate the capacity of the sewer network to accommodate current and future storm and wastewater loads. This includes assessing the system's ability to handle population growth, urban expansion, and changes in land use patterns.
- Use SewerGEMS to simulate various scenarios and predict future demand requirements, allowing for proactive infrastructure planning and capacity upgrades.
- Minimize the risk of urban flooding by designing the sewer network to effectively manage storm water runoff and prevent inundation of streets, properties, and critical infrastructure. Utilize SewerGEMS to model rainfall-runoff processes, analyze surface drainage patterns, and design hydraulic structures such as detention basins, culverts, and overflow weirs to mitigate flood risk.
- Further work can be done using SewerGEMS to:
- Simulate pollutant transport and assess the effectiveness of various control strategies in reducing pollutant loads. Optimize the lifecycle performance and maintenance of sewer infrastructure assets.
- Develop asset replacement plans that prioritize investments based on condition assessment data, risk analysis, and life cycle cost considerations. Implement predictive modeling techniques to anticipate asset failures and optimize replacement schedules.
- Enhance the energy efficiency of the sewer network by minimizing energy consumption associated with pumping stations, treatment plants, and other infrastructure components.
- Use SewerGEMS to optimize pump operations, control strategies, and energy recovery systems to reduce overall energy usage and operational costs while maintaining system reliability and performance.
- Enhance the resilience of the sewer network to withstand and recover from disruptive events such as extreme weather events, infrastructure failures, and population growth. Incorporate climate change projections and risk assessments into the design process to identify vulnerabilities and implement adaptive measures such as green infrastructure, decentralized systems, and redundancy measures to enhance system resilience. Ensure compliance with regulatory requirements and standards governing wastewater management, water quality, and environmental protection.
- Use SewerGEMS to model regulatory constraints, permit conditions, and discharge limits to assess compliance and identify necessary upgrades or modifications to achieve regulatory compliance. The use of SewerGEMS for sewer network analysis and design is a structured process that leverages accurate data and advanced modeling techniques. By following these

steps, engineers can ensure that the sewer system is designed efficiently to handle current and future demands, minimizing risks of overflows and surcharges while optimizing resource usage and system performance. This comprehensive approach not only improves the reliability of the sewer network but also supports sustainable urban development.

References

- Asfaw, B. (2016). Assessment of Storm Water Drainage System in Kemise Town. *M.E Thesis, School of Graduate studies Addis Ababa Institute of Technology, Addis Ababa University*.
- Belete, A.D. (2011). Road and Urban Storm Water Drainage Network Integration in Addis Ababa: Addis Ketema Sub-city. *Journal of Engineering and Technology*, 3(7), 217-255.
- Bhadiyadra, J.K, Goyani, V.C., Dobariya, T.N., Vaghani, C.R. and Gajera, D.J. (2015), Study of Storm Water Drainage Problem of Surat City and its Solutions due to Flood in River Tapi. *International Journal of Civil and Structural Engineering Research*, 3(1), 61-89.
- Burian, S.J., Nix, S.J., Pitt, R.E. and Durran, S.R. (2000). Urban waste water management in the United States: past, present, and future. *Journal of Urban Technology*, 7(3), 33-62.
- D'Asaro, F. and Grillone, G. (2010). Runoff Curve Number Method in Silicy: CN Determination and Analysis of The Initial Abstraction Ratio. 2nd Joint Interagency, Las Vegas, NV, USA.
- Gajjar, H.H., Dholakia, M.B. (2014). Storm Water Network Design of Jodhpur Tekra Area of City of Ahmedabad. *International Journal of Engineering Development and Research*, 2(1), 744-747.
- Katti, M., B.M, K. (2015). Design of Sanitary Sewer Network using Sewer GEMS V8i Software. *International Journal of Science Technology & Engineering*, 2(1), 254-258.
- Kannur, S.S., Patil, S., Kannur, S.S. (2015). Hydraulic Design & Analysis of Underground Drainage System: for a Zone in Tumkur City. *International Research of Engineering and Technology*, 2(5), 326-332.
- Katti, M., Krishna, B.M., Manoj, K.B. (2015). Design of Sanitary Sewer Network for District 2B, Vijayapur city using Sewer GEMS V8i Software. *International Journal of Science, Engineering and Technology Research*, 4(8), 2766-2771.
- Kothai, A., Muthupriya, R., Rajkumar, A. (2018). Design of Underground Sewerage System for Kalapatti, East Zone Coimbatore. *International Journal of Engineering Research*, 7(7), 127-132.
- Kumar, S.P., Santhi, T., Srivastav, M.P., Reddy, S.V.S., Prasad, A.M. and Praveen, T.V. (2015). Storm Water Drainage Design (Case Study Vijayawada). *International Journal of Earth Sciences and Engineering*, 8(2), 507-511.
- Lloyd, S.D., Wong, T.H.F. and Porter, B. (2002). The planning and construction of an Urban storm water management scheme. *Water Science and Technology*, 45(7), 1-10.
- Mitchell, V.G. (2006). Applying Integrated Urban Water Management Concepts: A Review of Australian Experience. *Environmental Management*, 37(5), 589- 605.

- Kyi, M.P,Zin, W.W., Kyi, C.C.T. and Maung, T. (2017).Study on Storm Water Drainage System of Kyeemyaindaing Township. Department of Civil Engineering, Yangon Technological University, 1-5.
- Molla, R. (2018). Change of Land Use Pattern and the Present Status of Land Use Planning: A Case Study of Howrah New Town, North 24 Parganas, West Bengal. *Pramana Research Journal*,8(1), 135-141.
- Manual on Sewerage and Sewage Treatment, Part A, (2012), Central Public Health and Environmental Engineering Organization.
- Mukhopadhyay, R. (2017). Study of Storm Water Drainage System at Agarpara in West Bengal based on Civilstorm Software. M.E. Thesis, School of Water Resources Engineering, Jadavpur University.
- Natsis, K. (2008). Decision support for sustainable option selection in integrated urban water management.*Environmental Modeling & Software*, 23(12), 1448- 1460.
- Needhidasan, S. and Nallaathel, M. (2013).Design of Storm Water Drains by Rational Method and Approach to Storm Water Management for Environmental Protection.*International Journal of Engineering and Technology*, 5(4), 3203-3214.
- Raval, S. K. (2018) Storm Water Drainage Solutions for Urban Area.*International Journal of Innovative Research in Science, Engineering and Technology*, 7(4), 3706-3711.
- Ravikiran, K., Arjun, S.V. (2016). Design of sewer network system for the Janwad villageusingSewerCADV8i.*InternationalResearchJournalof Engineering Technology*, 3(7), pp. 1375-1378.
- Sharma, D. (2008). Sustainable Drainage System (SuDs) for Storm Water Management: A Technological and Policy Intervention to Combat Diffuse Pollution.11th International Conference on Urban Drainage, Edinburgh, Scotland, UK.
- Subramanya, K. (2013).Engineering Hydrology, 4th Edition, Tata McGraw-Hill Publishing Company Limited.
- Pitta, S.K., Santhi.T.,Srivatsav. P.M., Reddy, S.V.S. (2015).Storm Water Drainage Design (CaseStudyVijayawada). *International Journal of Earth Sciences and Engineering*, 8(2),507-511.
- Uttara,S.,Bhuvandas, N., Aggarwal, V. (2012). Impacts of Urbanization on Environment.*International Journal of Research in Engineering & Applied Sciences*, 2(2), pp. 1637-1645