



**Republic of Iraq**

**Ministry of Higher Education & Scientific Research**

**University of Kerbala**

**College of Engineering**

**Civil Engineering Department**

# **Integrated Stormwater Network Management: A Case Study Al-Hur District-Kerbala**

A Thesis Submitted to the Council of the Faculty of the College of the  
Engineering/University Of Kerbala in Partial Fulfillment of the Requirements for  
the Master Degree in Civil Engineering (Infrastructure Engineering)

**By:**

Ali Mostafa Abbas

B.Sc. in Civil Engineering (2019)

**Supervisors**

Prof. Dr. Basim Khalil Nile

Asst. Prof. Dr. Muhammad A. Abduredha

July 2025

Muharram 1447



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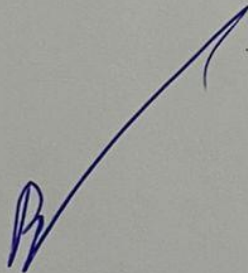
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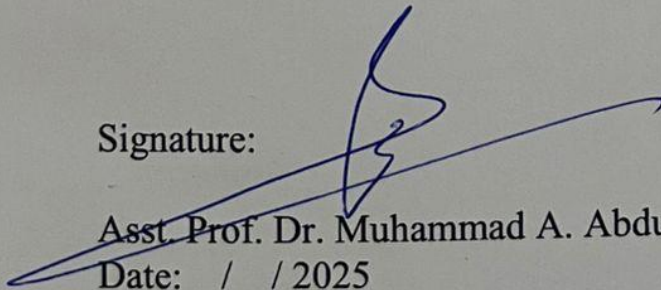
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## **Undertaking**

I certify that research work titled " **Integrated Stormwater Network Management: A Case Study Al-Hur District-Kerbala** " is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged / referred.

Ali Mostafa Abbas

Date: / / 2025

## **Dedication**

This work is dedicated to Imam Mahdi (May Allah hasten his reappearance)

To my parents, who devoted their lives to providing for us and guiding us  
toward religious and science

In honor of the Iraqi martyrs and homeland guardians who defended our  
country and gave their lives to ensure our survival

A devotion to our martyred leaders and symbols of our pride who  
have always urged us to specialize and follow the path of science and  
technology to create life for our people.

Ali Mostafa Abbas

Date: / / 2025

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Ali Mostafa Abbas

Date: / / 2025

## **Abstract**

Urbanization, population expansion, and changes in the climate make cities more susceptible to flash floods, severe storms, and drainage network problems. Rainwater network management is essential for controlling flooding, forecasting behavior, and assessing fixes for operational and structural issues. In order to achieve the integrated management of the storm network of the study region, the current network will analyze and identify the total volume of floods and the amount of flooding pipelines and junctions, assess how well the stormwater network is performing regarding rainfall intensity of 2, 5, 10, and 20-year return periods, and suggest the sustainable techniques to mitigate the floodings. The rainwater network will be analyzed using analytical equations in rainwater network management, in addition to analyzing the network using the stormwater management model. The results of the analytical equations of the rainwater drainage network management in the study area showed that after a ten year period of return, the system seems to be unable to release excess rainfall, which causes stormwater to accumulate downstream. These results were consistent with the simulation results using the stormwater management model. Storm Water Management Model (SWMM) software was utilized since it contains the components required to meet the goals of the research. Based on the validation results of the model, which were the coefficient of determination  $R^2$  (0.62-0.79), the Nash-Sutcliffe efficiency NSE (0.65-0.79), and the normalized mean square error NMSE (0.06-0.08). It can be concluded that the stormwater management model is valid, eliminating the need for model calibration. Also, the study included modelling the techniques of low impact development (LID) for the purpose of mitigating the flooding in the stormwater drainage network. In response to the

increase in the rainfall intensity, volume of all floods in the drainage network, and the amount of inundated manholes ratio grew from 1220 m<sup>3</sup> and 5% to 13450 m<sup>3</sup> and 20.5%, respectively, while the return periods lengthened from 2 to 20 years. The suggested low-impact development (LID) approach decreased flooding volumes during various return times of 2, 5, 10, and 20 years to 793, 1708, 6947, and 11915 m<sup>3</sup>. Decision-makers can use the study's technical assistance to build-infrastructure for upcoming difficulties.

Keywords:

Rainwater Networks, Drainage System, Flood Mitigation, Low Impact Development, Infiltration Trenches, Climate Change.

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## List of Abbreviations

<b>SWMM</b>	Stromwater Management Model
<b>EPA</b>	Environment Protection Agency
<b>LID</b>	Low Impact Developement
<b>BMP</b>	Best Management Practices
<b>GIS</b>	Geographical Information System
<b>IDF</b>	Intensity Duration Frequency
<b>DSK</b>	Directorate Sewage Kerbala
<b>SSA</b>	Sanitary Storm Analysis
<b>GIs</b>	Green Infrastructures
<b>DEM</b>	Degital Elevation Map
<b>IPCC</b>	Intergovernmental Panal on Climate Change
<b>GAMCO</b>	General Authority for Meteorology and Seismic Observation
<b>PVC</b>	Polyvinyl Chloride
<b>NMSE</b>	Normalized Mean Square Error
<b>NSE</b>	Nash-Sutcliffe Efficiency
<b>USGS</b>	United States Geological Survey
<b>ECEF</b>	Earth Centered, Earth Fixed

## **Chapter One: Introduction**

### **1.1 Background**

Integrated management of rainwater networks refers to the strategic planning, execution, and efficient management of the resources and infrastructure needed to collect and release rainwater in a way that minimizes floods, safeguards the environment, and promotes the sustainability of water resources. Storm water networks are necessary in cities to ensure that surface runoff is safely collected, and removed from the sub-catchments, as well as to maintain infrastructure. Many factors, such as population growth, climate changes, urbanization, and the negligent usage of drainage networks, contribute to flood occurrences in rainwater drainage networks, which is why there is flooding in the streets (Jefferson et al., 2017; Nayel et al., 2018).

In metropolitan locations, the storm system's flooding has a detrimental impact on infrastructure and delays the society's economic vitality. The majority of factors influencing the pace of floods were caused by climate change brought on by global warming, which increased the amount of runoff by intensifying rainfall. Furthermore, civilization will expand the amount of paved surfaces and alter the hydrological cycle and reduce infiltration, while population expansion can increase the hazards associated with rainfall floods (Tikkanen, 2013). Rapid urbanization and development have led to a degradation of the earth's accessible green space (Jayasooriya & Ng, 2014; Nile, 2018). The expansion of cities enhances urbanization, resulting in a rise in impermeable surfaces, which diminishes the rate of penetration and subsequently elevates runoff amount and flood quantity.

As a result, managing storm water in cities becomes more crucial. Surface runoff from precipitation on regions whose natural condition has

changed because of human and natural activity known as rainwater runoff in urban cities. Urban floods is a common occurrence that delays a community's economic vitality and causes serious issues with roads and buildings (Nile et al., 2018). The inadequate rainwater drainage systems, improper management and operation, and overcrowding all contribute to these floods. To address these issues, storm water drainage systems must be updated frequently and maintained on a regular basis (Laouacheria et al., 2019).

### **1.2 Storm water Networks Simulation**

Through mathematical modeling of the storm system, the impact of changes in hydrological processes and all other conditions on the flooding event could be simulated. Urban simulation plays a crucial role in the creation, and management of the urban drainage system. There have been numerous studies done to increase the efficiency of storm networks using rainfall-runoff simulation (Mohsen et al., 2020). The U.S. Environmental Protection Agency (EPA) developed the dynamic, numerical, conceptual rainfall-runoff model known as the SWMM (Storm water Management Model) (Rossman, 2010). It can simulate and evaluate the quantity and quality of runoff in urban areas based on isolated or continuous precipitation events (Ahmed et al., 2017). At every point in the sewer system, models can forecast the volume of floods and the depth of the water. Additionally, connect the impacts of different variables on the storm system's hydraulic performance. The runoff-rainfall modeling process requires a number of variables and bits of data in order to replicate the relationship between runoff and the drainage system. In the Storm Water Management Model (SWMM), the amount of runoff generated is determined by factors such as terrain, land use, rainfall intensity, and preexisting moisture levels (Zoppou, 2001).

### **1.3 The Problem Statement**

The case study Al-Hur district's Al-Abed quarter situated north of Kerbala, Iraq. Storm water network management in urban areas presents a challenge to drainage specialists, urban engineers, and officials. This study highlights Kerbala's growing environmental and economic safety concerns due to climate change-induced urban flooding, a urbanization. Green infrastructures can manage storm water at its place of origin. There are no green infrastructures being employed in the region. So these techniques will use in this study through one of the low impact development (LID) to mitigate floods.

### **1.4 Thesis Objectives**

The study aims to achieve integrated management of the rainwater network in Karbala, Al-Hur district, Al-Abed neighborhood as a research area, by evaluating the performance and effectiveness of the rainwater network in the research region under the influence of different rainfall intensities derived from the intensity-duration-frequency curve (IDF) for Karbala city by using the mathematical equations in storm water network management analysis, and the Storm Water Management Model (SWMM). Also, applying Low-Impact Development techniques (LID) to reduce the impact of floods that may happen. The research provides stakeholders with the technical assistance in improving infrastructure for upcoming difficulties.

## **1.5 Thesis Significance**

Feasible to assist engineers and the people who make decisions with some of the following processes by using this study:

1. The study assessed the performance of the storm drainage network of Al-Abed quarter through the mathematical equations in storm water network management analysis and used the storm water management model to calculate the flood areas and flood amounts.
2. The study showed the effectiveness of using Low Impact Development techniques (LID) in mitigating the impact of flood problems in light of climate change and increasing urbanization. This might encourage policymakers to follow this study's lead and take preventative action to lessen flooding in other areas of the city.

## **1.6 Chapters Layout**

This thesis organized into the following chapters:

1. Chapter 1, highlight the background, problem statement, thesis objectives, thesis significance, scope of the study, and thesis layout.
2. Chapter 2, show the literatures about the integrated management of rainwater networks. The following topics reviewed in this chapter: storm water drainage systems, management of storm water networks, flooding in cities, storm water simulation model, and applications for improving storm water networks management.
3. Chapter 3, explains the study's methodology, and Describe all the characteristics and information of the research region and explain the analysis equations of rainwater networks and the methods for simulating floods using the SWMM model, as well as the method of

applying low-impact development LID techniques that used to mitigate flooding.

4. Chapter 4, In this chapter, the findings of the analysis equations of rainwater networks management and for the SWMM model's simulation of urban floods in the research region will show. Then display the effect of using LID on flooding reduction.
5. Chapter 5 gives the study's conclusions, which are based on the data from earlier chapters. In addition, suggestions for more research provided.

## **Chapter Two: Literature Review and Theoretical Background**

### **2.1 Introduction**

A comprehensive review of previous research conducted to improve understanding of storm water network management and the procedures that should be used to accomplish effective management. The management of sanitary systems in public services extends beyond the technical design that prolongs the lifespan of equipment and enhances its usability and efficiency, but it also has other ecological, social, and financial goals. As stated by (Ibrahim et al., 2007) is a group of actions intended to keep the infrastructure in good health, the ecological, the financial system, etc. Since the beginning of time, humans have attempted to manage the water flow (Agarwal & Kumar, 2019). Mesopotamia in the city of Ur About 3000 years BC is where the earliest rainfall drainage system was found. Indicators of rainfall drainage systems in the streets were discovered (De Feo et al., 2014).

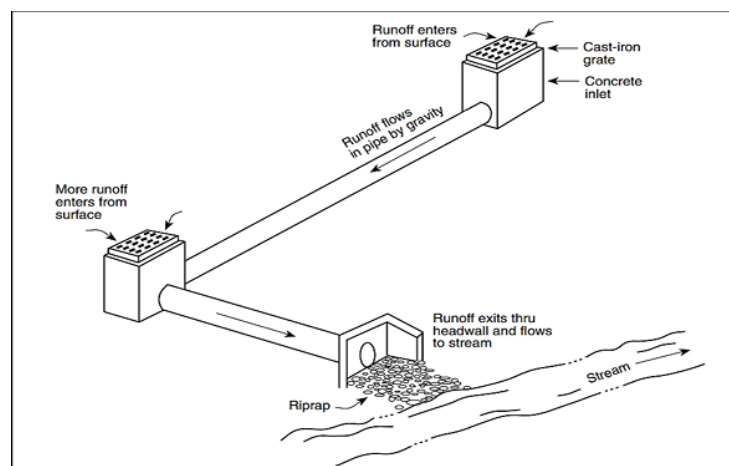
The following topics were reviewed in this chapter: storm water drainage systems, management of storm water networks, flooding in cities, storm water simulation model, and applications for improving storm water networks management.

### **2.2 Storm water Drainage Systems**

Rainwater systems are essential pieces of infrastructure that help metropolitan areas drain water and manage flooding. It facilitates the effective and uncomplicated transfer of rainwater from cities through the storm water drainage networks (which comprise conduits, junctions, gutters, pump stations) to naturally occurring bodies of water, such as lakes and streams (Ahiablame et al., 2012). They are frequently used in parking lots and on

roadways. These technologies are essential for enhancing cities' resistance to catastrophic weather events and mitigating the negative impacts of urbanization on the hydrological cycle (Nayel et al., 2018). Additionally, a storm sewer needs to prevent deterioration and the loss of strength and load-bearing capability. In addition, storm sewers support sustainability, ecology, and safety for the public (Asfaw, 2016). Before drainage networks were built, engineers who directed storm water into a network of swales that flowed alongside streets and pathways and eventually into the river, this method is still employed in developing nations today (Gribbin, 2013).

Because the water remained on the surface of the earth, it caused annoyance and spread disease. For the past 100 years, storm drains have been employed in cities to move both rainwater and sewage waste through the same conduits. These systems known as combined sewers, which completely replaced by separate sanitary and storm sewers. The fundamental components of a storm drain system consist of inlets, pipes, junctions, outfalls, catch basins, pump stations, as shown in Figure 2.1.



**Figure 2.1 Basic Components of a Storm Drainage System (Gribbin, 2013)**

### **2.3 Storm water Drainage Systems and Flooding in Cities**

In policy agendas and academics, storm water management and flooding's the most talked about topics (Teshome, 2020). Urban flooding is a major catastrophic feature of many cities worldwide. It caused by a variety of unpredictable factors, including hydrological factors, urbanization, climate change, and inadequate or defective infrastructure that causes property damage, disable of vital infrastructure, and fatalities. It has a significant impact on the local economy and the city as a whole (Morita, 2014; Mugume & Butler, 2017). Storm water network management is becoming more and more popular because of these environmental concerns facing humans (ten Veldhuis et al., 2011). The danger of flooding in urban rainwater drainage systems has grown because of expanding urbanization and climate change. It is therefore more crucial to evaluate how these factors can influence flooding in the future and implement efficient flood control measures (Agarwal & Kumar, 2020; Hussain et al., 2022).

The impact of urban floods on people and their properties can be disastrous (Rainey et al., 2021). Because these areas have dense populations and often house valuable assets, they are particularly susceptible to structural and property damage due to economic activity. These include missed income from people who are unable to report to work, time lost from delays and flooded roads, inundation of homes in low lying areas, communication system disruptions, student-impacting school closures, unplanned power outages, the spread of diseases linked to water, and health risks. These challenges highlight the need for adaptation to climate change and urbanizations in order to create resilient urban ecosystems (Salimi & Al-Ghamdi, 2019; Weber, 2019). Recently, there have been several fatalities and property damages in countries

such as Japan, Singapore, Britain, and others due to urban floods (Duan et al., 2014).

Surface runoff is the amount of water that drains from an area because of flow across the land's surface. It occurs when the intensity of the rain exceeds the rate at which the earth can absorb it (Anni et al., 2020). Storm water runoff causes urban flooding poses challenges in various country. Rainfall that is heavier than the intensity at which the soil can absorb it results in runoff (Rabori & Ghazavi, 2018). The catchment's lowest points are where this surface runoff gathers before draining, penetrating, or evaporating. Surface runoff, or the buildup of precipitation that drains to a stream, and base flow, which starts in groundwater, are the two main components of runoff flow. Additionally, a watershed's geology, soil type, plant cover, mean precipitation, drainage area, and antecedent moisture conditions all have an impact on runoff (Bellal et al., 1996).

### **2.3.1 Changes in Rainfall Intensity Effect on Storm Water Networks**

Because climate change has an impact on hydrologic components, it is a major issue that influences how urban drainage networks function (Moghadas et al., 2018). Where the volume and intensity of precipitation in an urban area are the key factors that determine how effective urban storm water drainage systems are. The IPCC Evaluation Report predicts that while global precipitation would vary depending on latitude, global mean temperature trends will continue to rise in the twenty-first century (Pachauri et al., 2014). The current global warming anticipated causing severe storms in numerous parts of the world to increase higher than the planned intensity of current systems (Willems, 2013).

Therefore, rising flooding rates brought on by climate change may eventually have an even greater influence on the current drainage infrastructure, particularly storm water drainage systems. Extreme precipitation and urban floods regarded as natural occurrences when there is a lot of rainfall (Gaudio et al., 2016; Nile, 2018). Keeping in mind that while light rains will not immediately damage storm water drainage systems, they might make subsequent events more severe if they cause saturated areas to raise the groundwater table. Moreover, higher peak intensity and decreased precipitation volume may cause quick runoff, which lowers the infiltration capacity (Jung et al., 2015).

Within the continent of North America, and in accordance with a prior research by (Zahmatkesh et al., 2015), carried out in the Bronx River watershed, the state of New York. In the watersheds, this analysis predicts that future climatic conditions would result in an average 51% increase in runoff volumes. A research by Kumar et al. (2021) in Delhi, India, examined the impact of climate change on urban floods using validated hydraulic models and past rainfall records (1990–2016). Study areas included the Jahangirpuri drain watershed and the Qudesia Nallah watershed. Under future climate conditions (2021–2100), the study shows an increase in flooding period and frequency in two research areas, with node counts rising from 11 to 51 and 42 to 91, respectively.

Research by (Guptha et al., 2021), found that in Gurugram, India, climate change poses a greater threat than urbanization, and that the two together significantly weaken the resilience of the urban drainage network. This research looked at the structural factors for failure and found that 11 out of 25 conduits were flooded. Furthermore, even in Gurugram City, where there is often rainfall, there was urban flooding (Rawat et al., 2021).

Due to the associated risks of climate change, such as an increase in the frequency of extreme rainfall events and the intensification of urban settlements, urban flooding significantly contributed to social instability in Cairo, Egypt. Short term rainfall forecast at specific places is necessary for decision-making in the hydrological, agricultural, and economic sectors since rainfall data differs from station to station-using different approaches (Pirone et al., 2023).

Research by Sun et al. (2021) used a simulation with various rainfall return intervals to examine the risks of floods in the scenario of future climate change in central Shanghai, China. The results shown that nonlinear increases in urban flooding associated with increasing rainfall intensity enlarge the maximum flooding area. (Hou et al., 2020) also examined the impact of climate change on floods in China, and their findings supported those of the earlier research. Because of climate change, the city is one of those chosen in China for the Sponge City Project, which aims to lessen flood risks and prepare for them.

Research by Hussain et al. (2022) conducted a research in Al Najaf, Iraq, discussing the effects of land use and climate change on the storm water drainage system in the chosen location. The findings showed that land use had less of an adverse effect on storm water drainage than climate change. By the time the return periods reached twenty-five years, a significant system breakdown had happened, flooding 26 percent of the research area. Furthermore, only the next ten years expected to be safe to the impacts of climate change on the system.

### **2.3.2 Urbanization's Impact on Storm Water Network**

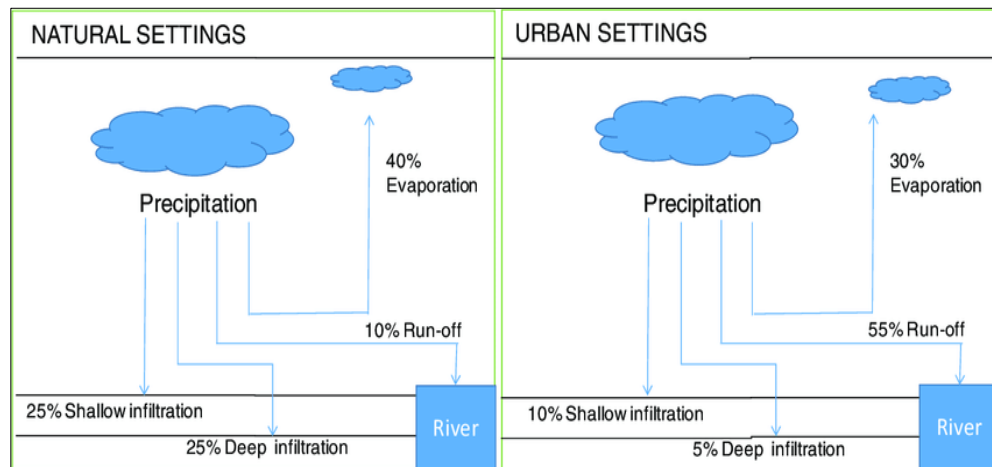
Land use changing because of increased urbanization and population, taking into account factors other than climate change, which has a negative impact on storm water drainage networks. Causes urban drainage system failure and floods as well (Abd-Elhamid et al., 2020). Because of converting rural or farmed regions to impermeable surfaces, urbanization increases the amount of impermeable surface in metropolitan areas (Lee & Bang, 2000). In areas where urbanization affects the hydrology of the natural environment by increasing peak flooding values and reducing time lag, which raises runoff volume (Browne et al., 2021). Alongside the rise in urbanization came a rise in the volume and peak of water floods and a reduction in the time to peak (Nirupama & Simonovic, 2007).

The management of urban drainage is a vitally significant topic given the global expansion in urbanization and the effects of urban storm water on both humans and aquatic environments (Chocat et al., 2001). The risk of urban flooding has grown due to the effect of land use changes, which has increased the volume and peak flow of water floods and reduced the time to peak (Goonetilleke et al., 2005; Saghafian et al., 2008).

Therefore, if human density increases, especially in low-lying areas, there may be an increased danger of flooding in urban areas (Zhou et al., 2019). Cities everywhere struggle to manage storm water effectively, and the problem gets worse as cities' populations increase (Jefferson et al., 2017). According to a research by (Hussain et al., 2022; Nile, 2018), the hydrological effects of urbanization also result in lower river base flow, worse water quality, and decreased groundwater penetration because they impair groundwater recharge. In addition, storage, erosion of riverbanks, and worse water quality in bodies of water (Brandes et al., 2005; Leandro et al., 2016).

Significant flooding is often associated with metropolitan areas even with storm water drainage-systems in place (Agnese et al., 2007; Hallema et al., 2016; Sheng & Wilson, 2009). As a result, evaluating the consequences of floods in communities and developing the appropriate treatment, reduction, or adaptation strategies have been the recent focus of interest for several studies worldwide.

According to (Durrans et al., 2003), surface runoff happens when rainfall causes the pervious or impermeable surfaces to get saturated. When precipitation turns into runoff and flows to the river via gravity, pervious surfaces hold onto the water until full saturation happens. The soil type, evaporation, and terrain all affect the saturation limit (Pierpont, 2008). Surface runoff in natural regions is only around 10% of total precipitation; but, as urbanization grows, this percentage jumps substantially to roughly 55%, as Figure 2.2 illustrate.



**Figure 2.2 Surface Runoff Variations in Natural and Urban Areas(Saraswat et al., 2016)**

## 2.4 Storm water Simulation Model

Numerous models exist for the analysis and assessment of a rainwater network in order to identify and address degradation. An overview of SWMM

software based on literature studies provided in order to evaluate the effectiveness of the rainwater system. An international application for storm water runoff, drainage systems, and sewer planning, analysis, and design is the US EPA's SWMM (Behrouz et al., 2020) (Hassan et al., 2017). It makes it possible to create ecologically acceptable, reasonably priced green/gray hybrid storm water solutions as well as storm water management strategies for gray infrastructure, such as pipelines and drains (Ahmed et al., 2017).

Because SWMM may include infiltration, snow cover, evaporation parameters, and urban drainage features, it has become more and more popular in the modeling community (Rossman & Huber, 2016a). (Pittman, 2011) It is simple to manipulate the SWMM output in other programs, such as Microsoft Excel.

Based on a study by (Paule-Mercado & Lee, 2017) used a computer-based hydrological model, SWMM, a geographic information system (GIS), and statistical analysis to model rainfall-runoff events in an urban watershed in Yongin City, Gyeonggi Province, South Korea, that is mixed land use and land cover (LULC). The study's findings demonstrate an excellent match between pollution charts and observed and calibrated hydrographs, indicating the validity and suitability of the SWMM model for simulation.

Rabori and Ghazavi (2018) computed urban floods in Zanjan, Iran, using SWMM. The study examined the effectiveness of the drainage networks in the area. Urban floods could have predicted with accuracy by SWMM. Moreover, there was no need for modification because the major canals could transport the peak runoff for a design storm with a 50-year return period. There was surface flooding in a few major cities, according to local observations and model results.

Nile et al. (2019) in Karbala, Iraq, constructed models using SWMM to anticipate the impact of future changes in rainfall events to prevent the storm water network's infrastructure from overflowing. Using historical data from 1980 to 2016, the first study forecasts the amount of rainfall that will fall between 2017 and 2070. This study evaluated the overflow situation of the study region for projected rainfall intensity using Artificial Neural Network (ANN) mode and SWMM result construction. The findings showed that in 2067, the maximum rainfall intensity would be 46 mm/hr., or 400% of the storm water network's design intensity.

### **2.5 Applications for Improving Storm Water Networks Management**

There are techniques used to improve storm water management, Low Impact Development (LID) solutions are strategies to collect runoff from the ground and give it with a combination of infiltration, evapotranspiration, and storage (Ahiablame et al., 2012; Davis, 2005; Qin et al., 2013). This method lowers the quantity of contaminants during precipitation occurrences. An effective way to store, infiltrate, and evaporate sub-catchment runoff over a research area is to employ Low-Impact Development controls, or LIDs. Because of its per-square-foot construction, the control may put in any of the sub-catchments, regardless of their size or quantity. The SWMM provides the capacity to examine storm water best management practices (BMPs) for pollutants reduction at source utilizing LID techniques in addition to qualitative simulation.

In order to mitigate urban overflow catastrophes, (Bai et al., 2019) carried out the study in Jiangsu province, China, utilizing LID technology to regulate runoff. Using SWMM software, simulation results of a real rainwater network in Jiangsu, China, revealed that LID facilities may significantly

reduce overflow and that infiltration facilities (Green Roofs) reduce surface runoff more quickly than storage facilities (Rain Garden). The conclusions of this study may offer some technical assistance for the development of urban drainage networks. LID thought to be a sustainable approach to managing urban storm water. The Environmental Protection Agency (EPA) of the United States (US) used the SWMM to create a thorough evaluation methodology for this project that took into account both the economic and environmental advantages.

Simpson et al. (2010) conducted research in Collins, Atlanta, USA, to determine if LID can preserve the predevelopment of site hydrology and whether it can be utilized alone to fulfill storm water requirements. The cost evaluation revealed that the additional LID costs might be recovered in particular land that no longer needed. Simulation results by SWMM demonstrated that LID could restore predevelopment site hydrology, although the amount of LID required was large. The users of LID should thus be cautious when planning and developing the system and should first calculate the costs and determine whether it was a worthwhile investment.

A study by (Alyaseri et al., 2017) was conduct to evaluate how rain gardens affect the combined sewer area's water quality and storm runoff volume decrease from urban roadways. At one of the study locations, the installation of rain gardens reduced storm water runoff volume by 76%.

Simulation, designing, building, and managing LID is more difficult than it is for traditional equivalents. Planning and creating LID systems requires careful consideration (Simpson et al., 2010). Therefore, anyone thinking about using LID should first calculate the costs and determine if it is a wise investment. Although LID has many advantages, it is not a "magic fix" for managing storm water.

### 2.6 Summary

This chapter provides a succinct overview of the earlier research that the thesis relies on. Through a comprehensive analysis and discussion of several past works about the variables such as rainfall intensity, land use, terrain, and urbanization that impact the management of the rainwater drainage system. Along with daily attempts to evaluate and identify prospective effects of employing new techniques to lessen flooding and save people and property. Past studies demonstrated the efficacy of the SWMM model in simulating and analysis of storm water drainage systems and providing outcomes that were quite accurate. In order to analyze and assess the performance of the storm water drainage system in the Al-Abed quarter of the Al-Hur district in Kerbala, Iraq, this study employed the SWMM model.

(A. Al-Khuzai et al., 2023; Hassan et al., 2024; Jiang et al., 2015; Rangari et al., 2018) was the primary source taken into consideration for the study since it matched with the main research idea, particularly the section where [SWMM] was used to model flooding events, with the exception of the data supply for the study region.

For the control and mitigation of floods in the drainage system, (A. H. Al-Khuzai et al., 2023) has taken into consideration, using another technique for flooding control.

## **Chapter Three: Methodology and Data Collection**

### **3.1 Introduction**

The research area in Al-Abed quarter, Al-Hur district of Kerbala City, will be discussed in this chapter first. Explain the mathematical equations in storm water network management analysis. It also describes the data utilized in this research, the simulation software and the input data that were utilized. The portions of the chapter are as follows:

1. Research area specification: included information on the topography, slope, land use, overall area, and sub-catchment characteristics (e.g., area, width, impervious, infiltration).
2. Provide information on hydrological process data represented by rainfall intensities generated from IDF curve of Kerbala city.
3. Explain the procedure of the mathematical equations in storm water network management analysis.
4. Identify information on hydrologic processes, such as characteristics of the drainage network primary component (pipelines, junctions or manholes, and pump stations).
5. Explain the physical model (SWMM), which is used to simulate hydrologic and hydraulic data, which enables the creation of accurate simulations and assessments of system performance.
6. Explain the influence of the Low Impacts Development simulation on the rainwater network and the improvement to mitigate the effect of floods. Figure 3.1 illustrates the work's method for the study:

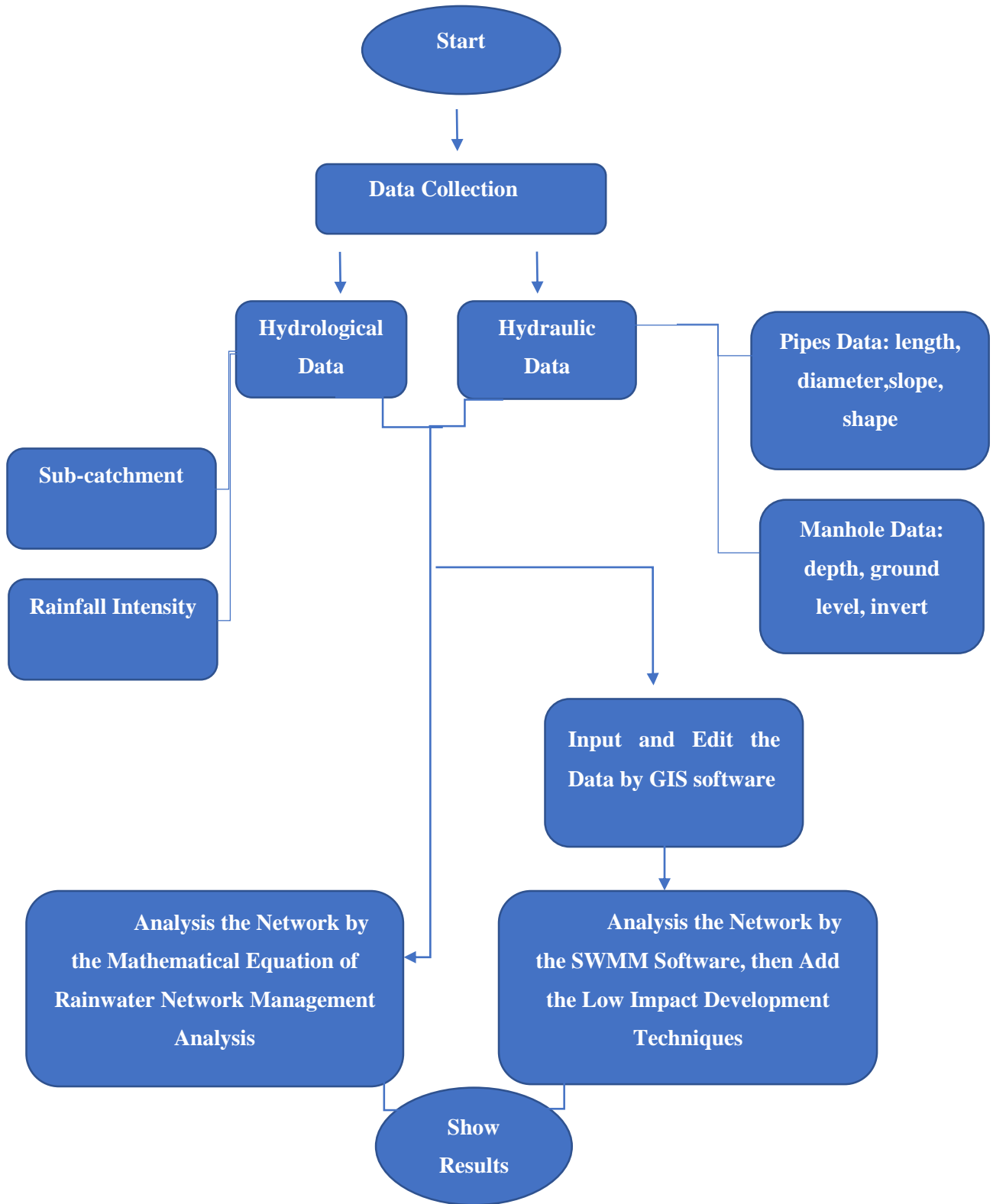


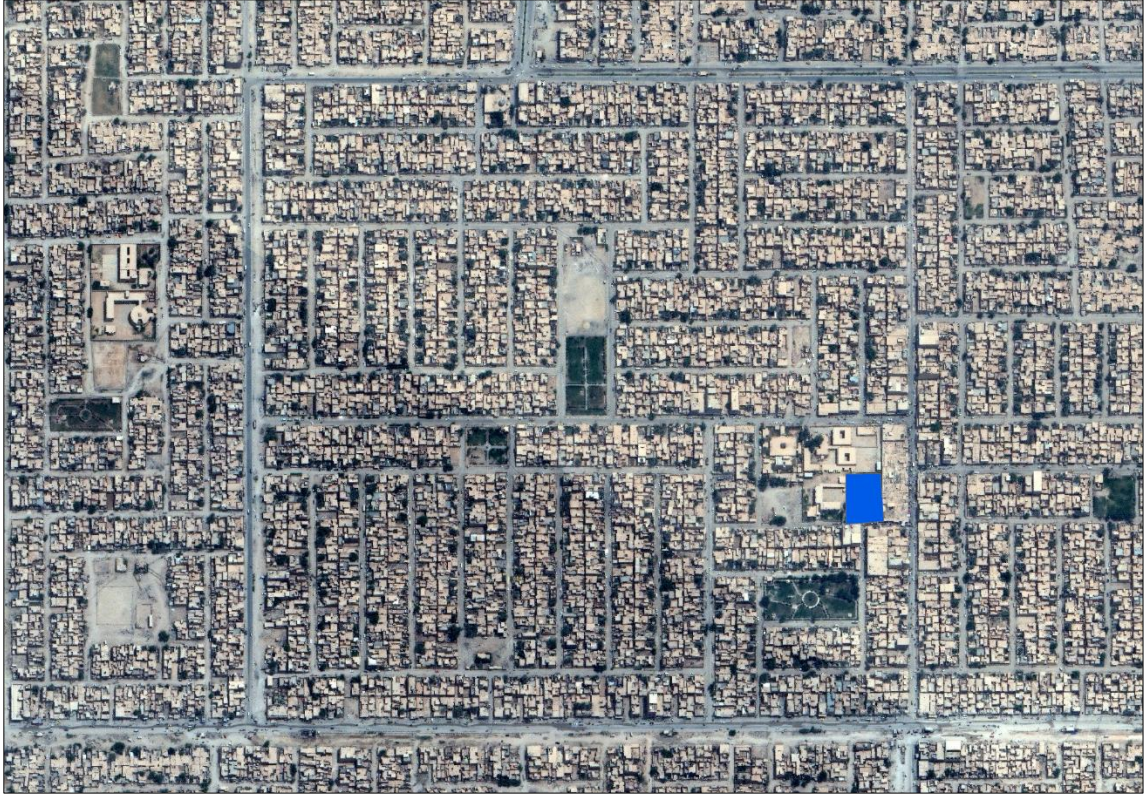
Figure 3.1 Total Methodology Chart

## **3.2 The Research Area**

### **3.2.1 Location and Description**

According to geography, as seen in figure 3.2, the research area [Al-Abed quarter] is situated between latitudes [32°27'47" N - 32° 26' 16" N] and longitudes [43°58'20" E - 43° 09' 22" E], with an overall area of 0.705 km<sup>2</sup> (70.5 hectares) north of the Kerbala province center, Iraq. According to Kerbala's Sewage Director [KSD], 2015, it has a level surface with a relatively high slope and sandy clay soil. The research area is situated in an area where elevation is between 38 and 46 meters above sea level.

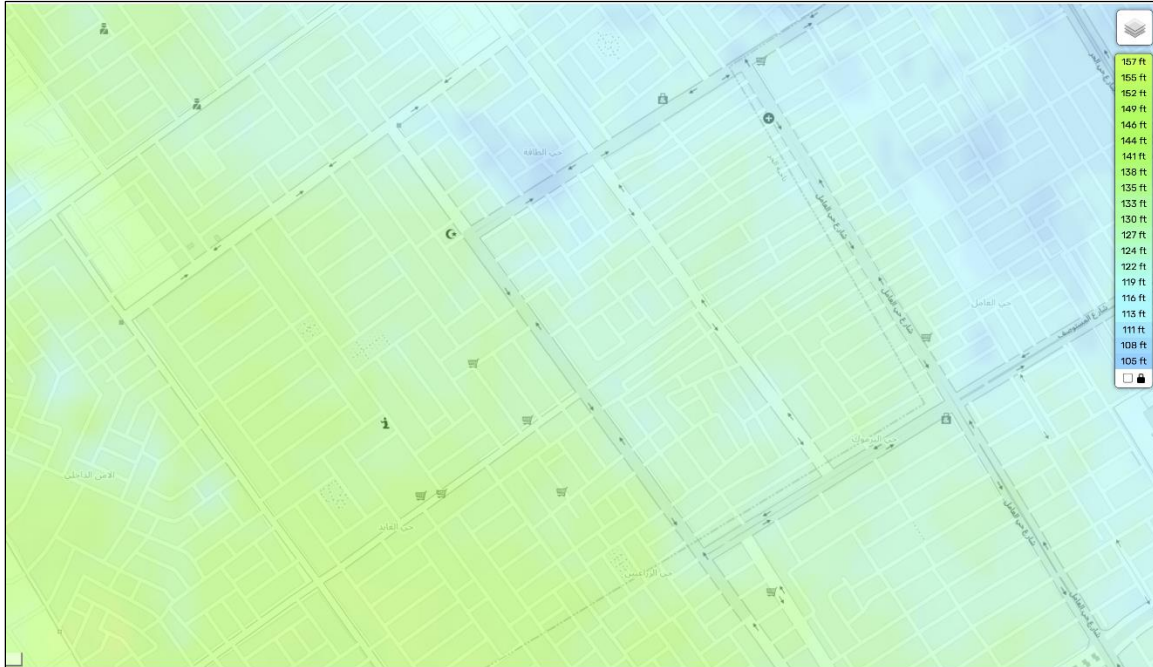
Impervious zones include roofs, walkways, and highways, whereas pervious regions include green areas and unpaved roads. The chosen research region has a desert climate with dry, scorching summers from May to September and cold, wet winters from October through April. In Kerbala, the yearly precipitation total is less than 92 mm, with summer temperatures reaching 48 °C and winter temperatures reaching 8 °C (Nile et al., 2018). Using digital aerial images and plan maps, the impervious percentage of the Al-Abed quarter is estimated by calculating the percentage of walkways, roads, and roofs covering the total area at each sub catchment. The entire area of Al-Abed quarter is split into [132] sub catchments based on the kind of land use and slope of the research region. Every sub catchment is modeled and connected to the rainwater drainage system directly.



**Figure 3.2** Arial Picture of Al-Abed Quarter in Kerbala, Iraq.

### **3.2.2 Topography**

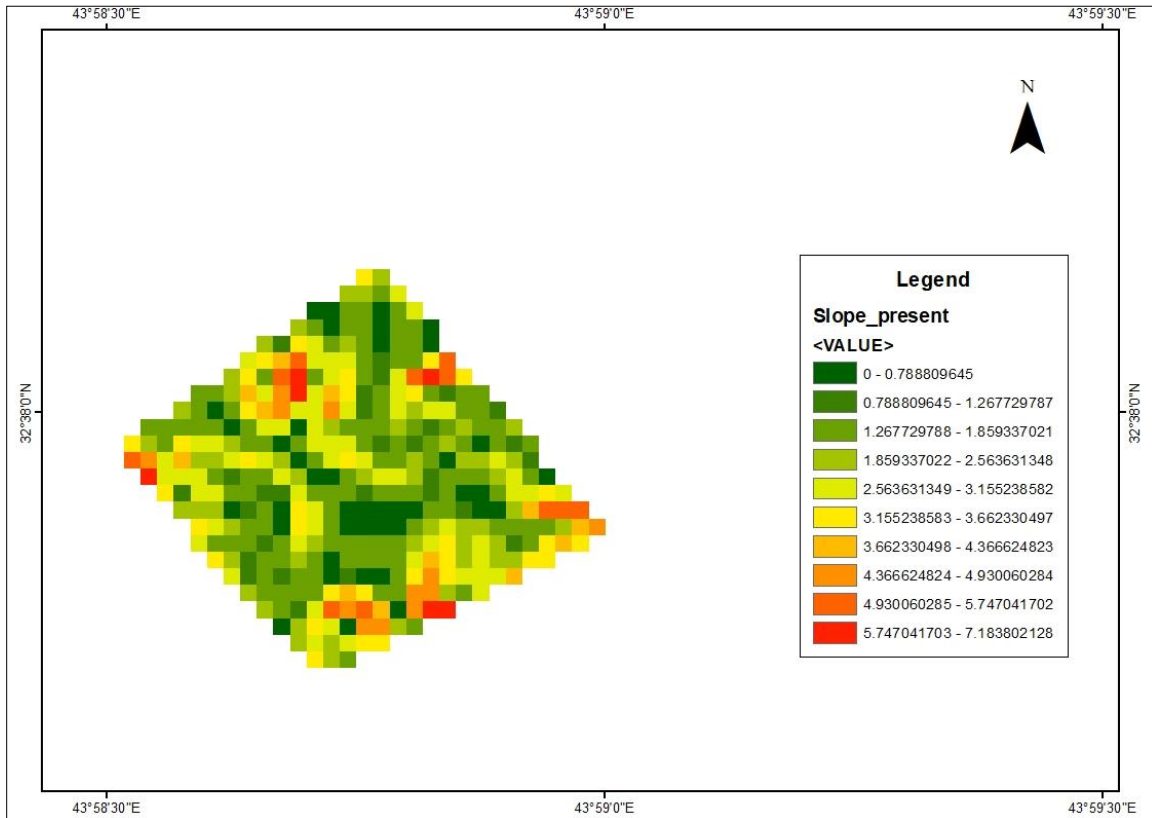
Figure 3.3 displays a map of Kerbala's topography. The purpose of this map is to serve as a reference for GIS. Along with the city's administrative borders, the map also shows parks, physiographic characteristics, water bodies, sights, highways, roads, land cover, and topographic images. GIS produced this base map from a variety of the most reliable sources. The Food and Agriculture Organization of the United-Nations (FAO), the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), the National Park Service (NPS), and other organizations are some of the sources used. Kerbala City's topography facilitates drainage water flow by gravity. High slopes cause surface runoff to flow downstream. The height of the land is between 38 and 46 meters above sea level, according to the map.



**Figure 3.3 Topography Map of Research Area by Google Map**

### **3.2.3 Slope**

Figure 3.4 depicts the Al-Abed quarter's slope map. The landscape gets flatter as the slope value decreases and becomes steeper as the slope value increases. GIS Arc Map 10.7 software created a slope map of the research area based on a digital elevation model (DEM). With a recognition accuracy of (12.5) meters, according to NASA and the US Geological Survey (USGS). Using a geocentric 3D coordinate system, commonly known as the Earth Centered, Earth Fixed (ECEF) coordinate system, the geodesic technique calculates slope. by assuming that the Earth is an ellipsoid in form. The research area's average slope, as seen in the figure, is 0.25%.



**Figure 3.4 Map of the Al-Abed Quarter Slope by GIS Software**

### **3.2.4 The Research Area's Land Use**

Determining the amount and quality of surface water generated in the study region requires an understanding of its land use features. Al-Abed Quarter's current land uses include residential, commercial, educational, industrial, green space, and other uses that are common to Iraq. In the study survey area, there are 71% residential blocks, 6% gardens and service buildings, 20% paved roads, and 3% spaces. Land use subdivisions illustrate in Figure 3.5.



**Figure 3.5 Research Area Land Use Map**

### **3.2.5 Features of Karbala's Soil**

The features of the soil have a significant role in the inflow and infiltration processes in the drainage system. The drainage area's soil characteristics affect the rate of infiltration. Consequently, SWMM5.2 utilized soil parameters as an input to determine how much water into the drainage system. There are seven different types of soil in Karbala: lake soils, saline lake bottom land, mixed gypsiferous desert land, river basin soils silted, sand dune land, water bodies, and DO, or poorly drained phase (Obaid, 2015). Figure 3.6 displays the city's soil map.

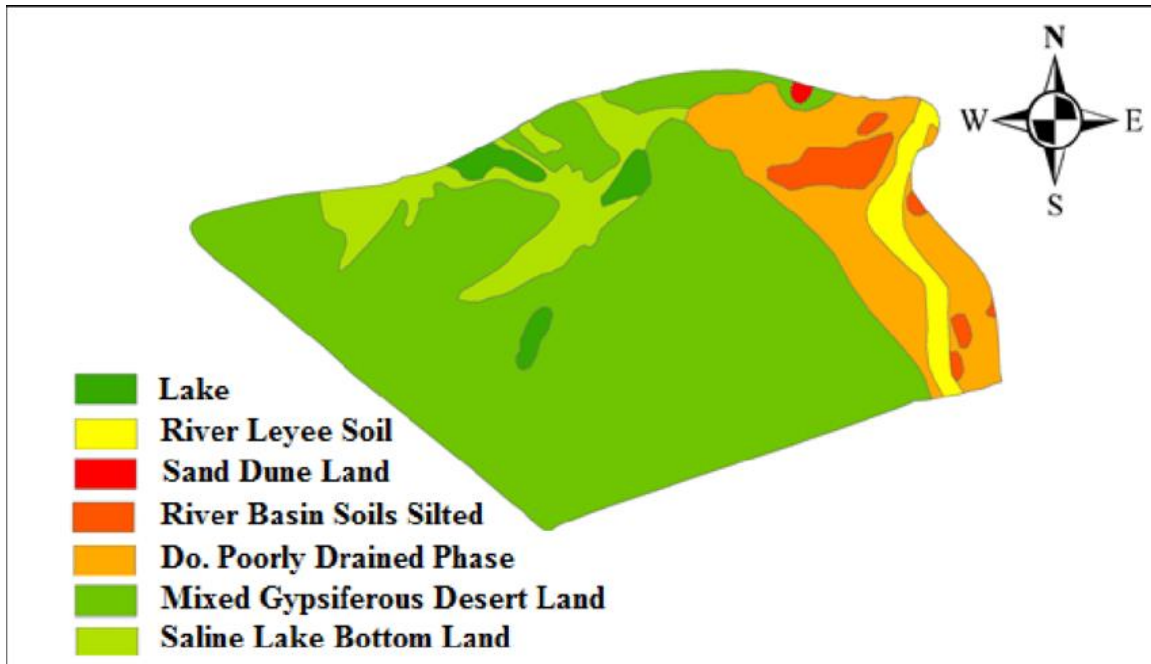


Figure 3.6 Kerbala City Soil Map Created Using a GIS-Based DEM Data (Obaid, 2015)

### 3.3 The Analytical Equations in Rainwater Network Management Analyses

An accurate and understandable framework for understanding the analytical equations in rainwater network management studies is provided by these relationships, which provide a clearer picture of the parameters, units, and equations involved in each analysis stage.

#### 3.3.1 Hydrological Modeling (Inflow Calculation)

Use the rational formula:

$$Q_{\text{inflow}} = C * I * A / 360 \quad (\text{McGhee \& Steel, 1991}) \quad (3.1)$$

- $Q_{\text{inflow}}$ : the flow rate entering the system ( $\text{m}^3/\text{sec.}$ ).
- I: the intensity rainfall ( $\text{mm}/\text{hr.}$ ).
- C: runoff coefficient (unit less).
- A: area of the catchment (ha).

### 3.3.2 Verify with Hydraulic Modeling (Pipe Flow Capacity)

Use the manning equation:

$$Q_{\text{pipe}} = 1/n R^{2/3} S^{1/2} A \quad (3.2)$$

- n: coefficient of manning roughness (0.009 for polyvinyl chloride pipe).
- R: hydraulic radius = D/4.
- S: pipe slope.
- A: area of the pipe cross-sectional (m<sup>2</sup>).

The ratio of actual depth flow to full flow depth (d/D) must be within the limits 0.3 to 0.8, this ratio gets through divided  $Q_{\text{inflow}} / Q_{\text{pipe}}$  then go to the chart of the hydraulic elements of circular pipes (McGhee & Steel, 1991) which shown in appendix (figure A.1).

Verification: ensure d/D (0.3-0.8)

### 3.3.3 Capacity Design Validation

Use the equation:

$$Q = V * A \quad (3.3)$$

- A: area of the pipe cross-sectional (m<sup>2</sup>).
- V: velocity (m/sec.).

Verification that the actual flow velocity which also gets from the chart of the hydraulic elements of circular pipes through the ratio of (v/v<sub>full</sub>) are less than 3 m/sec. (McGhee & Steel, 1991).

### 3.3.4 Validation with Simulated Data

Use storm water management model SWMM (which we will find out in detail later) to compare simulated and observed data.

### **3.4 The Model for Simulation**

This study chose to utilize SWMM software since it contains the components required to meet its goals. The United States Environmental Protection Agency (US EPA) created the Storm Water Management Model (SWMM) in 1971 (version 1) as a dynamic rainfall runoff simulation model (Rossman & Huber, 2016b). SWMM software used to simulate the quality and amount of runoff in the long term or to mimic a single rainfall event. Primarily, the SWMM applied in urban locations. Work with Microsoft Windows; the new SWMM v5.2 is comparable to the previous versions, the distinction between them is the ability to monitor each pipe and channel's water quality at different modeling run durations, as well as the flow depth and rate, created runoff volume, and each of the separate catchments (Rossman & Simon, 2022). According to (Rossman & Huber, 2016a), SWMM provides an integrated environment for data editing, simulations, running and status of hydraulic and hydrologic drainage system conditions, water quality, and eventually, findings visualization. Utilizing a variety of methods, the SWMM simulation helps the country meet its objectives for optimal storm water management and decreased surface runoff.

Geological data (terrain type), land use, the hydraulic data (drainage system size and the spatial distribution), climatic data (mostly precipitation and temperature), topography, and hydrologic qualities are among the data required for modeling. Due to its proficiency in storm water, sanitary and mixed network planning, analysis, and design, SWMM is a very popular model globally (Pittman, 2011; Rossman & Supply, 2006). Moreover, it is readily available for free online download.

### **3.5 Hydrological Modeling**

For estimating water flow in sub-catchments, runoff, the hydrological data-modeling target provides the most accurate representation of the precipitation in the research region. (Remesan & Mathew, 2015). The enhancement of the temporal and spatial representation of precipitation fields has received a great deal of attention in hydrological research in the past several decades. The creation of different multi-scaling and basic models is one of the most important problems. As a result, rainfall modeling considers this. "Some models are useful; all models are incorrect." Because there are unanswered issues and well-researched hypotheses, this statement is crucial to the data-based modeling of hydrological conditions (Remesan & Mathew, 2015). Numerous characteristics, including Rain Gage, Sub-catchments, Aquifers, Snow Packs, Unit Hydrographs, and Low Impact Development (LID) Controls, are part of the hydrological data used for the SWMM modeling.

#### **3.5.1 Rain Gauge**

In a research area, rain gauges gather rainfall data for one or more sub-catchment areas. Rainfall data can be obtained from a user-defined time series or an external file. In addition to a common user-defined format, it supports many widely used rainfall file formats (James et al., 2010; Rossman, 2010). Since precipitation is the main driving force behind the Storm Water Management Model (SWMM), rainfall data is crucial. When designing urban drainage systems to avert floods, models might be useful.

Depending on the catchment reaction, variations in rainfall need a certain amount of time. The reaction times of large, flat catchments slower compared to those of small, steep catchments (AL-Hamami et al., 2021). The

precipitation intensity data serves as the primary parameter in the hydrological data modeling. The current SWMM modeling takes into account the high rainfall intensities for the different return periods 2, 5, 10, and 20 years. The IDF curve for the city of Kerbala displayed in Figure 3.8 below, which created based on regional studies (Al-Busaltan et al., 2021; Nayel et al., 2018). Additionally, Table 3.2 shows the rainfall intensity at five-minute intervals for the following return periods: 2, 5, 10, and 20 years.

**Table 3.1 Intensity of Rainfall (mm/h) Across Different Return periods**

Duration of the Storm/min	Return periods/years				Duration of the Storm/min	Return periods/years			
	2	5	10	20		2	5	10	20
5	40.51	60.42	73.62	86.25	65	9.17	13.67	16.62	19.5
10	27.11	40.44	49.21	57.72	70	8.78	13.1	15.9	18
15	21.44	31.97	38.93	45.64	75	8.44	12.5	15.3	17.9
20	18.15	27.06	32.91	38.63	80	8.13	12.12	14.7	17
25	15.95	23.78	28.91	33.95	85	7.85	11.7	14.2	16.7
30	14.35	21.4	26.11	30.54	90	7.59	11.3	13.7	16.11
35	12.6	19.2	23.22	27.94	95	7.36	10.9	13.3	15.62
40	12.14	18.11	22.4	25.86	100	7.14	10.6	12.9	15.21
45	11.3	16	20.5	24.15	105	6.94	10.31	12.6	14.71
50	10.67	15.92	19.3	22.72	110	6.70	10.08	12.2	14.30
55	10.1	14.9	18.55	21.5	115	6.58	9.82	11.9	14.1
60	9.6	14.32	17.41	20.44	120	6.42	9.58	11.6	13.6

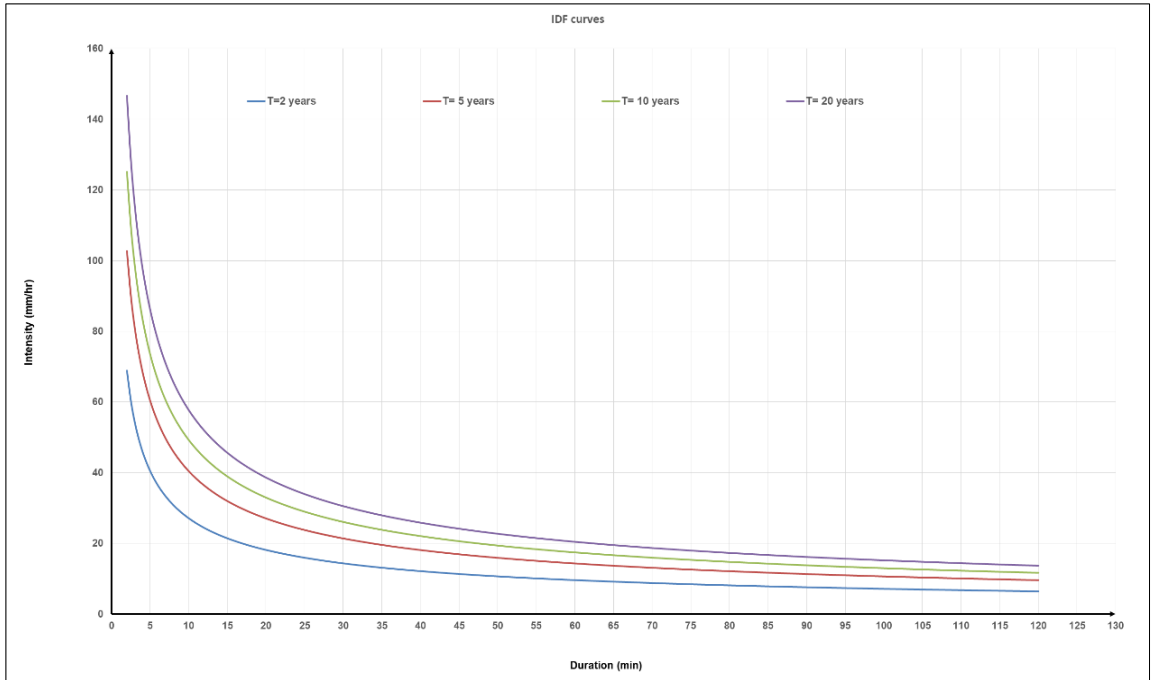


Figure 3.7 Karbala City's IDF Curves (Nayel et al., 2018)

### 3.5.2 Sub Catchments Characteristics

Sub-catchments are regarded as hydrologic units of the lands in the SWMM modeling where runoff is directed to a single location by the sub-catchment's topography and drainage system components, which discharge runoff. It is the user's responsibility to determine the sub-catchments' outlet locations and divide the study land into the proper number of sub-catchments. The drainage system nodes themselves or other sub-catchments may have the discharge outlets sites (Rossman, 2010). In 2023, KSD provided an aerial picture and shape file for the research region that showed the geographical distribution of the sub-catchments and their characteristics using GIS Arc Map. To get a greater accuracy while conducting the simulation, it is essential to know the sub-catchment features and their information, which include total and singular areas, width, permeability, slopes, and the drainage outlets for

the sub-catchments, because it regulates the flow and volume of surface runoff (Rossman & Huber, 2016a). The sub catchments in the current research have an area ranging from 0.05 to 1.05 hectares.

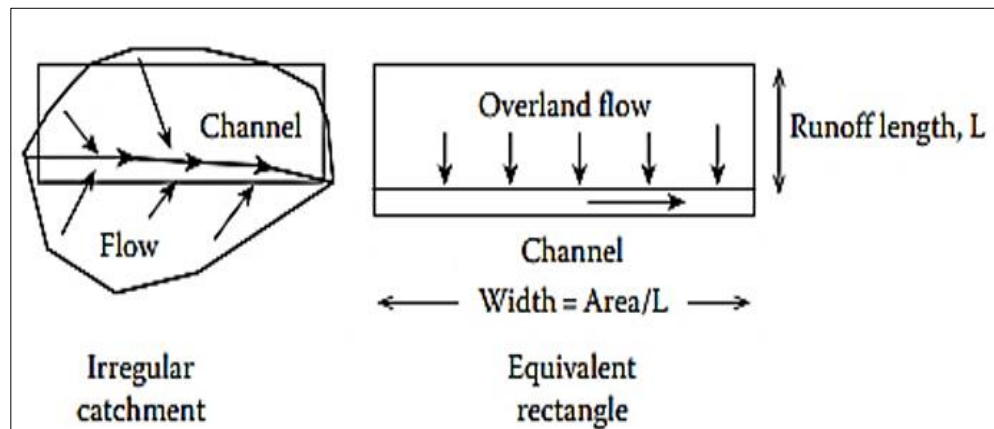
### **3.5.2.1 Sub Catchment Area and Width**

The region that the sub catchment border encloses is known as the sub catchment area. When drawing the sub catchment to scale on the research area map, SWMM's Auto-Length tool utilized to determine its value, or it may directly have derived from the map or field surveys of the site. The present research area, the Al-Abed quarter, covers 70.5 hectares. As Figure 3.10 illustrates, it subdivided into 132 sub catchments, with sizes varying from 0.05 hectares to 0.9 hectares. The width of the overland flow inside a sub catchment is its width ( $W$ ). True overland flow in natural places occurs 500 feet (152.4 m) before moving to river flow. It may be short in catchments that are urbanized. The width parameter takes peak flow rates, reduction, and internal routing into consideration. Area and runoff length determine the width magnitude (Rossman & Huber, 2016b). Simplify the sub catchment's geometric shape to a rectangle with the same area in order to calculate the

width. The width is equivalent to the maximum runoff length (Eslamian, 2014), figure 3.11.



**Figure 3.8 Research Area Sub Catchments Areas Utilizing SWMM**



**Figure 3.9 Calculating the Width of Sub Catchments (Eslamian, 2014)**

Using equation 3.4, one may determine the width of a sub catchment by dividing its area by the longest overland flow path (Rossman, 2010).

$$W = A / L_{\max} \quad (3.4)$$

Where:

W: Sub catchment width / m

A: Sub catchment area / m<sup>2</sup>

$L_{\max}$ : Runoff length, represent the maximum distance between each vertex and the outlet point (Shen & Zhang, 2014). As shown in figure 3.12 below:

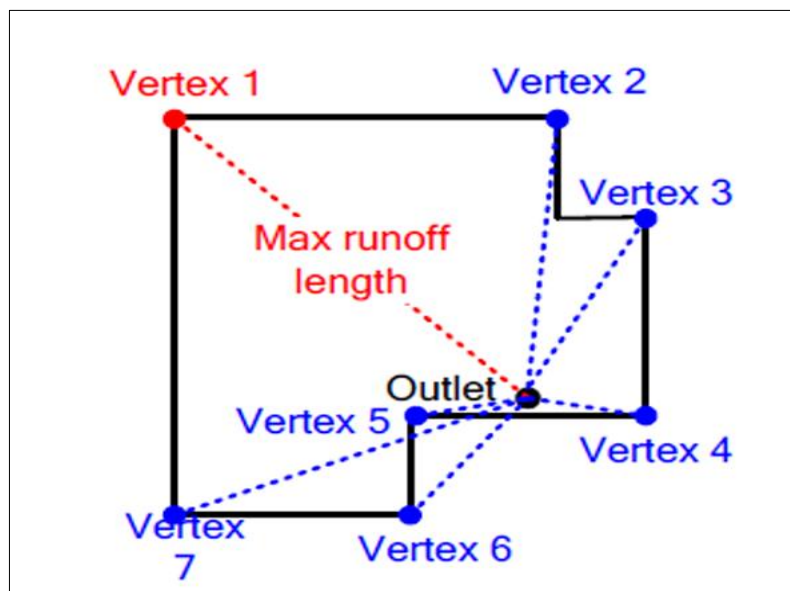
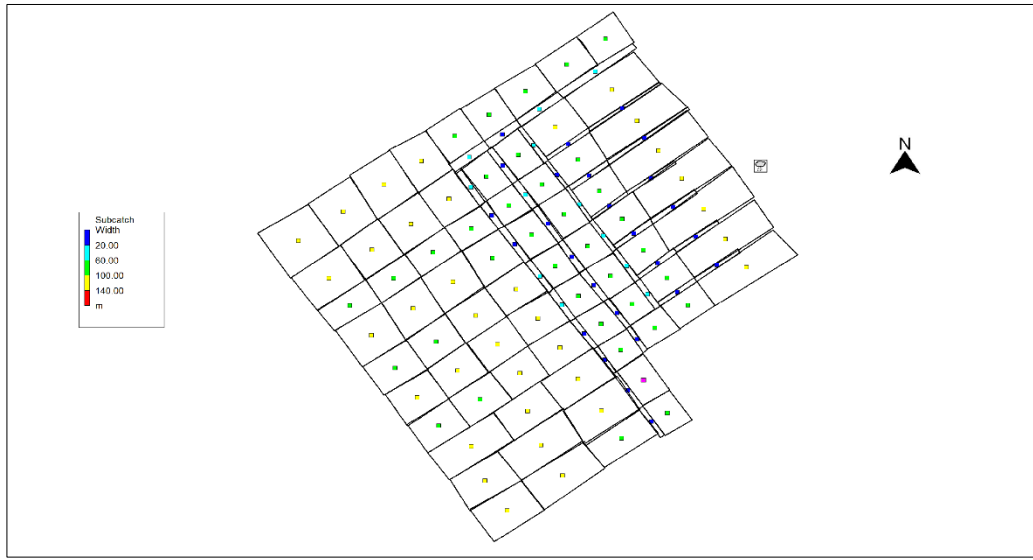


Figure 3.10 Maximum Runoff Length Estimation (Shen and Zhang, 2014)

According to Figure 3.13, the sub catchments width of the research area spans from 13 to 115 meters.



**Figure 3.11 Research Region Sub Catchments' Width via SWMM**

### **3.5.2.2 Sub Catchments Slope**

The overland flow route, or its area-weighted average, is the slope of the land surface across which runoff flows. For both pervious and impermeable surfaces, it is the same. The idealized sub catchment's slope runs perpendicular to its width (James et al., 2010). When it comes to sub catchments in the current research region, for example, the form and slope of the sub catchment really change within the sub catchment. DEM data and GIS software were utilized to determine sub catchment slopes, and the geodesic method was employed to measure them, as seen in this chapter's 3.2.3. The research area slopes revealed that the average was 0.25%, (see Figure 3.4).

### **3.5.2.3 Permeable and Impermeable Sub Catchments**

There are two types of sub catchments: permeable and impermeable. The region that is impermeable to precipitation due to surfaces like roofs, sloping metal roofs, and roads is known as the impervious area. There are two types of impervious regions: those with depression storage and those with no depression storage (zero impermeable areas). It is possible to direct runoff to

drain into the sub catchment outlet from one subarea to another or from both subareas (James et al., 2010; Rossman, 2010). Surface runoff cannot pass through the impervious region, but it can enter the upper soil zone of the pervious region. When impermeable surfaces need to refill slowly because they are only drained by evaporation (Rossman & Huber, 2016a). As a result, flow rates and runoff volume affect imperviousness. It is possible to evaluate imperviousness regions using aerial photographs or land use maps. Table 3.3 presents some values of the percentage of impervious area for different land uses (UDFCD, 2016), In addition, as shown in Table 3.4, the ratios for depression storage in the region of depression storage in SWMM modeling for the pervious and impervious area (Federation & Engineers, 1992).

**Table 3.2 Percentage of the Impervious Area in Land Use (UDFCD, 2016)**

Surface Properties	Imperviousness percent
Downtown Regions	95%
Suburban regions	75%
Residential	
≤ 2.5 acres	12%
0.75-2.5 acres	20%
0.25-0.75	30%
≥0.25	45%
Apartments	75%
Industrial	
light regions	80%
Heavy regions	90%
Parks	10%

playgrounds	25%
schools	55%
Streets	
Paved	100%
Lawns	2%

**Table 3.3 Values of the Depression Storage According to (Federation and Engineers, 1992)**

Depression Storage Values	
Impervious surfaces	0.05-0.1 inch
Lawns	0.1-0.2 inch
Pasture	0.2 inch
Forest litter	0.3 inch

### 3.5.2.4 The Roughness Coefficient of Manning for Sub Catchments

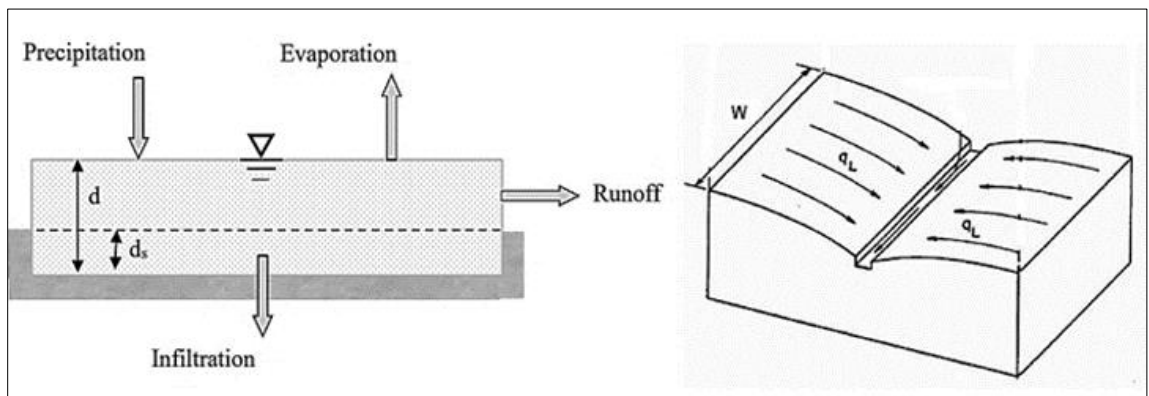
The degree of roughness coefficient shows how much resistance overland flow encounters as it exits the sub catchment surface. The values of these hydrologic modeling parameters are functionally helpful, and they depend on the kind of land use in a given sub-catchment. Table 3.5 displays the manning roughness value according to the source for a number of overland kinds (McCuen, 1989). In the present research, the roughness coefficient (n) for impermeable areas was determined to be 0.011, the same value as smooth asphalt, and 0.012 for residential roofs (smooth concrete), The n value of 0.13 was utilized while analyzing previous regions.

**Table 3.4 Sub-Catchments' Manning Coefficient (McCuen, 1989)**

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

### 3.5.2.5 Surface Runoff

Surface runoff on wet gradient surfaces results in ponding and flooding when the ponding depth is greater than the ground's roughness. Rainfall, which is an indivisible inflow, treats every sub-catchment surface as a non-linear storage. The evaporation, surface runoff, and filtration are regarded as outflows (Rossman, 2010). Put more simply, a nonlinear reservoir model recognizes that water flow behavior in a catchment area can be more complex and fluctuating, particularly at different phases of rainfall and runoff events. As shown in the Figure 3.14, SWMM forecasts surface runoff from precipitation across a sub catchment through a nonlinear reservoir model. Ponds, surface moisture, and other similar features serve as symbols for the reservoir capacity ( $dp$ ) (Lockie, 2009).



**Figure 3.12 Formulation of Nonlinear Reservoir in a Sub-Catchment (Rossman & Simon, 2022)**

The sub catchment empties into a single outlet channel and is a rectangular area with width ( $W$ ) and slope ( $S$ ). Modeling the sub catchment of a nonlinear reservoir with rainfall inflow and losses from evaporation and water infiltration produces overland flow. The ponded water over the depression storage depth ( $ds$ ) becomes the runoff outflow ( $q$ ), and the net surplus ponds to a depth of ( $d$ ).

When the reservoir of water depth is greater than the depression storage, surface runoff happens (Rossman, 2010) (Gupta et al., 2016) (Yu & Duan, 2017). The change in depth per time based on the difference between the input and outflow rates over the sub catchment (Kiraz, 2018). Equation 3.8 of water balance illustrate below

$$Q_{\text{storage}} = Q_{\text{in}} - Q_{\text{out}} \quad (3.5)$$

Where:

$Q_{\text{storage}}$ : max. Storage of depression ( $\text{m}^3/\text{sec}$ ).

$Q_{\text{in}}$ : flow inter the sub catchment, from other sub catchment flow, or from precipitation ( $\text{m}^3/\text{sec}$ ).

$Q_{\text{out}}$ : flow that get out from sub catchment through infiltration, evaporation, and surface runoff ( $\text{m}^3/\text{sec}$ ).

There is a positive or negative water balance. During dry seasons, when evaporation rates are higher than precipitation rates and plants take water from sub-catchment stocks, a fall in water levels results in a negative balance. Conversely, the positive balance happens during the rainy seasons when the rate of precipitation exceeds the rate of evaporation. This leads to an overflow of water that fills the sub-catchment storage, resulting in floods and surface runoff.

### 3.6 Hydraulic Modeling

The Directorate Kerbala Sewage [DSK,], GIS Division provided the storm water network data for the research region. These details include the characteristics of pump stations, manholes, and pipelines, as seen in Figure 3.15, encoded from points and lines using Arc Map 10.7, Figure 3.15 displays the hydraulic data as a Shape file. The information input into the Arc Map 10.7 program, which produced a geometric network to identify the path of

water movement. Utilizing GIS Arc Catalog 10.7, the data transformed to Shape file format before imported into Autodesk Storm and Sanitary Analysis 2021 (SSA) program. Before sent to the SWMM program, the data reviewed, updated, subjected to preliminary analysis, and a model created.

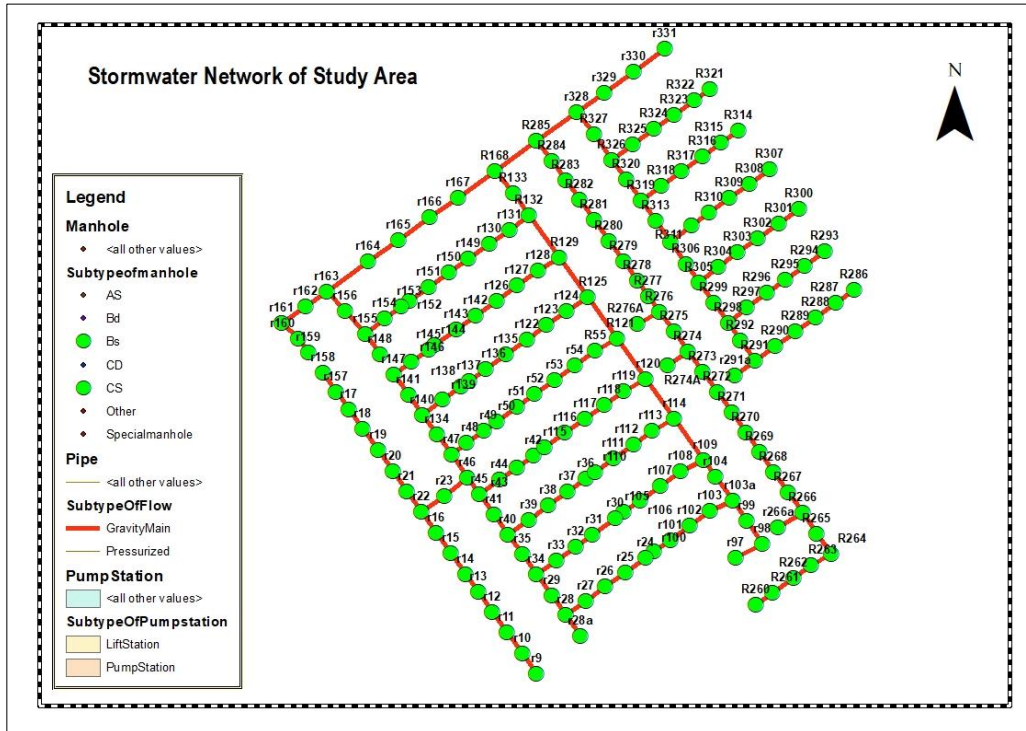
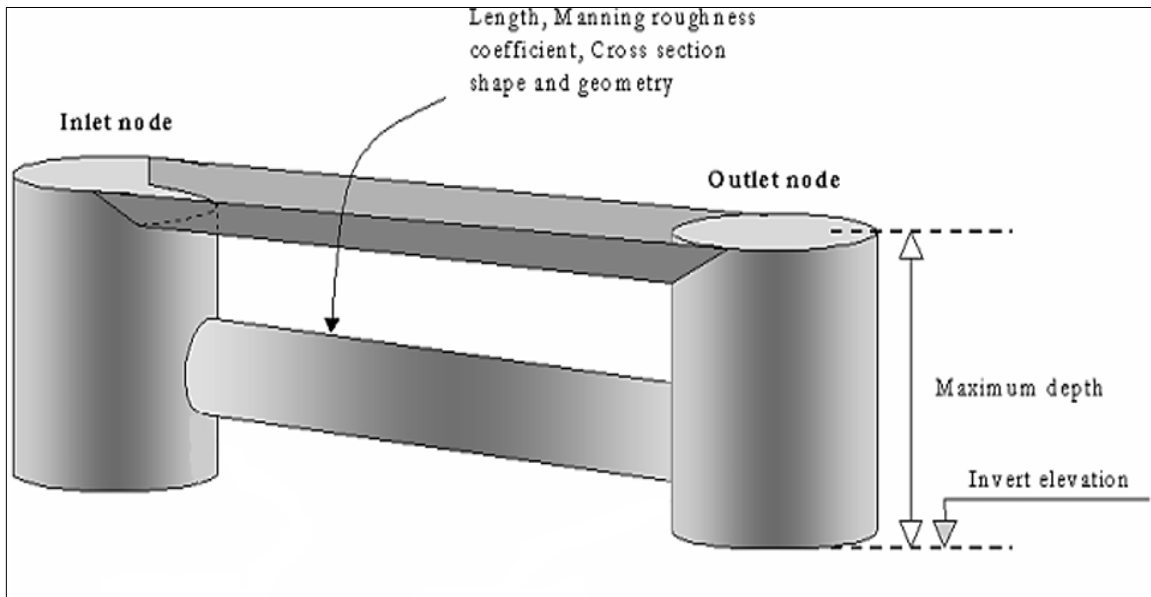


Figure 3.13 Research area's Storm Water Network by GIS

### 3.6.1 Manholes

In drainage systems, manholes are the nodes where connections converge. A manhole junction must include the following features: (i) elevation invert of manholes (m), or the elevation of the bottom with relation to the model's datum, such as sea level. This establishes the SWMM model junction's vertical location. (ii) Maximum depth (m) or the space between the invert of the manhole and the height of the ground surface at which street flooding takes place (Rossman & Huber, 2016a). Manholes and pipe links are

the essential parts of a drainage network. Figure 3.16 shows the characteristics of a circular pipe attached to manhole joints on either end (James et al., 2010).

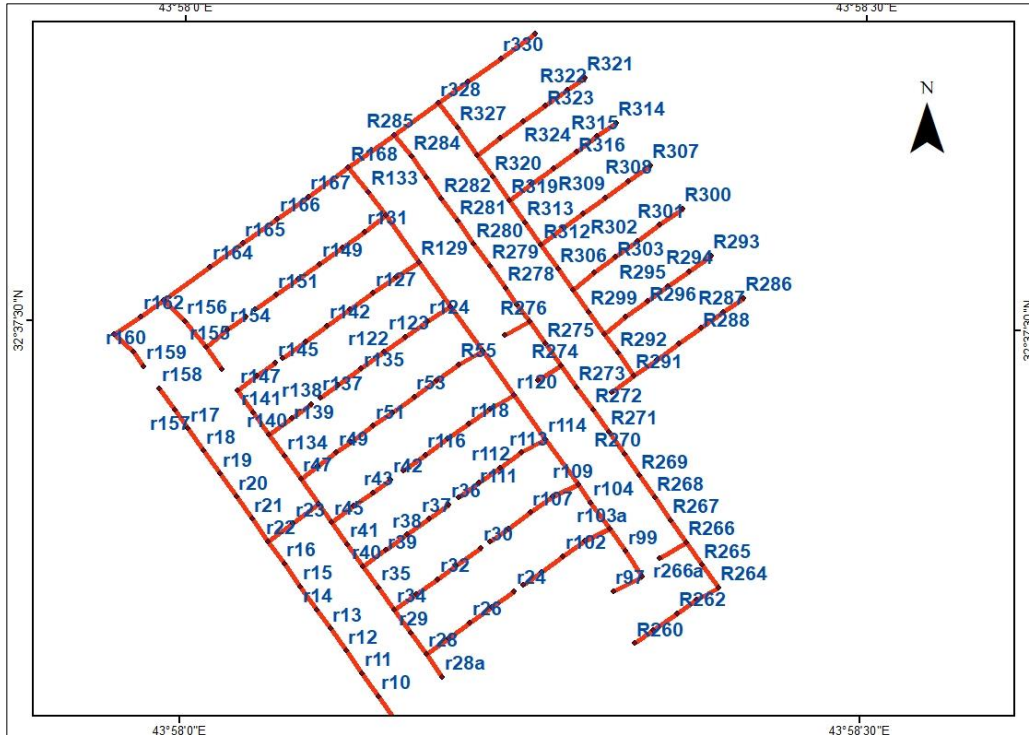


**Figure 3.14 The Fundamental Components of a Storm Water Network (James et al., 2010)**

The rainwater network in the research region has 201 manholes, divided into two categories: CS and BS. Table 3.6 displays the manhole parameters of the research area from the Directorate Kerbala Sewage [DSK]. In addition, manholes ID illustrated in figure 3.17.

**Table 3.5 Storm Water System Properties of Manholes in the Research Area (DSK)**

Manholes Information	Data
Number of manholes	201
Manholes subtypes	CS, BS
Manholes material	Concrete
Ground elevation (m)	36.66 - 41.58
Invert elevation (m)	34.39 – 39.78
Manhole depth (m)	1.12 - 4
Diameter (cm)	55



**Figure 3.15 Manholes ID of the Drainage System Produced by GIS**

### 3.6.2 Pipes

In a conveyance system, pipelines are tubes that move water between nodes. Common shapes are arch, elliptical, and circular pipes. The inlet and outlet nodes, together with their shape, maximum depth, length, roughness coefficient, starting flow, maximum flow rate, and entry and exit loss coefficients, are the conduits' input parameters (James et al., 2010). The association between the rate of flow ( $Q$ ), area of cross-section ( $A$ ), hydraulic radius ( $R$ ), and gradient in all conduits ( $S$ ) represented by the Manning equation, which is applied by SWMM. Regarding US unit's equation 3.6 and SI unit equation 3.7:

$$Q = \left(\frac{1.49}{n}\right) AR^{2/3} S^{1/2} \quad \text{US} \quad (3.6)$$

$$Q = \frac{1}{n} AR^{2/3} S^{1/2} \quad \text{SI} \quad (3.7)$$

Where:

n: The pipes' Manning roughness coefficient (table 3.7).

S: The pipeline slope

Q: flow rate ( $\text{m}^3/\text{s}$ ).

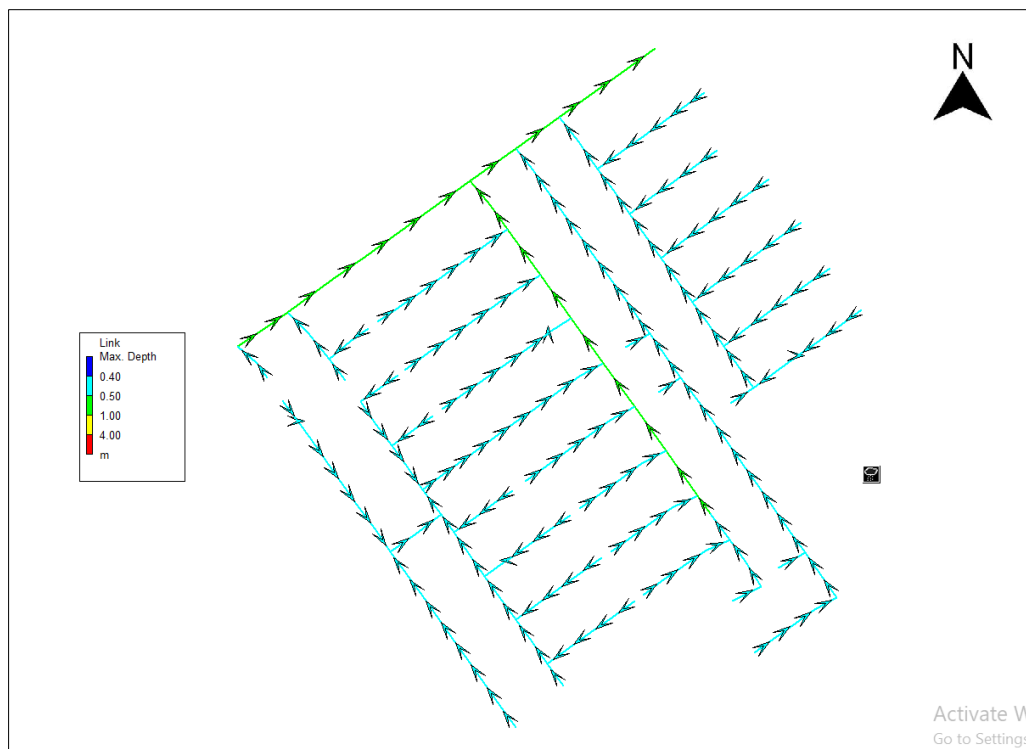
R: hydraulic radius (m).

A: area of cross section ( $\text{m}^2$ ).

**Table 3.6 The Pipes Manning Roughness Coefficient (Bizier, 2007)**

Pipe materials	Manning coefficient
Asbestos	0.11-0.015
Brick	0.13-0.017
Cast iron	0.011-0.015
Concrete conduits	0.011-0.017
Plastic (smooth)	0.011-0.015
Poly vinyl chloride	0.009
Open channels -lined	
Asphalt	0.013-0.017
Brick	0.012-0.018
Concrete	0.011-0.02

Circular pipes with diameters of 400 and 500 mm and lengths ranging from 20 to 66 meters make up the drainage system of the research area. The pipes' material is polyvinyl chloride (PVC), and table 3.7 above displays the pipes' manning roughness coefficient values. Polyvinyl chloride pipes (plastic pipe) has a manning value of 0.009. Figure 3.18 shows pipe diameters and the flowing directions in the research region; also, table 3.8 illustrates properties of network pipes. Figure 3.19 displays the pipe characteristics window in SWMM simulation.



**Figure 3.16 Pipes Diameters and Flowing Directions**

**Table 3.7 Pipelines Characteristics of the Storm Drainage System**

Pipeline Properties	Storm water system
Pipelines number	200
Slope	0.002-0.041
Pipelines length	20-66 (m)
Pipelines diameters	400-500 (mm)
Type of cross section	Circular
Material of pipeline	PVC
Flow type	Gravity

### 3.7 Modeling of the Low Impact Development

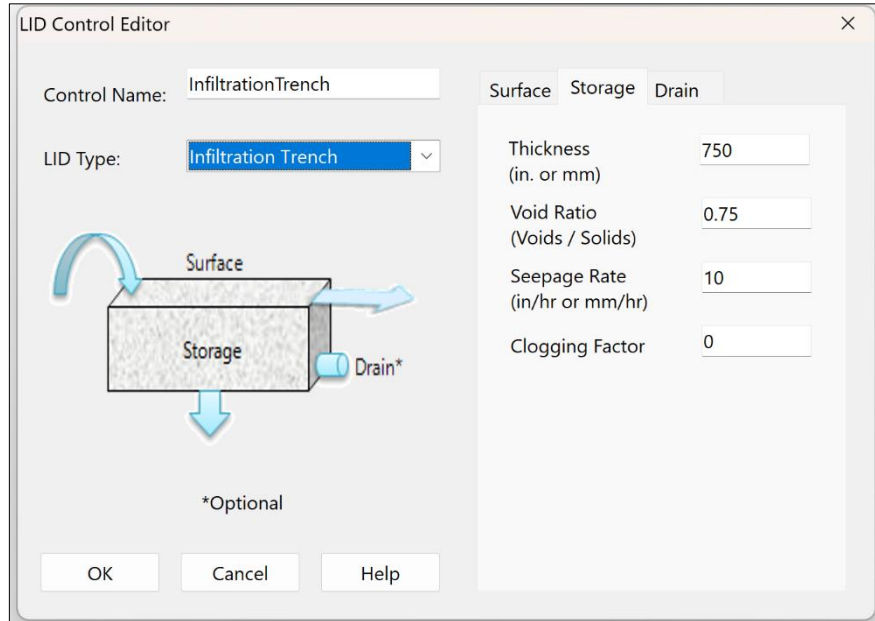
Approaches to low-impact development (LID) collect surface runoff and manage it using a mix of evaporation, infiltration, and retention. They get the same consideration as sub-catchment characteristics like groundwater and snow packs (Dietz, 2007; Eckart et al., 2017; Rossman, 2010). The concept of "low impact development" was initially presented in Prince George's County, Maryland, in 1999 as a way to reduce the consequences of increasing impervious surfaces. However, certain specific strategies were in use even prior to the term's invention (Eckart et al., 2017). By taking into account a site's natural characteristics throughout the design process, LID seeks to lower storm water management expenses. LID controls are small-scale storm water treatment devices that placed at or close to the runoff source and promote infiltration and evaporation. One suggested substitute for conventional storm water design is the low-impact development (LID) strategy (Ahmed et al., 2017; Damodaram et al., 2010). In recent years, there has been a surge in research on specific LID techniques such as bio retention, pervious pavements, and infiltration trenches (Dietz, 2007; Pyke et al., 2011). Some examples of LID controls that may clearly represented using SWMM include the following kinds of GI (Rossman & Supply, 2006):

1. **Infiltration Trenches:** little trenches filled with gravel that collect rainfall from upslope impermeable regions. They provide more time and storage capacity for the caught runoff to seep into the underlying native soil. Infiltration trench is a crucial component of the modern sustainable urban drainage system, either by itself or in conjunction with other storm water management techniques (Chahar et al., 2012).
2. **Bio-retention Cells:** include plants grown in specially designed soil mixtures in depressions created over a gravel drainage bed. They retain, penetrate, and evaporate runoff from surrounding places as well as direct rainfall.
3. **Rain Gardens:** consist of an artificial permeable soil layer without a gravel bed underneath, representing an example of the bio-retention cell.
4. **Green Roof:** Another type of bio-retention cell is a green roof, which has a soil layer resting on top of a certain drainage mat material that collects and channels surplus rainfall that has trickled down the roof.
5. **Permeable pavement:** methods include spaces, filling them with gravel, and then paving them with porous concrete or asphalt mix. Block paver systems: use impervious paver blocks on a sand or pea gravel base, with a gravel retention layer beneath.
6. **Rain Barrels:** During storms, these tanks collect roof runoff, which they may then reuse in the dry seasons.
7. **Rooftop Disconnection:** Drains flow onto permeable areas and lawns rather than storm sewers. It can simulate roofs with linked drains that overflow into pervious regions.

8. **Vegetative Swales:** are grass and other vegetable covered canals or low spots with sloping sides. They give collected runoff more time to seep into the natural soil underneath them by slowing down their conveyance.

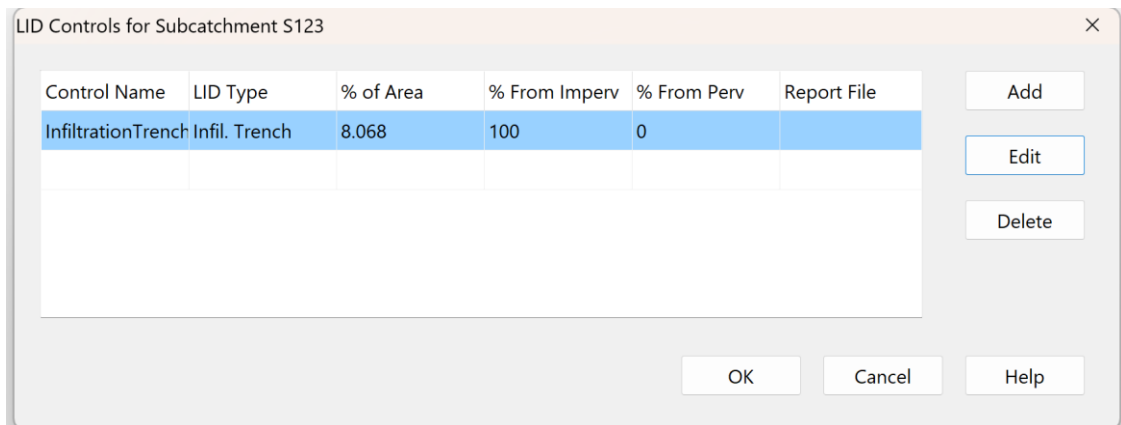
The LID design process involved the following phases:

1. Each sub-catchment that receives inflow runoff into the storm water network has its LID set to it using the LID control editor specific to that sub-catchment. The chosen LID for this project is Infiltration Trenches. Infiltration trenches are a landscaping and storm runoff management technique. Through the penetration of storm water into groundwater, evaporation into the atmosphere, and absorption by vegetation, GIs reduce floods of the drainage system and enhance the quality of the water. Their main purpose is to maintain the site's natural infiltration hydrology and evaporation by bringing green spaces into cities, infiltration trench also have a positive impact on the environment, society, and economy (Arjenaki et al., 2021; Freni et al., 2009). Infiltration trenches are rock or gravel-filled, shallow, and narrow trenches that collect runoff and let it seep into the earth. The building's purpose of the infiltration trench is to absorb rainwater runoff and store it until it seeps into the nearby soil. Trench construction and sizing must be appropriate to manage the anticipated water volume and provide effective infiltration (Chahar et al., 2012). Figure 3.19 displays the editor window of infiltration trench in SWMM program.



**Figure 3.19 Editor Window of Infiltration Trench**

2. Depending on the SWMM user's manual (Rossman & Simon, 2022), the infiltration trench configuration parameters used in this investigation, as shown in table 3.9.
3. As seen in appendices (figure A.4), add LID for every sub-catchment. Sub-catchment 123 served as an example of one of the sub-catchments in the research area. The selected LID in this catchment occupies 8% of total area, see figure 3.20.



**Figure 3.17 Editor for LID Use**

**Table 3.8 Input Parameters of Infiltration Trench (Rossman and Simon, 2022)**

Surface Layer	Storage Layer	Drain Layer
Berm height 150 mm	Thickness 750 mm	Flow coefficient 0
Vegetation volume fraction 0	Void ratio 0.75	Flow exponent 0.5
Surface roughness 0	Seepage rate 10 mm/h	Offset height 6
Surface slope 0	Storage clogging factor 0	

### 3.8 The Model Performance's Equations Statistics

(Obaid, 2015), and (Hassan et al., 2024) recommended using three statistical tests to assess the model's fit quality during its validation: the Coefficient of Determination ( $R^2$ ), Normalized Mean Square Error (NMSE), and the Nash-Sutcliffe Efficiency (NSE). A correlation coefficient ( $R^2$ ) of 0.0 to 1.0 signifies a perfect match between the simulated and observed data. We took into account the variation between simulation and observation using the NSE. If the simulation value is excellent, the NSE value is close to one; if it is not, it is zero. Mean relative scatter (NMSE) is a statistical measure that accounts for both systematic and unsystematic mistakes. A value of that is close to 0 characterizes the optimal fit NMSE. Equations provide the statistical factors that employed (3.11), (3.12), and (3.13).

$$R = \frac{\sum_i^n (x - \bar{x})(y - \bar{y})}{\sqrt{\sum_i^n (x - \bar{x})^2 \sum_i^n (y - \bar{y})^2}}, \quad i = 1, 2, 3, \dots, n \quad (3.11)$$

The correlation coefficient's square, or R<sup>2</sup>. In this case,  $x$ ,  $y$  represent the modeled and observed datasets, and  $\bar{x}$ ,  $\bar{y}$  represent the mean of the modeled and observed datasets.

$$NMSE = \frac{(C_0 - C_P)^2}{C_0 - C_P} \quad (3.12)$$

Where  $C_0$ : observed discharge,  $C_P$ : predicted discharge,  $C_0^-$ : average observed discharge,  $C_P^-$ : average predicted discharge.

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - O_i^-)^2} \quad (3.13)$$

Where  $P_i$ : simulation data,  $o_i$ : observed data,  $O_i^-$ : average observed data.

### 3.9 Summary

This chapter covered the use of the analysis equations to recognize the storm water drainage system's integrated management in the study region of Kerbala City. Summaries of the data utilized for hydraulics, hydrology, and modeling are provided in this chapter. Hydrology and hydraulic issues are resolved by using the SWMM model and routing techniques. In order to model rainfall runoff and assess storm water networks' efficiency and emergency response capacities in the case of future extreme rain events, dynamic flow routing was used.

## **Chapter Four: Results and Discussion**

### **4.1 Introduction**

This chapter presents the study results obtained using the analytical equations in storm water network management analysis, for different return periods of rainfall intensities. Selected and examined are these findings in order to fulfill the goals outlined in Chapter 1. This chapter shows the analytical results derived from the Storm Water Management Model SWMM for modeling the rainwater network under storms in the Al-Abed quarter and the results of the rainwater network analysis after optimizing the network by adding the low-impact development techniques. Also, the model validation results would be shown.

### **4.2 The Results of the Analytical Equations**

Along with presenting the findings of the analysis equations, it assesses how well the storm water network is performing regard to rainfall intensity of 2, 5, 10, and 20-year return periods and pinpoints the areas that are most susceptible to floods from severe storms. Flooding in the rainfall network is a result of climate change, which has an impact on low-lying regions and transportation infrastructure. There is a prediction that excessive rainfall may surpass the current systems' design intensity, resulting in further flooding in Kerbala's Al-Abed quarter. It is essential to analyze the storm drainage network in order to anticipate large flood threats. Climate change directly affects the intensity of rainfall, which in turn influences the formation of surface runoff. The influence of climate change led to the selection of several return periods, which include 2, 5, 10, and 20 years and correspond to a range of rainfall intensities. Since the IDF curve indicates that the intensity

of the rainfall persisted for one hour before decreasing and staying at the same level, the simulation's period was set at one hour.

**Case 1:** Rainfall intensity of the two-year return periods was 9.6 mm/h after a one-hour rainfall event. Table 4.1 below shows the results of the analytical equations in rainwater network management analyses. The results indicate that the rainwater drainage network effectively has been controlled during this period since it was observed that the pipelines drained the flow through manholes from the sub-catchments to the outlet without obstructing the flow. Also, the velocity was within the limits and the capacity of the pipelines.

**Table 4.1 Results of the Analytical Equations During Rainfall Events of 2-years Return Period**

Pipe ID	Pipe Dia. mm	Q inflow m <sup>3</sup> /sec. (eq 3.1)	Q pipe m <sup>3</sup> /sec. (eq 3.2)	Q <sub>inflow</sub> / Q <sub>pipe</sub>	d/D ratio (chart A1)	V <sub>act.</sub> m/sec	Check pipe
16786	400	0.112	0.15	0.74	0.7	1.14	satisfied
16785	400	0.112	0.15	0.74	0.7	1.14	satisfied
16784	400	0.117	0.15	0.78	0.74	1.19	satisfied
16783	400	0.117	0.15	0.78	0.74	1.19	satisfied
16782	400	0.12	0.15	0.8	0.75	1.2	satisfied
16781	400	0.12	0.15	0.8	0.75	1.2	satisfied

16780	400	0.12	0.15	0.8	0.75	1.2	satisfied
16779	400	0.12	0.15	0.8	0.75	1.2	satisfied
16776	400	0.056	0.15	0.37	0.45	0.9	satisfied
16775	400	0.056	0.15	0.37	0.45	0.9	satisfied
16774	400	0.062	0.15	0.41	0.49	0.96	satisfied
16773	400	0.062	0.15	0.41	0.49	0.96	satisfied
16772	400	0.065	0.15	0.43	0.49	0.96	satisfied
16771	400	0.056	0.15	0.37	0.45	0.9	satisfied
16770	400	0.056	0.15	0.37	0.45	0.9	satisfied
16778	400	0.098	0.15	0.65	0.6	1.08	satisfied
16777	400	0.112	0.15	0.74	0.7	1.14	satisfied
16724	400	0.112	0.15	0.74	0.7	1.14	satisfied
16711	400	0.112	0.15	0.74	0.7	1.14	satisfied

**Case 2:** In the five-year return periods with an intensity rainfall of 14.32 mm/h, after a one-hour rainfall event, the rainwater drainage network performed well except some pipelines downstream with (500 mm) diameter where the flow was higher than the flow capacity depending on the results of the analysis equations of the rainwater drainage network management shown in table 4.2 below. Also, the velocity was within the limits and the capacity of the pipelines.

**Table 4.2 Results of the Analytical Equations During Rainfall Events of 5-years Return Period**

Pipe ID	Pipe Dia. mm	Q inflow m <sup>3</sup> /sec. (eq 3.1)	Q pipe m <sup>3</sup> /sec. (eq 3.2)	Q <sub>inflow</sub> / Q <sub>pipe</sub>	d/D ratio (chart A1)	V <sub>act.</sub> m/sec	Check pipe
16786	400	0.116	0.15	0.77	0.73	1.15	satisfied
16785	400	0.116	0.15	0.77	0.73	1.15	satisfied
16784	400	0.12	0.15	0.8	0.75	1.17	satisfied
16783	400	0.12	0.15	0.8	0.75	1.17	satisfied
16782	400	0.128	0.15	0.85	0.78	1.21	satisfied
16781	400	0.128	0.15	0.85	0.78	1.21	satisfied
16780	400	0.128	0.15	0.85	0.78	1.21	satisfied

16779	400	0.128	0.15	0.85	0.78	1.21	satisfied
16776	400	0.064	0.15	0.42	0.51	0.96	satisfied
16775	400	0.064	0.15	0.42	0.51	0.96	satisfied
16774	400	0.072	0.15	0.48	0.56	1.1	satisfied
16773	400	0.072	0.15	0.48	0.56	1.1	satisfied
16772	400	0.072	0.15	0.48	0.56	1.1	satisfied
16771	400	0.064	0.15	0.42	0.51	0.96	satisfied
16770	400	0.064	0.15	0.42	0.51	0.96	satisfied
16778	400	0.11	0.15	0.73	0.73	1.15	satisfied
16777	400	0.116	0.15	0.77	0.73	1.15	satisfied
16724	400	0.116	0.15	0.77	0.73	1.15	satisfied
16711	400	0.116	0.15	0.77	0.73	1.15	satisfied
16710	400	0.116	0.15	0.77	0.73	1.15	satisfied

**Case 3:** In the ten-year return periods with an intensity rainfall of 17.41 mm/h, after a one-hour rainfall event, the rainwater drainage network failed to resist the increment of rainfall intensity; this was shown through the flooding of the primary pipelines in the center of the network. After a ten-year period of return, the system seems to be unable to release excess rainfall, which causes storm water to accumulate downstream. Depending on the results of the analysis equations of the rainwater drainage network management shown in table 4.3 below, the pipelines with a diameter of (400, 500 mm) in the middle and the end of the drainage network showed the inability to drain rainwater due to the rainfall intensity increase.

**Table 4.3 Results of the Analytical Equations During Rainfall Events of 10-years Return Period**

Pipe ID	Pipe Dia. mm	Q inflow m <sup>3</sup> /sec. (eq 3.1)	Q pipe m <sup>3</sup> /sec. (eq 3.2)	Q inflow / Q pipe	d/D ratio (chart A1)	V act. m/sec	Check pipe
16786	400	0.12	0.15	0.8	0.75	1.14	satisfied
16785	400	0.12	0.15	0.8	0.75	1.14	satisfied
16784	400	0.123	0.15	0.82	0.76	1.16	satisfied
16783	400	0.123	0.15	0.82	0.76	1.16	satisfied
16782	400	0.123	0.15	0.82	0.76	1.16	satisfied

16781	400	0.128	0.15	0.85	0.78	1.21	satisfied
16780	400	0.128	0.15	0.85	0.78	1.21	satisfied
16779	400	0.128	0.15	0.85	0.78	1.21	satisfied
16776	400	0.08	0.15	0.53	0.57	0.98	satisfied
16775	400	0.08	0.15	0.53	0.57	0.98	satisfied
16774	400	0.095	0.15	0.63	0.64	1.1	satisfied
16773	400	0.095	0.15	0.63	0.64	1.1	satisfied
16772	400	0.095	0.15	0.63	0.64	1.1	satisfied
16771	400	0.08	0.15	0.53	0.57	0.98	satisfied
16770	400	0.08	0.15	0.53	0.57	0.98	satisfied
16778	400	0.119	0.15	0.79	0.74	1.17	satisfied
16777	400	0.12	0.15	0.8	0.75	1.14	satisfied
16724	400	0.12	0.15	0.8	0.75	1.14	satisfied

**Case 4:** In the twenty-year return periods with an intensity rainfall of 20.44 mm/h, after a one-hour rainfall event, the pipelines flooding in the rainwater drainage network increased due to the increase in rainfall intensity. It is noteworthy to mention that in addition to the main pipelines, branch pipes also inundated, and there was flooding in many places, upstream, downstream, and in the middle, depending on the results of the analysis equations of the rainwater drainage network management shown in table 4.4. A significant system breakdown resulted in about 21% of network pipes flooding with a diameter of 400 and 500 mm. The results reveal that with the increase in return period, the intensity of rainfall in response to rainfall events increases, resulting in large storm water inflows into the system and thus the pipes' inability to drain storm water and increase surface runoff. The anticipated high rainfall intensity of 86 mm/hr. at the start of the precipitation event in 20-years return periods is what causes large amounts of flooding.

**Table 4.4 Results of the Analytical Equations During Rainfall Events of 20-years Return Period**

Pipe ID	Pipe Dia. mm	Q inflow m <sup>3</sup> /sec. (eq 3.1)	Q pipe m <sup>3</sup> /sec. (eq 3.2)	Q <sub>inflow</sub> / Q <sub>pipe</sub>	d/D ratio (chart A1)	V <sub>act.</sub> m/sec	Check pipe
16786	400	0.123	0.15	0.82	0.76	1.18	satisfied
16785	400	0.123	0.15	0.82	0.76	1.18	satisfied
16784	400	0.127	0.15	0.84	0.78	1.21	satisfied

16783	400	0.127	0.15	0.84	0.78	1.21	satisfied
16665	400	0.26	0.25	1.04	1	1.27	Not satisfied
16664	500	0.26	0.25	1.04	1	1.27	Not satisfied
16663	500	0.29	0.25	1.16	1	1.27	Not satisfied
16662	500	0.29	0.25	1.16	1	1.27	Not satisfied
16661	500	0.29	0.25	1.16	1	1.27	Not satisfied
16660	500	0.35	0.25	1.4	1	1.27	Not satisfied
16659	500	0.61	0.25	2.4	1	1.27	Not satisfied
16595	500	0.97	0.25	3.8	1	1.27	Not satisfied
16594	500	1.26	0.25	5.04	1	1.27	Not satisfied
16593	500	1.26	0.25	5.04	1	1.27	Not satisfied
16592	500	1.26	0.25	5.04	1	1.27	Not satisfied
16665	400	0.26	0.25	1.04	1	1.27	Not satisfied

16664	500	0.26	0.25	1.04	1	1.27	Not satisfied
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The evaluation findings are displayed in the tables above, along with rainfall intensities calculated over a one-hour rainfall period using the Kerbala city IDF curve. In light of this, the results of the analysis equations suggest that the system may only be able to endure the effects of climate change for the next ten years. Generally, more flooding pipelines occurred with longer return periods. In the same way, an increase in peak runoff was noted, and as the return time lengthened, so did the overall rainfall.

### 4.3 Simulation Results of the SWMM Model

The storm water management model SWMM assessed how well the storm water network is performing with regard to rainfall intensity of 2, 5, 10, and 20-year return periods as well as for one hour of rainfall duration and pinpointed the areas most susceptible to floods from severe storms. According to predicting future rainfall intensity increasing in the Al-Abed quarter, a metropolitan hydrological model built on the SWMM software was utilized. There are 132 sub-catchments, 201 junctions, 200 conduits, and one outfall in the model. The highest flow rate in the manholes used to categorize the five levels of flooding in the research region, as illustrate in table 4.5, suggested by (Hassan et al., 2017).

**Table 4.5 Manholes Flooding Categorize**

Levels	State of Flooding	Flow Rate Values (m <sup>3</sup> /s)
1	No flooding	0-0.001
2	Minor floods	0.001-0.01
3	Medium floods	0.01-0.05

4	High floods	0.05-0.1
5	Very high floods	> 0.1

To demonstrate this occurrence, one can utilize the total flooded volume at the outlet junctions, the maximum discharge in the manholes, and the quantity of manholes flooding. The amount of flooding created in the research region has been shown to significantly rise with an increase in return periods. For instance, after a two-year return periods and one hour of rainfall duration, the maximum flow rate was 0.51 m<sup>3</sup>/s, the total flooded volume at the outflow was 1220 m<sup>3</sup>, and there were ten flooding manholes (5% of the total manholes). Comparatively, during 20-year period, there was a considerable rise in the maximum flow rate, total flooded volume, and number of flooding manholes, reaching 1.33 m<sup>3</sup>/s, 13540 m<sup>3</sup>, and 41 (20.5% of total manholes), respectively. The simulation findings included as a summary in table 4.6 below with the rate of the infiltration for the catchments in the model.

**Table 4.6 Impact of Rainfall Intensity Variations on the Drainage System in AL-Abed quarter**

Return periods (years)	Simulation Period (Hour)	Maximum Manhole Flow rate (m <sup>3</sup> /s)	Total Flooding Volume (m <sup>3</sup> )	Quantity of Flooded Manholes	Infiltration rate mm/h
2	1	0.51	1220	10	5.6
5	1	0.72	2135	15	7.12
10	1	1.02	8370	22	9.32
20	1	1.33	13540	41	12

To provide a more accurate assessment of the rainwater drainage network, the network was evaluated following a one-hour period of rainfall. Figures 4.1 to 4.4 displayed the locations, volume, and extent of flooding in manholes. Furthermore, analyze the drainage system of the study region and show the flooding volume. Anytime the water outflows from manholes beyond the maximum intended values, flooding may happen.

Figure 4.1 shows the locations of flooded manholes caused by surface runoff and the flooding in the drainage system with an intensity of rainfall of 9.6 mm/hour during a **two-year period**. There were 10-flooded manholes out of 201 total, or 5% of the manhole total. There are five categories for flooded manholes: 0.5% minor floods (level 2), 2% medium floods (level 3), 2% high floods (level 4), and 0.5% very high floods (level 5) which at flow rates greater than 0.1 m<sup>3</sup>/s. Total flood volume is 1220 m<sup>3</sup>, ID16554 manhole was mostly flooded in water with flow rate of 0.15 m<sup>3</sup>/s. Surface runoff may effectively have controlled during the 2-year return periods.

Figure 4.2 evaluates the storm water network after a one-hour rainfall event and a **five-year return time** with 14.32 mm/hr. Intensity of rainfall. 7.5% of the total manholes were flooded, or 15 out of the 201 manholes overall. 0.5% minor floods (level 2), 2.5% medium floods (level 3), 2% high floods (level 4), and 2.5% very high floods (level 5) which at flow rates greater than 0.1 m<sup>3</sup>/s, results in the worst floods, are the categories for flooded manholes, and total flood volume is 2135 m<sup>3</sup>. In addition, the flood with the longest duration is again in manhole ID16554, and flow rate is 0.31 m<sup>3</sup>/s. Storm water overflow can create floods in this location, since manholes close to the main sewer were the first to overflow. Although rising rainfall intensity is the cause of increased floods, the network can still resist a five-year return

periods with the effects of climate change. Furthermore, based on the same Figure, it is evident that the flooding discharge situation for the return periods of five years decreased by around 2.5% in level 1, level 2 stay the same, level 3 increased with 0.5%, level 4 stay the same, and level 5 increased by 2% which is the highest flooding level, regard to the return periods of two years. Not much change has taken place during this time frame since that duration is too short.

Regarding a **10-year return** time with 17.4 mm/hr. Intensity of rainfall, Figure 4.3 describes the state of the rainwater drainage network. Out of 201 manholes, or 11.5% of the total, 22 had floods. 3% minor flooding (level 2), 1% medium flooding (level 3), 3% of high floods (level 4), and 4.5% very severe floods (level 5), which at flow rates greater than 0.1 m<sup>3</sup>/s, make up the categories for flooded manholes. It has been observed that the count of flooded manholes is of lesser significance compared to the extent of the flooding. In manhole ID16554 (level 5), for instance, the flooding is of a magnitude equivalent to six times more than other manholes, having a flow rate of 0.4 m<sup>3</sup>/s, also the total flood volume reached 8370 m<sup>3</sup>. Consequently, the major pipelines that cross through the area's center experience the most flooding, as seen by the figure. The system appears to be unable to release surplus rainfall during the 10-year return periods, which causes rainwater to build up downstream. There will be a significant increase in floods, and the level of the water may surge over the curbstone depth of 13 cm and enter homes, damaging structures and infrastructure. Furthermore, based on the same Figure, it is evident that the flooding discharge situation for the return periods of ten years decreased by around 4% in level 1 (no floods), level 2 increased by 2.5%, level 3 decreased by 1.5%, level 4 increased by 1%, and

level 5 increased by 2% which is the highest flooding level, regard to the return periods of five years.

Figure 4.4 revealed that 41 of the 201 manholes—or 20.5% of all manholes were flooded after a **20-year return periods** with rainfall intensity 20.5 mm/hr. Once more, the number of flooded manholes does not have the same impact on the region as the amount of flooding. Consequently, there was a distribution of flooding magnitudes: 2.5% for minor floods (level 2), 2.5% for medium floods (level 3), 1.5% for high floods (level 4), and 14% for extreme high floods (level 5) which at flow rates greater than 0.1 m<sup>3</sup>/s. A significant system breakdown resulted in about 20% of AL-Hur District AL-Abed quarter flooding. There was flooding in many places, upstream, downstream, and in the middle, with volume of 13540 m<sup>3</sup>. Furthermore, based on the same Figure, it is evident that the flooding discharge situation for the return periods of twenty years decreased by around 9% in level 1 (no floods), decreased with 0.5% in level 2, increase by 1.5% in level 3, decreased with 1.5% in level 4, and increase by 9.5% for level 5 which is the highest flooding level, regard to the return periods of ten years. Storm water drains into residential areas results in harm to houses and infrastructure, as seen by Figure 4.4 as well. The anticipated high rainfall intensity of 86 mm/hr. at the start of the precipitation event in 20-years return periods is what causes large amounts of flooding. Because it exceeded the design capacity, the system was unable to discharge surface runoff.



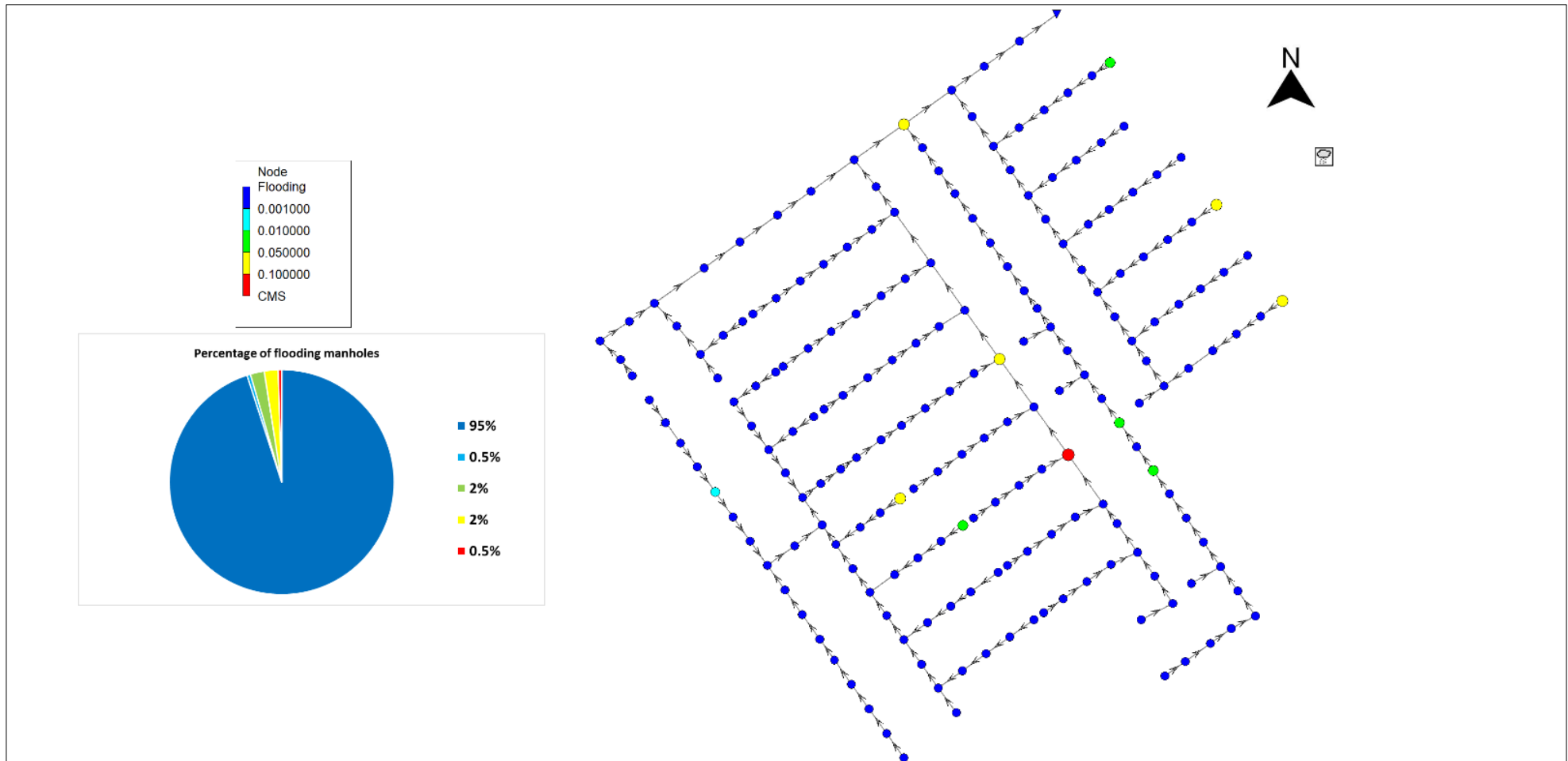


Figure 4.1 Behavior of the Storm Water Network During 2-Year Periods of Return

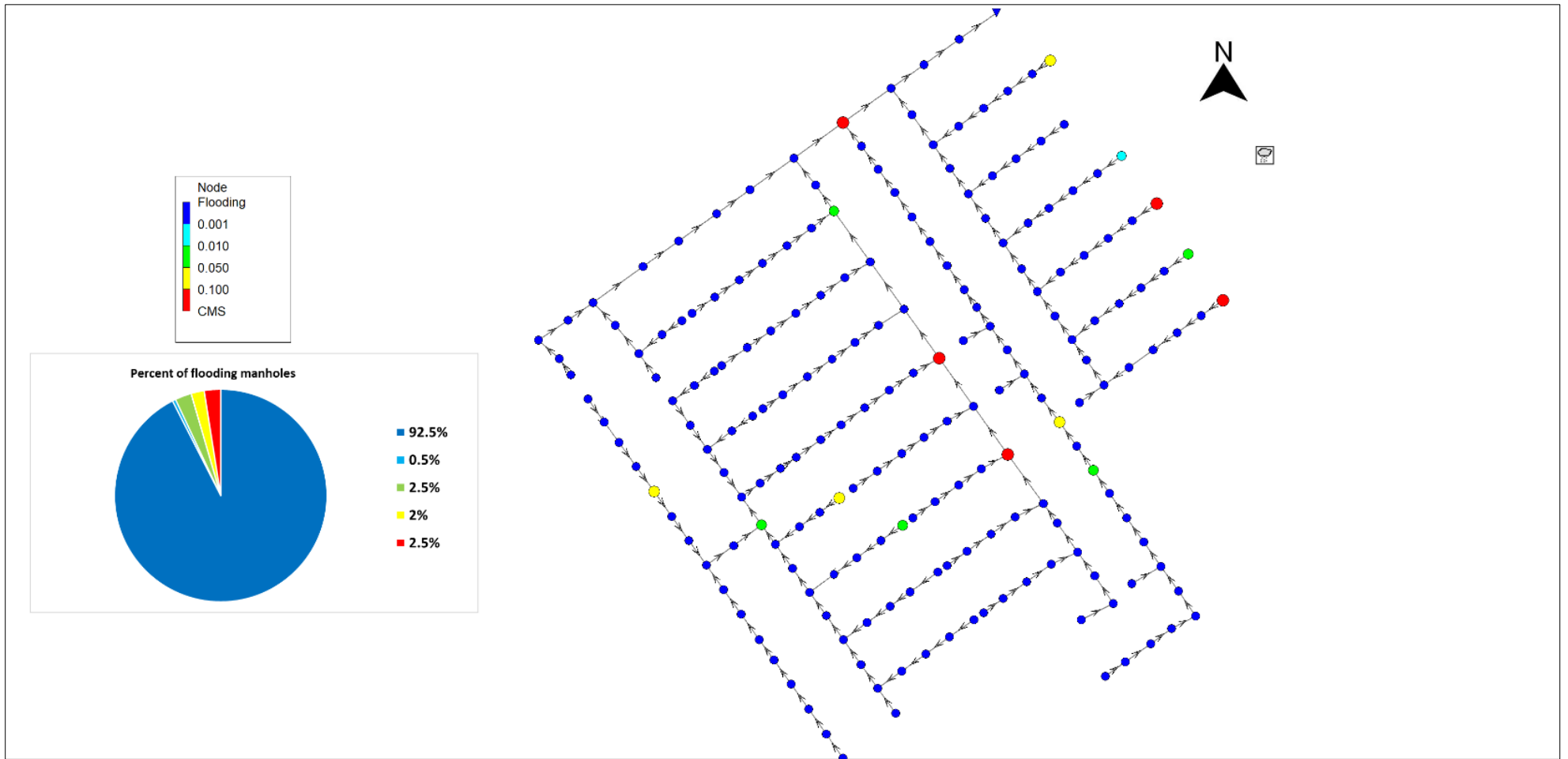


Figure 4.2 Behavior of the Storm Water Network During 5-Year Periods of Return

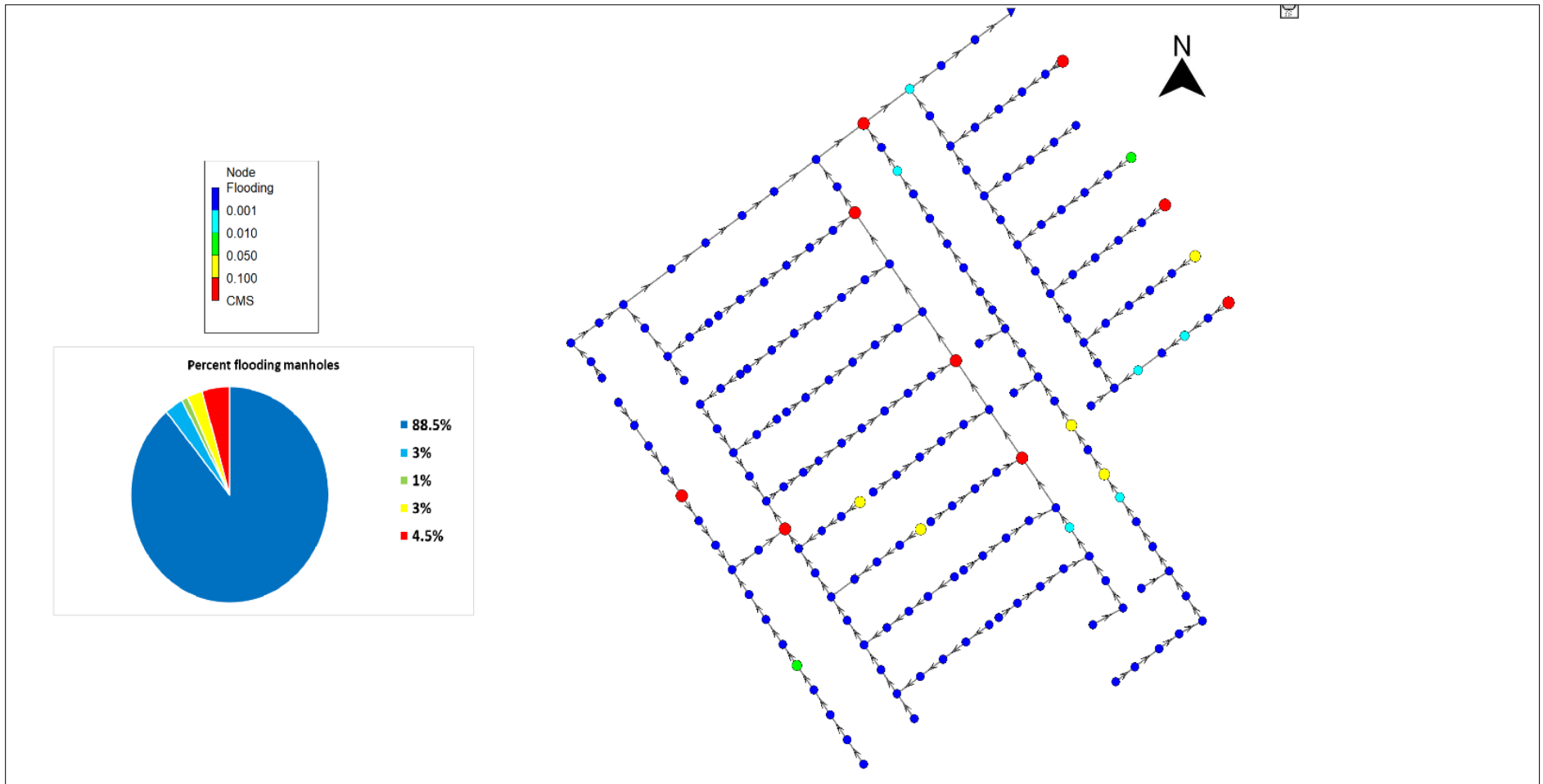


Figure 4.3 Behavior of the Storm Water Network During 10-Year Periods of Return

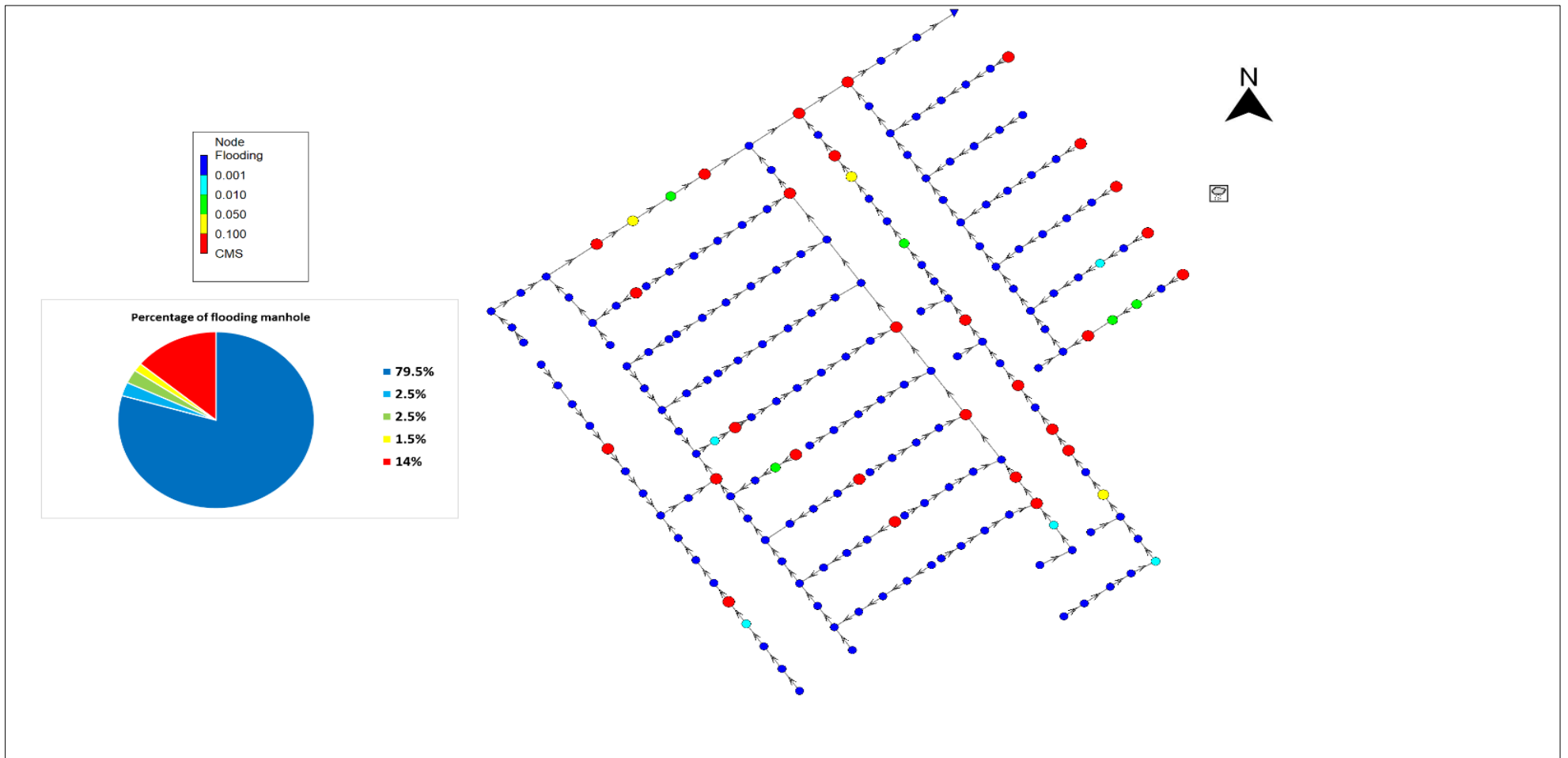


Figure 4.4 Behavior of the Storm Water Network During 20-Year Periods of Return

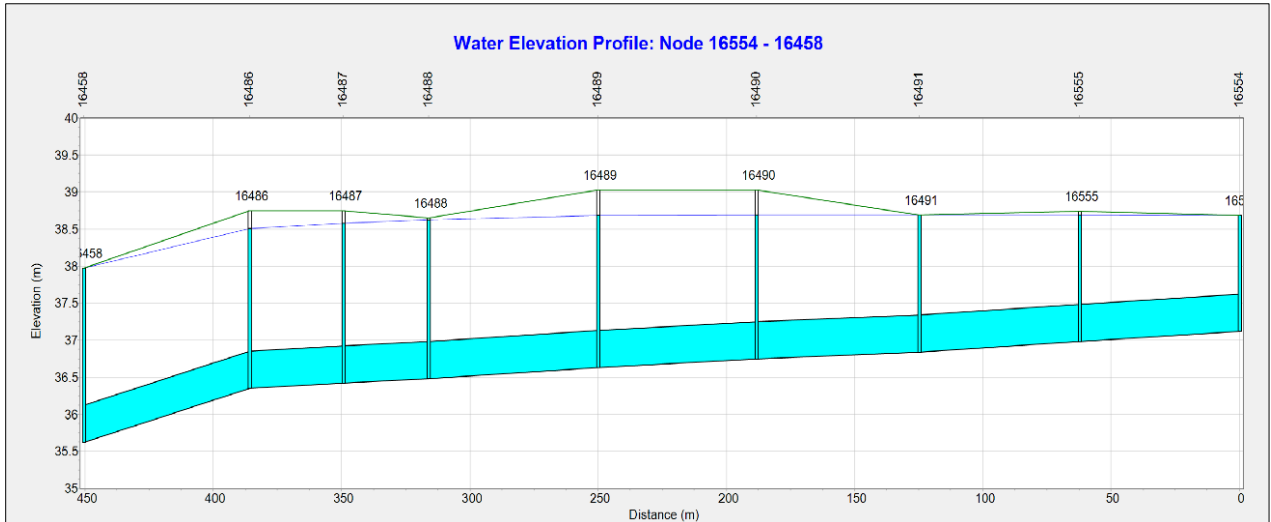
This shows that future rainfall intensity, predictions required for storm system design did not take the influence of climate change into account. Therefore, it is important to include the influence of climate change while creating IDF curves. It is determined that this rainfall intensity forecast has severe consequences for the system and its characteristics, making it one of the most dangerous forecasts. Table 4.7 below shows the proportions of manholes that were affected by floods in the five levels.

**Table 4.7 The Various Levels of Manhole Flooding During Return periods**

Return periods	Flooding levels				
	Level 1 No floods	Level 2 Minor floods	Level 3 Medium floods	Level 4 High floods	Level 5 Very high floods
2	95%	0.5%	2%	2%	0.5%
5	92.5%	0.5%	2.5%	2 %	2.5%
10	88.5%	3%	1%	3%	4.5%
20	79.5%	2.5%	2.5%	1.5%	14%

The findings demonstrate how floods gradually become more frequent as rainfall intensities and years of return periods, as well as the risks associated with manhole flooding, which has an impact on areas with low elevations and the road networks. The simulation results indicate that manholes with ID 16554, 16491, and 16458 experience continuous flooding and overflows for all return periods. Figure 4.5 depicts the profile of water level of the path that contains these manholes at the minimal amount of rainfall intensity recorded during the two-year return periods. The associated data on the

flooding manholes and the duration of floods can be found in Tables 4.8 to 4.11 for all return periods.



**Figure 4.5 Profile of Water Level for Most Flooding Manholes**

**Table 4.8 Summary Results of Nodes Flooding During Two-Year Return periods**

Nodes/manholes	Hours of floods	Flood rate (CMS)	Peak flood hours
16458	1.58	0.057	00:22
16491	1.67	0.09	00:24
16554	1.67	0.13	00:24

**Table 4.9 Summary Results of Nodes Flooding During Five-Year Return periods**

Nodes/manholes	Hours of floods	Flood rate (CMS)	Peak flood hours
16458	1.77	0.13	00:18
16491	1.76	0.18	00:18
16554	1.76	0.19	00:15

**Table 4.10 Summary Results of Nodes Flooding During Ten-Year Return periods**

Nodes/manholes	Hours of floods	Flood rate (CMS)	Peak flood hours
16458	1.8	0.17	00:15
16491	1.81	0.22	00:16
16554	1.79	0.23	00:15

**Table 4.11 Summary Results of Nodes Flooding During Twenty-Year Return periods**

Nodes/manholes	Hours of floods	Flood rate (CMS)	Peak flood hours
16458	1.83	0.19	00:15
16491	1.84	0.25	00:15
16554	1.86	0.26	00:15

#### 4.4 Simulation Results of Added LID Technique

This section of the results addresses the implementation of the low impact development techniques to mitigate floods, specifically through the use of infiltration trenches. The simulation results indicated that employing a Low Impact Development approach, specifically infiltration trenches, effectively mitigates the overall amount of flooding and the number of flooded manholes within the drainage network of the Al-Abed quarter, as shown in the table below. Table 4.12 illustrates the impact of the LID technique (infiltration trenches) on the storm water network of the region, explaining the highest flow rate, total volume of flooding, and the amount of inundated manholes with periods 2, 5, 10, and 20 years, with a storms duration of one hours.

**Table 4.12 Impact of Rainfall Intensity Variations on the Drainage System in AL-Abed Quarter with LID Technique**

Return periods (years)	Simulation Period (Hour)	Maximum Manhole Flow rate (m <sup>3</sup> /s)	Total Flooding Volume (m <sup>3</sup> )	Quantity of Flooded Manholes
2	1	0.34	793	6
5	1	0.56	1708	11
10	1	0.85	6947	18
20	1	1.18	11915	36

In contrast to the actual situation devoid of the LID technique, as illustrated in Table 4.6, a decrease of 32.5% in highest discharge, 35% in the overall volume of flooding, and 40% in overflowing junctions/manholes has been distinctly achieved throughout a 2-year return periods. Over a 5-year

return periods, a 21% reduction in the highest discharge occurred and the overall volume of flooding reduced by 20%, while the overflowing junctions/manholes diminished to 26% of the original count. Over a 10-year return periods, a 16% reduction in the highest discharge occurred and the overall volume of flooding reduced by 17%, while the overflowing junctions/manholes diminished to 18% of the original count. Despite elevated rainfall intensity during 20-year return periods, the highest discharge diminished by 11%, the volume of total flooding declined by 12%, and the number of inundated junctions/manholes decreased to 12.2% of the inundated total. The proposed method of incorporating LID technique into the rainwater drainage network has much better improved its efficacy, demonstrating an excellent performance suitable for applications in reality in the study region.

Figures 4.6 to 4.9 analyze the drainage network of the Al-Abed quarter following return periods of 2, 5, 10, and 20 years, respectively, over a one-hour rainfall duration, incorporating the LID technique. Figure 4.6 illustrates that in **2-year** return periods, the percentage of overflowing junctions/manholes at level 3 diminished from 2% to 1%, while at level 4 it decreased from 2% to 1.5%. Additionally, at level 5, which at flow rates greater than 0.1 m<sup>3</sup>/s, the ratio was eliminated to 0%, with 9.6 /hr rainfall intensity. The junctions that had no floods rose up to 97% of the overall junctions.

Figure 4.7 below illustrates that in **5-year** return periods, the percentage of overflowing junctions/manholes at level 3 declined from 2.5% to 2%, while at level 4 it diminished from 2% to 1.5%, and the largest share was for the level 5, which at flow rates greater than 0.1 m<sup>3</sup>/s, where it dropped from 2.5%

to 1.5 % of the overall junctions. The junctions that had no floods rose up from 92.5% to 95%, with 14.32 mm/hr rainfall intensity.

Figure 4.8 below illustrates that in a **10-year** return periods, the percentage of overflowing junctions/manholes at level 2 dropped from 3% to 2%, while at level 4 it diminished from 3% to 1.5%, and at level 5, at flow rates greater than 0.1 m<sup>3</sup>/s, it reduced from 4.5% to 2.5% of the overall junctions. The junctions that had no floods rose up from 88.5% to 91%, with 17.4 mm/hr rainfall intensity.

Figure 4.9 below illustrates that in **20-year** return periods, the percentage of overflowing junctions/manholes at level 3 reduced from 2.5% to 2%, while at level 4, it stays the same, and level 5, at flow rates greater than 0.1 m<sup>3</sup>/s, had the largest share; it dropped from 14% to 11% of the overall junctions. The junctions that had no floods rose up from 79.5% to 82%, with 20.44 mm/hr rainfall intensity.

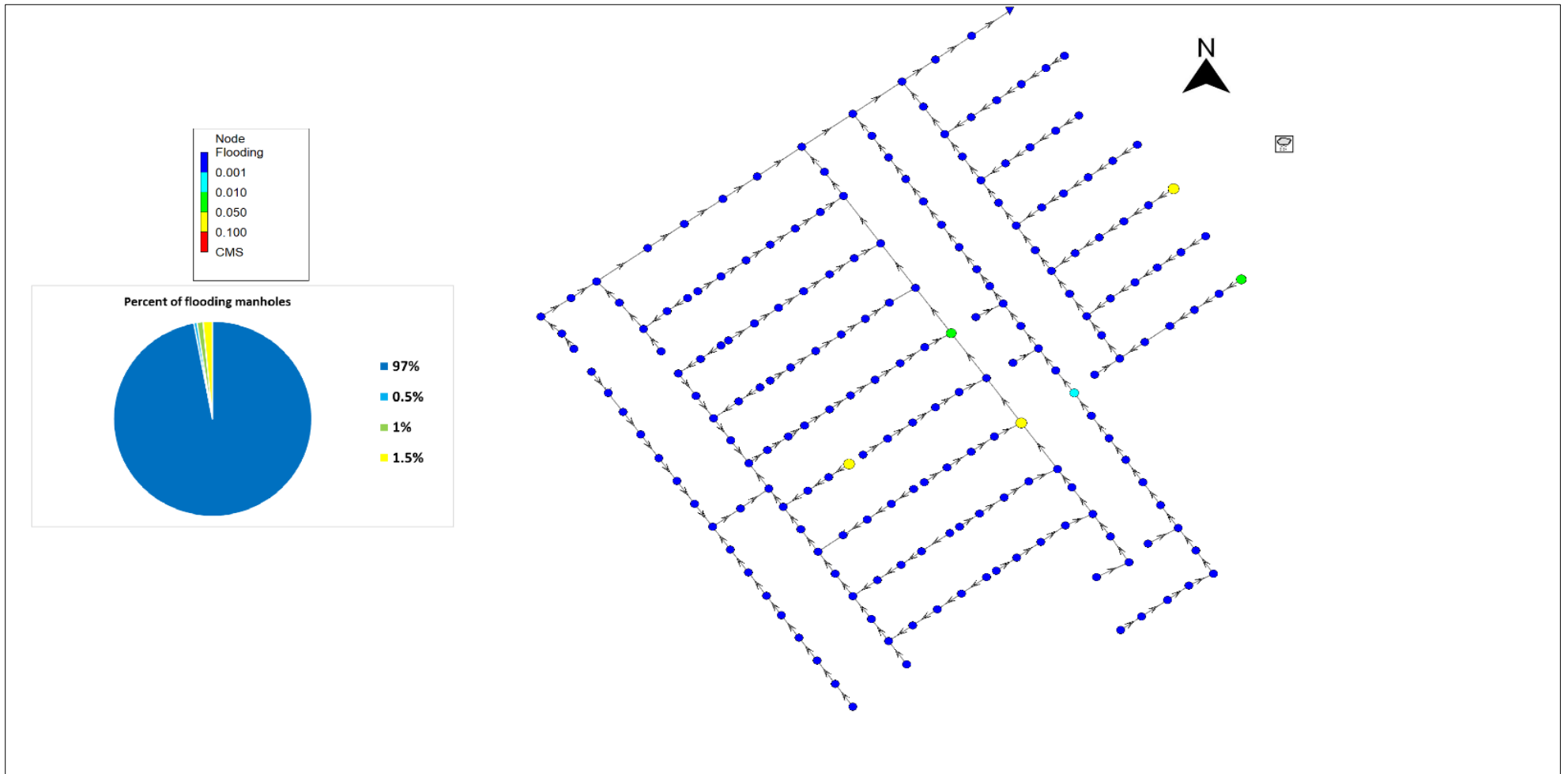


Figure 4.6 Behavior of the Storm Water Network During 2-Year Periods of Return with LID Techniques

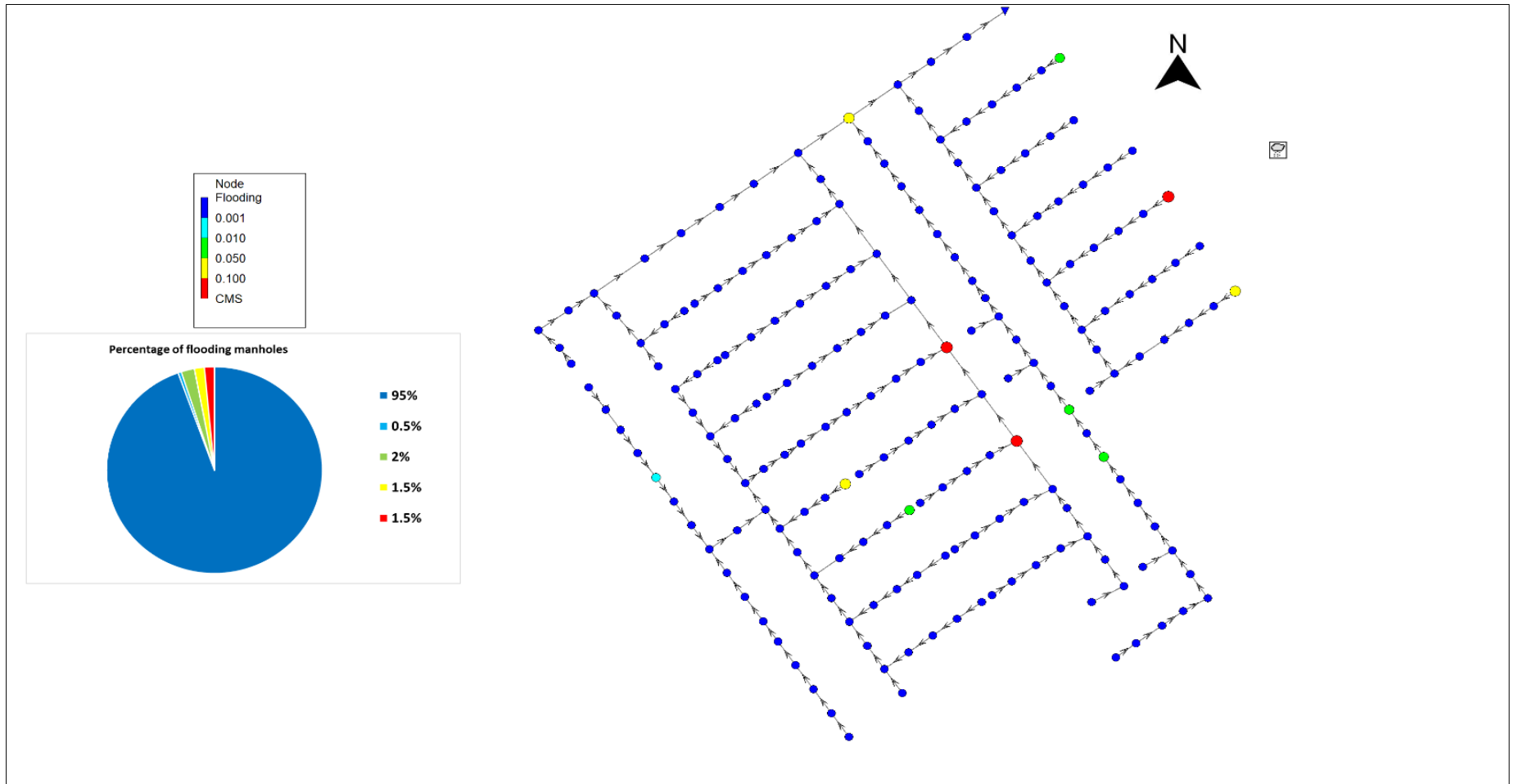


Figure 4.7 Behavior of the Storm Water Network During 5-Year Periods of Return with LID Techniques

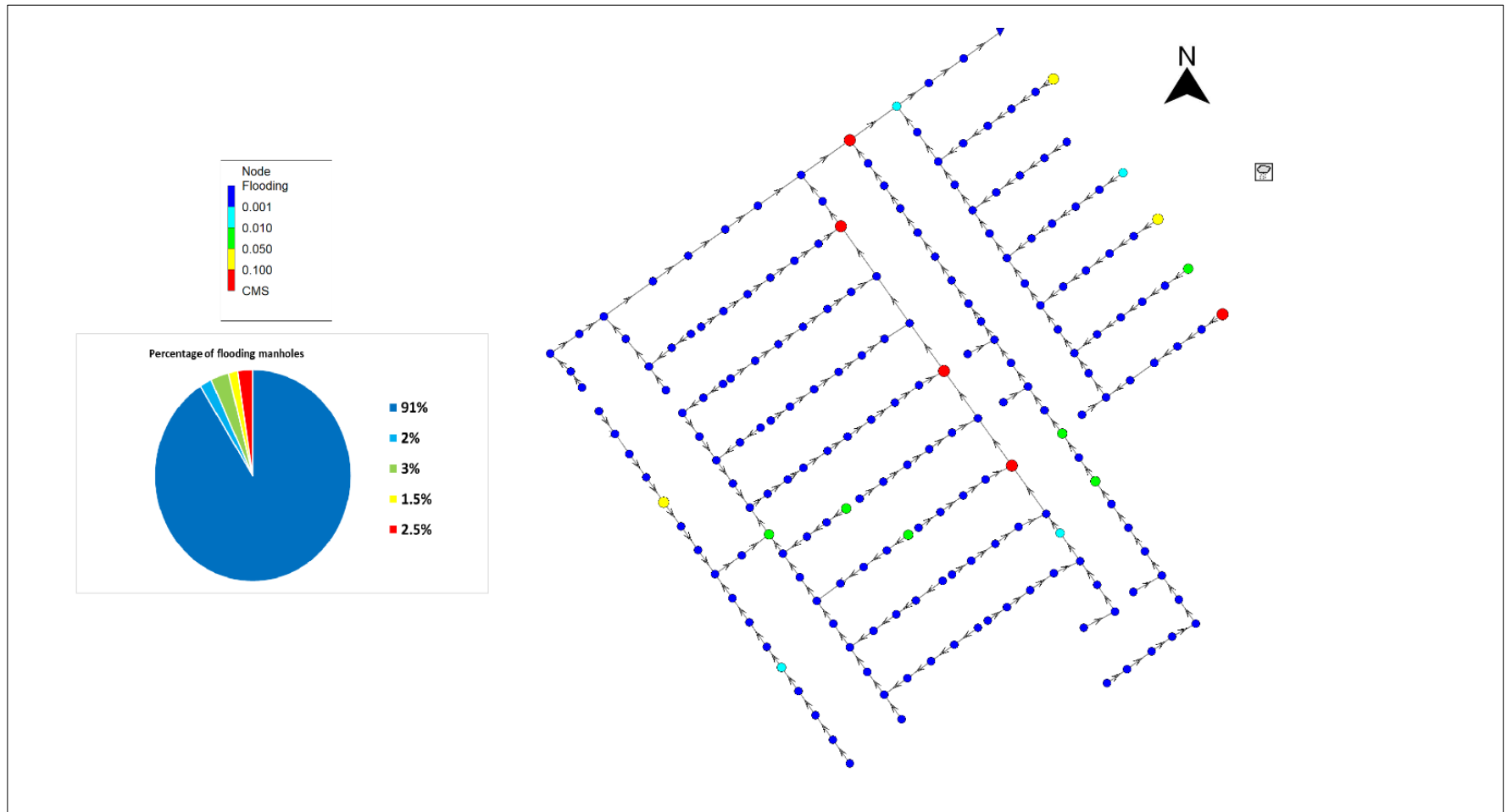


Figure 4.8 Behavior of the Storm Water Network During 10-Year Periods of Return with LID Techniques

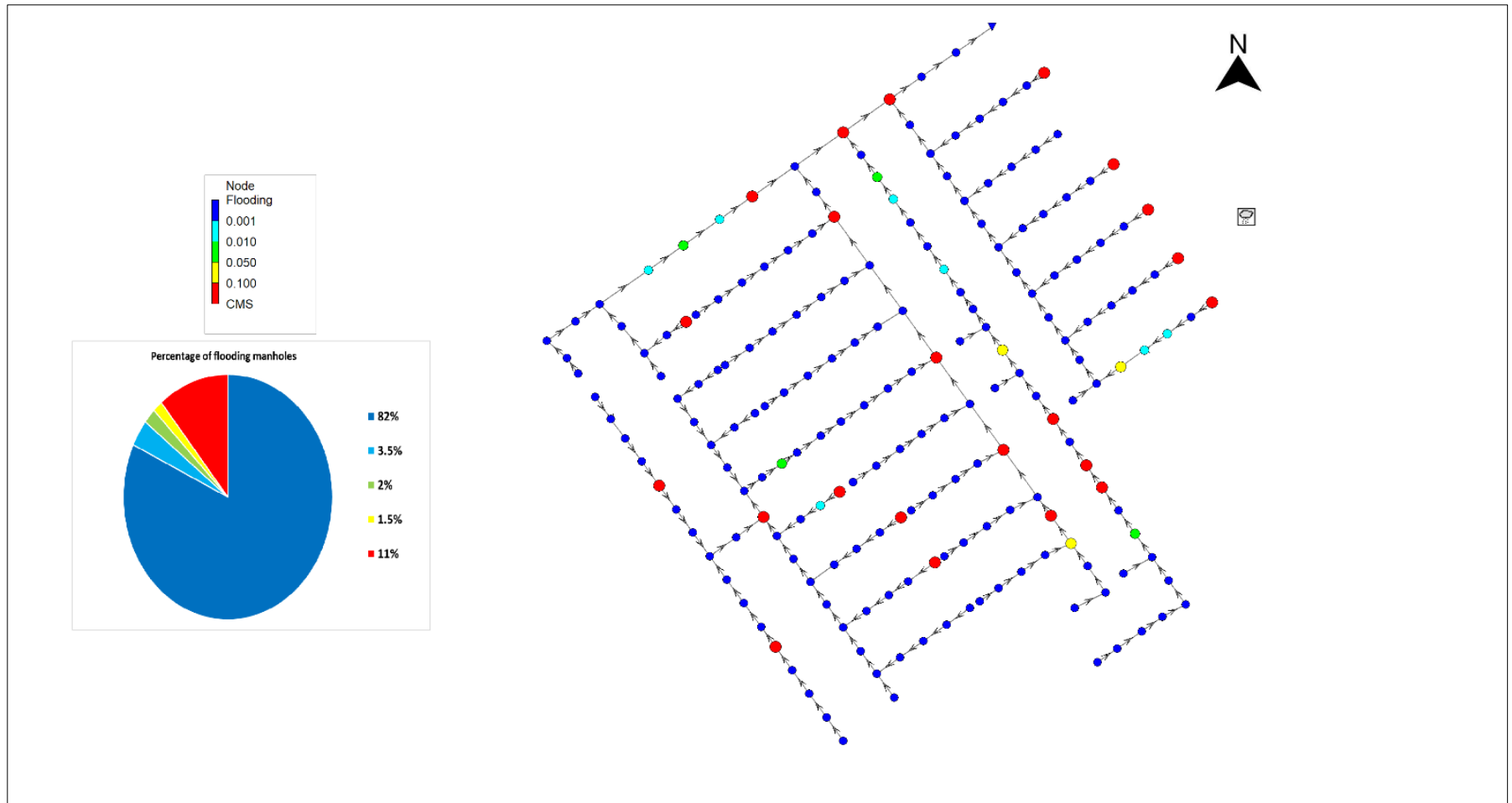


Figure 4.9 Behavior of the Storm Water Network During 20-Year Periods of Return with LID Techniques

Table 4.13 illustrates the proportional variations of flooded junctions after added techniques of LIDs, it shows the reduction of the percentage of flooding junctions, especially junctions in level 5, as shown below. The results show that, while employing the amount of precipitation model for a two-year return periods, the LID efficiency in the reduction of flooding was of a greater value compared to the other intensity of rainfall models. Furthermore, these findings demonstrated a negative correlation between the LID efficiency and the intensity of rainfall's return periods. Put another way, because of the increased runoff brought on by high rainfall intensities, the LID efficiency reduces as return periods increase.

**Table 4.13 The Various Levels of Manhole Flooding During Return periods After Added Technique of LID**

Return periods	Flooding levels				
	Level 1 No floods	Level 2 Minor floods	Level 3 Medium floods	Level 4 High floods	Level 5 Very high floods
2	97%	0.5%	1%	1.5%	0
5	95%	0.5%	2%	1.5 %	1.5%
10	91%	2%	3%	1.5%	2.5%
20	82%	3.5%	2%	1.5%	11%

The simulation results indicated that employing a Low Impact Development approach, specifically infiltration trenches, effectively mitigates the overall amount of flooding within the drainage network of the Al-Abed quarter. This study is in line with earlier research (Zhang et al., 2020) for instance, suggested adding LID to the drainage network to lower the total

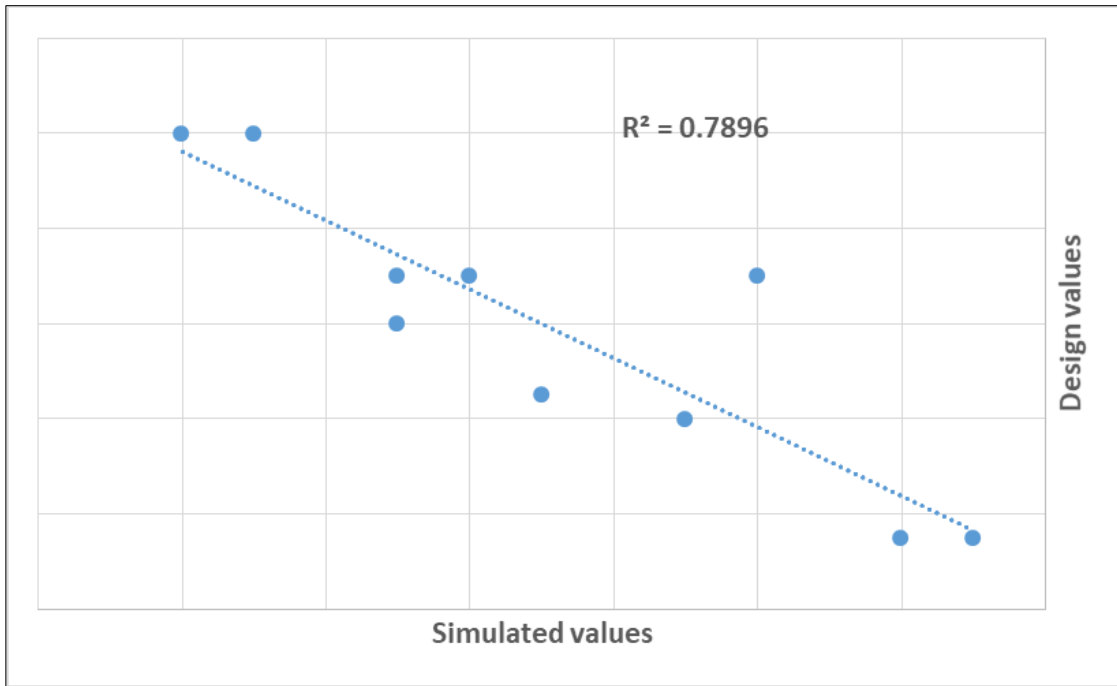
runoff volume over a 5-year period, hence lowering the number of inundation nodes, proving that LID in Kyoto, Japan, can efficiently mitigate rainwater floods over a five-year return periods. LID techniques were utilized by (Bai et al., 2019) in Suqian City, China. The researchers compared four situations in which the area of one technique is altered while the areas of the other techniques stay the same, confirming its efficacy in using LID facilities. The results of this study showed that for infiltration trenches scenarios with different percentages, the reduction in the volume of runoff and highest discharge changed from 30% and 27% to 44% and 40%, respectively.

#### 4.5 Results of the Model Performance Statistics

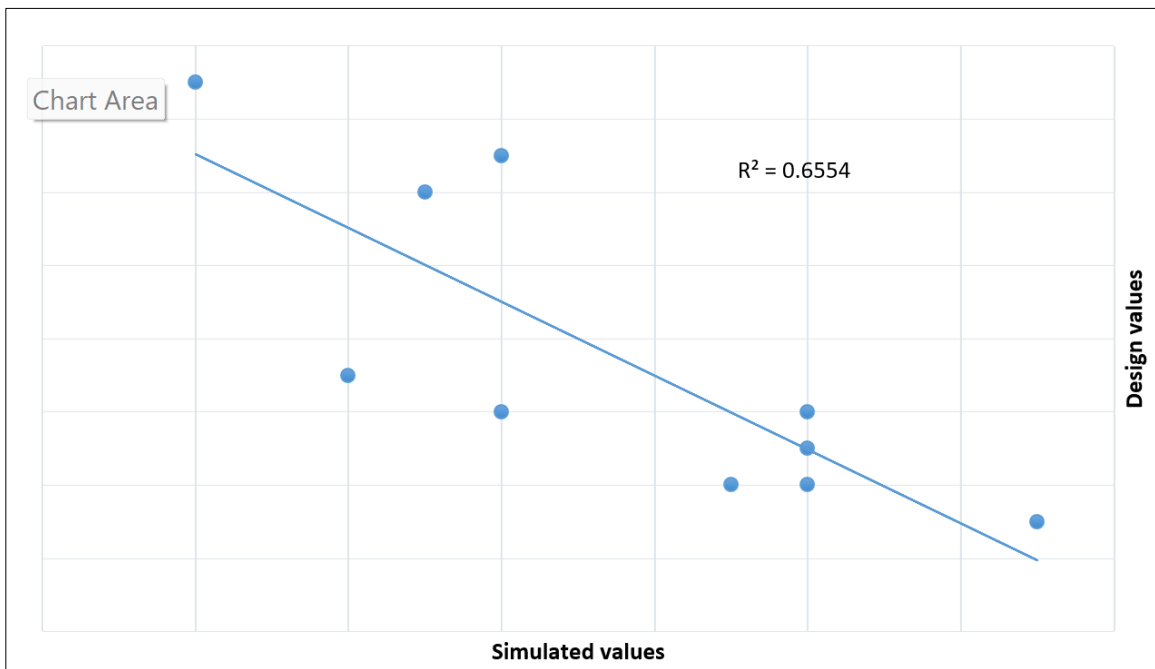
Using the projected data from the simulated storm water management model's findings and observed data represents flow discharge in pipes calculated manually using manning equation for the rainfall events in the study region, the Storm Water Management Program validated. Table 4.14 displays the results of statistical analysis of  $R^2$ , NMSE, and NSE parameters; Figures 4.10, 4.11, 4.12, and 4.13 display  $R^2$  of the projected data over the design data or observed data.

**Table 4.14 SWMM Calibration's Statistical Parameters**

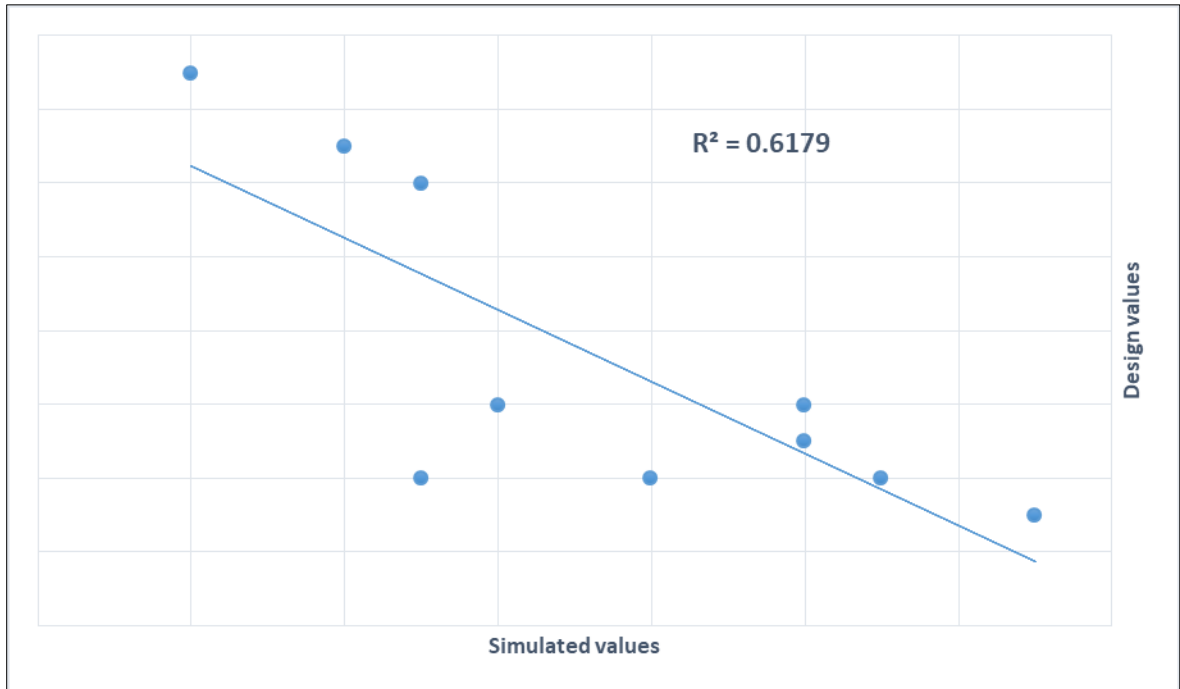
Indicators Periods	$R^2$	NMSE	NSE
2	0.79	0.08	0.79
5	0.66	0.072	0.79
10	0.63	0.069	0.65
20	0.62	0.06	0.71



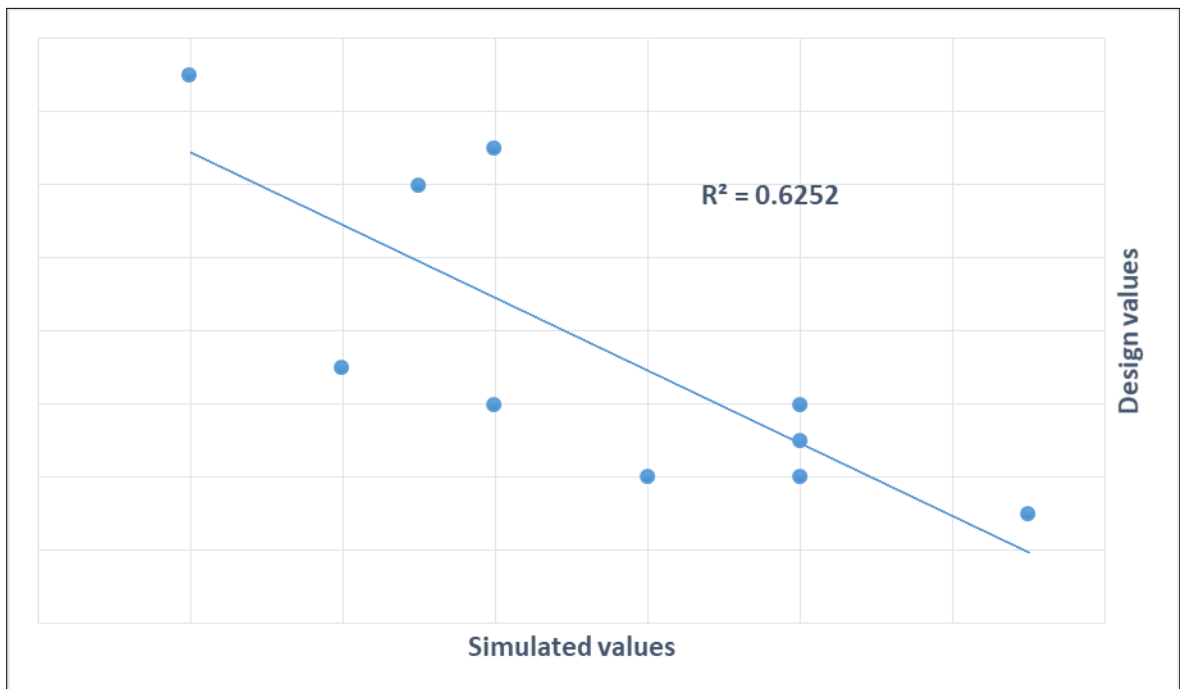
**Figure 4.10 Coefficient of Determination for the Flow Rates in Simulation and Observation Data During 2 years Periods of Return**



**Figure 4.11 Coefficient of Determination for the Flow rates in Simulation and Observation Data During 5 years Return periods**



**Figure 4.12 Coefficient of Determination for the Flow Rates in Simulation and Observation Data During 10 Years Periods of Return**



**Figure 4.13 Coefficient of Determination for the Flow Rates in Simulation and Observation Data During 20 Years Periods of Return**

The NMSE had a value that was a close-to-ideal fit of zero according to the findings, whereas the R<sup>2</sup> and NSE levels had close-to-ideal fits of one. As a result, the SWMM model runs rather well and is useful for forecasting future flooding in the research region. Natural systems are never closed, which makes them non-unique, making it difficult to validate and verify numerical models of natural systems. Models are only truly measurable in relative terms, and there is never a guarantee that they will be predictive. The primary utility of models is heuristic (Council et al., 2012; Hills & Trucano, 1999; Oreskes et al., 1994). Based on the results, it can be concluded that the SWMM simulation accurately predicted the data, eliminating the need for model calibration in the current model.

### **4.6 Summary**

The study presents the results that were derived using the analytical equations in storm water network management analysis and SWMM simulation tool for different return periods of rainfall intensities derived from the IDF curve of Kerbala city. The rainwater network of the Al-Abed quarter has been analyzed and its performance evaluated through number of flooded pipelines, junctions, and flood volumes. Furthermore, the LID techniques in the research region to mitigate the flooding of the rainwater network, which was applied due to increased rainfall intensity and urbanization.

## Chapter Five: Conclusions and Recommendations

### 5.1 Conclusions

Conclusions based on the findings presented in Chapter 4 have been reached. This can be condensed into:

1. The results of the analytical equations of the rainwater drainage network management in the study area showed that after a ten-year period of return, the system seems to be unable to release excess rainfall, which causes storm water to accumulate downstream.
2. The study utilized the SWMM model to evaluate the storm drainage network in the Al-Abed quarter of Kerbala, Iraq. Validation of the model was conducted by comparing its flow rates with the design flow discharge calculated manually using Manning equations. Three performance indicators were employed: (NSE), ( $R^2$ ), and (NMSE). Results showed NSE values between 0.65 and 0.79,  $R^2$  values between 0.62 and 0.79, and NMSE values between 0.06 and 0.08, all indicating a close fit to ideal values without requiring calibration.
3. The simulation results identified the amount of total floods in the manholes and the pipes under rainfall intensity until 20 years' return periods. The modelling demonstrated how well the drainage system performed during the two and five-year return periods of storm occurrences. The system is unable to release excess precipitation after a ten-years return period, which causes flooding in many locations in the drainage network.
4. The study included modelling the techniques of LID in order to mitigate the flooding in the storm water drainage network. Infiltration trenches

was the used technique Which had an important and clear role in reducing the amount of total floods, number of inundated manholes, and the highest discharge in return periods from 20 to 2 year, with 12% to 35%, 12.2% to 40%, and 11% to 33%, correspondingly.

### **5.2 Recommendations**

The recommendations are outlined below:

1. Future efforts should implement additional strategies to mitigate inundation in the drainage network during rainy events, as the research region utilized only a singular sort of Low Impact Development (LID). Additionally, when new Low Impact Development (LID) strategies are accessible to further reduce the volume of flooding and flooding junctions, it is advisable to evaluate the efficacy of alternative LIDs.
2. It is advisable to evaluate the performance of alternative infiltration trench designs in the region.
3. Altering the conduit diameter from 400 mm to 600 mm, situated in the core of the region, may be regarded as a viable approach to alleviate the flooding issue inside the storm-water network of the Al-Abed quarter.
4. SWMM efficacy modeling was promising in this research, indicating its applicability to various areas inside Kerbala city.

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Appendices

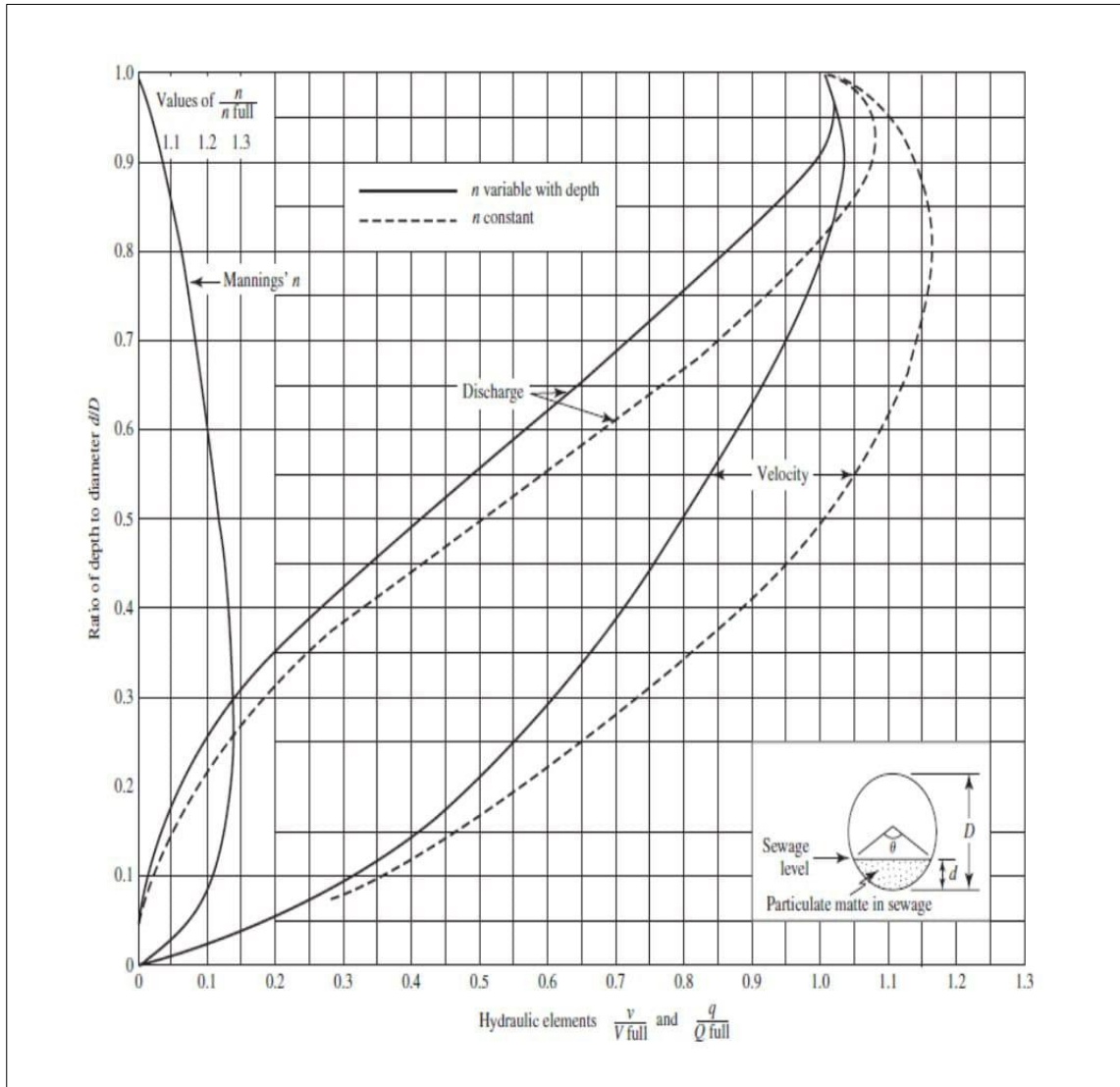
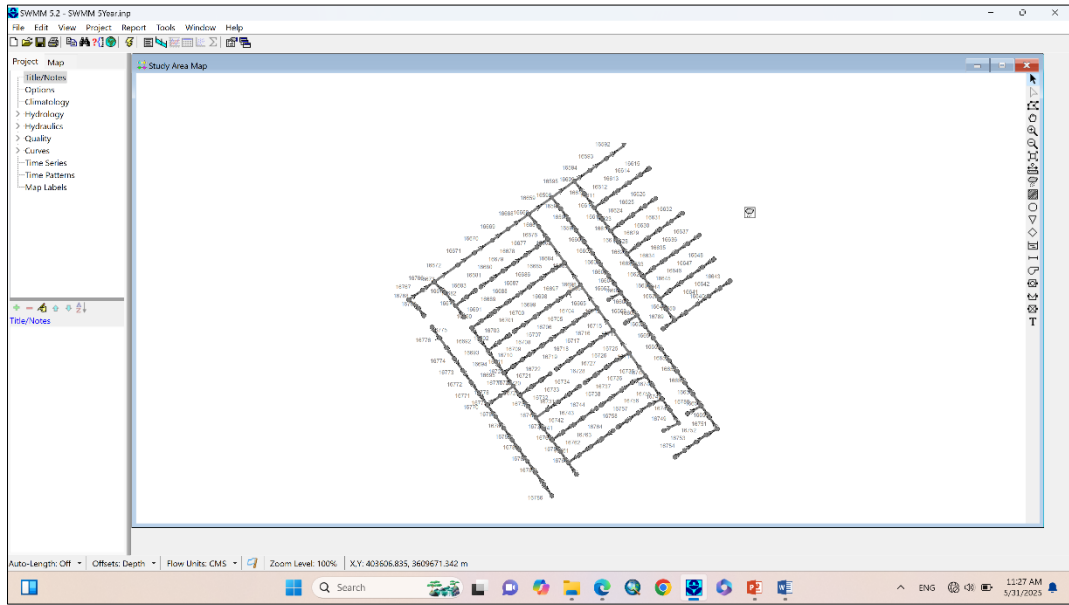
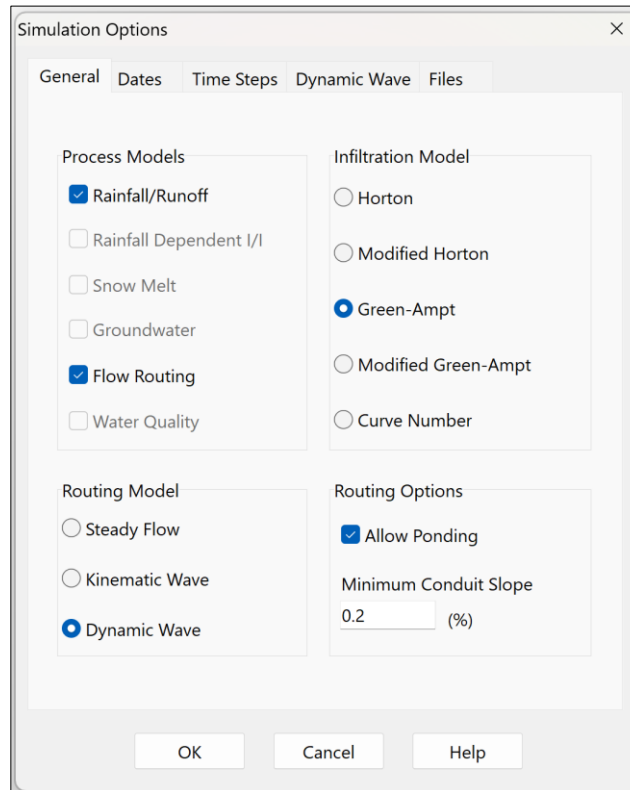


Figure A.1 Hydraulic Elements of Circular Pipes (McGhee & Steel, 1991)



**Figure A.2 Front of SWMM Model**



**Figure A.3 General options of SWMM Model**

Subcatchment S123	
Property	Value
Area	0.880000
Width	115
% Slope	0.25
% Imperv	75
N-Imperv	0.013
N-Perv	0.13
Dstore-Imperv	2.54
Dstore-Perv	5.08
%Zero-Imperv	25
Subarea Routing	OUTLET
Percent Routed	100
Infiltration Data	GREEN_AMPT
Groundwater	NO
Snow Pack	
LID Controls	1 ...
Land Uses	0
Initial Buildup	NONE

LID controls (click to edit)

**Figure A.4 Characteristics of the Sub catchment**

Conduit 16641	
Property	Value
Name	16641
Inlet Node	16454
Outlet Node	16453
Description	
Tag	
Shape	CIRCULAR
Max. Depth	0.4
Length	31.00
Roughness	0.009
Inlet Offset	0
Outlet Offset	0

Maximum flow allowed - use 0 if not applicable

**Figure A.5 Characteristics of the Pipelines**

Junction 16518	
Property	Value
Name	16518
X-Coordinate	403109.210
Y-Coordinate	3610133.080
Description	
Tag	
Inflows	NO
Treatment	NO
Invert El.	38.08
Max. Depth	2.86
Initial Depth	0
User-assigned name of junction	

**Figure A.6 Characteristics of the Junctions**

Rain Gage Rain Gage-1	
Property	Value
Name	Rain Gage-1
X-Coordinate	403746.100
Y-Coordinate	3610308.150
Description	
Tag	
Rain Format	INTENSITY
Time Interval	0:05
Snow Catch Factor	1.0
Data Source	TIMESERIES
TIME SERIES:	
- Series Name	20-year/13
DATA FILE:	
- File Name	
- Station ID	*
- Rain Units	MM
Rainfall units for user-prepared file format	

**Figure A.7 Characteristics of the Rain-Gages**

## الخلاصة

يؤثر التوسع الحضري والتوسع السكاني والتغيرات المناخية على المدن مما يجعلها أكثر عرضة للفيضانات المفاجئة والعواصف الشديدة ومشاكل شبكات الصرف. تُعد إدارة شبكات تصريف مياه الأمطار أمرًا بالغ الأهمية للسيطرة على الفيضانات، والتنبيه بسلوكها، وتقييم الحلول للمشاكل التشغيلية والهيكلية. لتحقيق الإدارة المتكاملة لشبكة تصريف مياه الأمطار في منطقة الدراسة، سنقوم بتحليل وتحديد إجمالي حجم الفيضانات وعدد الانابيب وغرف التفريغ الفائضة لشبكة الامطار في هذه الدراسة، وتقييم أداء شبكة تصريف مياه الأمطار فيما يتعلق بكثافة هطول الأمطار لفترات عودة مدتها 2 و5 و10 و20 عامًا، وتحديد المناطق الأكثر عرضة للفيضانات. أظهرت نتائج المعادلات التحليلية لإدارة شبكة تصريف مياه الأمطار في منطقة الدراسة أنه بعد فترة عودة مدتها عشر سنوات، يبدو أن النظام غير قادر على تصريف فائض الأمطار، مما يتسبب في تراكم مياه الأمطار في المصب. تتوافق هذه النتائج مع نتائج المحاكاة باستخدام نموذج إدارة مياه الأمطار. تم استخدام برنامج نموذج إدارة مياه الأمطار (SWMM) لاحتوائه على المكونات اللازمة لتحقيق أهداف البحث. بناءً على نتائج التحقق من صحة النموذج، يمكن الاستنتاج أن نموذج إدارة مياه الأمطار صالح، مما يلغي الحاجة إلى معايرة النموذج. كما تضمنت الدراسة نمذجة تقنيات التطوير منخفض التأثير (LID) بغرض التخفيف من فيضانات شبكة تصريف مياه الأمطار. واستجابةً لزيادة شدة هطول الأمطار، ازداد حجم جميع الفيضانات في شبكة الصرف، وعدد غرق التفريغ الفائضة من 1220 مترًا مكعبًا و5% على التوالي، إلى 13450 مترًا مكعبًا و20.5%، على التوالي، بينما طالقت فترات العودة من عامين إلى 20 عامًا. أدى نهج التنمية منخفضة التأثير المقترح إلى خفض أحجام الفيضانات خلال فترات عودة مختلفة (2، 5، 10، و20 سنة) إلى 793، 1708، 6947، و11915 مترًا مكعبًا. ويمكن لصانعي القرار الاستفادة من المساعدة الفنية التي توفرها الدراسة في بناء البنية التحتية لمواجهة الصعوبات المستقبلية.



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## إدارة شبكات مياه الأمطار التكاملية: دراسة حالة قضاء الحر- كربلاء

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في  
علوم الهندسة المدنية (هندسة البنى التحتية)

المؤلف:

علي مصطفى عباس

بكلوريوس في الهندسة المدنية 2019

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