Republic of Iraq

Ministry of Higher Education & Scientific Research

University of Kerbala

College of Engineering

Civil Engineering Department

EVALUATION OF USING GREEN INFRASTRUCTURES FOR IMPROVEMENT OF STORMWATER MANAGEMENT IN AL-MUTHANNA GOVERNORATE

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 Infrastructure Engineering

Written By:

Afnan Hussein Mandeel

(B.Sc., 2016)

Supervised By:

Prof. Dr. Basim Khalil Nile

Prof. Dr. Isam Jawad Alyaseri

May 2022 Shawal 1443

بسم الله الرحمن الرحيم

﴿ نَرْفَعُ دَرَجَٰتٍ مَّن نَّشَآءُ

وَفَوْقَ كُلِّ ذِى عِلْمٍ عَلِيمٌ ﴾

صدق الله العلي العظيم

يوسف-(الاية ٧٦)

DEDICATION

To whom who encouraged me to walk in the path of science and helped me all the way through

My Father

(Prof.Dr. Hussein M.)

To whom who spent her youth for us to obtain the best and highest position

My Mother

(Ghaidaa)

To whom who supported and stood with me in this difficult year and the circumstances, it went through

My Husband

(Ali)

To whom who was there to help, listen, and support me

My Friend

(Maryam)

ACKNOWLEDGMENTS

First of all, I thank Allah for all granting, who gave me the ability and helped me in this journey.

I would like to express my sincere thanks to my supervisors Prof. Dr. Basim K. Nile and Prof. Dr. Isam J. Alyaseri who helped me with the information that I looked for. It was great luck and honor to be under their supervision, for their constant encouragement and valuable guidance throughout this thesis.

Also extend my sincere thanks to the manager of the Samawah Sewer Directorate; engineer Qassem, who helped me to obtain the necessary data from the sewer directorate of the city.

I would also like to thank the Dean of the College of Engineering and the Department of Civil Engineering, as well as all the Doctors.

special thank and gratitude are extended to my family, especially my father, mother, brothers, and my husband for their support and help along the way.

Finally, I would like to express my extreme appreciation to everyone who has supported this work.

For you all, my deep respects.

Afnan Hussein

Abstract

Stormwater surface runoff and its inflow to sewer systems have increased lately due to vast urbanization, climate change and aging of existed infrastructure, thus led to the occurrence of floods.

This study defines the using of stormwater management model SWMM for predicting the stormwater quantity resulting from the surface runoff into the sewer system during rainfall events at different return periods as well as applying low impact development (LID) on the municipal separate storm sewer system (MS4) of Al-Soob Al-Kabeer quarter, also redesign MS4 by changing diameter of trunk line.

Also, a solution to reduce the quantity and improve the sewer system during rainfall events was suggested. The quantity of MS4 discharge model was manually determined by altering the effective sub-catchment features using design flowrates and simulated flowrates.

Values of average normalized of mean square error (NMSE) (1.0145) and average coefficient of correlation R (0.957) were within the acceptable boundaries and confirmed the validity of the model. Results of the quantity model indicated that the system was at critical conditions and flood might happen during wet weather, high flow rate into many manholes.

As a response to rainfall event, when the return period increased from 2 to 25 years showed a raise in MS4 flooding volume and flooding manholes ratio from 1466 m^3 and 10% to 13731 m^3 and 42%, respectively.

The proposed solution of LID was compared to without Added LID, it reduced the volume flooding at different return periods 2,5,10 and 25 to 998, 2292.4, 7959, and 11967, respectively, while the other proposed solution of redesign of stormwater sewer system by changing the diameter

of the trunk line was compared to without changing diameters, reduced the volume flooding at different return periods 2,5,10 and 25 to 1084.5, 2003, 7375, and 12546, respectively.

When comparing between the two solutions, the preference is given to LID technically and construction point in reducing the flood.

SUPERVISOR CERTIFICATE

I certify that the thesis entitled "**Evaluation of Using Green Infrastructures for Improvement of Stormwater Management in Al-Muthanna Governorate**" Prepared by **Afnan Hussein Mandeel**, has been carried out completely under our supervision at College of Engineering, University of Kerbala, in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Infrastructure Engineering).

Signature:

Prof. Dr. Basim Khalil Nile

(Supervisor)

Date: / / 2022

Signature:

Prof. Dr. Isam Jawad Alyaseri

(Supervisor)

Date: 15/ 4/2022

LINGUISTIC CERTIFICATE

I certify that this thesis entitled "**Evaluation of Using Green Infrastructures for Improvement of Stormwater Management in Al-Muthanna Governorate**", which is prepared by "**Afnan Hussein Mandeel** ", is under my linguistic supervision. It was amended to meet the English style.

Signature:

Linguistic Supervisor: Dr. Raad Mohammad Abd AlZahra

Date: 12 / 5 / 2022

EXAMININTION COMMITTEE CERTIFICATION

We certify that we have read the thesis entitled **"Evaluation of Using Green Infrastructures for Improvement of Stormwater Management in Al-Muthanna Governorate"** and as an examining committee, we examined the student "Afnan Hussein Mandeel " in its content and in what is connected with it, and that in our opinion it is adequate as a thesis for degree of Master of Science in Civil Engineering (Infrastructure Engineering).

Signature:

Name: Prof. Dr. Basim Khalil Nile

Date: 12/ 5 / 2022

(Supervisor)

Signature:

Name: Prof. Dr. Isam J. Alyaseri

Date: 12/ 5 / 2022

(Supervisor)

Signature:

Name: Dr. Muhammed Abdulredha

Date: 12/ 5 / 2022

(Member)

Signature:

Name: Prof. Dr. Saif Salah Alquzweeni

Date: 12/ 5 / 2022

(Member)

Signature: Waqed H.H

Name: Prof. Dr. Waqed H. Hassan

Date: 12/ 5 / 2022

(Chairman)

Approval of the Department of Civil Engineering

Signature:

Name: assist. Prof. Dr. Sajad Amir Hemzah

(Head of civil Engineering Dept.)

Date: / / 2022

Approval of Deanery of the College of Engineering - University of Kerbala

Signature:

Name: Prof. Dr. Laith Sh. Rasheed (Dean of the College of Engineering)

Date: / / 2022

TABLE OF CONTENTS

List of Figures

List of Table

List of Abbreviations

Description	symbols
Analytic hierarchy process	AHP
Best management practices	BMPs
Combined sewer overflows	CSOs
Digital elevation model	DEM
Department of sewer directorate	DSD
General authority for meteorology and seismic observation	GAMSO
General circulation models	GCM
Green infrastructure	GI
Geographic information system	GIS
Intensity duration frequency	IDF
Indian meteorological department	IMD
Intergovernmental panel on climate change	IPCC
Low impact development	LID
Municipal Separate Storm Sewer System	MS4
Normalized mean square error	NMSE
Probable maximum precipitation	PMP
Correlation coefficient	R
Stormwater Management Model	SWMM
Un plasticized polyvinyl chloride	UPVC
U.S. environmental protection agency	USEPA
Wastewater treatment plant	WWTP

CHAPTER ONE

Introduction

1.1 Introduction

The available green area on the earth's surface has been degraded as a result of fast urban growth and development (Jayasooriya et al., 2014). One of the issues facing cities is the management of urban flooding in which urban storm sewer systems are under increasing strain as a result of increased urbanization, population, and changes in urban flooding, which causes environmental problems, damages in the existed infrastructure and high cost of maintenance (Hussein et al., 2015, Hassan et al., 2017).

Currently, many cities around the world have two sewer systems; a sanitary system and a municipal separate storm sewer system (MS4). MS4 is a collection of buildings, channels, and underground pipes that transport stormwater to a treatment plant then to a water body or directly discharged to a water body without treatment.

It is an important system of an urban area's stormwater management to control flooding and water quality. This system is not connected to the sanitary sewer system, which transports wastewater from sinks, bathtubs, showers, and toilets to a wastewater treatment plant (WWTP) where it is treated and discharged to the nearest water body. In many cases, especially in Iraq, the stormwater is not routed to a treatment facility but discharged directly to rivers and lakes. Furthermore, the flooding in the streets might happen due to of many variables that influence flood events in urban areas, including urbanization, climate change, and the careless use of drainage networks (Nile et al., 2018).

1.2. Stormwater Management Modelling

Recently, storm sewer modelling is one of the most active fields of hydraulics and hydrology studies. Many studies utilizing rainfall-runoff simulation have been conducted to improve the effectiveness of storm networks (Mohsen et al., 2020). The stormwater management model (SWMM), which was created by the U.S. environmental protection agency (USEPA), has been used in various catchment areas in all around the world (Bhaduri et al., 2001, Selvalingam et al., 1987). SWMM provided a recent state-of-the-art critical analysis of current developments in integrating GIS with predictive water resource models (Martin et al., 2005). Environmental protection agency storm water management model EPA-SWMM is a dynamic rainfall-runoff simulation model that can be used to model runoff quantity and quality for single events or long-term (continuous) simulations (Ahmed et al., 2017). SWMM is widely used in planning and designing urban stormwater sewer system (Gironás et al., 2010).

1.3. Green Infrastructures

Green infrastructure (GI) is a unique mix of economic, social, and environmental aims and benefits that need flexible planning, implementation, and evaluation framework (Chini et al., 2017). One facet of urban sustainability is stormwater runoff management, which becomes more difficult as the quantity of impervious land in dense urban contexts grows. Increased political, social, and environmental demands push planners and engineers to assist in reducing the quantity and severity of floods, as well as improving the quality of receiving water (Chini et al., 2017). One of the techniques used to characterize a site-scale GI project is low impact development (LID). Developers have been looking for the best management practices (BMPs) to reduce the risk of floods in rapidly growing urban areas. LID is regarded as one of the most suitable solutions for urban stormwater management, therefore, the USEPA's SWMM5.1 added the hydrological simulation function for LID structures in 2009.

1.4. Statement of the Problem

Al-Samawah City, the capital of Al-Muthanna Governorate in Southern Iraq suffers from the problem of flooding in many rain events during winter season. This problem arises with climate change, population and urbanization growth (Ammar et al., 2021). The climate change resulted to increase the rainfall intensity over than the design rainfall intensity of the storm network of the studied area. The recent used method for managing stormwater is to discharge the collected water to the nearest water body which causes the problems of combined sewer overflows (CSOs). Although, green infrastructures (GIs) are able to treat stormwater at source, the GI has not used in the Governorate. There are many studies address the development of a systematic procedure to decide the values for LID design specification and how many LID structures should be used for the target at the LID planning (Ahmed et al., 2017).

1.5 Objectives of the Study

The main objective of this research is to assess the performance of the MS4 in Al-Samawah City during various rainfall events and to determine the expected flood ratios in the network and find the suitable solution for the study area. The objectives of the study, therefore:

1. To forecast the intensities of rainfall of Al-Muthanna Governorate for next twenty-five years, through creating an Intensity-Duration-Frequency (IDF) curve.
2. To assess the performance of Al-Soob Al-Kabeer stormwater network during the inflow of stormwater from events flooding in studied area (Al-Samawah City, Iraq), using the SWMM simulation.

3. To develop a solution for reducing the flood via using simulation in the SWMM program:
   a. using the best management practices, one of which is green infrastructure and/or
   b. suggest another solution, by increasing diameter of main pipeline for reduction both volume and number of manholes flooding.

1.6 Methodology of the Study

The methodology of the study is explained in the following:

Metrological data including daily rainfall (mm) for the period from 1989 to 2019 for the study area, were gathered from Iraqi Meteorological and Seismic Monitoring Authority.

1. Using gathered data of daily rainfall to calculate the probability and drawing IDF curve for Al-Samawah City over various periods of time.
2. Gathering the geographic information system (GIS) data from the Department of Sewer Directorate (DSD) in the province. The data include characteristics of the sectoral area, stormwater systems data, including the parameters of a study, area, manholes, pipes, and all accessories for the study area. GIS was used to build points and lines network from the collected data.
3. The predicted (IDF) curves, Storm Water Management Model (SWMM v5.1) and ArcGIS (v10.4), are used in the analysis of the MS4 for the study area to simulate and assess flooding.
4. Analysis of the Stormwater Network using the SWMM program, utilizing the previously collected data and find the percentage of the stormwater network deficit to the city's stormwater network to calculate the required actions and design scenarios to resolve the flood

problem in the future years using the simulation of LID and development MS4 by changing the diameter.

1.7 Hypothesis

Because of the potential problems caused by climate change, which may increase potential rainfall intensity, as well as the increasing of urbanization and the possibility of flooding, it's critical to assess the stormwater network's performance as well as the contribution of green infrastructure to reduce flooding when this change occurs. As a result, the following study imposed:

1- A flood is predicted at various return periods.

2 - It is assumed that network performance degrades with age, resulting in more flooding.

3- It asserts that implementing the green infrastructure solution will minimize the amount of surface run-off, hence lowering the rate of floods.

4- When a different solution, such as re-design, is employed to reduce floods, it will be less effective than green infrastructure.

5- Compared to re-design, green infrastructure technology will be more effective and simpler to apply.

1.8 Limitations of the Study

1. The study is on the stormwater network of Al-Soob Al-Kabeer in Al-Samawah City, this network was chosen for this area because the hydraulic data is available.

2. The data of metrological was collected from general authority for meteorology and seismic observation (GAMSO) for thirty years ago to give an accurate data for probability of rainfall intensity and find IDF curve for next twenty-five years.

3. The programs were used in the study are Easyfit, GIS and SWMM.

4. LID was applied on the network as a technique to reduce the flooding in the study area using model of previous study.

5. Redesign the network with changing the diameters of trunk pipeline.

1.9 Thesis Structure

This thesis includes five chapters, each chapter contents are briefly summarized, as the following:

Chapter 1 shows the introduction, description of problems, objectives, significance, and scope of the study,

Chapter 2 reviews published studies on the effects of rain events on the amount and of stormwater systems,

Chapter 3 explains the methodology used in this study, such as, data collection, analysis, and model construction methods,

Chapter 4 provides the findings of the performed analysis. It also goes through the findings of the model application for decreasing the flooding in the MS4 during wet seasons, and

Chapter 5 summarizes the most important conclusions and recommendations for future studies and applications.

CHAPTER TWO

Literature Review

2.1 Introduction

A review of previous studies was conducted to obtain a sufficient understanding of stormwater networks, The relationship between flooding and rainfall, the impacts of urbanization and rainfall on sewer overflow, and a review of popular approaches and models for simulating stormwater sewer discharge, using IDF curve and a review about LID techniques.

Water is essential for life on the earth. About 71 percent of the earth surface is covered by water (Ballard and Hively, 2017).The water on the earth always changes its state from liquid to vapor to ice or back again in a form of liquid (i.e., rain). Rain is crucial for life, but, sometimes, it exceeds the limit within human control. In some cases, it becomes a great danger and may cause overflows. Man has tried since ancient times to control overflows (Te et al., 1988). The first rainwater drainage network was discovered in Mesopotamia (Ur City, ca. 2500 – 4000 BC). Evidences were found of rainwater drains in the streets (De Feo et al., 2014).

2.2 The Sewer Networks Management and Maintenance.

Huge efforts have been conducted to deal with the problem of floods and sewer system deterioration. Many studies used various methodologies and approaches for sewer rehabilitation or reconstruction, for example, (Abraham et al. (1998); Gokhale et al. (2000); Diab and Morand (2001) and (Dias, 2007)). Chughtai and Zayed (2008) suggested that the main factors dealing with pipe are age, diameter, and material. Another factor is the soil type.

Other studies used an analytic hierarchy process (AHP) to define the priority of the rebuilding of a city drainage system (Hirai; Fenner (2000); Plenker (2002); Ennaouri et al. (2013); and Bouamrane et al. (2014).

In the past 15 years, bioretention, which is a type of GIs, has become one of the most popular storm-water BMPs in the United States and now is a key component of the LID storm-water management. Recent monitoring studies highlight the ability of bioretention facilities to reduce flood peaks, runoff volumes, and pollutant loads, while increasing runoff lag times, groundwater infiltration, and evapotranspiration (Davis et al., 2009).

2.3 Urbanization and Population Effects on Management of Stormwater Network

Given the increase in urbanisation worldwide, and the impact of urban stormwater on both humans and aquatic ecosystems, the management of urban drainage is a critically important challenge (Chocat et al., 2001).

The influence of urban usage changes has increased the risk of urban flooding, resulting in an increase in the volume and peak discharge of water flooding, as well as a shorter time to peak, as shown in Figure (2-1) (Liu et al., 2005; Nirupama and Simonovic, 2007; Saghafian et al., 2008; and Butler et al., 2018).

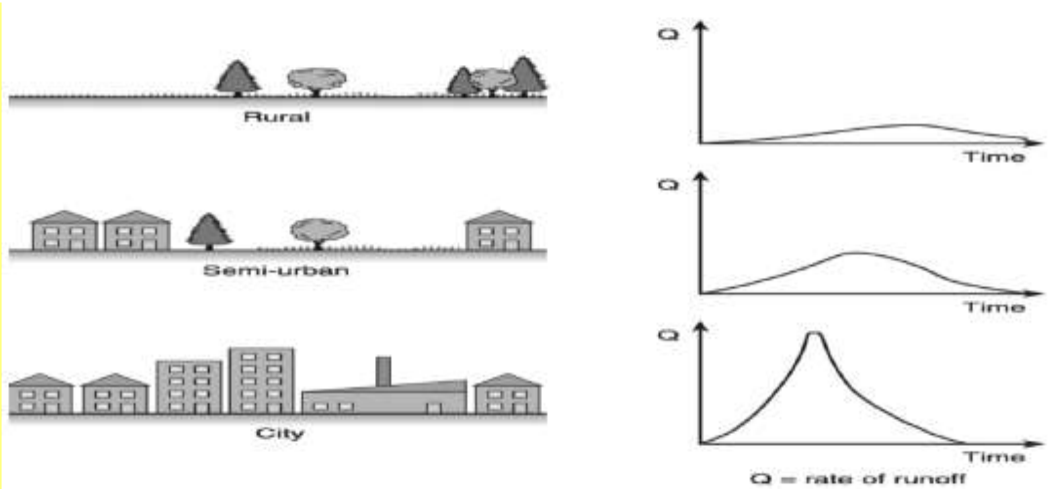


Figure 2-1: Changes in land usage and its influence on flooding (Butler et al., 2018).

Flooding in MS4s could result in the losing of lives, injuries and public's health issues, significant property damages, and environmental damages. Stormwater run-off is a dramatic hydrologic manifestation of many changes that result from urbanization in addition it cannot infiltrate or be evapotranspiration because impervious rooftops and pavements which limit the access to soil (Jefferson et al., 2017).

Because of large variations in urban land use, rising population, and changing climates, along with a variety of causes, such as deficient maintenance of MS4s, which are antiquated and of low capacity, flooding occurrences have been repeated in many cities in Iraq. Outdated systems suffer from clogging in pipes, problems in electricity and other issues in operation and the regular usage of MS4s (Nile, 2018).

About 54% of world's population lives in urban areas and it is expected to increase to be 66% by 2050, and most of these urban areas are coastal cities. The 2014 revision of the world urbanization prospects by united nation department of economic and social affairs' (UN DESA) population division says that the huge rate of urban growth will take place (Andimuthu et al., 2019).

Land use changes affect storm runoff characteristics, significant increases in runoff volume is caused by increased impervious areas such as roofs, roads, parking lots, footpaths and other imperviousness in the urbanized landscape (Akhter et al., 2020).

2.4 The Effect of the Rainfall Intensity's Change on the Stormwater Network:

Al-Aboodi et al. (2006) demonstrated that the overall rainfall and intensity in Basrah, Iraq, for a certain time period fluctuated from year to year. The depth and intensity of rainfall vary depending on the climate and the length of the study period. They discovered that the depth of rain in dry and semi-arid areas varies significantly from one season to another. They recommend that the design and construction of stormwater drainage and flood control systems should be based not only on the average of long-term rainfall records, but also on specific depths of precipitation that can be predicted for a given probability or return period; due to the significant variation in rainfall and its intensity over time. Only a complete investigation of a lengthy time series of historical rainfall data can estimate these rainfall depths.

The most significant impact on evaluating the hydraulic capacity of urban drainage systems is the growth of urbanization and the predicted increases in intense rainfall due to climate change. As a result, to this change there is significant evidence that the risks of sewer surcharge and flooding are increasing, according to the intergovernmental panel on climate change (IPCC 2007).

Hassan et al. (2017) found that the climate change can worsen floods in stormwater drainage systems. Hassan et al., (2017) conducted a study at Al-Eskari Quarter in Kerbala, Iraq, for flooding simulation SWMM was utilized the storm sewer system in the area. According to their findings, rainfall intensity has increased to 33.54 mm/h as a result of climate change. Flooding occurred in 47% of the stormwater system manholes as a result of this alteration. At this rainfall intensity, the unlawful sewage process will enhance flooding in the system by a proportion ranging from 39 to 52 percent.

According to a study by Nile et al. (2018), climate change and global warming increased rainfall intensities to levels that were higher than the design capacity of current systems; and ultimately result in flooding events.

Climate change, land use change, and an increase in urbanization and population all contribute to storm water network floods. This research focuses on the creation of models to estimate future changes in rainfall events in order to preserve the storm water network's infrastructure from flooding. The Al-Abbas neighborhood in Karbala, Iraq, was chosen as a case study. For the first analysis, the impact of climate change on expected rainfall intensity for the future period (2017-2070) is based on 1980-2016 historical data. The artificial neural network (ANN) model was used for this. After that, a Storm Water Management Model (SWMM) is built to analyze the flood conditions of the study area for anticipated rainfall intensities. The data show that in 2067, the highest rainfall intensity will be 46.48 mm/h. This number reflects 400% of the design's intensity (Nile et al. 2019).

Hussain et al. (2022) used SWMM to model the effects of land-use change and climate change on the Al-Ameer District's stormwater sewer system. As a result of altering the return period from 2 to 5 years in response to climate change, total surface runoff increased by 48 percent, from 14,120 to 27,110 m^3, and total flooding increased from 5,914 to 17,591 m^3 (accounting 72% of increment). To summarize, flooding areas and magnitudes were found, while the system failed to discharge stormwater runoff under critical circumstances, and the impact of climate change on the stormwater drainage system was more detrimental than the impact of land use.

2.5 Intensity–Duration–Frequency (IDF) Curves

The rainfall Intensity-Duration-Frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for planning, designing and operating of water resource projects, or for various engineering projects against floods (Nhat et al., 2006a)

De Paola et al. (2014) conducted a study in three African towns to forecast IDF for a chain of data and climatic projections. The rainfall patterns of the three cities were studied, and the IDF curves were evaluated. A specific rainfall simulation was also used to estimate the influence of climate change on IDF for the years 2010 to 2050. Using only the historical data set, the evaluation results of the IDF curves enabled framing the rainfall development of three cases studied. Then, to check for changes in rainfall patterns, climate forecasts were employed. Finally, the study calculated the likely maximum precipitation using the same data and climatic predictions (PMP).

Al-Awadi (2016) investigated the subject of IDF model evaluation for Baghdad City in Iraq. Using rainfall data, many analysis approaches have been used to build a relationship between rainfall intensities, storm length, and return period. Gumbel, LPT III, and Lognormal were the three major distributions techniques were utilized to find IDF curves. The IDF equations for various return durations were also discovered using non-linear regression analysis. Their results revealed no significant differences between the three methods used, with all distributions falling below an acceptable significance level, with a little preference for the LPT III distribution.

Dakheel (2017) did research to create IDF curves for Nasiriyah City, Iraq. The findings revealed that when storm duration diminishes, rainfall intensity increases. In addition, if the return period is long, rainfall frequencies for particular durations become more intense.

In an arid region in Saudi Arabia, Al-Amri et al. (2017) developed an IDF curve for ungauged situations. In non-gauged arid areas, the study created IDF configuration standards for water schemes.

2.6 Storm Sewer Design

2.6.1 Rational Method

Several studies have been conducted to design storm drainage system using the rational method. According to Pennington (2012), the oldest known method for designing storm drainage is the rational method, attributed to Kuichling, 1889.

For decades, hydraulic structures have been designed using the rational method for determining peak flood discharges. Despite the method's popularity, little emphasis has been made to enhancing runoff coefficient selection guidance. Using a frequency-based technique, this study estimated rational runoff coefficients the rational C for 72 gauged rural watersheds in Kansas ranging in size from 0.45 to 76.6 km^2. The median reasonable C values in Kansas ranged from 0.17 in western Kansas for the 2-year recurrence interval to 0.97 in eastern Kansas for the 100-year recurrence interval (Young et al., 2009).

Pennington (2012) conducted study in New Zealand used rational method and his study was intended to a practitioner audience including details to derive runoff coefficients, and some less-widely known applications of the method including "probabilistic approach". Therefore, rational method produced a ratio of inflow to outflow, under the specific conditions of rainfall duration equal to catchment time of concentration.

Needhidasan et al. (2013) conducted a study in India using rational method to find peak discharge for the storm drainage in Calicut City, India. A great effort was made to finalize the value of runoff coefficient "C" it was noted that the current sections are not sufficient in most of places to absorb runoff. In those places where space constrains are acute trapezoidal sections may be replaced with existing rectangular sections.

The rational method formula is given by:

Q = C i A (U.S. units), or Q = 0.0028 C i A (S.I. units)

Where: Q = peak discharge (c f s for U.S. units), or (m^3/s for S.I. units).

C = dimensionless runoff coefficient

i = rainfall intensity for duration equal to catchment time of concentration (in/hr for U.S. units), or (mm/hr for S.I. units)

A = catchment area (acres for U.S. units), or (ha for S.I. units)

Then, the computer programs for drainage design and analysis were developed and emerged in 1970 (Butler and W. Davies 2011). The purposes of models in urban drainage engineering were expressed by (Mays 2004), as following:

1- Represent a drainage system for better understanding of urban stream.

2- Know the factors that affect the network such as climate change, land cover and population in order to answer questions about it.

3- Suggest solutions for problems and to reduce the cost.

2.6.2 Stormwater Management Model (SWMM).

SWMM is a dynamic rainfall-runoff simulation model that can be used to simulate runoff quantity and quality from mostly metropolitan regions for single-event or long-term (continuous) simulations. It is one of the most successful water environment models developed by EPA. Developed in 1969-71, it has stood the test of time and is still widely used across the world for analyzing quantity and quality concerns in stormwater runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well (Rossman et al., 2004).

Wu et al. (2013) conducted a study in Iowa, USA using SWMM to simulate current and projected watershed conditions and the results showed that land cover and climate changes had strong effects on urban stream hydrology. However, the effect of land cover was much greater than those generated by climate change.

Fortunato et al. (2014) conducted a study in Italy, the SWMM was used for identifying the optimal rainfall return period for designing urban drainage system in Palermo, Italy, both in socio-environment term and in term of avoided economic losses from possible overflowing. This study modified curves in order to obtain damage per unit area suitable depth-damage curves. Traffic models have been modified to calculate the damage to the buildings and their content as well as damage to the vehicles. These curves were relying on the results obtained from the simulation of the network using SWMM software.

Obaid et al. (2014) conducted a study in Karbala City, Iraq using SWMM and GIS. The aim of that study was to choose places where sewer flows or overflowing occurs during peak time and heavy rain and the SWMM software succeeded in identifying the part of sewer network in Shohada Al-Maudfeen zone, Karbala city as the most vulnerable to overflowing.

Obaid (2015) conducted a study in Karbala City, Iraq, the Physical model EPA SWMM and statistical model artificial neural network (ANN) were used for simulation of sewer discharge response to change in population and rainfall for determining the effect of the increasing in the number of populations on the sewer network in the city. Solutions were suggested to the problem of overflowing and after simulating the network by using SWMM software, the study concluded that population increase was the main responsible factor for city sewage overflowing, and rainfall factor was less influential.

Hadi et al. (2015) conducted study in Al-Kut, Iraq using SWMM and GIS to provide a suitable modern technology in designing, developing and expanding sewage networks instead of the usual method which required a lot of time, and high cost. By analysing the sewer network of Al-Anwar zones, the networks worked efficiently. The researcher concluded that the use of these programs in sewage pipes is an appropriate way to analyze sewage networks.

Waikar and Namita (2015) conducted a study in India, using rational method and SWMM model to compare between the result of runoff obtained by rational method and SWMM in Nanded, India. The results showed that the total runoff from whole catchment by SWMM was 2.177/sec where by rational method was 1.109/sec, this means that SWMM gives relatively excess runoff values as compared to rational method. Using SWMM and Arc GIS as a useful tool and time sever modelling tool that can be used for large watershed.

Azawi[1] and Sachit (2018) conducted a study that addressed (investigation of permeable pavement implementation in Baghdad, Iraq, using the PCSWMM Model), where PCSWMM is advanced modelling software, which is shown three scenarios were proposed based on PCSWMM model and time series for rainfall period (2014 – 2015) to develop Al-Huryai zone Permeable Pavement in Baghdad City and use permeable pavement to solve the problem of surface runoff. The simulation showed that permeable pavement had the ability to reduce the total surface runoff, beak discharge and that minimize the overflows. Permeable pavement in Baghdad City was recommended to solve the phenomena of overflows in the city.

Nile et al. (2019) in Karbala, Iraq, used SWMM to develop models to extrapolate the effect of future change in rainfall events to protect infrastructure of storm water network from overflowing, and with the first analysis takes historical data for the period (1980-2016) to predict rainfall intensity for the future period (2017-2070) this analysis was conducted by using ANN mode and the result by SWMM was constructed in order to assess the overflow condition of the study area for expected rainfall intensity. The results indicated that the maximum rainfall intensity will reach

46.48mm/hr in 2067, and it is represented 400% of the design intensity for the storm water network.

2.7 Low Impact Development (LID)

LID controls are low impact development practices designed to capture surface runoff and provide some combination of detention, infiltration, and evapotranspiration. This technique is used to reduce the amount of pollutants during rainy events. The LID is a term used to describe a low-impact development control that can be utilized to store, infiltrate, and evaporate sub-catchment runoff. The control is designed on a per-square-foot basis, allowing it to be installed in any of the sub-catchments of various sizes or numbers. In addition to qualitative simulation, the SWMM also offers the capability to assess stormwater best management practices (BMPs) for pollutants reduction at source using LID strategies.

Simpson, (2010) studied a stormwater network in Collins, Atlanta, USA, to investigate using LID can be used exclusively to meet storm water requirement and whether LID can maintain the predevelopment of site hydrology. The results of simulation by using SWMM showed that LID can restore predevelopment site hydrology, but the amount of LID required was substantial, the cost review shown that the extra LID expense could be recovered in certain land which is no longer needed. Therefore, to be careful when planning and designing LID system, the users of LID should be first count the cost and decide where it was a worthwhile investment or not.

Mustafa et al. (2017) investigated the impact of rainfall intensity on stormwater volume reduction in combined sewers through the use of permeable pavements. The study illustrated site locations of the three studied alleys by Eads, Cardinal, and Geyer Avenue, respectively. The intensity of rainfall had an impact on storm runoff reduction. Increased rainfall intensities were linked to lower storm runoff volumes. Eads, Cardinal, and

Geyer Avenue reduced the percentage decreases for each type of pavement from 60 percent to 10%, 36 percent to 9%, and 69 percent to 23 percent for alleys, respectively.

A pilot experiment was carried out by Alyaseri et al. (2017) to assess the influence of rain gardens on the water quality and volume reduction of storm runoff from urban streets in a combined sewer area. The addition of rain gardens at one of the research sites resulted in a 76 percent reduction in stormwater runoff volume.

Bai et al., (2019a) conducted a study in Jiangsu province, China, using LID technology to control runoff which is used to solve urban overflow disasters. Simulation results of rainwater network reality in Jiangsu, China using SWWM software showed that infiltration facilities have the greater reduction rate of surface runoff compared with storage facilities and LID facilities can greatly mitigate overflow. The result of this study can provide some technical support for the construction of drainage system in urban areas.

LID is regarded as a sustainable solution for urban stormwater management. A comprehensive evaluation system was developed based on environmental and economic benefits using the analytic hierarchy process (AHP) and the SWMM of the United States Environmental Protection Agency (EPA) (Bai et al., 2019b).

Low-impact development (LID) approaches absorb surface runoff and treat it with a combination of detention, infiltration, and evapotranspiration. They are treated as sub-catchment properties in the same way that aquifers and snow packs treated (Rossman, 2015).

The following types of GIs are some examples of the LID controls that can be explicitly modelled using the SWMM:

1. **1.** Bio-retention Cells: are depressions over gravel drainage bed that hold vegetation cultivated in an engineered soil combination. Both direct rainfall and runoff acquired from nearby areas are stored, infiltrated, and evaporated.
2. **2.** Rain Gardens: are a sort of bio-retention cell made up entirely of artificial permeable soil with no gravel bed beneath it.
3. **3.** Green Roofs: A soil layer at top that transports surplus percolated rainfall off of the roof.
4. **4.** Infiltration Trenches: are thin gravel-filled ditches that capture rainwater from impermeable areas on the upslope. They give additional storage space and time for captured runoff to penetrate the native soil beneath.
5. **5.** Continuous Permeable Pavement: Excavated areas that are filled with gravel and then covered over with a porous concrete or asphalt mixture. Impervious paver blocks are set on a sand or pea gravel bed with a gravel storage layer underneath in block paver systems.
6. **6.** Rain Barrels (or Cisterns): These are containers that collect roof runoff during storms and can discharge or reuse the rainwater during dry seasons.
7. **7.** Rooftop Disconnection: downspouts are diverted to pervious planted areas and lawns rather than storm drains. Roofs with directly connected drains that overflow into pervious regions can also be modelled.
8. **8.** Vegetative Swales: are depression areas or canals with sloping sides covered in grass and other vegetation. They slow the flow of collected runoff, giving it more time to percolate into the native soil beneath it.

2.8 Summary

The review of the past studied indicated that SWMM software has been widely used for urban drainage design and planning. The previous studies linked with some elements impacting the flooding of various types of sewer systems (separated and combined) were summarized in this chapter. The consequences of densely populated areas and urbanization, as well as the methods and causes of flooding in sewer systems, such as the effects of land use and impervious area on stormwater and combined sewer systems, are among these issues. In addition, the chapter discussed the effects of climate change on increasing rainfall intensities for various return periods, and the previous studies about methodologies and techniques used to derive intensity duration frequency (IDF) curves.

At the end of chapter there are many studies about solve the problem of flooding by LID using SWMM or empirical models. The details will explain in the next chapter.

CHAPTER THREE

Methodology and Case Study

3.1 Introduction

This chapter explains the methods used to model the MS4 in Al-Soob Al-Kabeer Quarter in the city of Al-Samawa. Simulate the consequences of land use changes, climate change, topography, and period of concentration, as well as flood mitigation alternatives. It also explains the basis for running the program, the data that was used in the presence study and a summarize the research method.

The required data were divided into four types:

the first was to describe data related to hydrological processes (e.g., precipitation data) operated by the SWMM.

The second type described the parameters of the study area in Al-Soob Al-Kabeer Quarter as (sub-catchment width, area, percentage of impermeablility, infiltration and groundwater data, etc.) and MS4 as (diameter, length, slope, and depth of manhole).

The third was to describe how to stimulate flow in the MS4s and identify system issues caused by changes in rainfall events.

The fourth was to describe the simulation of the LID effects on the storm sewer system and development of MS4.It was difficult to obtain all essential data from competent authorities for this study, thus in this chapter, the basic data and information references needed to meet the needs of the model building will be discussed in order to simulate the MS4 quantity.

A description of the study area is given, and also includes a description of how to calculate rainfall intensity for return periods and determine the IDF curve, as well as a short introduction of the SWMM model. The methodology for calculating the parameters required to construct the model is explained, such as, sub-collection slope, width, imperviousness, infiltration, land use, sewage volume, and other factors. The methodology of the performed work is represented in Figure (3-1).

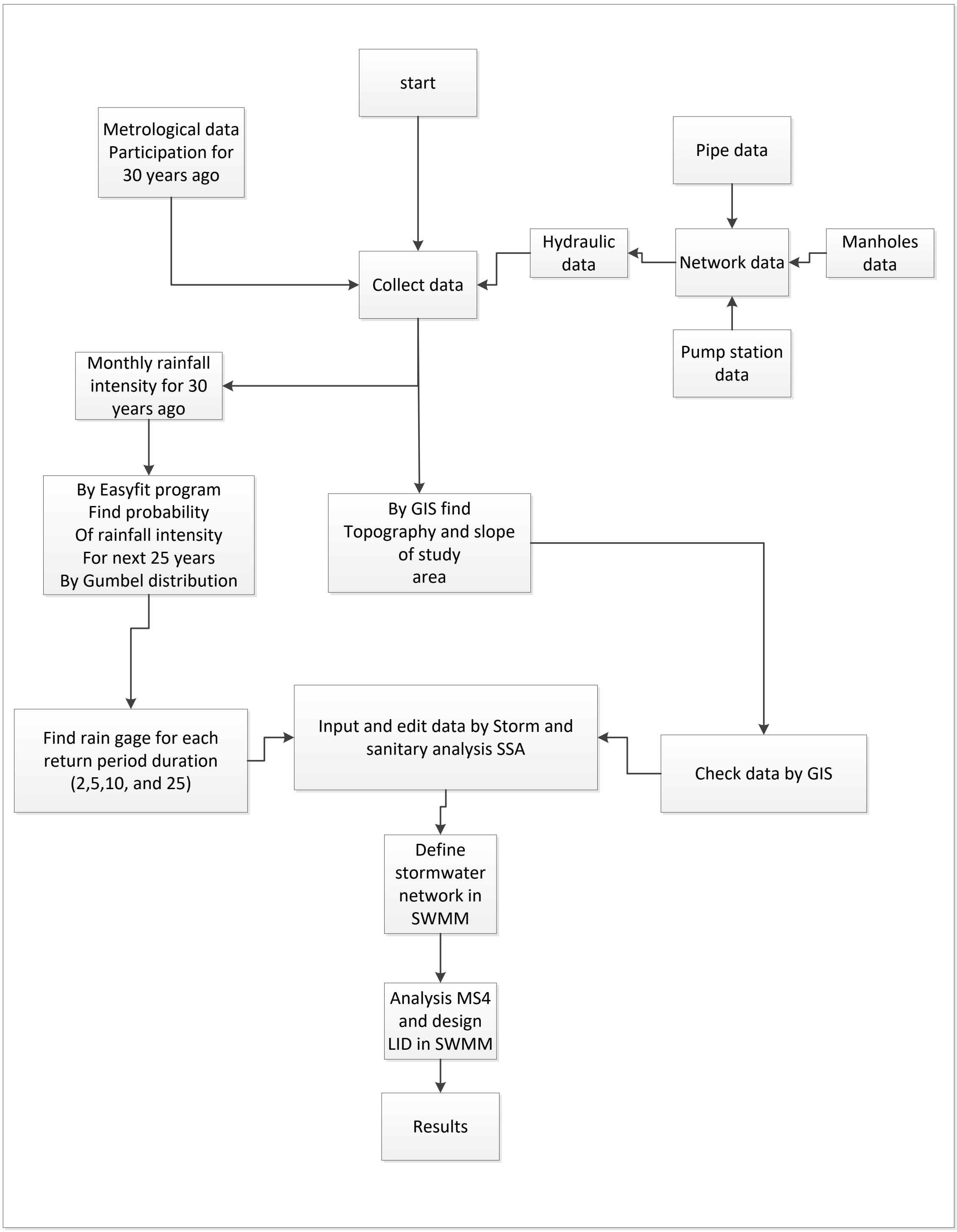


Figure 3-1: A flowchart shows the methodology conducted in this work.

3.2 Description of the studied area

The studied area (Al-Soob Al-Kabeer Quarter) in Al-Samawah City, the centre of Al-Muthanna Governorate in southern Iraq. It is approximately 266 km south of Baghdad and is located near the Euphrates River. The study area is located between latitudes 31˚ 19′ 13″ north and longitudes 45˚ 16′ 38″ east as shown in Figure (3-2). The area is almost governed by flat and low slope surface, the ele8.84 meters above sea level. The overall investigated area is roughly 2.6 Km^2, with 0.73 Km^2 of pervious (28 % of the total area) and 1.8 km^2 impervious (almost 72 % of the total area), with 0.07 km^2 of paved roads. Roofs, highways, and walkways are examples of impervious areas, where gardens and unpaved roads are examples of pervious areas (DSD, 2014). The climate of the studied area is characterized by cold and rainy winters, from November through April, dry and hot summers from May through October. Average of the highest temperature is 32.38 C° and the average of the lowest temperature is 17.9 C°, average annual rainfall is 13.17mm/year, average humidity is 39.6% and wind speed is 12.24 km/hr (the General Authority for Meteorology and Seismic Observation in the province (GAMSO)). During the rainy season the study area is severely flooded and this causes an overflow of MS4 as shown in Appendix (A).

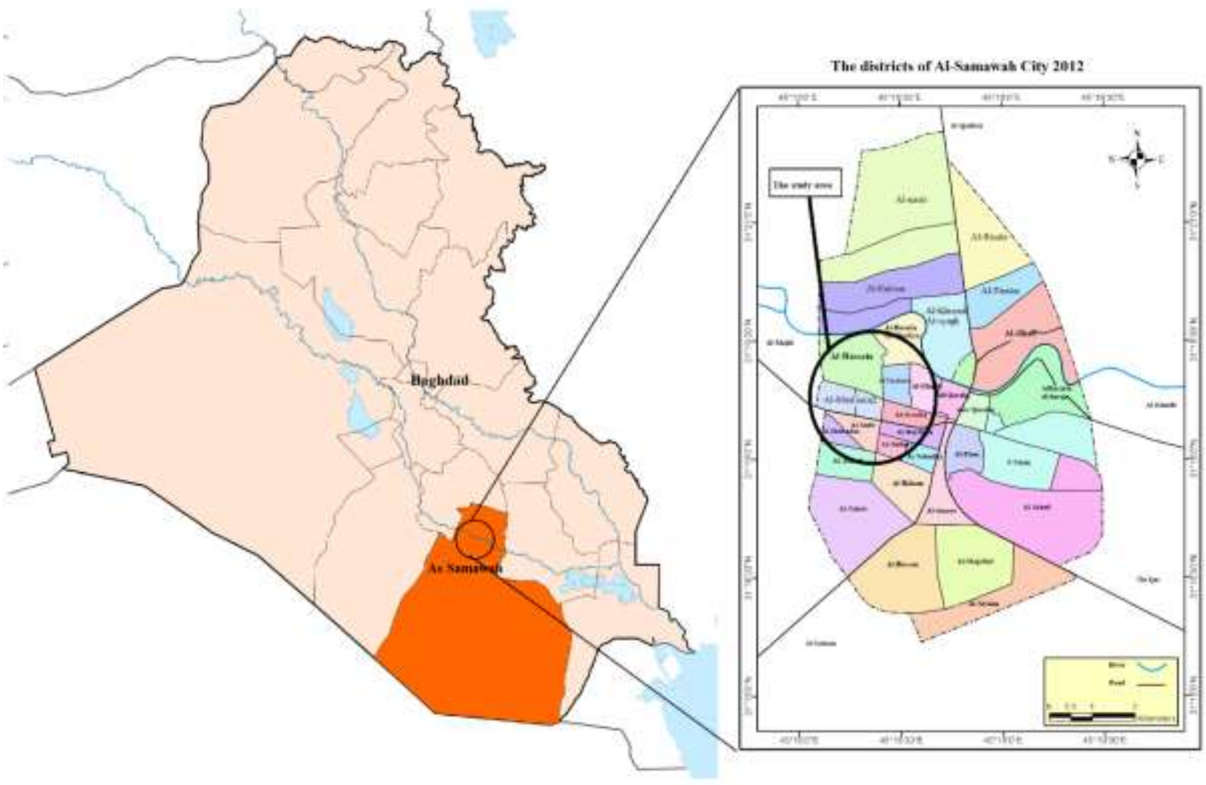


Figure3-2: Location of the studies area, (DSD, 2016).

3.3. Data Collection

3.3.1 Topography

Using GIS software, the slope map was determined. The map was built using a USGS (United States Geological Survey) DEM (digital elevation model) surface raster file (USGS, 2018). Random points were formed for the studied area after importing the DEM file into GIS (ARC MAP V10.4.1), and then the elevation (Z) was taken from the DEM file and applied to the obtained random points. This procedure resulted in data points having XYZ information. Finally, the slope map was created using the ARC tool box, which came as part of the GIS software package. It's worth noting that Al-Samawah City has a flat ground. Figure 3-3 shows a slope map of the studies area. This map helps to specify the slopes for each sub-catchment in the study area, see, Appendix (B) for the slope value for each sub-catchment.

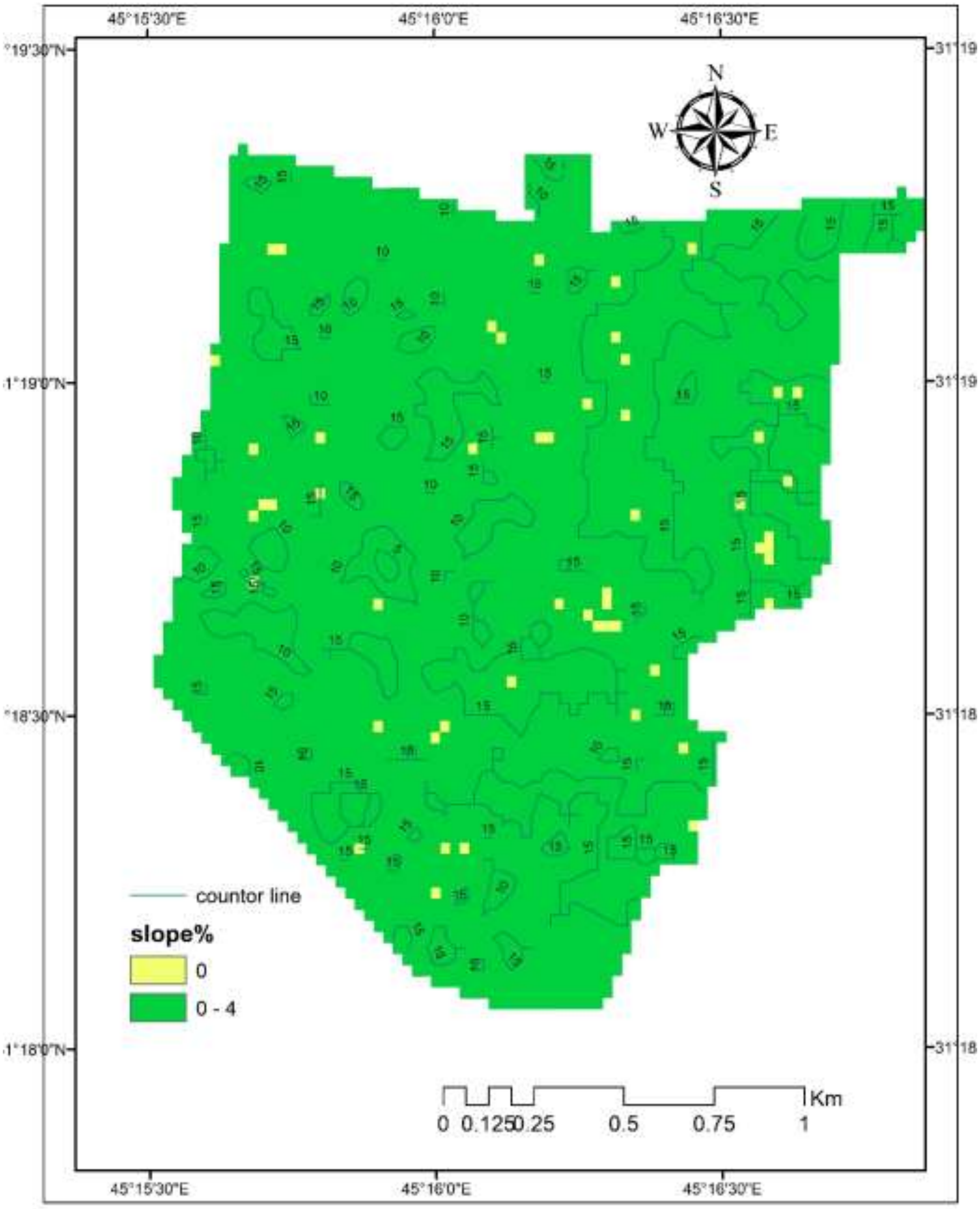


Figure3-3: The countor and slope map of Al-Samawah City, Source (U.S Geological survey,2018

3.3.2 Land Use

Current land use in Al-Soob Al-Kabeer Quarter includes residential, commercial, educational, green land, industrial, and other uses. The research area is a residential quarter with 4% gardens and service buildings, 9% paved roads, 1% commercial structures, and 86 % residential blocks. Figure (3-4) is shown the land use types for Al-Soob Al-Kabeer Quarter.

Figure 3-4: The map for Al-Soob Al-Kabeer Quarter with all features, (Department of Urban Planning of Samawah, 2008).

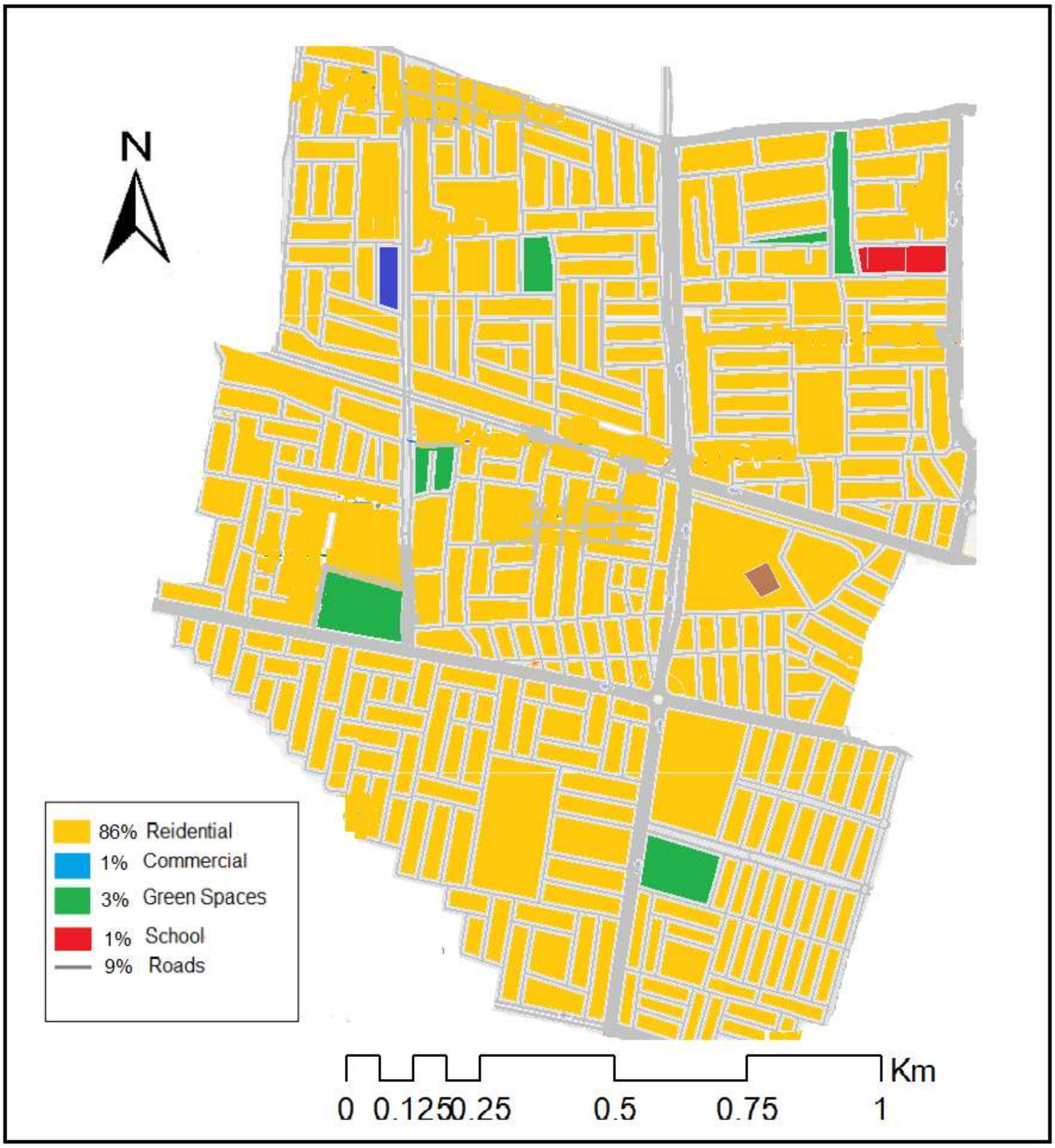


Figure 3-5: The land use map for Al-Soob Al-Kabeer Quarter, (Department of Urban Planning of Samawah, 2008).

3.3.3 Soil Map

Quantity and quality of sewage system characteristics are the major factors that affect its contribution to inflow and infiltration processes (Staufer et al., 2012). The rate at which infiltration occurs is a function of soil properties of the drainage area. Therefore, soil properties were used as input in the SWMM to estimate the amount of water infiltration into sewer system. In addition, soil properties were used to design a proposed sewer line for mitigation of sewer overflow. Al-

Samawah City has five types of soil; saline lake bottom land, mixed gypsiferous desert land, sand dune land, river levee soils, and poorly drained phase (Exploratory soil map of Iraq, 1996). The soil map of the city is shown in Figure (3-5).

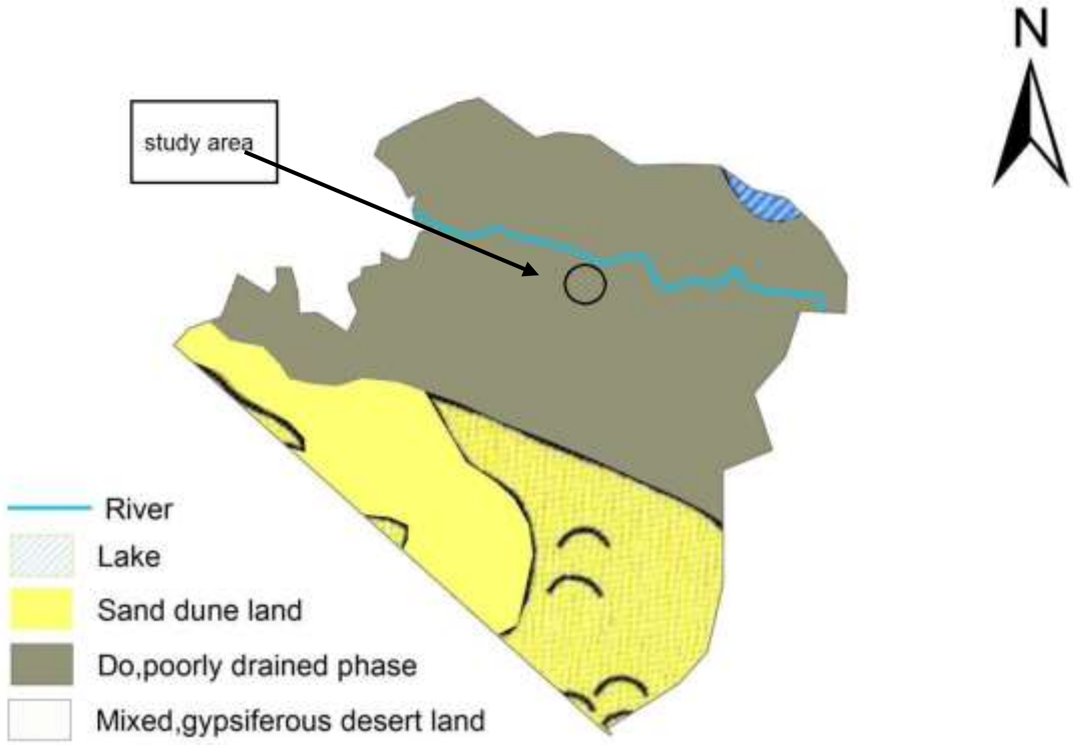


Figure 3-6: Soil map of Al-Samawah City by GIS based DEM data, (Exploratory soil map of Iraq, 1996).

The soil of studied area contains of fill material with organic, medium to stiff silty clay and dense to very dense sand. Three types of sub-soil profile can be observed in Al-Samawah City. The soil profile characteristics of Al-Samawah are given in Figure 3.6, and Table 3.1 (Al-Khuzaie, 1997)

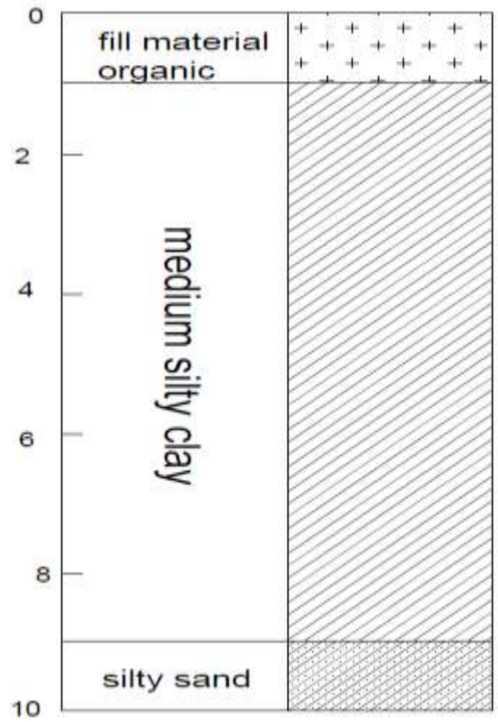


Figure3-7: Sub - Soil Profile for Al-Samawah City, (Al-Khuzaie, 1997)

Table 3-1: Characteristic of Al-Samawah soils**,** (Al-Khuzaie, 1997).

Depth soil(m)	Description of the soil.
0-1	Fill material with organic.
1-9	Medium to stiff silty clay and dense to very dense sand.
9-10	Dense to very dense sand.

3.3.4 Hydraulic Data

Hydraulic data for Al-Soob Al-Kabeer Quarter was provided by the Al-Samawah sewage directorate, it included pipes, inspection manholes, and their features. Hydraulic data was represented as bitmap and line shape files in GIS ARCMAP. The network was imported into SWMM software after charting and evaluating the data. Figure (3.7) shows the pipe, manhole and pump station of Al-Soob Al-Kabeer. It was noticed that the overflow rate occurred in the stormwater sewer system when the rainfall intensity was increased to three times the designed rain intensity 14mm/hr.

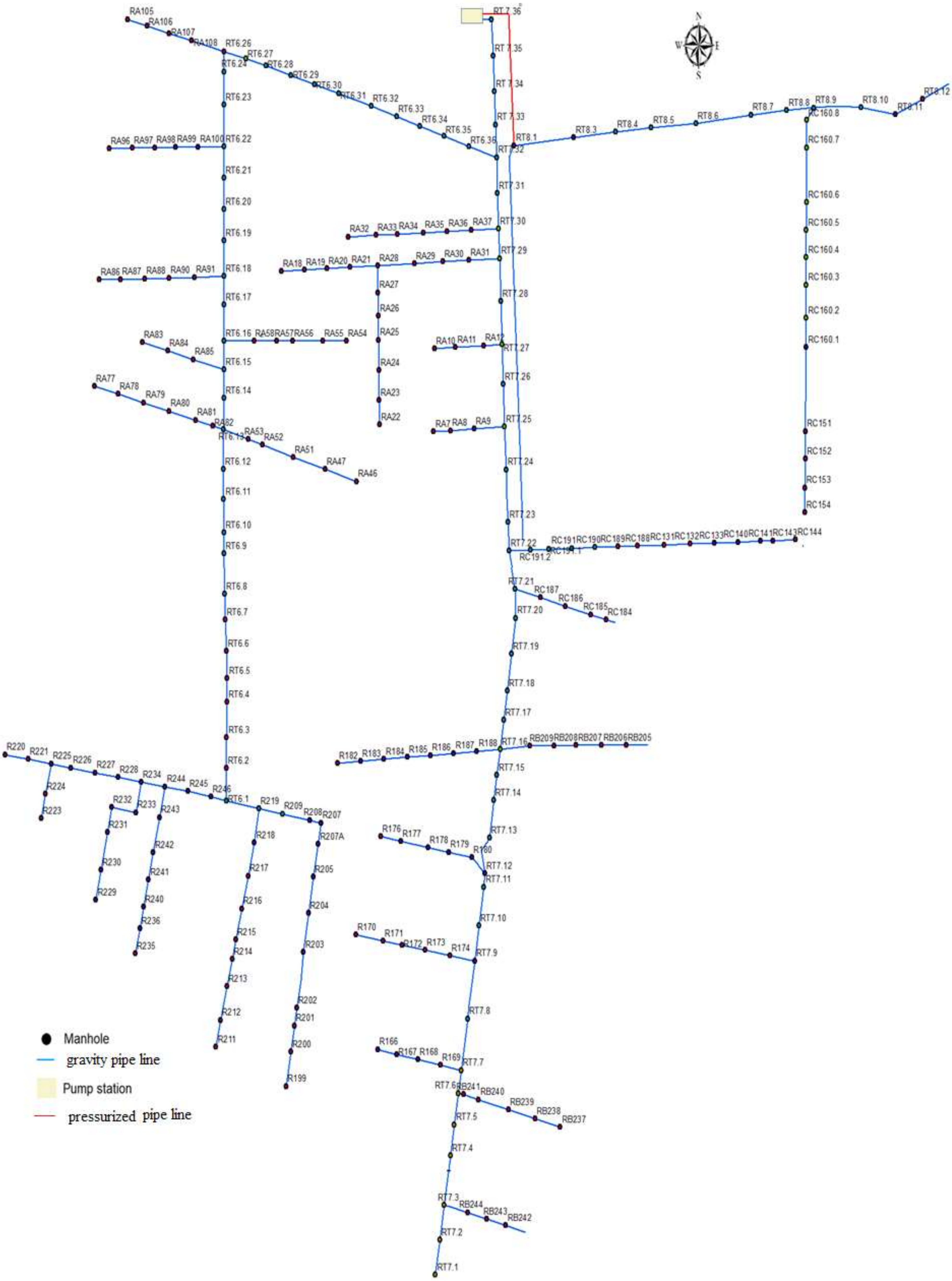


Figure 3-8: Hydraulic data of the studied area. (DSD. 2019)

-3.3.5 Rainfall Intensity Analysis

The rain depth data was provided by the Meteorological and Seismic Authority. Records cover the time period from 1989 to 2019 (General Authority for Metrology and Seismic Observations (GAMSOs, 2020). Since there is no very high spatial-temporal variance in rainfall in Al-Samawah, so these data were utilized to create a hydrological process in area of the study. All these data were re-entered into a single rain gauge for all sub-catchments that inflow into MS4. Figure (3.8) shows the rainfall data from 1989 to 2019 (GAMSOs, 2020) used in the modelling.

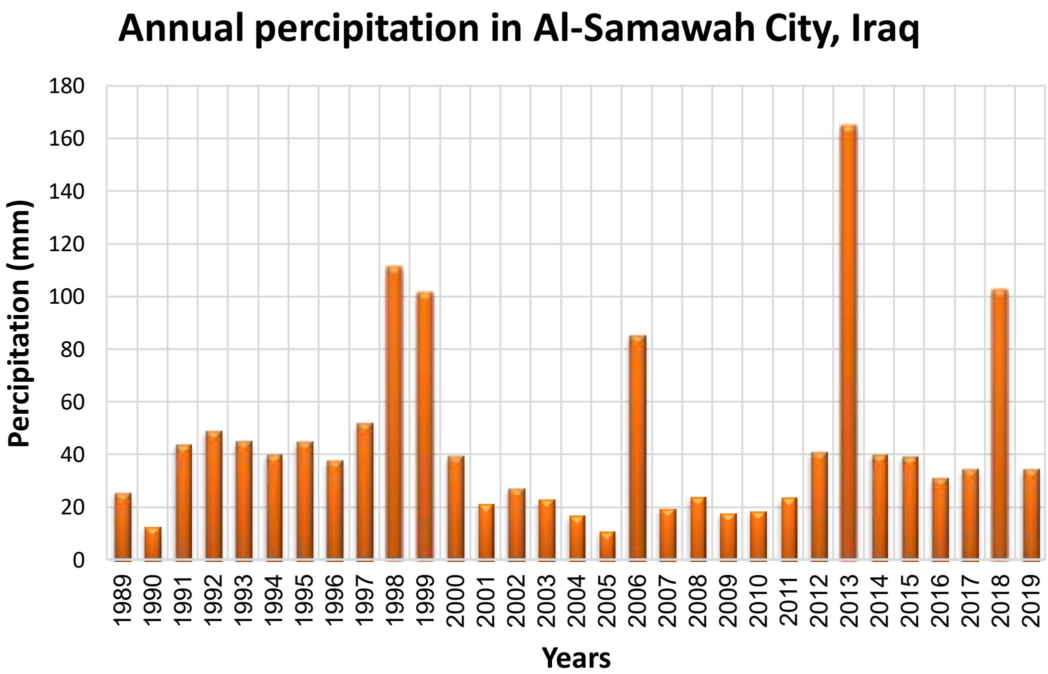


Figure 3-9: Maximum annual rainfall of the studied area (GAMSOs).

The following are the steps for creating an IDF drawing with Easy Fit 5.6 and Microsoft EXCEL2016:

1- Calculate the annual maximum daily rainfall, as shown in Table (3-2).

Table 3-2: The maximum daily rainfall in Al-Muthanna Governorate reported for the period from 1989 to 2019(G.A.M.S.O).

Year	Maximum daily rainfall (mm)	Year	Maximum daily rainfall (mm)	Year	Maximum daily rainfall (mm)
1989	25.6	1999	101.5	2009	17.7
1990	12.5	2000	39.6	2010	18.5
1991	43.9	2001	21.3	2011	23.7
1992	49	2002	27.2	2012	41
1993	45.3	2003	23	2013	164.8
1994	40.2	2004	16.9	2014	40
1995	44.9	2005	10.8	2015	39.4
1996	37.8	2006	85.4	2016	31.1
1997	52.1	2007	19.5	2017	34.5
1998	111.3	2008	24.1	2018	102.6

2- The maximum precipitation of 5, 10, 20, 30, 60, and 120 minutes is computed using the Indian Meteorological Department (IMD) reduction formula (Rathnam et al., 2001), and the results are given in Table 3.3.

$$pt = p24 * (\frac{t}{24})^{\frac{1}{3}} \quad (3\text{-}1)$$

Where:

pt denotes the required precipitation depth for a given duration in millimetres, P24 is the precipitation per day in millimetres, and t denotes the time length in hours for which the depth of precipitation is required.

As an example,

$$pt = 25.6 * (\frac{5}{24 * 60})^{\frac{1}{3}} = 3.876524\ mm$$

Table 3-3: Maximum daily precipitation depth (mm) for the duration T-minutes.

Precipitation depth (mm)						
year	**5(min)**	**10(min)**	**20(min)**	**30(min)**	**60(min)**	**120 (min)**
1989	3.876597	4.884195	6.153686	7.044202	8.875118	11.18192
1990	1.89287	2.384861	3.004729	3.439552	4.333554	5.459923
1991	6.647758	8.375631	10.55261	12.07971	15.21944	19.17525
1992	7.420049	9.348655	11.77854	13.48304	16.98753	21.4029
1993	6.85976	8.642736	10.88914	12.46494	15.7048	19.78676
1994	6.087469	7.669712	9.66321	11.0616	13.93671	17.55911
1995	6.799188	8.56642	10.79299	12.35487	15.56613	19.61204
1996	5.724038	7.211819	9.086302	10.40121	13.10467	16.51081
1997	7.889481	9.9401	12.52371	14.33605	18.06225	22.75696
1998	16.85411	21.2348	26.75411	30.62577	38.58596	48.61516
1999	15.3701	19.36507	24.3984	27.92916	35.18846	44.33458
2000	5.996611	7.555239	9.518983	10.8965	13.7287	17.29704
2001	3.22545	4.063803	5.120059	5.860996	7.384376	9.303709
2002	4.118884	5.189457	6.538291	7.484465	9.429813	11.88079
2003	3.482814	4.388071	5.528623	6.328694	7.973655	10.04618
2004	2.559112	3.224278	4.062336	4.650214	5.858903	7.381755
2005	1.635439	2.06052	2.596086	2.971773	3.744191	4.717374
2006	12.93209	16.29337	20.52831	23.49902	29.60684	37.30219
2007	2.952877	3.720383	4.687378	5.365701	6.760344	8.51748
2008	3.649453	4.598012	5.793118	6.631456	8.355092	10.52673
2009	2.680303	3.376963	4.254697	4.870406	6.136312	7.731251
2010	2.801447	3.529594	4.447	5.090537	6.41366	8.080686
2011	3.588881	4.521696	5.696967	6.52139	8.216418	10.35201
2012	6.208613	7.822344	9.855513	11.28173	14.21406	17.90855
2013	24.95559	31.44201	39.61435	45.34705	57.13357	71.98363
2014	6.057183	7.631555	9.615134	11.00657	13.86737	17.47175
2015	5.966325	7.517081	9.470907	10.84147	13.65936	17.20968
2016	4.70946	5.933534	7.475767	8.557605	10.78188	13.58429
2017	5.22432	6.582216	8.293053	9.493163	11.96061	15.06939
2018	15.53667	19.57494	24.66282	28.23184	35.56981	44.81505
2019	5.209177	6.563137	8.269015	9.465647	11.92594	15.02571

3- The probability of rain per minute was calculated using the software Easy Fit 5.6 and the data in Table 3-2, by selecting the probability for 2, 5, 10, and 25 years, as well as the Gumbel Distribution. Gumbel distribution (EV-1, Generalized Extreme Values Distribution Type-I) is a distribution that is used to simulate the distribution of maximum (or minimum) sample numbers in various distributions. It's a common distribution for estimating IDF curves since it has a high agreement for maximum modelling. Gumbel distribution is almost simple, as it just utilizes extreme events. The maximum numbers indicate when the rains are at their heaviest (Lee, 2005)as shown in Table (3-4).

Table 3-4: Rainfall intensity for four return periods.

Time (Min) / Return period(year)	120	60	30	20	10	5
2	8.16	12.96	20.57	26.95	42.78	67.91
5	15.03	23.87	37.87	49.62	78.77	125.04
10	19.58	31.07	49.32	64.63	102.6	162.86
25	25.32	40.19	63.79	83.60	132.71	210.66

4- The IDF curve for Al-Samawah City is generated using the data in Table 3-3, as illustrated in Figure (3-9).

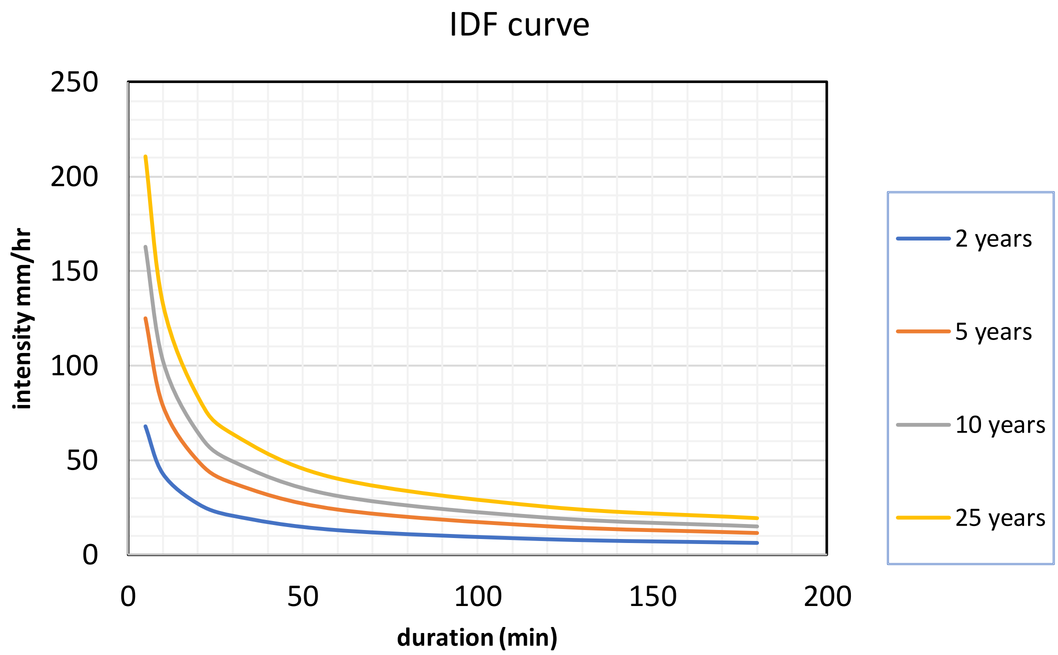


Figure 3-10: Rainfall intensity curve of Al-Samawah City from easy fit 5.6 software.

5- The probabilities of rainfall intensity at different return period (2,5,10, and 25) years within five-minute interval depending on Sherman Equation (3-2) (Nhat et al., 2006b), were found as shown in Table (3-5):

$$i = \frac{a}{(T+b)^c} \tag{3-2}$$

Where (i) represented the rainfall intensity in mm/hr, (a, b, and c) are the constant parameters related to the metrological conditions, and T is the duration in minute.

The following equations were found from Sherman Equation for each return period (years).

Table 3-5: Rainfall intensities (mm/hr) at various frequencies.

Storm Duration (min)	Storm frequency in years				Storm Duration (min)	Storm frequency in years			
	2	5	10	25		2	5	10	25
5	67.9	125	160.4	210.6	65	12.2	22.6	29.4	38.1
10	42.7	78	102.6	132.7	70	11.6	21.5	28.1	36.2
15	32.6	60	78.2	101.2	75	11.2	20.5	26.7	34.6
20	26.9	49.6	64.6	83.6	80	10.6	19.6	25.6	33.18
25	23.2	42.7	55.6	72.04	85	10.2	18.9	24.6	31.8
30	20.5	37.8	49.3	63.8	90	9.88	18.2	23.7	30.6
35	18.5	34.1	44.5	57.5	95	9.5	17.5	22.8	29.5
40	16.9	31.2	40.7	52.6	100	9.2	16.9	22.1	28.5
45	15.6	28.8	37.6	48.6	105	8.92	16.4	21.3	27.6
50	14.6	26.9	35	45.3	110	8.64	15.9	20.7	26.8
55	13.7	25.2	32.9	42.5	115	8.39	15.4	20.13	26
60	12.9	23.8	31	40.1	120	8.16	15	19.5	25.3

3.4 SWMM Simulation Setup

3.4.1 SWMM Model

The SWMM is planning simulation software, analyzing and designing storm network. It was developed in 1971 in the USA by the EPA, (Rossman, 2015).

Rangari et al. (2018) used the SWMM program to simulate quantity and quality of sanitary sewage system during different return period.

Field data for Al-Soob Al-Kabeer's case study were collected from DSD. Pipes, floor areas and inspection manholes, plus service data, green areas, and their features, are among the data. The data was plotted as a bitmap, line, and polygon file in GIS ARCMAP. The network was loaded into the SWMM software once the data had been plotted and corrected.

The SWMM routing module transports the generated runoff through a network of channels and pipes, storage and/or treatment devices, pumps and regulators. The SWMM maintains the flow rate and depth of the flow, runoff volume produced within each sub-catchment, and each pipe's and/or channel's water quality at different times of the simulation. It provides simulations, data input for the study area, and performing hydrological analysis. The program environment allows for simulations of hydraulics and water quantity, as well as examining the outcomes in a variety of forms. Appendix (B) shows input and output data for simulation SWMM. Maps of drainage areas and conveyance systems that are color-coded, profile plots, statistical frequency' graphs and tables, and time series' graphs and tables are among the available tools in the SWMM (Rossman, 2015). GIS 10.4.1 was used as a tool for preparation of input data for the SWMM.

3.4.2 Define Properties for Stormwater Sewer System

3.4.2.1 Pipes Properties

To calculate the slope and determine the flow direction of the fluid, the spatial distribution and upstream and downstream altitudes for each pipe in the model must be provided. The study area's sewer system is made up of circular pipes with diameters ranging from (315mm to 1400 mm) and lengths ranging from (11 m to 530 m). The pipes are made of unplasticized polyvinyl chloride (UPVC). The value of manning roughness coefficient for the PVC pipe (plastic pipe) is 0.009 (McGhee and Steel, 1991).

3.4.2.2 Manholes Properties

The maximum depth, invert level, intake, outflow, and the manhole dimensions are particularly essential information. The study area's stormwater drainage network includes 239 manholes with dimensions of (60cm * 60cm), (35cm * 50cm), and (50cm * 50cm). Aside from that, manholes are crucial in modelling since the SWMM calculates the flood volume in each one. Figure 3.10 depicts manhole ID, whereas Figure 3.11 depicts type of manhole and allocation in the study area. In MS4 of Al-Soob Al-Kabeer District, there are seven varieties of reinforced concrete manholes: the symbols of the manholes were taken as they were from DSD AS, BS, CS, BD, CD, Other, and Special.

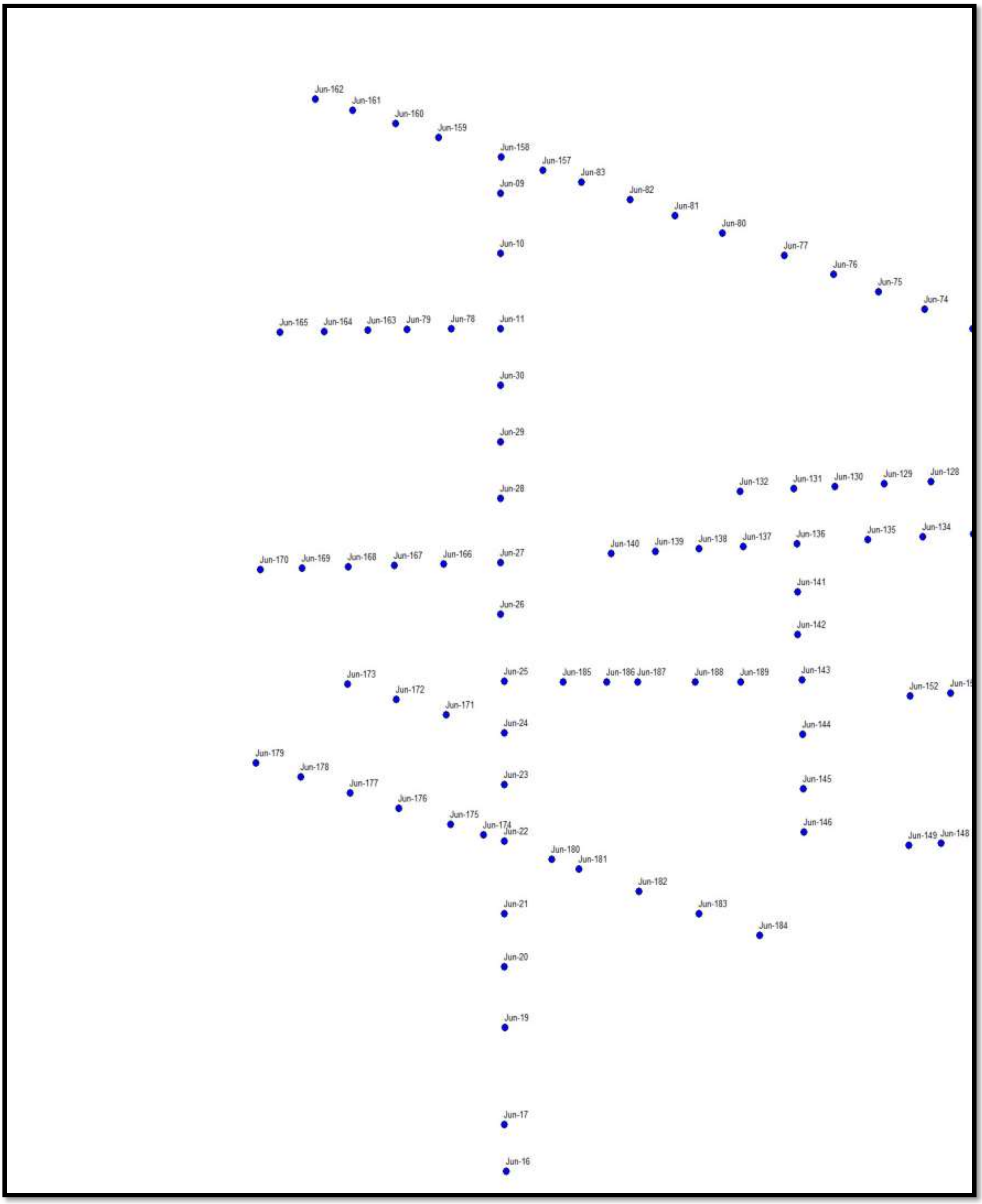


Figure 3-11: ID of manholes for MS4 in Al-Soob Al-Kabeer Quarter (SWMM).

A: Top left view

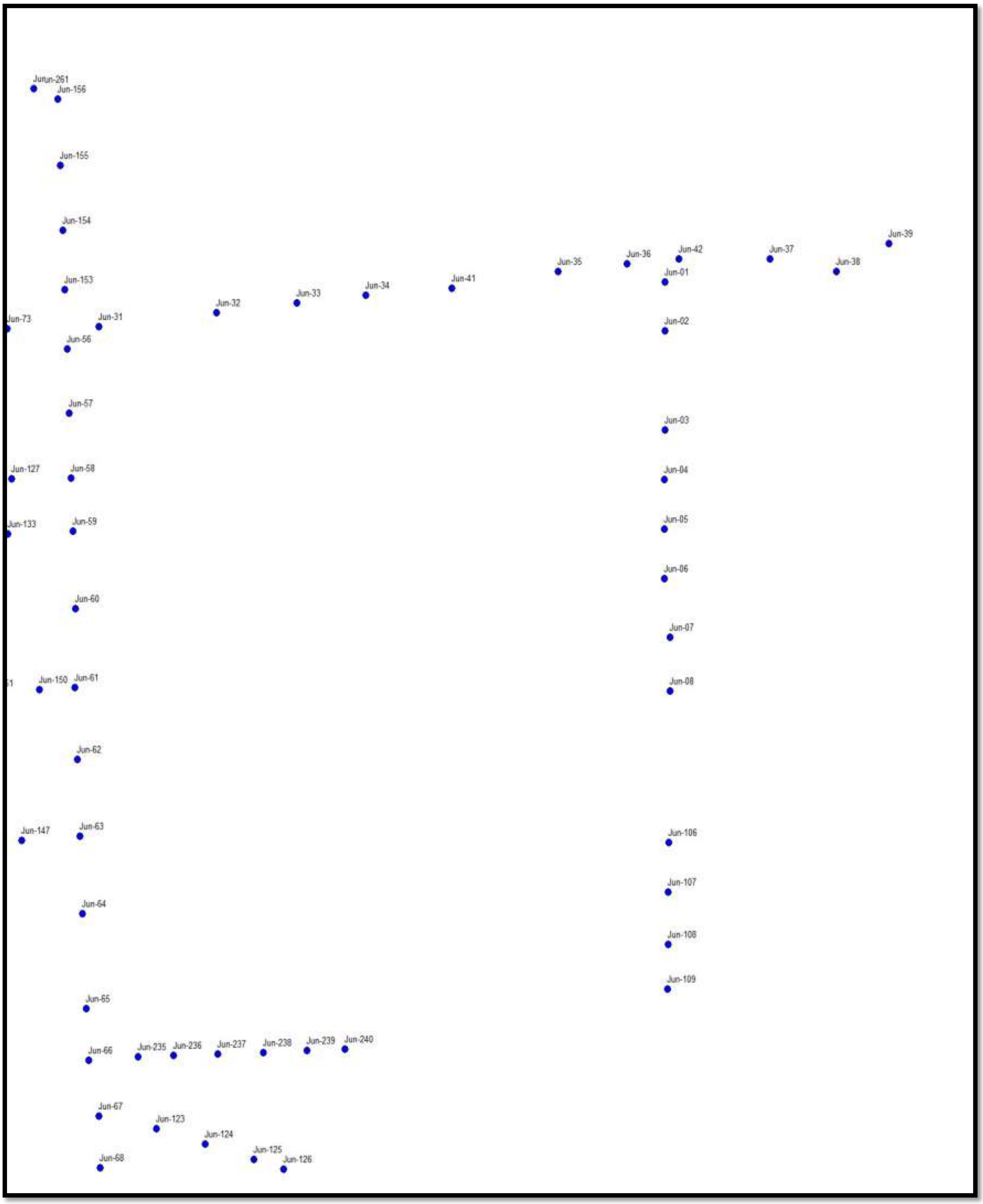


Figure 3-11: ID of manholes for MS4 in Al-Soob Al-Kabeer Quarter (SWMM).

B: Top right view

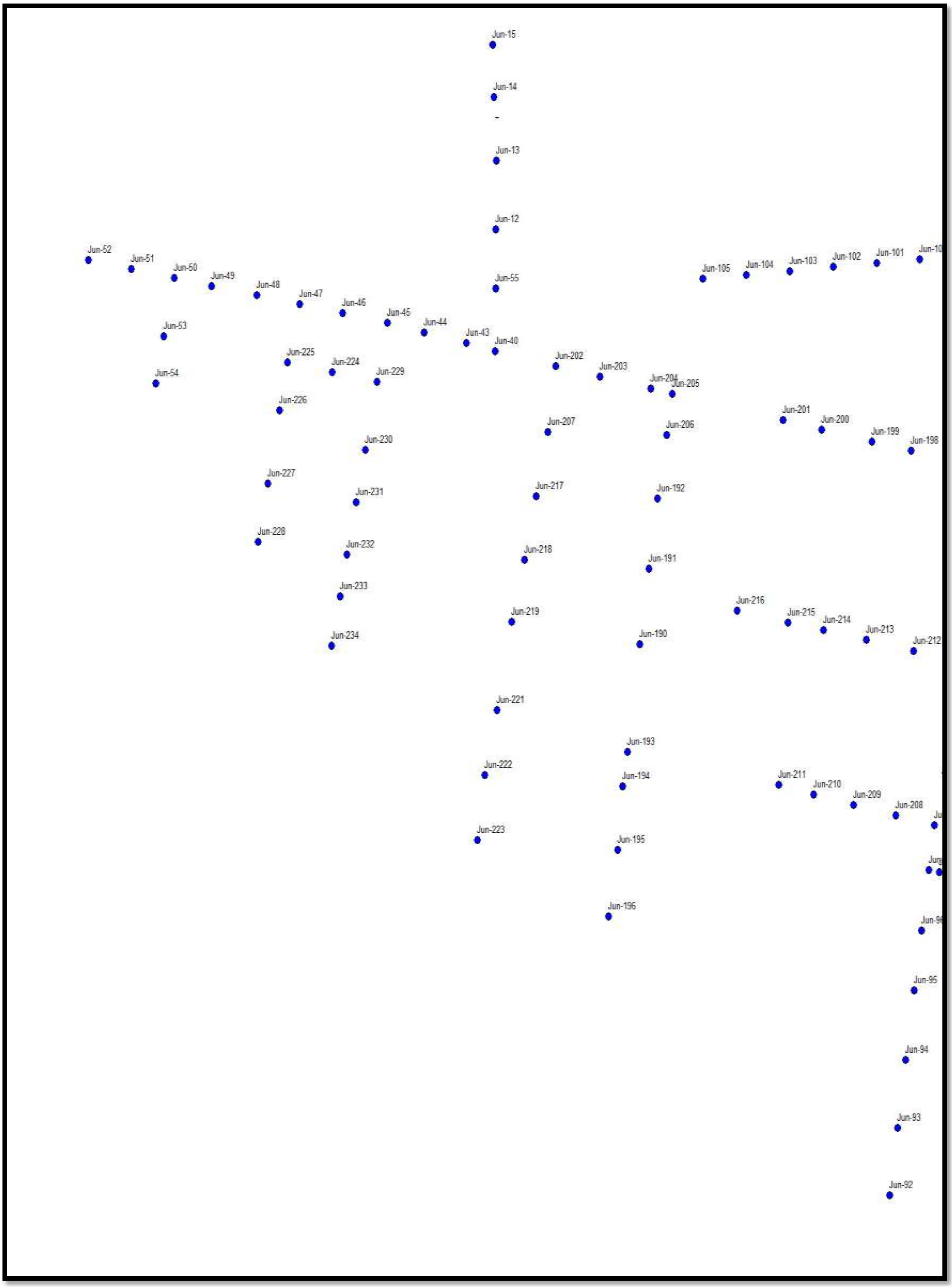


Figure 3-11: ID of manholes for MS4 in Al-Soob Al-Kabeer Quarter (SWMM).

C: Bottom left view

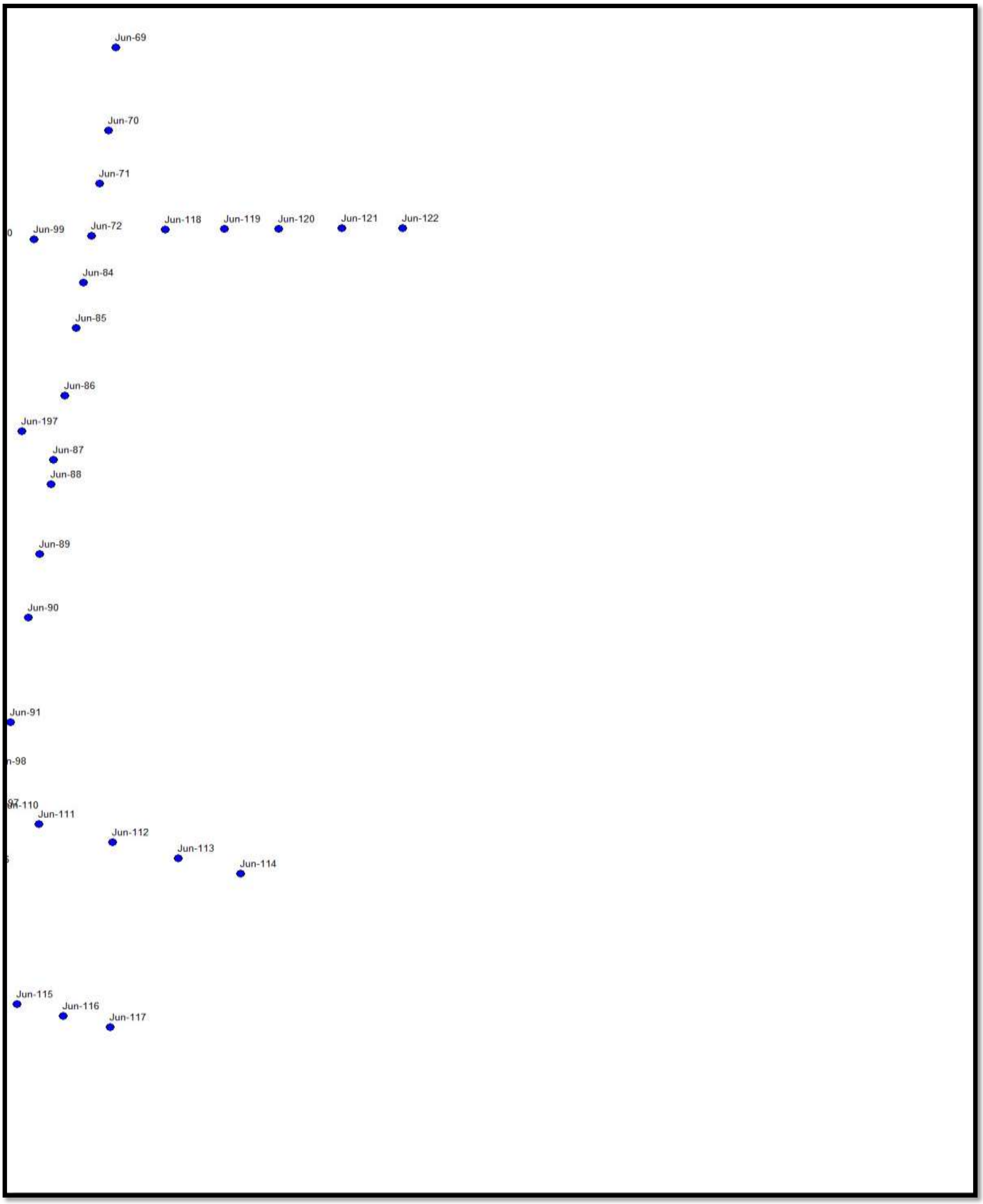


Figure 3-11: ID of manholes for MS4 in Al-Soob Al-Kabeer Quarter (SWMM).

D: Bottom right view

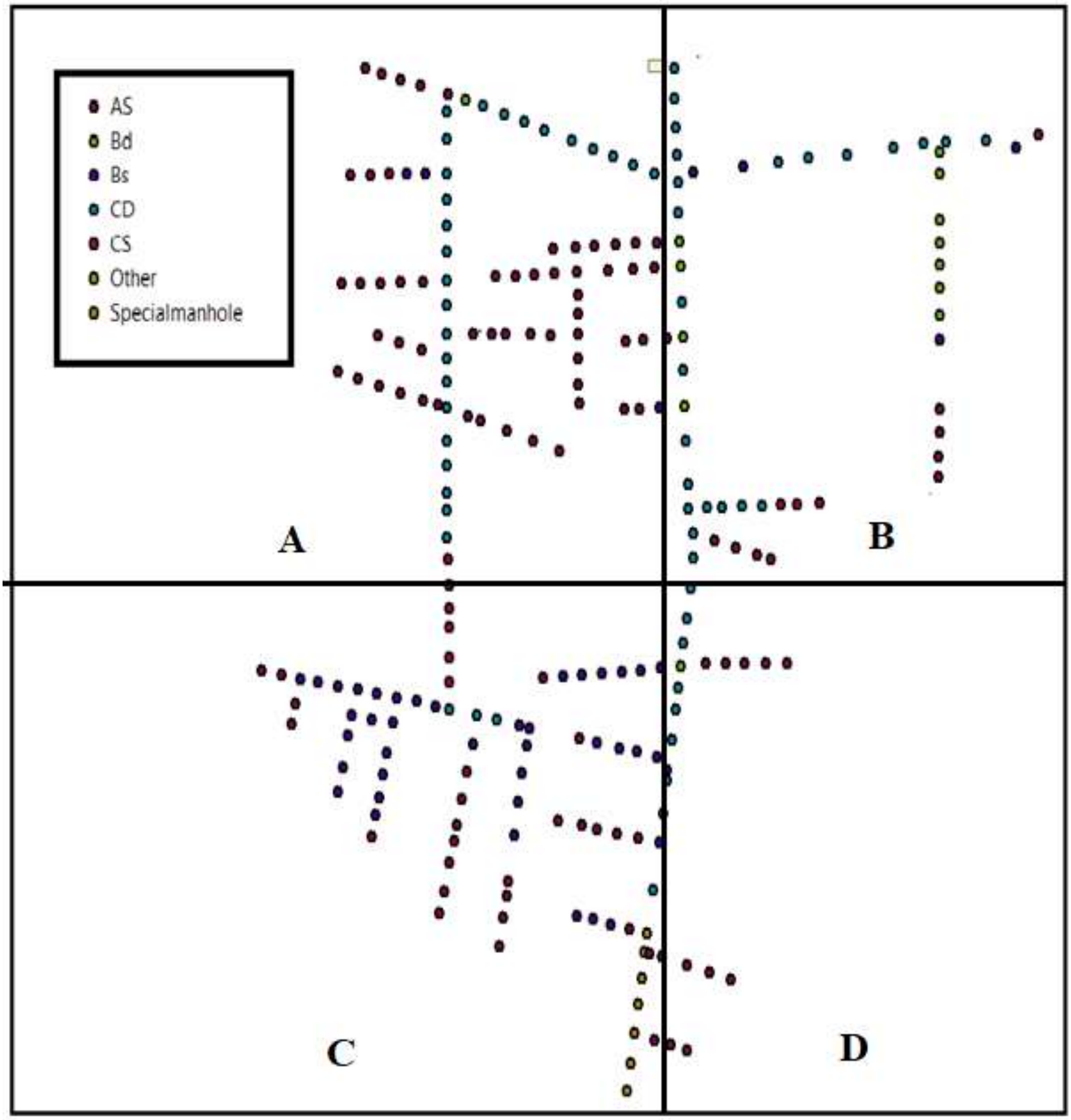


Figure 3-12: The allocation and kinds of manholes in area of the study (GIS) (DSD).

3.4.2.3 Pump Stations

The topography of the city of Al-Samawah is almost characterized by flat area. Therefore, pumping stations are needed in certain locations of the stormwater system to facilitate the flow of stormwater through the sewers. A submersible pumping station is used in Al-Soob Al-Kabeer Quarter stormwater sewer project. Two types of pump stations were used in the design of the stormwater sewer project for Al-Samawah City, these types are submersible and screw pump stations (Samawah sewage project, 2008). The pump station in Al-Soob Al-Kabeer Quarter received the stormwater from six districts in the study area. The station contains five submersible pumps. The pump station of the network contains a single inlet pipe of 1200mm and a single pressurized outlet pipe of 1000mm in diameter. Figure (3.12) shows location and details of the pump station of the MS4 of Al-Soob Al-Kabeer Quarter.

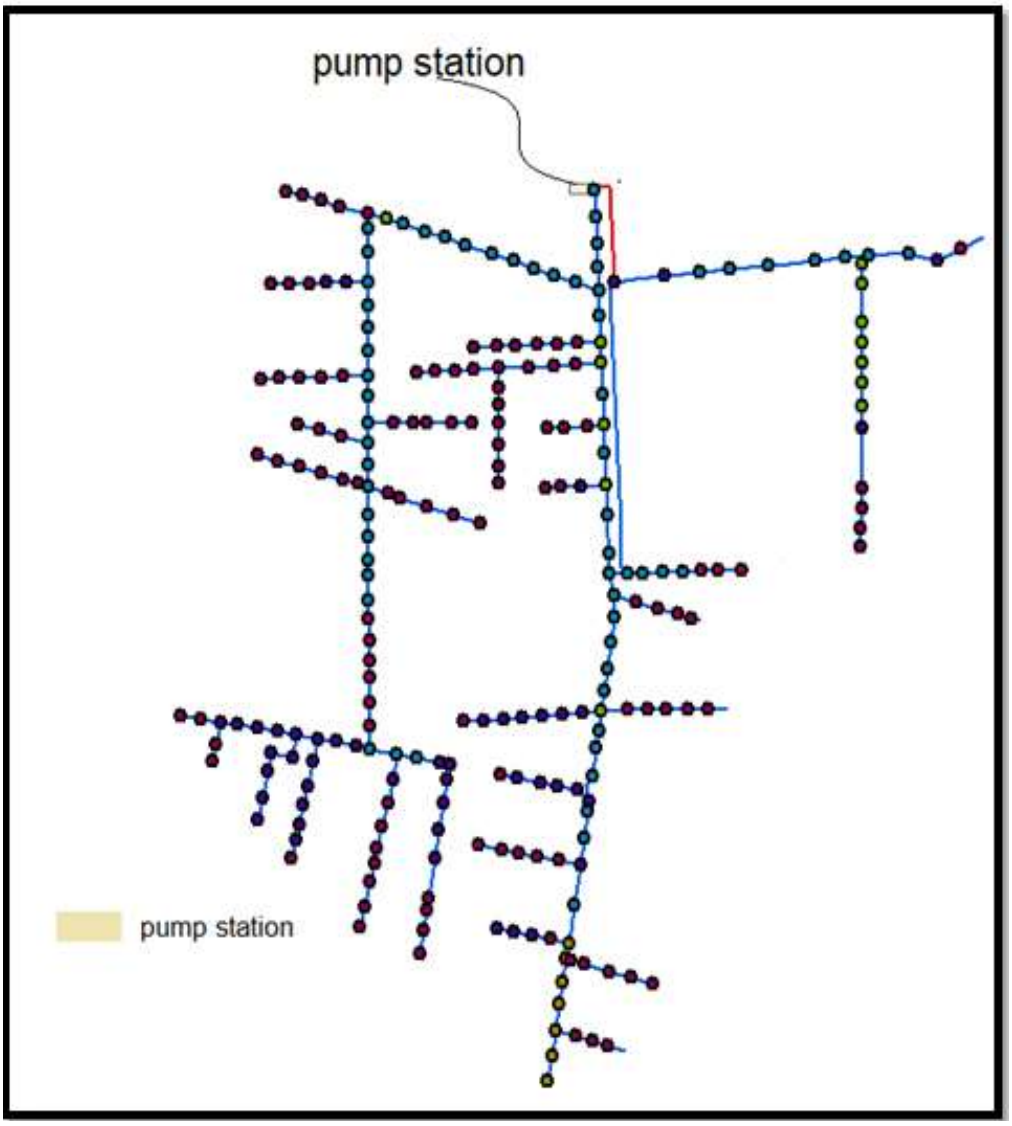


Figure 3-13: Location pump station and details MS4 of Al-Soob Al-Kabeer Quarter.

3.4.3 Physical Characteristics of Sub-catchments

In this study, the sub-catchments, that inflow into the MS4 through the manholes were drawn, and those areas were identified through a field survey of the area of study during the rainfall. Al-Soob Al-Kabeer Quarter's is divided into 28 % pervious surfaces and 72 % impervious surfaces. After components of the study area were defined, a sketch of the study area was drawn in the SWMM as represented in Figure (3-13). After plotting the sub-catchments, the rain gage is entered for each one.

Figure 3-14: Nodes, pipes and sub-catchments that inflow into the MS4 through the manholes.

3.4.3.1 Area and Width

After the aerial image was acquired from Al-Samawah Sewage Directorate, the map of the spatial distribution of sub-catchments was displayed. The area of every sub-catchment was estimated using the measurement tools in the GIS with assistant of the aerial image. The area of the sub-catchment in Al-Soob Al-Kabeer Quarter ranges from 12 m^2 to 73810 m^2. The width was determined by dividing the area by the runoff length, where runoff length is the length of the longest surface path of flow (Shen and Zhang, 2014) although the width of the sub-catchment has no real physical meaning (Cantone and Schmidt, 2011), it is required by the SWMM model inputs. According to definition of (Shen and Zhang, 2014), the estimate of the width was determined by the eq. (3-2):

$$W = \frac{A}{lmax} \quad \text{………………(3-2)}$$

A = the area of the sub-catchment (m^2),

lmax = The maximum runoff length in the sub-catchment

This arbitrary point represents the farthest point to the outlet and should be one of the vertexes of the sub-catchment, and the process was displayed in Figure (3-14). The width of the sub-catchment area was calculated on the basis of the area of sub-catchment by the maximum runoff length and was found to be 0.16–312 m.

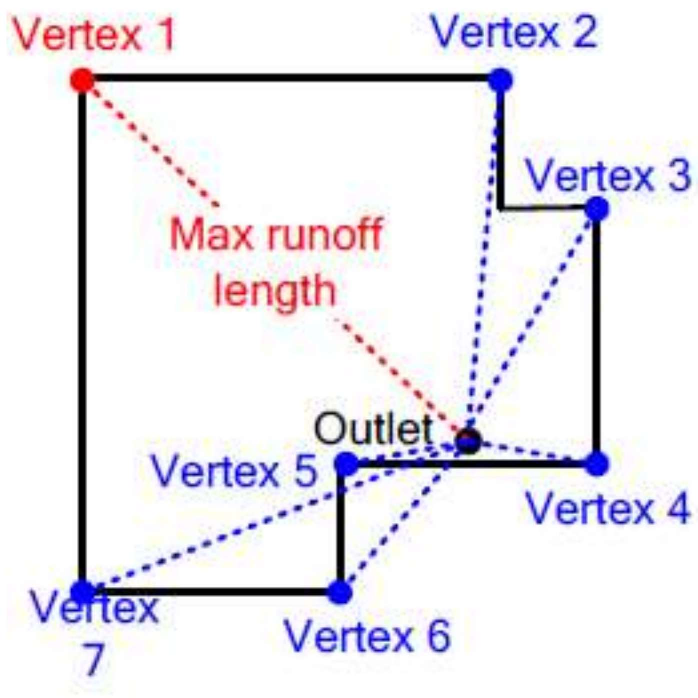


Figure 3-15: The calculation of the maximum runoff length, source (Zhang (2014)).

3.4.3.2 Slope

It is important in determining the stream of runoff over the sub-catchment surface, whose values for every sub-catchment were calculated by dividing the elevation between the manholes in downstream and upstream by the length between them, yielding a range average surface slope of 0.56 %, see Table B-2 in Appendix (B) shows the value of the slope for each sub-catchment.

3.4.3.3 Impervious Percent

Permeable and impermeable surfaces were split into two portions of every sub-catchment. The impermeable area is then split into two halves, one with storage of depression while the other without. The impermeable area only loses rainfall in the storage of water in low areas, while the remain is converting into runoff in the pipe flow. Impervious areas may contain depression storage or do not, so runoff flow from one subarea in a sub-catchment may be routed to the other subarea, or both subareas may drain to the sub-catchment outlet (Rossman, 2010).

The percentage of imperviousness impacts the downstream receiving streams indirectly, as well as it impacts local surface water directly (Chabaeva et al., 2009). By dividing the area of impervious surface to the entire area of the sub-catchment, the percent of perviousness and imperviousness can be calculated from a land use map enhanced by urban planning (DSD, 2016). In the studied area, the impervious percent for each sub-catchment ranges from 70% to 95%.

3.4.3.4 Manning Roughness

It is effectively useful hydrologic modelling parameter, whose values for an individual sub-catchment are determined by knowing the kind of land use. Appendix-C shows the manning roughness value for several overland types based on (McCuen, 2004). This study was based on a Manning roughness of 0.015.

3.4.3.5 Depression Storage Depth

The depression storage depth for impervious and pervious areas is an essential characteristic, its values are shown in Table (3-6). For each sub-catchment of impervious surface, the depression depth is 2 mm and pervious surfaces depression depth is 5mm.

Table 3-6: The depression storage depth for different land use, (Rossman, 2010).

Depression storage depth	
Impervious surfaces	0.05 - 0.1 in
Lawns	0.1- 0.2 in
Pasture	0.2 in
Forest litter	0.3 in

3.4.3.6 Rain Gage

Rain Gages collect rainfall data for one or more sub-catchment regions in the studied area. Rainfall data can be retrieved from an external file or a user-defined time series. It accepts a variety of popular rainfall file formats as well as a standard user-defined format (Rossman, 2010). The rain gauge's main input properties are listed below:

1. Rainfall data types (e.g., volume or intensity)
2. Time intervals (e.g., 5-minutes by hours, etc)
3. Source of rainfall data (by importing an external file or inserting a time series).
4. The name of the rainfall data source.

In this study, the names were selected to be associated with the return period, and they were inserted as: Rain Gage-02, Rain Gage-05, Rain Gage-10, and Rain Gage-25.

3.4.4 Simulation Options

The SWMM is a simulation model for dynamic rainfall–runoff. Wherever possible, it was based on mass and momentum conservation concepts, as well as water balance (Rossman, 2010).

All the computational practices of the hydrology and hydraulic process that effect in the study area are described as following:

3.4.4.1 System Flow Routing

Flow routing is the technique of identifying the time and amount of any event according to actual or hydrographs at one or more locations upstream sites in a stormwater sewer system. The SWWM solves the equations of momentum and mass conservation for open channel conduits using three levels of sophistication (Rossman, 2010). The amount of sophistication with which the equations should be solved using the SWMM software can be determined by the modeler. The three stages of flow routing in the SWMM software are kinematic, stable, and dynamic flow routing. In this study dynamic flow routing was employed as it is capable of calculating channel storage, backwater, pressured flow, entrance/exit losses, flow reversal, and dynamic flow routing. As a result, it takes into account the most theoretically precise implication. In dynamic routing, the full flow closed pipe indicates pressurized flow; when the water level increases above the maximum level, flooding occurs.

3.4.4.2 Infiltration Method

Infiltration method is commonly used in soil science and hydrology which is known as the process by which water on the ground enters the soil as input to the SWMM. Because it is a physics-based model, unlike purely empirical models like the Curve Number or Horton techniques, Green and Ampt's methodology was utilized to estimate infiltration in this study. In many cases, this approximate solution is suitable at representing the true infiltration into soils. For a given soil, three parameters are required to use the equation; k, ψ and ϕ. These parameters are specified in Table (3-7) (Rossman, 2015). Parameters of Green and Ampt's can be defined as:

K: Saturated hydraulic conductivity (mm/hr).

Ψ: Suction head (mm).

FC: Infiltration capacity (mm/hr).

Φ: Porosity of soil.

Table 3-7: Parameters of infilteration based on Green and Ampt's methodology for different soil type, (Rawls et al., 1983).

Soil texture class	K	Ψ	Φ	FC	WP Wilting point
Sand	4.74	1.93	0.437	0.062	0.024
Loamy Sand	1.18	2.4	0.437	0.105	0.047
Sandy Loam	0.43	4.33	0.453	0.19	0.085
Loam	0.13	3.5	0.463	0.232	0.116
Silt Loam	0.26	6.69	0.501	0.284	0.135
SandyClayLoam	0.06	8.66	0.398	0.244	0.136
Clay Loam	0.04	8.27	0.464	0.31	0.187
Silty Clay Loam	0.04	10.63	0.471	0.342	0.21
Sandy Clay	0.02	9.45	0.43	0.321	0.221
Silty Clay	0.02	11.42	0.479	0.371	0.251
Clay	0.01	12.6	0.475	0.378	0.265

The parameters of Green-Ampt equations embedded in the SWMM modelling. These parameters' values, according to (Rawls et al., 1983), are dependent on the type of soil in the area under study. The kind of soil employed in this study is silty clay, and the appropriate parameters were used in all sub-catchments, according to (Rawls et al., 1983), with the values displayed in Figure (3-15).

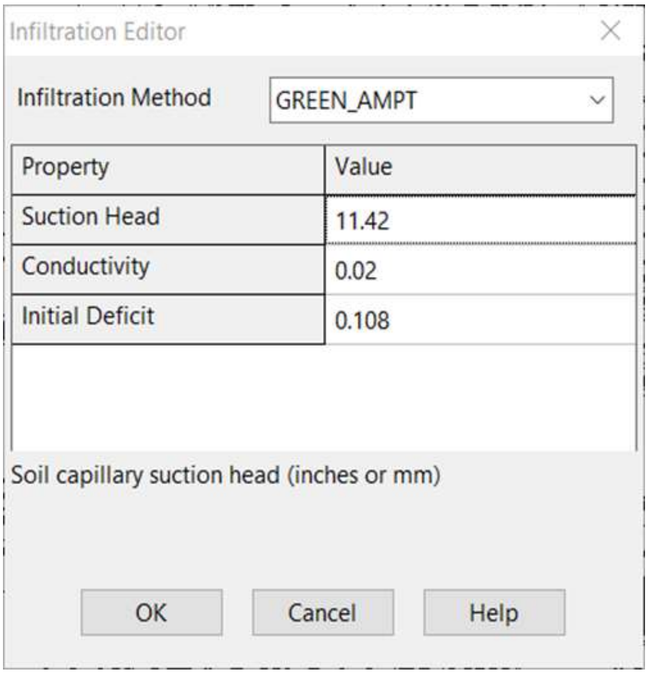


Figure 3-16: Parameters of Green-Ampt method for each sub-catchment.

3.5 Model Validation and Calibration for Quantity

Model calibration is the process of using a model to anticipate output data and comparing it to actual measured data. To calibrate the model, this study compared the modeled (predicted) discharge from the SWMM simulation to the design discharge in Al-Soob Al-Kabeer Quarter. Design flow discharge of the MS4 was provided from (DSD). To lessen the discrepancy between modeled and observed discharges, the procedure of trial-and-error was performed manually for the model calibration by modifying sub-catchment properties. These influential variables include the impervious percent factor, Manning's roughness coefficient, and the breadth of sub-catchments.

The goodness-of-fit was evaluated by comparing the differences between modeled and observed discharges using statistical measures proposed by (Zwain et al., 2020), such as normalized mean square error (NMSE) and correlation coefficient (R). The NMSE calculates the mean relative scatter, which accounts for both systematic and unsystematic (random) errors. It guards against over- or under-prediction by models and emphasizes the scatter in the complete data set of actual discharges seen. Ideal fit's NMSE value is near to 0 and is restricted by 1.5. The Correlation Coefficient (R), commonly known as the linear correlation coefficient, is a mathematical formula for calculating the intensity and direction of a two-variable relationship. R is assigned a value such that -1 <R <+1. The + and - marks signify positive and negative linear correlations, respectively. In equations (3-3) and (3-4), the statistical parameters employed are listed (Zwain et al., 2020):

$$\boldsymbol{NMSE} = \frac{\overline{(\mathrm{CO}-\mathrm{CP})^2}}{\overline{COCP}} \tag{3-3}$$

$$\mathbf{R} = \frac{\overline{(C_O-\overline{C_O})(C_P-\overline{C_P})}}{\sigma_{C_O}\sigma_{C_P}} \tag{3-4}$$

Where $\boldsymbol{c_o}$ represents the designed volume flow rate, $\boldsymbol{c_p}$ represents the modeled volume flow rate, $\boldsymbol{\overline{c}_o}$represents the average designed flow rate data, $\boldsymbol{\overline{c}_p}$ represents the average of simulated data. σ_C is the standard deviation over dataset.

3.7 Low Impact Development Simulation

The following steps were used for LID design:

The LID is assigned to each sub-catchment that is inflow runoff into the MS4 using the sub-catchment's LID control editor as shown in Figure (3-20). Rain garden is the LID that was chosen in this study. Rain gardens combine storm runoff management with landscaping. GIs allow stormwater to be penetrated into groundwater, evaporated into the atmosphere, and/or absorbed by plants, lowering CSOs and improving water quality. They are primarily used to restore the natural evapotranspiration and infiltration hydrology of a site. Rain gardens may also contribute to increased environmental, social, and economic advantages by providing green spaces in cities, it can be installed at walkway corners of the street's intersections (Alyaseri et al., 2021). Rain gardens are made up of a depressed area with vegetation, an engineered soil mixture, and sand or gravel drainage bed that meets the reuse water requirement. Different layers are included in the designed soil mixture to optimize infiltration and plant growth (Rossman, 2015). Figure 3-21 shows the diagram of rain garden as presented by (Zhang et al., 2020).

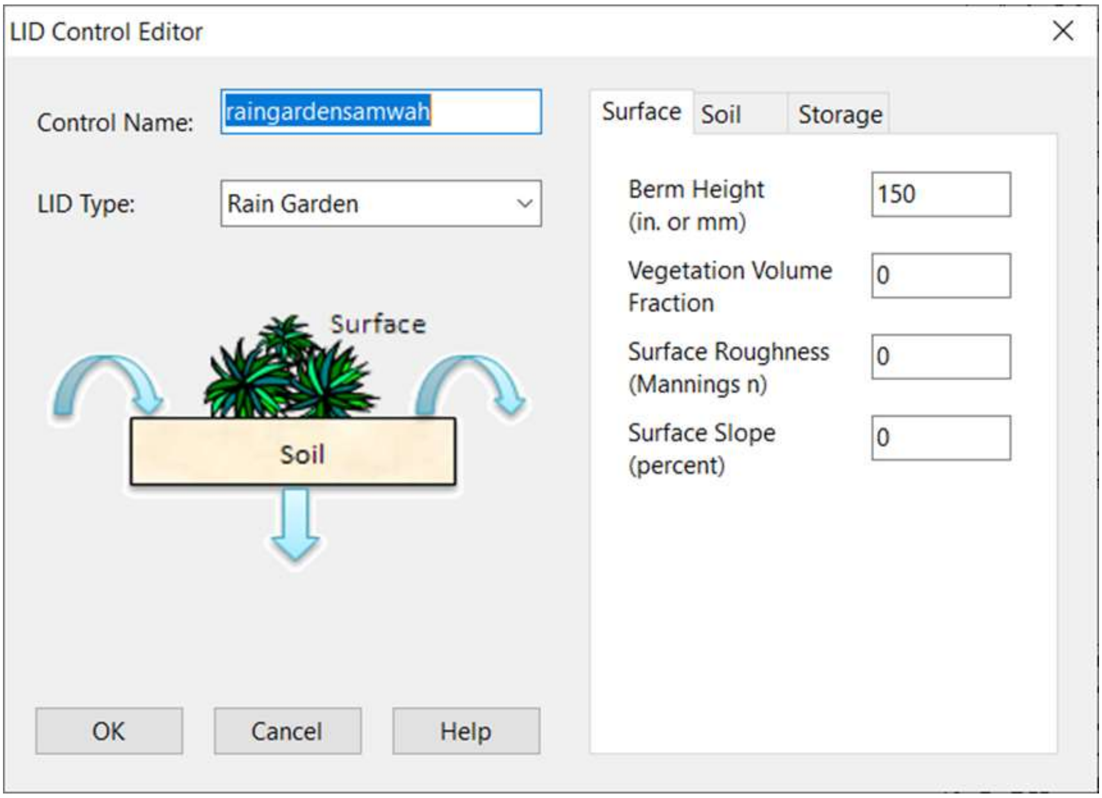


Figure 3-17: Editor LID

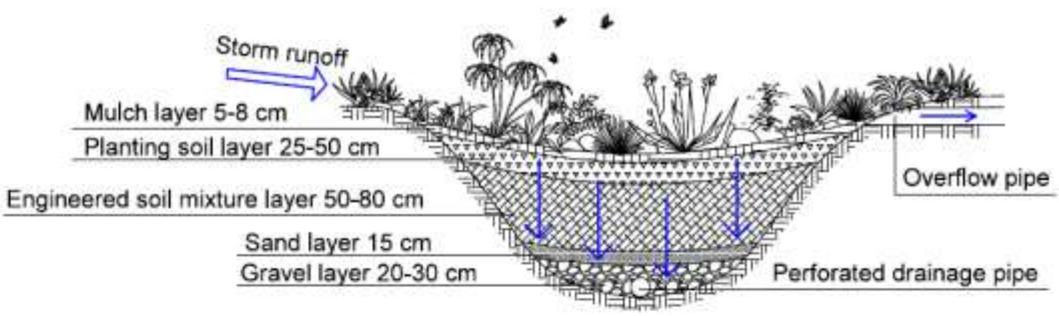


Figure 3-18: General structure of rain garden design, (Zhang et al., 2020)

1. In this study the rain garden configuration settings are an equally significant input condition according to (Zhang et al., 2020) and the SWMM user's manual (Rossman, 2015) as shown in Table (3-9).

Table 3-9: Rain Garden parameters, (Zhang et al., 2020)

Surface	Berm height	Vegetation volume fraction	Surface roughness	Surface slope
	150 mm	0	0	0
Soil	Soil thickness	Soil porosity	Field capacity	Wilting point
	700mm	0.453	0.19	0.085
	Conductivity	Conductivity slope	Suction head	
	10.92 mm/hr	50	109.2 mm	
Storage	Storage thickness	Void ratio	Seepage rate	Storage clogging factor
	300 mm	0.75	10.92 mm/h	0
Drain	Flow coefficient	Flow exponent	Offset height	
	0	0.5	6mm	

2. The LID for each sub-catchment can be added, as shown in Figure (3-17). Sub-catchment number 216 represents a sample of the sub-catchments in the study area, as shown in Figure (3-17). In this study, the chosen LID takes up 7% of each sub-catchment (Zhang et al., 2020) as a model for this study. The impervious area of each sub-

catchment is treated by a rain garden, which treats 40% of the impervious area in each sub-catchment (Rossman, 2015).

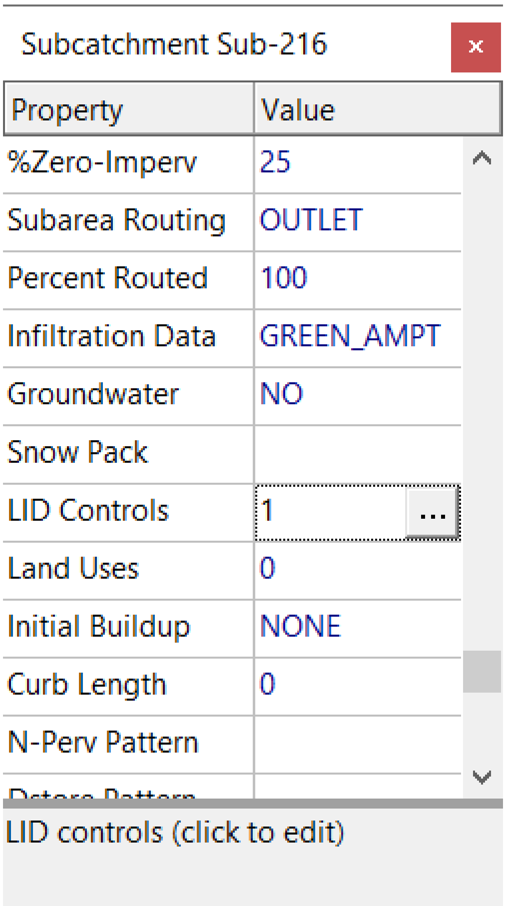


Figure 3-19-A: Properties of the sub-catchment number 216.

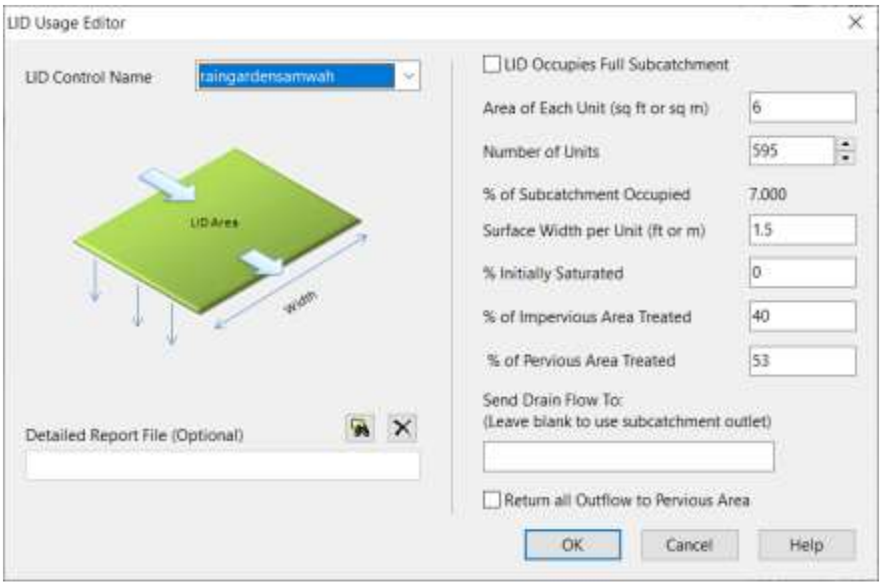


Figure 3-19-B: The LID usage editor to the sub-catchment number 216.

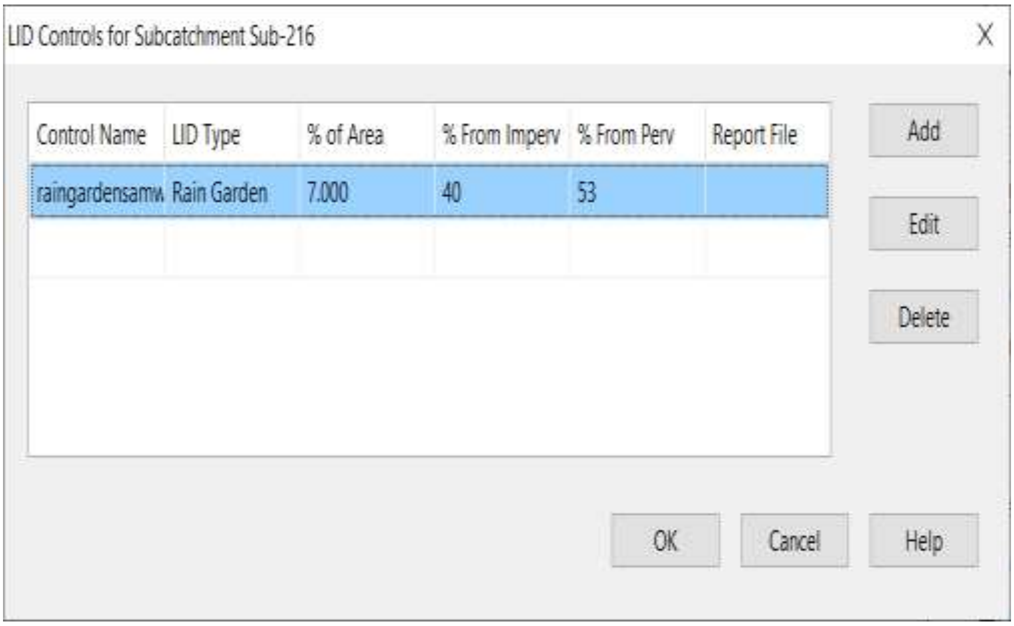


Figure 3-19-C: Add LID controls to the sub-catchment number 216.

3.8 Summery

The model was used is the MS4 of Al-Soob Al-Kabeer in Al-Samawah City, using SWMM model under different scenarios. The hydraulic data and meteorological data were clarified, also the impacting of the urbanization and climate change. The characteristic of the study area and the method of calculate the intensity of rainfall were explained. The validation and calibration were indicated, also the parameters of the LID model that was used to solve the flooding problem.

CHAPTER FOUR

Results and Discussion

4.1 Introduction

This chapter represents the results of analysis obtained from the SWMM modeling of stormwater system during rainfall events in Al-Soob Al-Kabeer Quarter. The results were evaluated for:

1- The amount of stormwater flow during wet weather without the LID and without increasing diameter of the trunk sewer system.

2- Propose a solution to reduce flood events via:

   I. Using one of the LID techniques.

   II. Increasing the diameter of main pipe line.

4.2 Performance of the SWMM Model

Modelled discharge and designed discharge were utilized to calibrate the model and to assure that results from the SWMM model are reliable. Changes in influential sub-catchment parameters were used to manually calibrate the SWMM model. For a given time period, to compare the modelled flow to a designed flow, the goodness-of-fit test was used. After calibration, corrected sub-catchment characteristics were used to validate the MS4's performance in Al-Soob Al-Kabeer Quarter and to further model it. Firstly, an investigation to study the relation between design discharge and predicted discharge from the SWMM modelling of the MS4 for 184 pipes was conducted. Secondly, the NMSE and R indicators were determined in order to assess the performance of the SWMM model. Table (4-1) and Figures 4-1, 4-2, 4-3, and 4-4 demonstrate the outcomes of these interactions.

Table 4-1: The SWMM model validation data.

Parameter's validation	Normalized Mean Square Error (NMSE)	Correlation Coefficient (R)
Ideal fit	0	1
Validation limits / Return period	≤1.5	>0.8
2	1.16	0.944
5	0.998	0.957
10	0.97	0.961
25	0.93	0.966

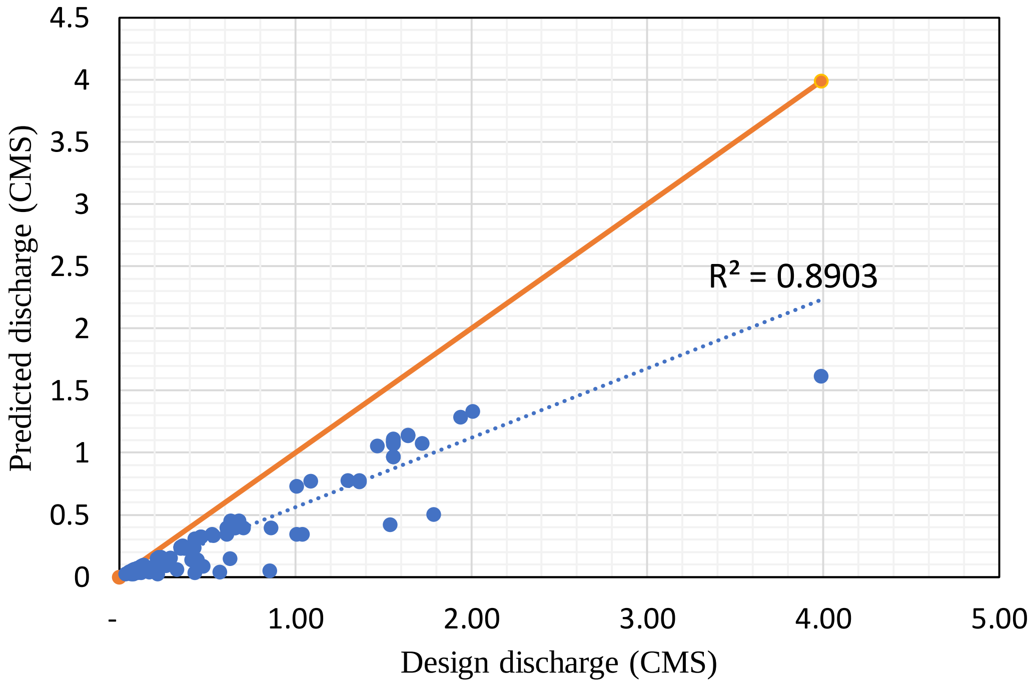


Figure 4-1: Relationship between the design discharge and the maximum predicted discharge derived by the SWMM utilizing precipitation intensity with a two-years recurrence interval (R^2).

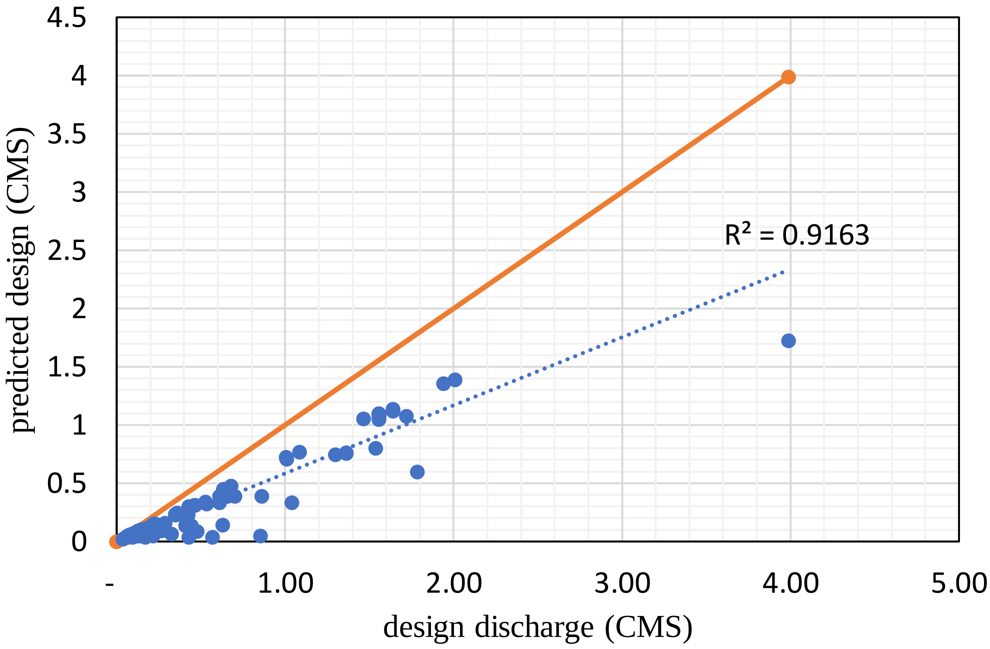


Figure 4-2: Relationship between the design discharge and the maximum predicted discharge derived by the SWMM utilizing precipitation intensity with a five-years recurrence interval (R^2).

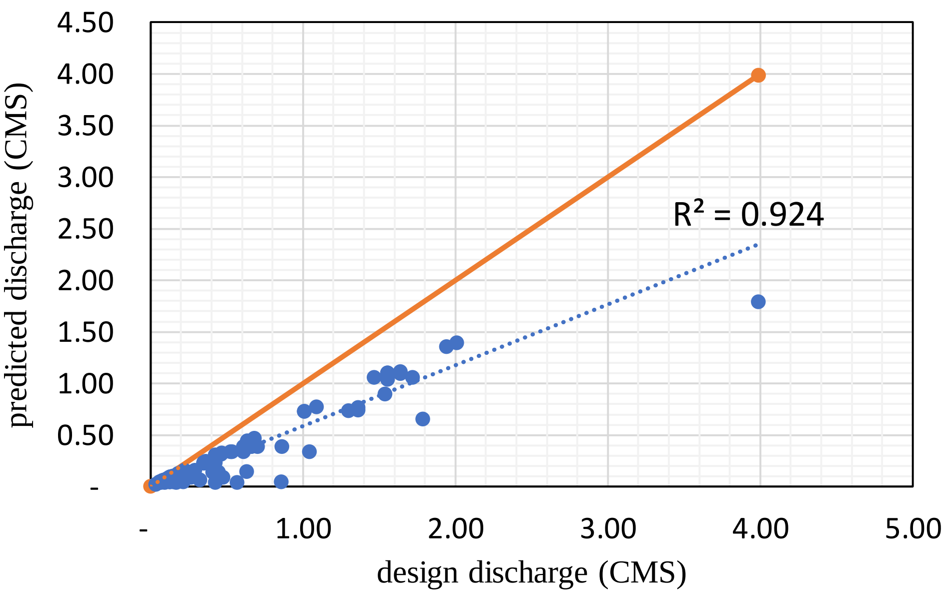


Figure 4-3: Relationship between the design discharge and the maximum predicted discharge derived by the SWMM utilizing precipitation intensity with a ten-years recurrence interval (R^2).

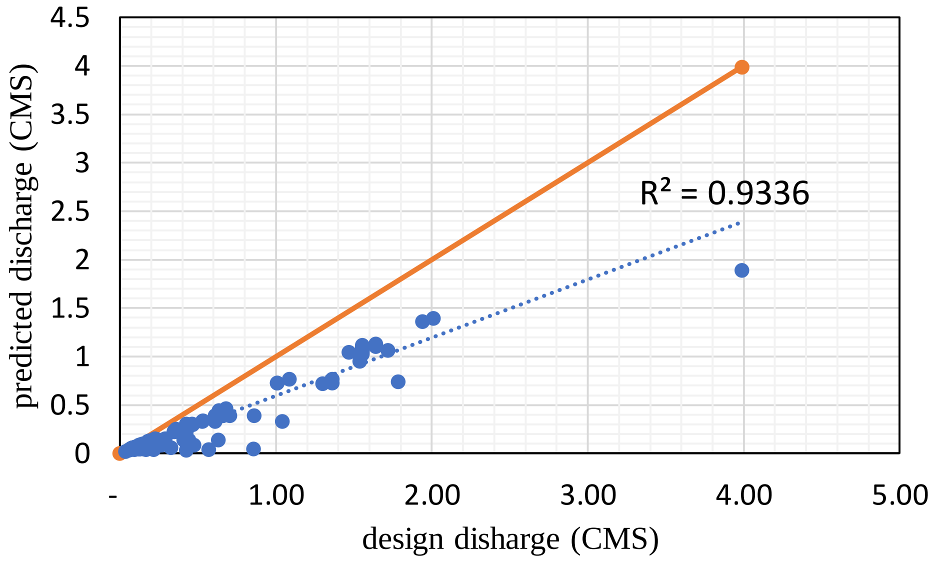


Figure 4-4: Relationship between the design discharge and the maximum predicted discharge derived by the SWMM utilizing precipitation intensity with a twenty-five-years recurrence interval (R^2).

The NMSE and R indicators were all below the setting limitations, as indicated in Table (4-1), implying that the SWMM model's derived data can be trusted. Also, Figures (4-1 to 4-4) all have high R^2 values which indicate good correlation between the design and predicted discharge values.

The rainfall intensities with varied return periods were used to calculate the range of the NMSE value (1.16 to 0.93), the findings show that the rainfall intensity with a 25-year return period model offered the lowest NMSE value. According to the NMSE data, the SWMM shows the best performance when using rainfall intensity with a 25-year return period. For the various return durations, the R value ranges from (0.944 to 0.966). The results showed that the SWMM modeling for rainfall intensity with a 25-year return period produced the best results, with maximum flow rates in pipes generated from the model being near to the maximum design flow rates.

The performance of the SWMM was found to be reliable and acceptable with the three indicators applied. The obtained results are consistent with findings from other researches, see, for example, (Mohammed et al., 2020), (Zaini et al. (2015), Hendrawan (2020), Badieizadeh (2016), Taatpour et al. (2019), and Kourtis et al. (2017) (Mohammed et al.,.z

4.3 The impact of Rainfall Intensity on Sewer System

Al-Soob Al-Kabeer Quarter and the MS4 were evaluated both before and after increasing diameter of trunk sewer line and adding the LID technology using the SWMM simulation. According to (Hassan et al., 2017) manhole flooding discharge is separated into five stages, depending on total volume flooded manhole and depth of runoff surface. In this study the depth of runoff surface was calculated by dividing the volume of manhole to the sub-catchment area and comparing with the standard depth of street (13cm). Appendix D shows the result of depths (cm) and the discharge of (Jun-22) that was chosen for distributing:

- The stage 1: There will be no flood and there will be no discharge between 0 and 0.001 m^3/s;
- The Stage 2: Minor flooding, with discharges ranging from 0.001to0.01m^3/s;
- The stage 3: Moderate flooding, with discharges ranging from 0.01 to 0.05 m^3/s;
- The stage 4: Severe flooding, with discharges ranging from 0.05 to 0.1 m^3/s;
- The stage 5: Extreme floods, with discharges exceeding 0.1 m^3/s.

4.3.1 Stormwater Quantity in Wet Weather Flow without Treatment

The influence of rainfall events was assessed by surface runoff of stormwater in the region into the sewer system which is caused by different intensities of rainfall in the area under study. When it rains, the quantity of water in the sewers rises due to the entry of rainfall into the system, creating overflows in some manholes.

Total flooded volume at outlet, the maximum discharge in sewer, and number of flooding manholes were calculated using the SWMM and shown in Table (4-1) for 2, 5, 10, and 25-year return periods and 2 hours of rainfall duration. Since, the rainfall intensity, observed from the IDF curve, has lasted for two hours and it has decreased after two hours and remained at the same level, therefore time duration was taken as two hours in the simulation. According to Hassan et al. (2017), when the return duration grows, the intensity of rainfall increases as a reaction to rainfall events which leads to significant stormwater intake to the system. Total flooded volume at outlet, the maximum discharge in sewer and number of flooding manholes can all be used to illustrate this phenomenon. For example, the greatest flowrate was 0.201 m^3/s, the total flooded volume at outlet was 1446 m^3, and the number of flooding manholes was 24 after 2 years (10% of total manholes). In comparison, the maximum flowrate, total flooded volume, and number of flooding manholes were all significantly increased over a 25-year period, reaching 2.696 m^3/s, 13731 m^3, and 100 (41.8% of total manholes), respectively.

Table 4-2: Effect of rainfall events on the MS4 of Al-Soob Al-Kabeer Quarter.

Return period (year)	During period (hr)	Maximum flowrate (m^3/s)	Total flood volume (m^3)	Number of flooded manholes	Percentage of flooded manholes%
2	2	0.207	1446	24	10
5	2	0.372	2678	76	32
10	2	1.205	8676	95	40
25	2	2.696	13731	100	42

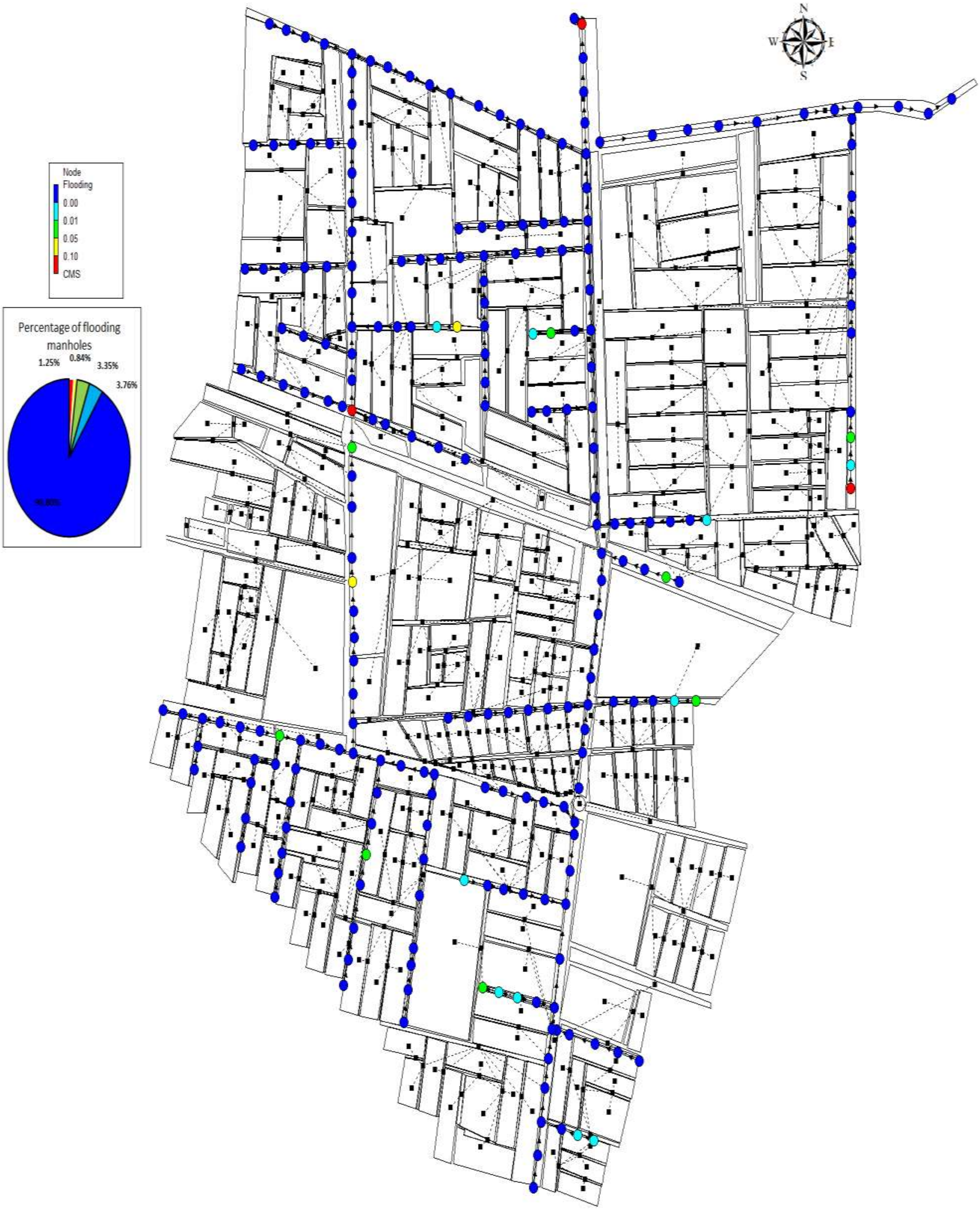


Figure 4-5: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 2- years' return period and an average intensity of rainfall of 17 mm/hr.

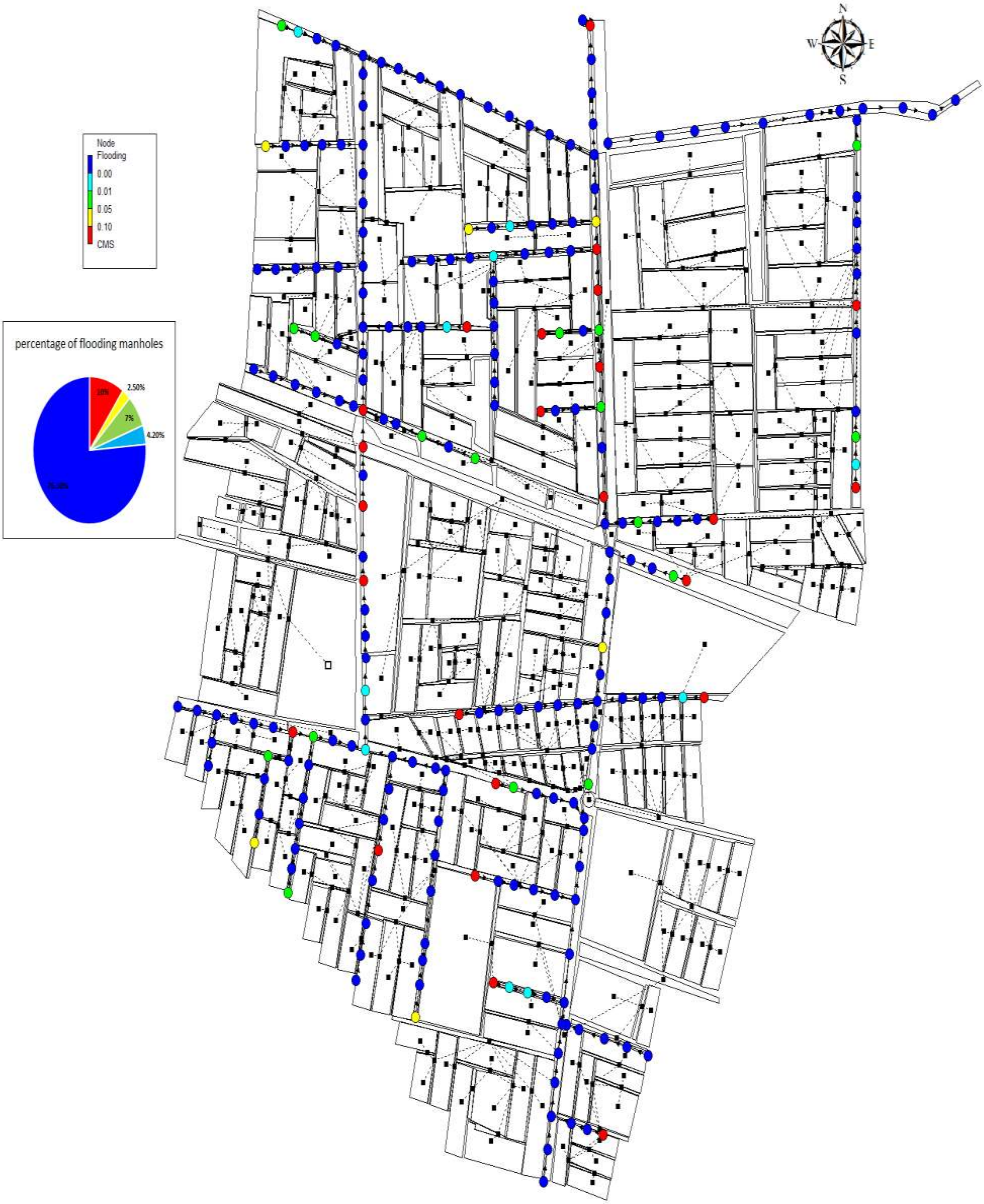


Figure 4-6: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 5 years return of period and an average intensity of rainfall of 33 mm/hr.

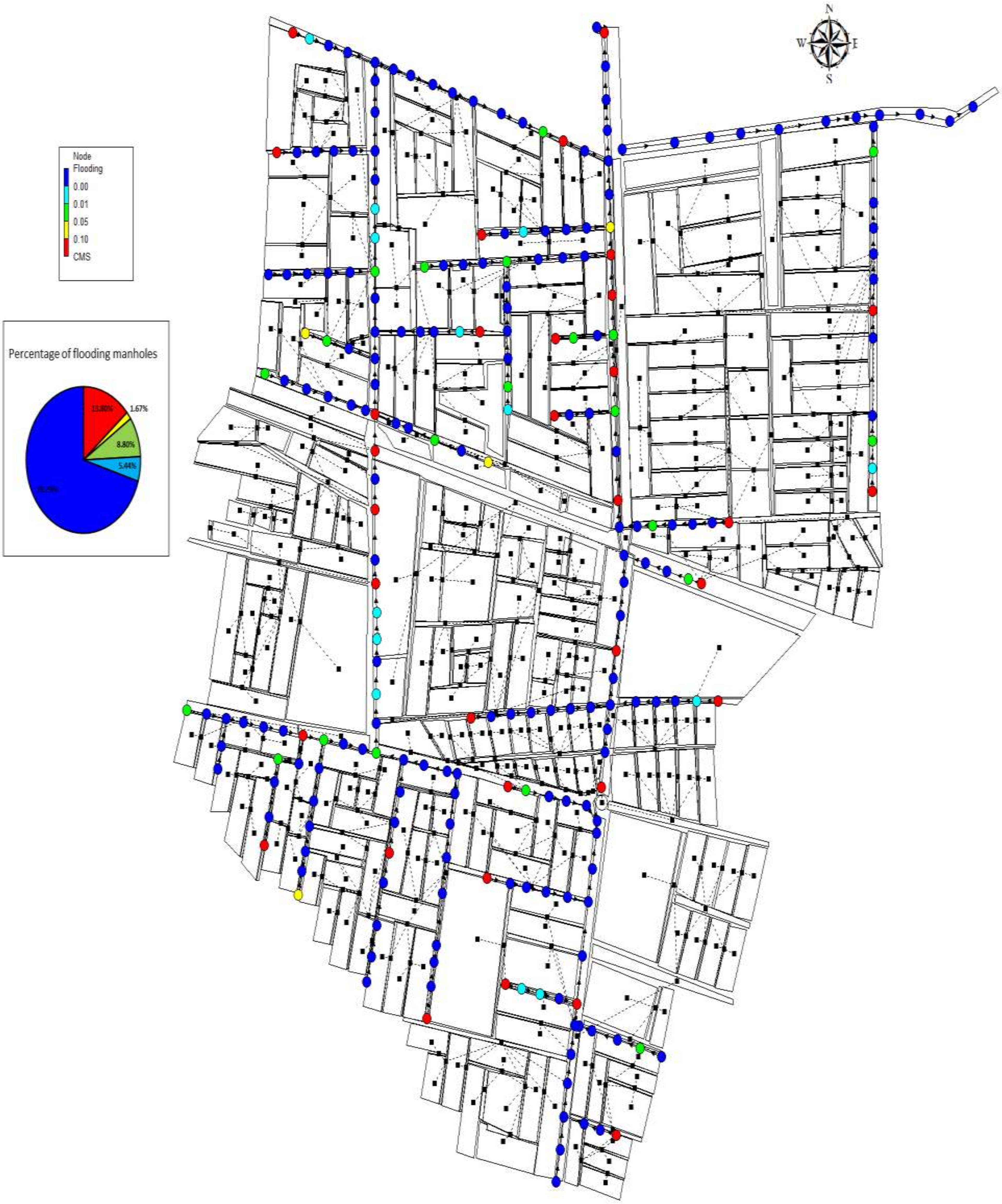


Figure 4-7: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 10 years return of period and an average intensity of rainfall of 42mm/hr.

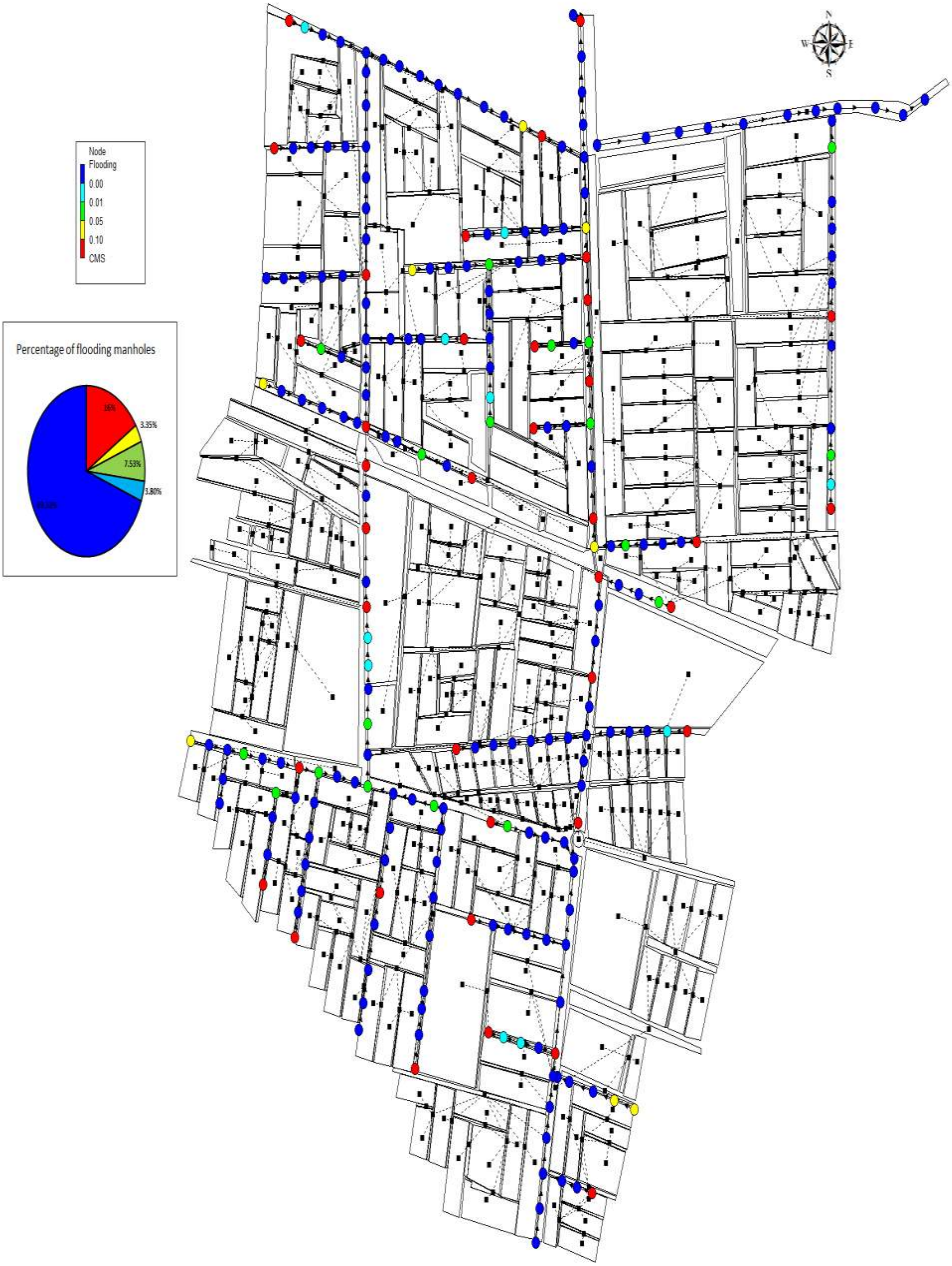


Figure 4-8: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 25- years return of period and an average intensity of rainfall of 55 mm/hr.

Rainfall occurrences caused an increasing in the overflow of surface runoff, thus the MS4 of the studied area suffer from flooding. Figure (4-5) to Figure (4-8) analyze Al-Soob Al-Kabeer Quarter MS4 over 2, 5, 10, and 25 years return periods, as well as at the ending of two hours of rainfall duration.

Figure 4-5 depicts the flooding in the sewer system and the sites of flooding manholes caused by surface runoff inflow over a two-year period with an average intensity of rainfall of 17 mm/ hour. The figure shows that 10% of the manholes would be flooded. Stage 1 (no flooding) was found in 90.8% of the manholes, while stage 2 (low flooding) was found in only 3.76% of the manholes, stage 3 (medium flooding) was found in 3.35% of the manholes, stage 4 (high flooding) was found in 0.84% of the manholes, and stage 5 was found in only 1.25% of the manholes (very high flooding). Manholes near the main sewer were the first to overflow, making this area highly exposed to flooding caused by stormwater overflow.

The flood continues to spread and become worse as the rainfall increases. Figure 4-6 shows the rainfall intensity at 33 mm/hr during a five-year period. Apparently, 76.3% of the manholes had stage 1 (no flooding), very light flooding had only 4.2% of the manholes in stage 2, 7% of the manholes had stage 3 (medium flooding), heavy flooding in stage 4 had 2.5% of the manholes, and stage 5 of the extreme flooding had only 10% of the manholes (very high flooding). The flooding manholes were on the main line sewer as well as the trunk sewer prior to the pump station, which led to an intercepting sewer. This finding agrees with Hassan et al. (2017) who found that if the rate of rainfall increased to 15mm/hr for 5-return periods, 32% of manholes would be flooded.

This occurrence was further observed in Figure 4-7, where flooded manholes were sited at the sewer main and trunk, and the manholes with no flooding in stage 1 had 70.3% of manholes, manholes in stage 2 of very low flooding had 5.44% of manholes, moderate flooding in stage 3 had 8.8% of manholes, the heavy flooding of stage 4 had 1.67% of manholes, and 13.8% of stage 5 with extreme flooding were noticed over a return period for 10-year with the rate of rainfall of 42 mm/ hrs.

The return period was then changed to 25 years, and the rainfall intensity was increased to 55 mm/hours. Figure 4-8 depicts a significant rise in flooding, with 69.32% having no flooding level (1), 3.8% having very light flooding (stage 2), 7.53% having medium flooding (stage 3), 3.35% having strong flooding (stage 4), and 16% having extremely high flooding (stage 5), Table 4-2 represents the percentages of flooding manholes in the five stages.

Table 4-3: The stages of flooded manholes in each return period.

Stages of flooding manholes / Return period (years)	St.1%	St.2%	St.3%	St.4%	St.5%
2	90.8	3.76	3.35	0.84	1.25
5	76	4.2	7	2.5	10
10	70.29	5.44	8.8	1.67	13.8
25	69.32	3.8	7.53	3.35	16

*St.1: Stage 1 (No flooding)
*St.2: Stage 2 (Light flooding)
*St.3: Stage 3 (Medium flooding)
*St.4: Stage 4 (Heavy flooding)
*St.5: Stage 5 (Extreme flooding)

Flooding manholes were found in almost all sewers of the main and trunk lines. According to Rabori et al. (2018), the peak flow of the pipes grew as the return period lengthened, while flooding spread from a few sites to many more. The MS4 in Al-Soob Al-Kabeer Quarter fails to cope with the huge amount of water in this study. The flooded manholes achieved very high flooding in the stage five with the range (1.25% to 16%). of return period 2, 5, 10, 25 years, as shown in Table 4-2

4.3.2 Stormwater Quantity in Wet Weather Flow with the LID

The obtained results from the simulation were compared before and after adding the LID. Results showed positive effect of the proposed solution on the network. Table (4-4) demonstrates the efficiency of the planned MS4 with an LID added, including maximum sewer flowrate, total flooding volume, and number of flooded manholes for return periods of 2, 5, 10, and 25 years, where the rain period was 2 hours.

Table 4-4: Effect of rainfall events on Al-Soob Al-Kabeer Quarter MS4 with the LID.

Return period (year)	Duration (hr)	Maximum flow rate CMS	Total flood volume (m^3)	Number of flooded manholes	Reduction of manholes flooding %
2	2	0.139	998	15	37.5
5	2	0.318	2292	70	8
10	2	1.105	7959	90	5.3
25	2	2.372	11967	96	4

In comparison to the real scenario without adding the LID, as shown in Table (4-2), the reduction of 33% in maximum flowrate, 31% in total flooded volume, and 37.5% in flooding manholes were accomplished during a 2-year return period, as displayed in Table (4-4).

During return period of 5-years, a decrease by 14.5% of the maximum sewer flowrate was achieved, and the total flooding volume had decreased by 14.4% while the numeral of flooding manholes had declined to 7% of flooded manholes.

During return period of 10-years, a decrease by 8.3% of the maximum sewer flowrate was achieved, and the total flooding volume had decreased by 8.26% while the numeral of flooding manholes had declined to 5.3% of flooded manholes.

Even with high rainfall intensity and a 25-year return time, the highest flowrate reduced by 12%, the overall flooding volume decreased by 13%, and the numeral of flooding manholes decreased to 4% of flooded manholes. As a result, the suggested approach by adding the LID to the MS4 has significantly enhanced it, and has a good performance and can be used in a real-scenario setting.

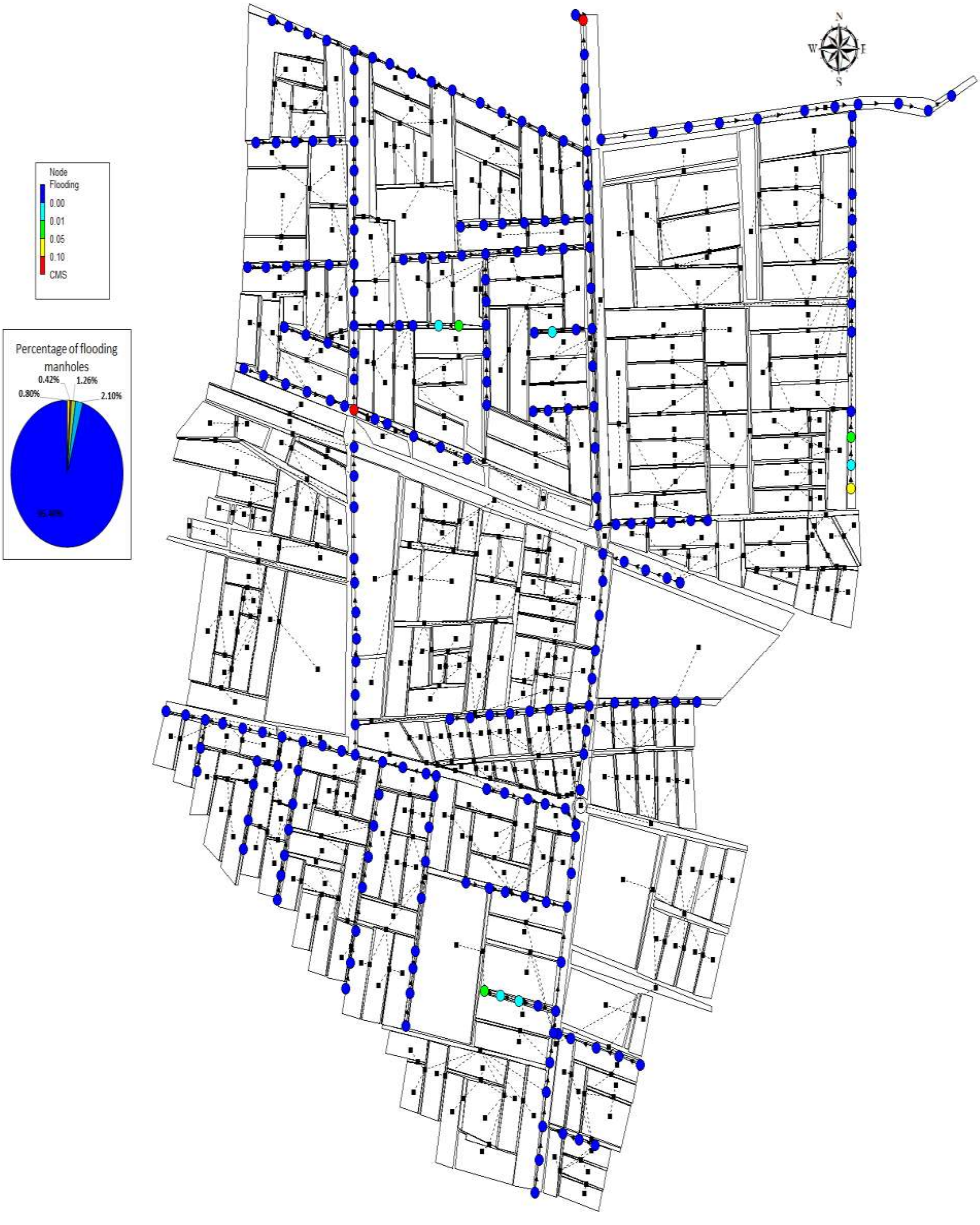
Figures from (4-9 to 4-12) examine Al-Soob Al-Kabeer Quarter MS4 after return periods of 2, 5, 10, and 25 years, respectively, within 2 hours of rainfall duration and the inclusion of the LID. Figure (4-9) demonstrates the a 2-year return period that in stage 2, the ratio of flooding manholes dropped from 3.76% to 2.1 %, while the ratio in stage 3 decreased from 3.35% to 1.26%, in stage 4, the ratio decreased from 0.84% to 0.42%, and stage 5 declined from 1.25% to 0.8% with intensity of rainfall 17 mm/hrs. Unflooded manholes climbed from 90.8 % to 95.4 % in general. Figure (4-10) illustrates that the ratio of flooding manholes in stage 2 dropped from 4.2% to 3.77% and stage 5 decreased from 10% to 7% over a 5-year period with an intensity of rainfall of 33 mm/hrs, while the percentage of unflooded manholes climbed from 76% to 78%. Figure (4-11) shows that, over a 10-year period with rainfall intensity of 42 mm/hrs, flooded manholes in stage 2 decreased from 5.44% to 4.6%, flooded manholes in stage five decreased from 13.8% to 11.7%, and unflooded manholes climbed from 70.3% to 82%.

Figure (4-12) illustrates that when the return period was changed to 25 years with a rainfall intensity of 55 mm/hrs, the proportion of flooding manholes in stage three declined from 7.53% to 7%, in stage five from 16% to 12%, and the percentage of unflooded manholes climbed from 69.3% to 70%, Table 4-4 shows the changes in percentages of flooding manholes.

Table4-5: The stages of flooded manholes in each return period after adding the LID.

Stages of flooding manholes / return period (years)	St.1% Before LID	St.1% After LID	St.2% Before LID	St.2% After LID	St.3% Before LID	St.3% After LID	St.4% Before LID	St.4% After LID	St.5% Before LID	St.5% After LID
2	90.8	↑95.4	3.76	↓2.1	3.35	↓1.26	0.84	↓0.42	1.25	↓0.8
5	76	↑78	4.20	↓3.8	7.00	7.11	2.50	3.77	10	↓7
10	70.29	↑82	5.44	↓4.6	8.8	↓7.11	1.67	4.2	13.8	↓11.7
25	69.32	↑70	3.80	7%	7.53	↓7	3.35	4	16	↓12

*St.1: Stage 1 (No flooding)
*St.2: Stage 2 (Light flooding)
*St.3: Stage 3 (Medium flooding)
*St.4: Stage 4 (Heavy flooding)
St.5: Stage 5 (Extreme flooding)
*↑: Increased, and ↓: Decreased. The color cells are the important changes for the study area.



4-9: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow two years return of period and an average intensity of rainfall of 17 mm/hr with adding the LID.

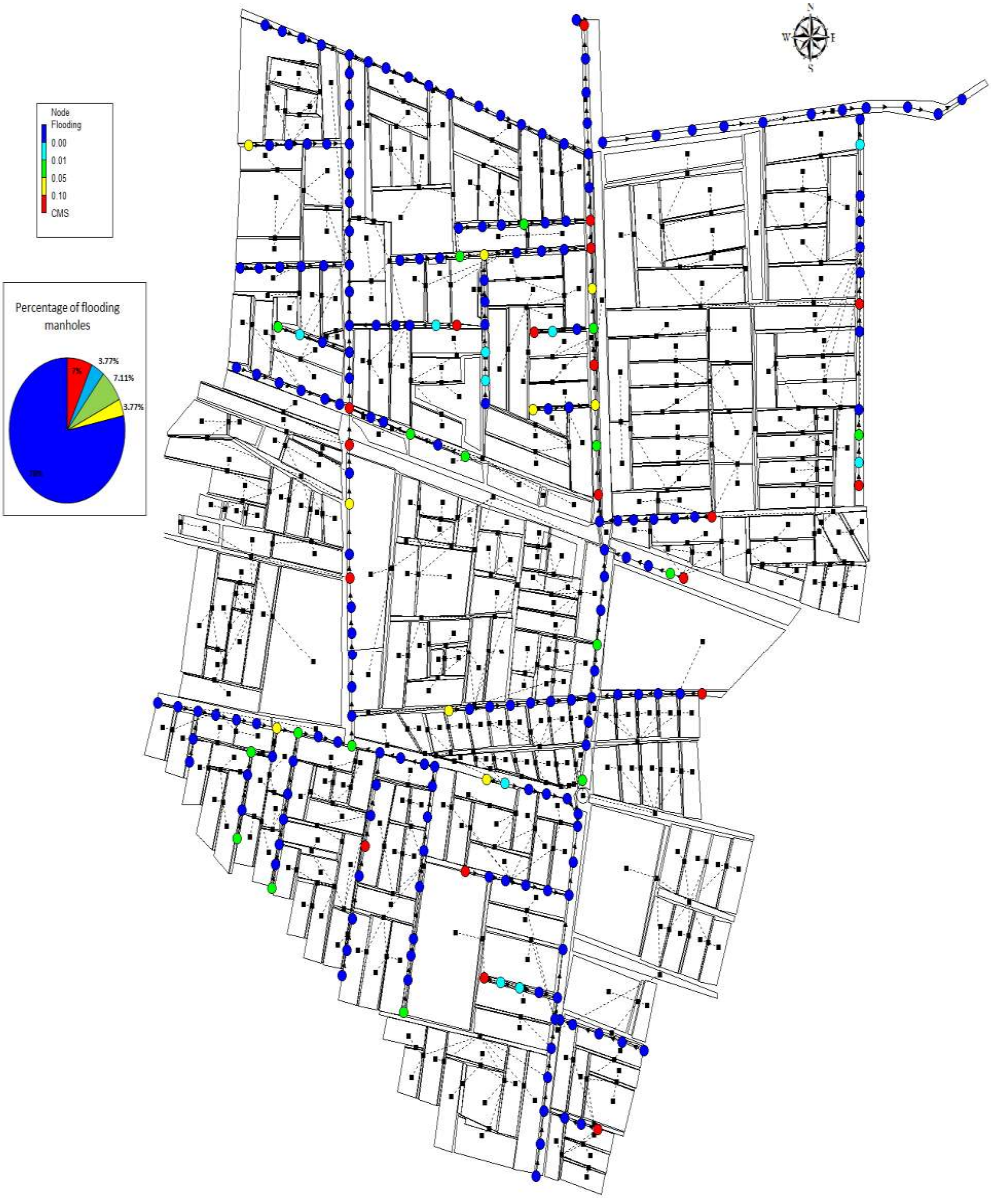


Figure 4-10: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow five years return of period and an average intensity of rainfall of 33 mm/hr with adding the LID.

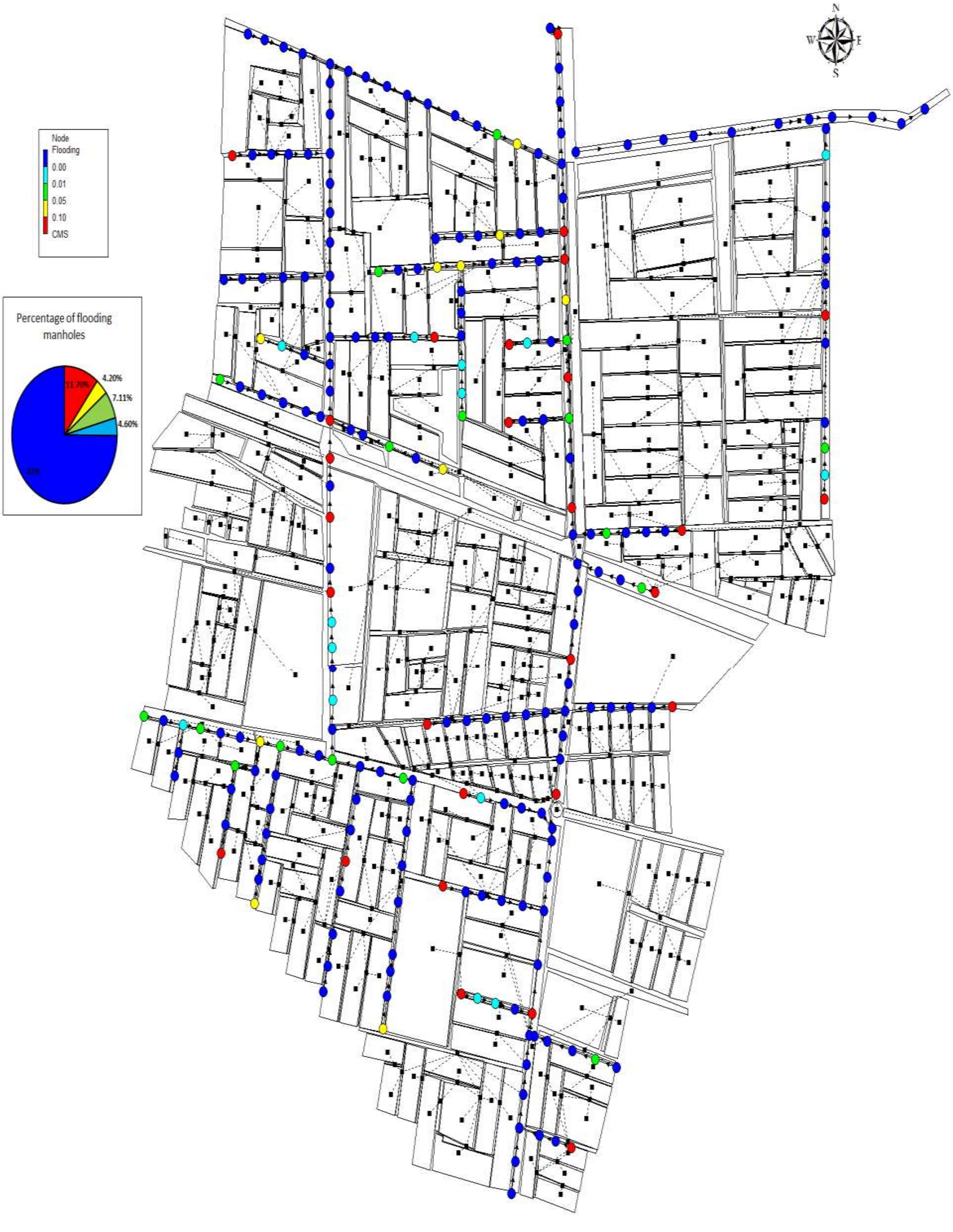


Figure 4-11: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow ten years return of period and an average intensity of rainfall of 42 mm/hr with adding the LID.

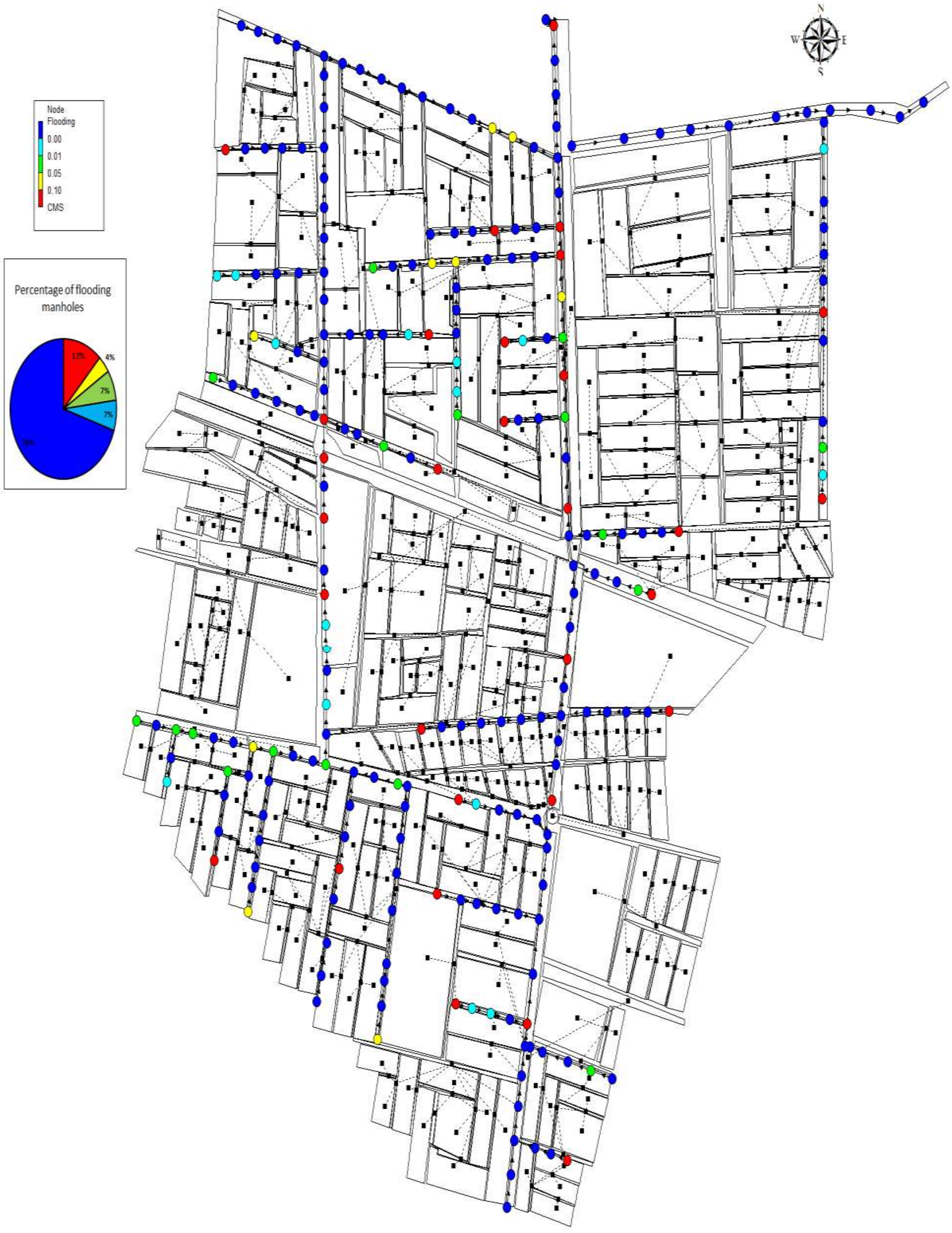


Figure 4-12: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow twenty-five years return of period and an average intensity of rainfall of 55 mm/hr with adding the LID.

These findings are consistent with previous studies; for example, Zhang et al. (2020) proposed the addition of rain gardens to MS4 to reduce total runoff volume by 46.56x10^6L over 5 years, reducing the maximum number of flooding nodes to 87, demonstrating that rain gardens handle rainfall effectively over a five-year return period in the NakagyoWard area of Kyoto in Japan. Bai et al. (2019) used the LID facilities (green roof, permeable pavement, concave greenbelt, and rain garden) in Sucheng district, Suqian City, China, and this study confirmed its effectiveness in using the LID facilities by comparing four scenarios in which the proportion of area of one facility is changed while the areas of the other facilities remain constant. Their findings revealed the reduction rates of runoff volume and peak flow changed from 30.4 % and 27.1 % to 44.1% and 40.3% for rain garden scenarios with varying proportions.

4.2.2 Stormwater Quantity in Wet Weather Flow with Increasing the Diameter of Trunk Pipe Line

The adjustment of pipe diameter scenario was used in Li et al. (2010) study among other methods for controlling overflow in sewer system. The trunk pipelines, chosen in this scenario, collect rainwater from studied area. The scenario entails changing the diameters of pipes in some of the MS4 pipelines, as illustrated in Figure (4-13), where some pipes with diameters of 1.2m and 1.4m were altered to 1.5m.

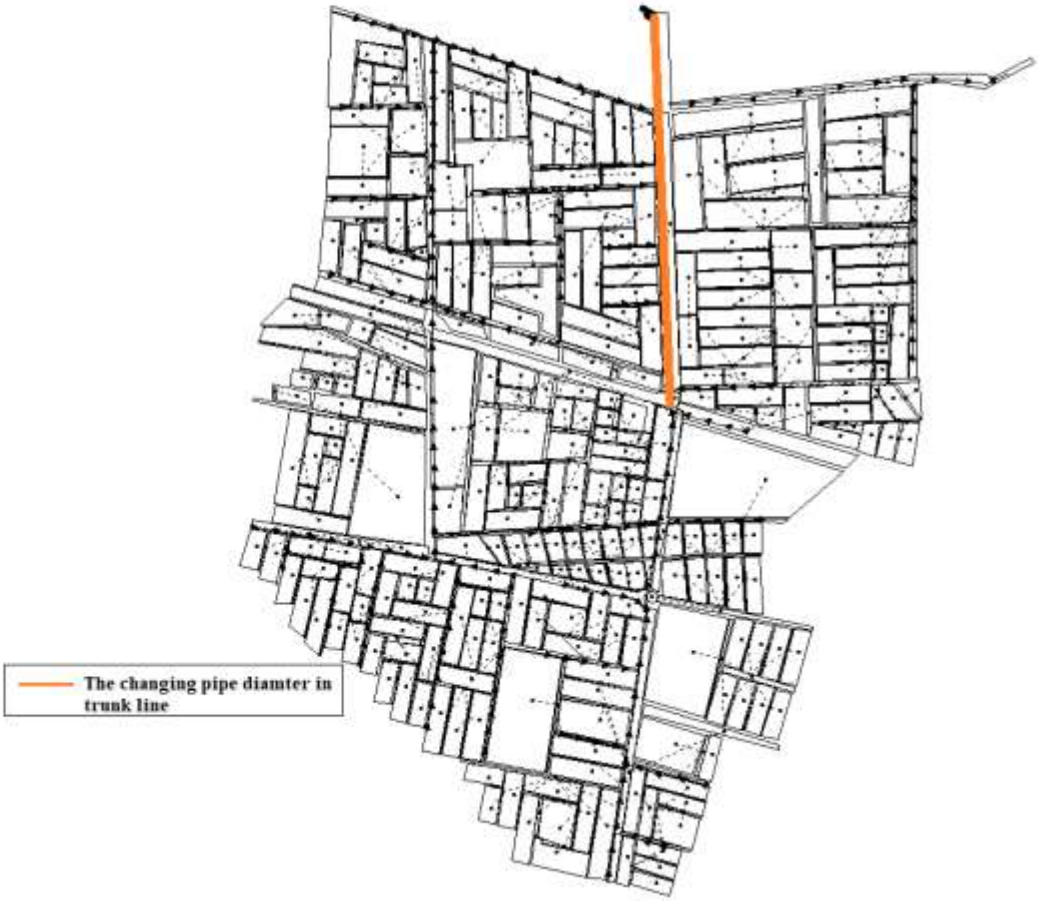


Figure 4-13: The pipeline of the MS4 after changing its diameter.

The outcomes of applying this scenario in the SWMM model, as reflected by the decrease in the peak discharge, total flood volume, and number of flooded manholes in the MS4 are shown in Table 4-6.

Table 4-6: Al-Soob Al-Kabeer Quarter MS4 performance under the effect of rainfall events when the diameter of trunk sewer line is changed.

Return period (years)	During period (hr)	Maximum flow rate M^3/s	Total flooding volume after change dia. (m^3)	Number of flooded manholes	Reduction of manholes flooding %
2	2	0.15	1084.5	22	10
5	2	0.278	2003	68	8
10	2	1.024	7375	88	7
25	2	1.7425	12546	94	6

The reflect of reduction of applying the second scenario in reducing the flooding of the MS4 is presented in Table 4-6. While the results demonstrate a suitable efficiency of this scenario in reducing the flood it is noticeable that the number of manholes decreased after changing the diameters to 10% at the return period of 2-years, and this is the highest percentage of the subsequent intensity of rainfall. Furthermore, these findings revealed that the reduction of manholes in the scenario have a negative association with the rainfall intensity return period. In other words, when the rainfall intensity returns period increases, the scenario efficiency reduces due to increased runoff caused by high rainfall intensities. Figures 4-14 to 4-17 examine Al-Soob Al-Kabeer Quarter MS4 during of 2, 5, 10, and 25 years return periods, respectively, after 2 hours of rainfall duration and increasing trunk sewer diameter. Figure (4-14) demonstrates, for a 2-year return period that in stage 3 the ratio of flooding manholes dropped from 8.8% to 6.7%, while the ratio in stage 5 decreased from 1.25% to 0.8%, and unflooded manholes climbed from 90.8% to 93.78% in general with intensity of rainfall 17 mm/hrs. Figure (4-15) illustrates that the ratio of flooding manholes in stage 3 dropped from 7% to 6% and in stage 5 decreased from 10% to 6.3%, and unflooded manholes increased from 76.3% to 78% over a five-year period with a rainfall intensity of 33 mm/hrs. Figure (4-16) shows that over a 10-year period with rainfall intensity of 42 mm/hr, flooded manholes in stage 5 decreased from 13.8% to 11.3%, and unflooded manholes climbed from 70.3% to 73%. Figure (4-17) illustrates that when the return period was changed to 25 years with rainfall intensity of 55 mm/hr, the proportion of flooding manholes in stage 4 declined from 3.35% to 2%, in stage 5 from 16% to 12%, and the percentage of unflooded manholes climbed from 69.32% to 70%. This scenario can be supported by a study conducted by Zhao et al. (2013), it was suggested that the increasing in diameter of pipes in the stormwater network and approved the efficiency of this scenario for reduction in flow rate and total volume flooding. Table 4-6 represents the changes in percentages of flooding manholes for five stages.

Table4-7: The stages of flooding manholes in each return period after changing the diameter of the pipes

Stages of flooding manholes / return period (years)	St.1% Before Change Dia.	St.1% After Change Dia.	St.2% Before Change Dia.	St.2% After Change Dia.	St.3% Before Change Dia.	St.3% After Change Dia.	St.4% Before Change Dia.	St.4% After Change Dia.	St.5% Before Change Dia.	St.5% After Change Dia.
2	90.8	↑93.78	3.76	↓2.5	3.35	↓2.5	0.84	↓0.42	1.25	↓0.8
5	76	↑78	4.2	7	7	↓6	2.5	2.5	10	↓6.3
10	70.29	↑73	5.44	7.11	8.8	↓6.7	1.67	1.7	13.8	↓11.3
25	69.32	↑70	3.8	8	7.53	8	3.35	↓2	16	↓12

*St.1: Stage 1 (No flooding)

*St.2: Stage 2 (Light flooding)

*St.3: Stage 3 (Medium flooding)

*St.4: Stage 4 (Heavy flooding)

*St.5: Stage 5 (Extreme flooding)

*↑: Increased, and ↓: Decreased. The color cells are the important changes for the study area.

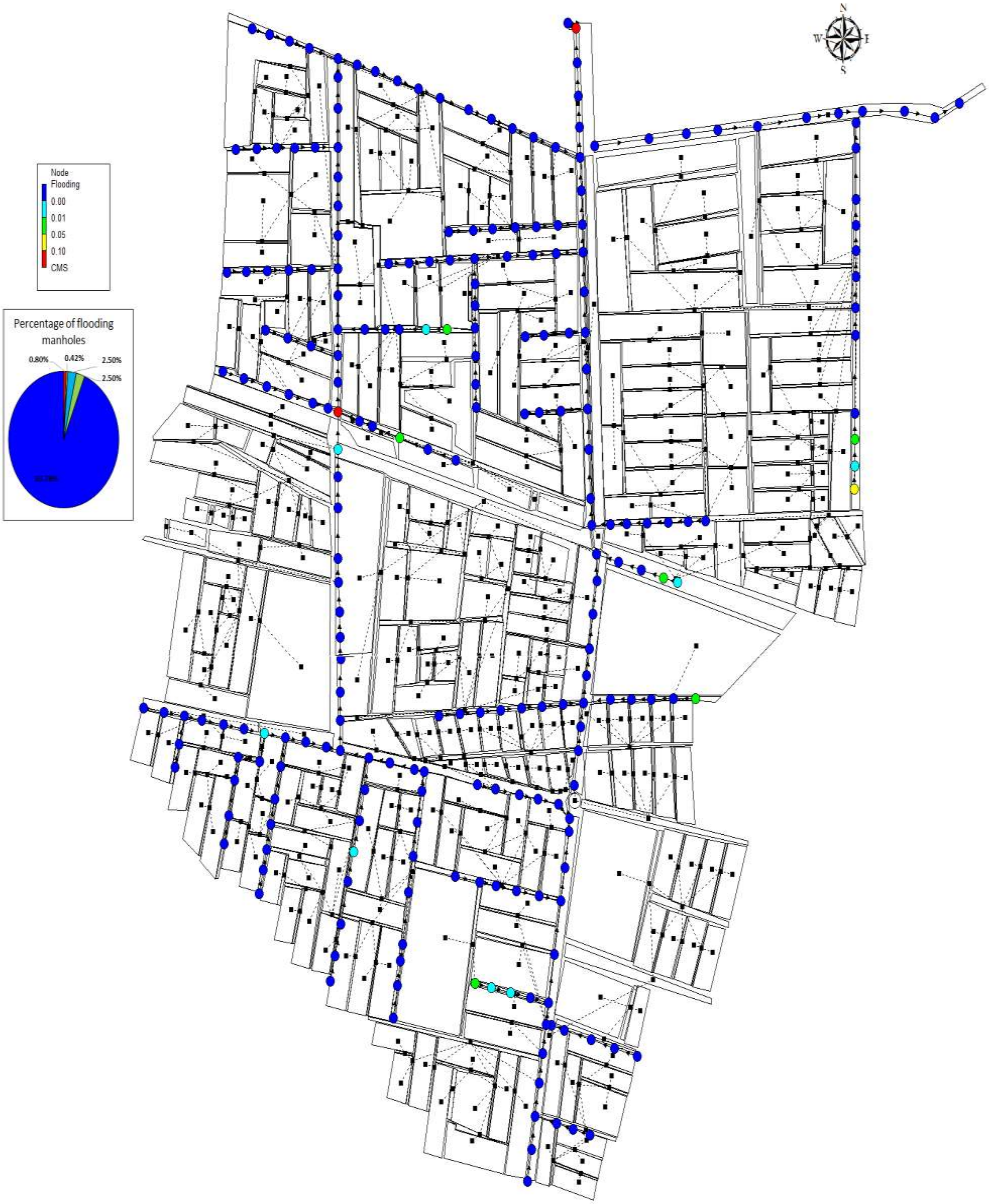


Figure 4-14: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 2-years return of period and an average intensity of rainfall of 17 mm/hr after changing the pipe's diameters.

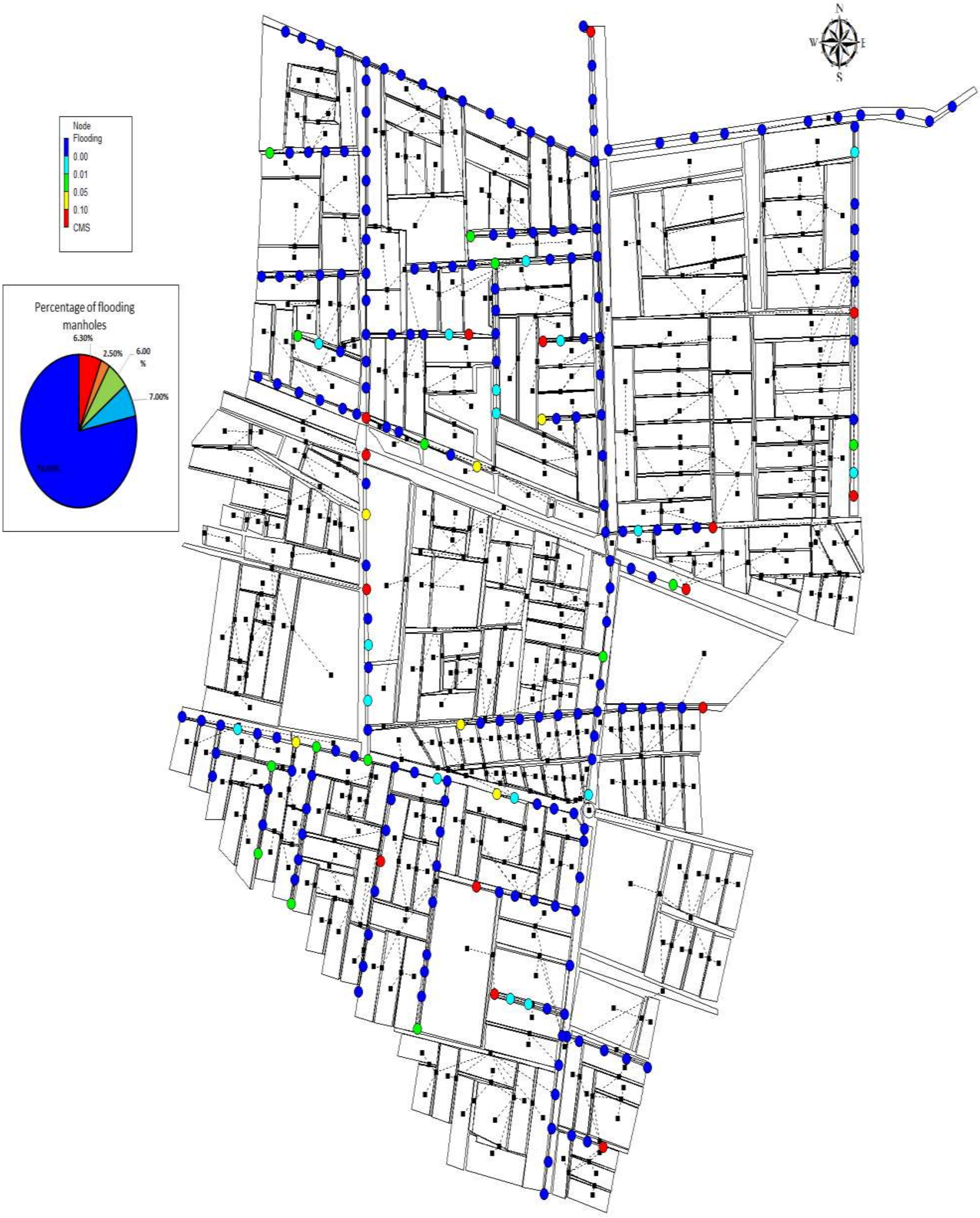


Figure 4-15: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 5-years return of period and an average intensity of rainfall of 33 mm/hr after changing the pipe's diameters.

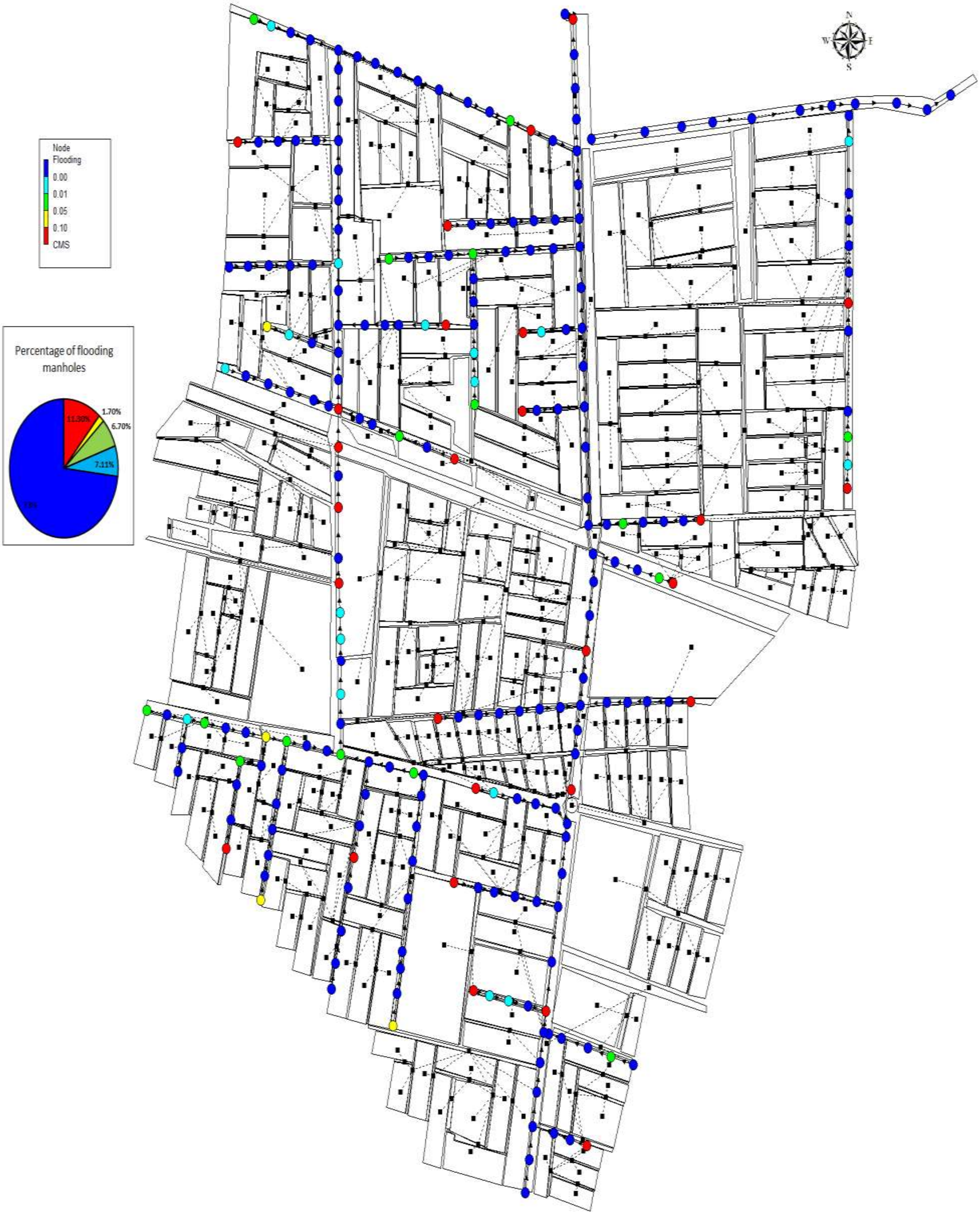


Figure 4-16: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 10-years return of period and an average intensity of rainfall of 42 mm/hr after changing the pipe's diameter.

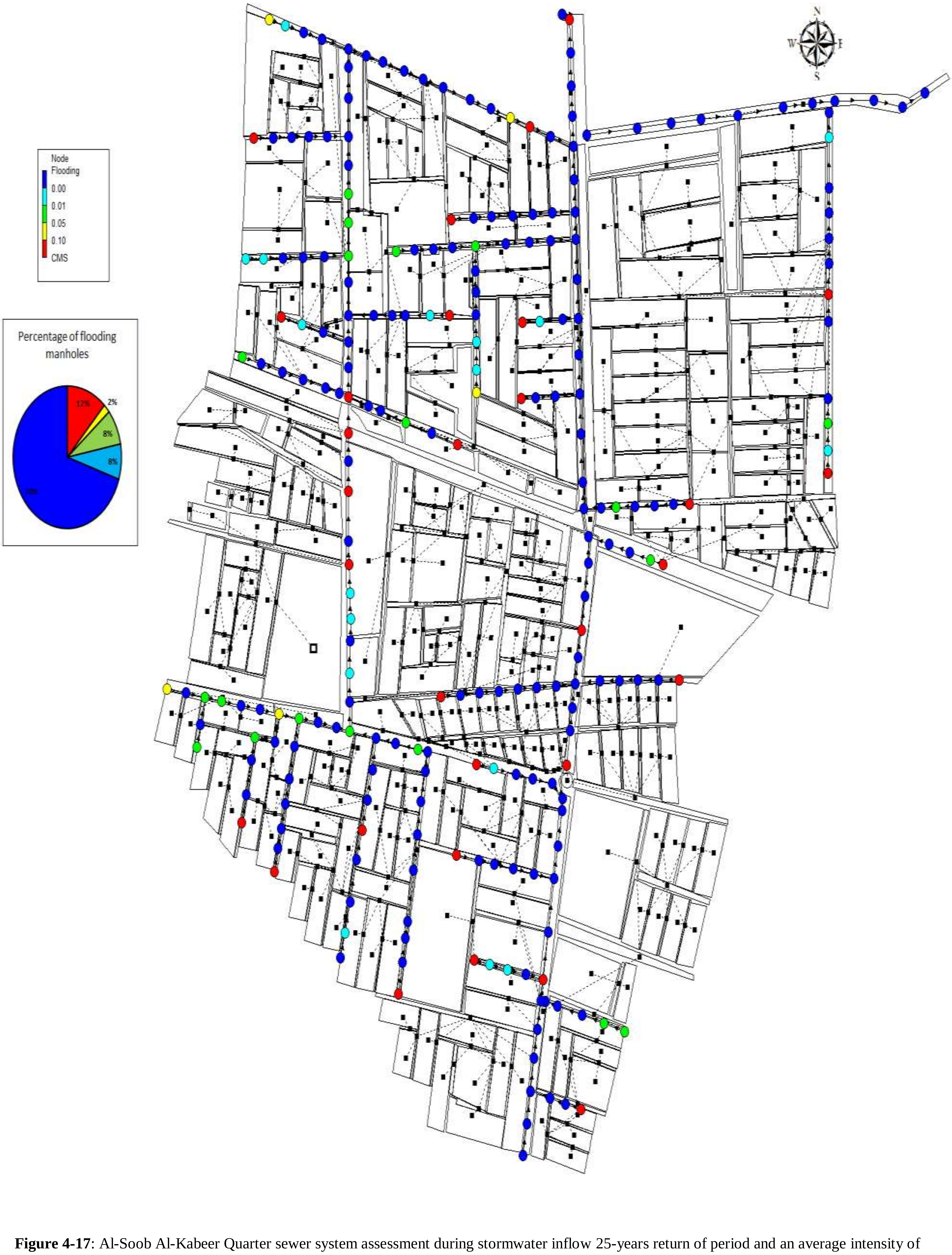


Figure 4-17: Al-Soob Al-Kabeer Quarter sewer system assessment during stormwater inflow 25-years return of period and an average intensity of rainfall of 55 mm/hr after changing the pipe's diameter.

CHAPTER FIVE

Conclusions and Recommendations

5.1 Conclusions

The obtained conclusions from this study are listed as following:

1- The study area suffered from flooding issue with flooded manholes between (10% to 42%) for the return period (2 to 25 years) respectively of all manholes and the flooded volume between (1446 m^3 to 13731 m^3).

2- The study showed that using the LID technique (i.e., rain garden) to reduce flooding is preferred on increasing the diameter of the trunk pipe. Increasing the trunk diameter had lowered the maximum flow rate, the total flood volume, and the number of flooded manholes in return periods between 25 to 2 years, by about 15% to 35%, 8% to 25%, and 6% to 10%, respectively.

3- . While the inclusion of the LID had lowered the maximum flow rate, the total flood volume, and the number of flooded manholes in return periods between 25 to 2 years, by about 8% to 32%, 8% to 31%, and 4% to 38%, respectively.

4- From a technical point of view, LID is easy to apply, and it is considered a help in reducing pressure on the existing infrastructure in the city and in terms of economic cost. This technology also shows that it has a benefit in terms of sustainability and an increase in green lands, and thus it has a positive impact on the environment and climate.

5.2 Recommendations

1. The finding of flooded manholes will aid in developing sewer overflow mitigation strategies by the municipal administration, stormwater and sewer control authorities, and other local organizations in Al-Samawah City, and in other cities in Iraq.
2. For future work, other ways to lower the MS4 quantity during rainstorm events should be applied, as in the investigated area only one type of the LID is utilized, although other LID techniques are available. Therefore, it is recommended to test the effectiveness of other LIDs techniques such as swales, green roofs, and infiltration trenches, etc.
3. Simulate other parameters and percentage of rain garden and choose the model suitable with the environment of study area.
4. Testing effectiveness of other designs of rain gardens in the investigated area is recommended.

REFERENCES

Abraham, D. M., Wirahadikusumah, R., Short, T., Shahbahrami, S. J. J. O. C. E. & Management1998. Optimization modeling for sewer network management. Journal of construction engineering and management, 124, 402-410.

Ahmed, K., Chung, E.-S., Song, J.-Y. & Shahid, S. J. W. 2017. Effective design and planning specification of low impact development practices using Water Management Analysis Module (WMAM): Case of Malaysia. Water, 9, 173.

Akhter, F., A Hewa, G., Ahammed, F., Myers, B. & R Argue, J. J. W. 2020. Performance Evaluation of Stormwater Management Systems and Its Impact on Development Costing. Water, 12, 375.

Al-aboodi, A. H., Hassan, A. A. & Ibrahim, H. T. 2006. Rainfall Intensity Probability for Design of Drainage System in Basrah City, south of Iraq. ARPN Journal of Engineering and Applied Sciences.

Al-amri, N. S., Subyani, A. M. J. E. S. 2017. Generation of rainfall intensity duration frequency (IDF) curves for ungauged sites in arid region. Earth Systems and Environment, 1, 1-12.

Al-Khuzaie, H. M. 1997. Geotechnical Properties of Samawa Soils. iraq geological journal 30, p. 147.

Al-Awadi, A. T. J. J. O. A. S. R. 2016. Assessment of intensity duration frequency (IDF) models for Baghdad city, Iraq. Journal of applied sciences research, 12, 7-11.

Al-Yaseri, I., Zhou, J. & Morgan, S. Sustainable stormwater management using rain gardens in urban areas. IOP Conference Series: Earth and Environmental Science, 2021. IOP Publishing, 012041.

Alyaseri, I., Zhou, J., Morgan, S.M. and Bartlett, A., 2017. Initial impacts of rain gardens' application on water quality and quantity in combined sewer: field-scale experiment. Frontiers of Environmental Science & Engineering, 11(4), pp.1-12.

Andimuthu, R., Kandasamy, P., Mudgal, B.V., Jeganathan, A., Balu, A. and Sankar, G., 2019. Performance of urban storm drainage network under changing climate scenarios: Flood mitigation in Indian coastal city. Scientific Reports, 9(1), pp.1-10.

Azawi[1], H.K.S. and Sachit, D.E., 2018. Investigation of Permeable Pavement Implementation in Baghdad using PCSWMM model.

Atiaa, A.M. and Al-Aboodi, A.H., 2006. Simulation of Flow Regime of Dibdibba Dandy Aquifer in Safwan-Zubair Area, South of Iraq. Iraqi Journal of Science, 47(1), pp.119-137.

Majeed, A.R., Nile, B.K. and Al-Baidhani, J.H., 2021, August. Selection of suitable PDF model and build of IDF curves for rainfall in Najaf city, Iraq. In Journal of Physics: Conference Series (Vol. 1973, No. 1, p. 012184). IOP Publishing.

Badieizadeh, S., Bahrehmand, A. and Ahmed, D.A., 2016. Calibration and Evaluation of the Hydrologic-Hydraulic Model SWMM to Simulate Runoff (Case Study: Gorgan).

Bai, Y., Li, Y., Zhang, R., Zhao, N. and Zeng, X., 2019. Comprehensive performance evaluation system based on environmental and economic benefits for optimal allocation of LID facilities. Water, 11(2), p.341.

Bai, Y., Zhao, N., Zhang, R. and Zeng, X., 2018. Storm water management of low impact development in urban areas based on SWMM. Water, 11(1), p.33.

Bhaduri, B., Minner, M., Tatalovich, S. and Harbor, J., 2001. Long-term hydrologic impact of urbanization: a tale of two models. Journal of Water Resources Planning and Management, 127(1), pp.13-19.

Bouamrane, A., Bouziane, M.T. and Boutebba, K., 2014. Decision Support System for the Management and Maintenance of Sewer Networks. Larhyss Journal P-ISSN 1112-3680/E-ISSN 2521-9782, (20).

Butler, D., Digman, C., Makropoulos, C. & Davies, J. W. 2018. Urban drainage, Crc Press.

Chughtai, F. and Zayed, T., 2008. Infrastructure condition prediction models for sustainable sewer pipelines. Journal of Performance of Constructed Facilities, 22(5), pp.333-341.

Majeed, A.R., Nile, B.K. and Al-Baidhani, J.H., 2021. The Effect of High Intensities of Rainfall on the Operation of the Combined Sewage System in Populated Areas. Kerbala Journal for Engineering Sciences, 1(1).

Nile, B.K., Hassan, W.H. and Alshama, G.A., 2019. Analysis of the effect of climate change on rainfall intensity and expected flooding by using ANN and SWMM programs. ARPN Journal of Engineering and Applied Sciences, 14(5), pp.974-984.

Hussain, S.N., Zwain, H.M. and Nile, B.K., 2022. Modeling the effects of land-use and climate change on the performance of stormwater sewer system using SWMM simulation: case study. Journal of Water and Climate Change, 13(1), pp.125-138.

Young, C.B., McEnroe, B.M. and Rome, A.C., 2009. Empirical determination of rational method runoff coefficients. Journal of Hydrologic Engineering, 14(12), pp.1283-1289.

Abraham, D.M., Wirahadikusumah, R., Short, T., Shahbahrami, S. J. O.C. E. 1998 Optimization modeling for sewer network management. Journal of construction engineering and management, 124, 402-410.

Ahmed, K., Chung, E. S., Song, J.Y. & Shahid, S. J. W. 2017. Effective design and planning specification of low impact development practices using Water Management Analysis Module (WMAM): Case of Malaysia. Water, 9, 173.

Akhter, F., A Hewa, G., Ahammed, F., Myers, B. & R Argue, J. J. W. 2020. Performance Evaluation of Stormwater Management Systems and Its Impact on Development Costing. Water, 12, 375.

AL-Amri, N. S., Subyani, A. M. J. E. S. & Environment 2017. Generation of rainfall intensity duration frequency (IDF) curves for ungauged sites in arid region. Earth Systems and Environment, 1, 1-12.

AL-Awadi, A. T. J. J. O. A. S. R. 2016. Assessment of intensity duration frequency (IDF) models for Baghdad city, Iraq. Journal of applied sciences research, 12, 7-11.

AL-Khuzaie, H. M. 1997. Geotechnical properties of Samawa soils. Iraq geological journal 30, p. 147.

ALYaseri, I., Zhou, J. & Morgan, S. Sustainable stormwater management using rain gardens in urban areas. IOP Conference Series: Earth and Environmental Science, 2021. IOP Publishing, 012041.

Azawi, H. K. S. & Sachit, D. E. 2018. Investigation of Permeable Pavement Implementation in Baghdad Using PCSWMM Model. Environment and Natural Resources Research, 8 No.3.

Badieizadeh, S., Bahrehmand, Abdolreza Ahmed, Dehghani Amir 2016. Calibration and Evaluation of the Hydrologic-Hydraulic Model SWMM to Simulate Runoff (Case Study: Gorgan).

Bai, Y., Li, Y., Zhang, R., Zhao, N. & Zeng, X. J. W. 2019. Comprehensive performance evaluation system based on environmental and economic benefits for optimal allocation of LID facilities. Water, 11, 341.

Ballard, R. D. & Hively, W. 2017. The eternal darkness: a personal history of deep-sea exploration, Princeton University Press.

Bhaduri, b., Minner, m., Tatalovich, s., Harbor, J. J. J. O. W. R. P. 2001. Long-term hydrologic impact of urbanization: a tale of two models. Journal of water resources planning and management, 127, 13-19.

Bouamrane, A., Bouziane, M. & Boutebba, k. J. L. J. P.-I. E. I. 2014. Decision support system for the management and maintenance of sewer networks. Larhyss journal.

Butler, D., Digman, C., Makropoulos, C. & Davies, J. W. 2018. Urban drainage, crc press.

Cantone, J. & Schmidt, A. J. W. R. R. 2011. Improved understanding and prediction of the hydrologic response of highly urbanized catchments through development of the Illinois Urban Hydrologic Model. Water resources research, 47(8).

Chabaeva, A., Civco, D. L. & Hurd, J. D. J. J. O. H. E. 2009. Assessment of Impervious Surface Estimation Techniques. Journal of Hydrologic Engineering, 14(4), 377–387., 14, 377-387.

Chini, C. M., Canning, J. F., Schreiber, K. L., Peschel, J. M. & Stillwell, A. S. J. S. 2017. The Green Experiment: Cities, Green Stormwater Infrastructure, and Sustainability. Sustainability, 9, 105.

Chocat, B., Krebs, P., Marsalek, J., Rauch, W., Schilling, W. J. W. S. & Technology 2001. Urban Drainage Redefined: from Stormwater Removal to Integrated Management. Water Science and Technology, 43, 61-68.

Dakheel, A. A. J. U. O. T.-q. J. 2017. Drawing Curves of the Rainfall Intensity Duration Frequency (IDF) and Assessment Equation Intensity Rainfall for Nasiriyah City, Iraq. University Of Thi-qar Journal, 12, 63-82.

Davis, A. P., Hunt, W. F., Traver, R. G. & Clar, M. J. J. O. E. E. 2009. Bioretention Technology: Overview of Current Practice and Future Needs. Journal Of Environmental Engineering, 135, 109-117.

De Feo, G., Antoniou, G., Fardin, H. F., El-gohary, F., Zheng, X. Y., Reklaityte, I., Butler, D., Yannopoulos, S. & Angelakis, A. N. J. S. 2014. The Historical Development of Sewers Worldwide. Sustainability, 6, 3936-3974.

De Feo, G., Antoniou, G., Fardin, H. F., El-gohary, F., Zheng, X. Y., Reklaityte, I., Butler, D., Yannopoulos, S. & Angelakis, A. N. J. S. 2014. The Historical Development of Sewers Worldwide. Sustainability, 6, 3936-3974.

De Paola, F., Giugni, M., Topa, M. E. & Bucchignani, E. J. S. 2014. Intensity-duration-frequency (IDF) Rainfall Curves, For Data Series and Climate Projection In African Cities. Springer Plus, 3, 1-18.

Diab, Y. & Morand, D. 2001. an Approach for the Choice of Rehabilitation Techniques of Urban Sewers. Pipelines 2001: Advances in

Pipelines Engineering and Construction. Advances in Pipelines Engineering and Construction.

Dias, L. C. J. R. I. O.-d., Annales Du Lamsade 2007. A Note an The Role of Robustness Analysis in Decision-aiding Processes. Robustness In Or-da, Annales Du Lamsade, 53-70.

Ennaouri, I., Fuamba, M. J. J. O. W. R. P. 2013. New Integrated Condition-assessment Model for Combined Storm-sewer Systems. Journal of Water Resources Planning and Management 139, 53-64.

Fenner, R. A. J. U. W. 2000. Approaches to Sewer Maintenance: A Review. Urban Water, 2, 343-356.

Fortunato, A., Oliveri, E. and Mazzola, M.R., 2014. Selection of the optimal design rainfall return period of urban drainage systems. Procedia Engineering, 89, pp.742-749.

Gironás, J., Roesner, L. A., Rossman, L. A., Davis, J. J. E. M. & Software 2010. A New Applications Manual for the Storm Water Management Model (SWMM). Environmental Modelling & Software, 25, 813-814.

Gokhale, S., Hastak, M. J. T. & Technology, U. S. 2000. Decision Aids for The Selection of Installation Technology for Underground Municipal Infrastructure Systems. Tunnelling and Underground Space Technology, 15, 1-11.

Hadi, M. O., El-mewafi, M., Metwally, S., Awadd, A. & Suliman, S. 2015. Evaluation of Wastewater Network of Al-anwaar In Al-kut City, Iraq by Using SWMM and GIS Techniques. International Journal of Scientific and Engineering Research.

Hassan, W. H., Nile, B. K. & Al-Masody, B. A. J. E. E. R. 2017. Climate Change Effect on Storm Drainage Networks by Storm Water Management Model. Environmental Engineering Research, 22, 393-400, 22, 393-400.

Hendrawan, A. P. Alternatives of Flood Control for The Linei River, City of Toboali (a Case Study of The Rawabangun Region). IOP Conference Series: Earth and Environmental Science, 2020 Earth and Environmental Science. IOP Publishing, 012047.

Hussein, A., Shahid, S., Basim, K. & Chelliapan, S. 2015. Modelling of Sewage Quality During Rainy Season. Asian Jr. Oof Microbiol. Biotech. Env. Sc.

Hirai, M., Iino, M. and Kawaguchi, T., 2000, August. Study on Priority Evaluating Process for Re-Constructing Planning of Urban Drainage System. In Proc. the Eighth International Conference on Urban Storm Drainage.

Jayasooriya, V., Ng, A. J. W., Air, & Pollution, S. 2014. Tools for Modeling of Stormwater Management and Economics of Green Infrastructure Practices: A Review. Water, Air, & Soil Pollution, 225, 1-20.

Jefferson, A. J., Bhaskar, A. S., Hopkins, K. G., Fanelli, R., Avellaneda, P. M. & Mcmillan, S. K. J. H. P. 2017. Stormwater Management Network Effectiveness and Implications for Urban Watershed Function: A Critical Review. Hydrological Processes, 31, 4056-4080.

Kourtis, I., Kopsiaftis, G., Bellos, V. & Tsihrintzis, V. 2017. Calibration And Validation of SWMM Model in Two Urban Catchments in Athens, Greece. International Conference on Environmental Science and Technology (CEST). In International Conference on Environmental Science and Technology.

Lee, C.Y., 2005. Application of rainfall frequency analysis on studying rainfall distribution characteristics of Chia-Nan plain area in Southern Taiwan. Crops, Environmental and Biological Information, 2(1), pp.31-38.38.

Li, Y., You, X., Ji, M., Wang, X., Zhao, L., Pan, L. J. C. W. & Wastewater 2010. Optimization Of Rainwater Drainage System Based on SWMM Model. 26, 40-43.

Li, Y., You, X., Ji, M., Wang, X., Zhao, L., Pan, L. J. C. W. & Wastewater 2010. Optimization of Rainwater Drainage System Based on SWMM Model. 26, 40-43.

Liu, Y. B., DE Smedt, F., Hoffmann, L., Pfister, L. J. E. M. 2005. Assessing land use impacts on flood processes in complex terrain by using GIS and modeling approach. Environmental modeling & assessment, 9, 227-235.

Martin, P. H., Leboeuf, E. J., Dobbins, J. P., Daniel, E. B. & Abkowitz, M. D. J. J. J. O. T. A. W. R. A. 2005. Interfacing GIS With Water Resource Models: A State-of-the-art Review 1. Jawra Journal of the American Water Resources Association, 41, 1471-1487.

Mccuen, R. H. J. J. O. T. A. W. R. A. 2004. Hydrologic Analysis and Design. Journal of Hydro informatics, 4(2), 75–81. , 40, 838.

Mcghee, T. J. & Steel, E. W. 1991. Water Supply and Sewerage, Tulane University Mcgraw-hill New York.

Mohammed, S. R., Nile, B. K. & Hassan, W. H. Modelling Stilling Basins for Sewage Networks. IOP Conference Series: Materials Science and Engineering, 2020. IOP Publishing, 012111.

Mohsen, K. A., Nile, B. K. & Hassan, W. H. Experimental Work on Improving the Efficiency of Storm Networks Using a New Galley Design Filter Bucket. IOP Conference Series: Materials Science and Engineering, 2020. IOP Publishing, 012094.

Mustafa, M., Zhou, J. and Alyaseri, I., Effect of Rainfall Intensity on Stormwater Reduction in Combined Sewers from the Impact of Permeable Pavements. In World Environmental and Water Resources Congress 2017 (pp. 383-390).

Needhidasan, S. and Nallanathel, M., 2013. Design of storm water drains by rational method–an approach to storm water management for environmental protection. International Journal of Engineering and technology, 5(4), pp.3203-3214.

Nhat, L. M., Tachikawa, Y. & Takara, K. J. A. O. D. P. R. I. 2006a. Establishment of Intensity-duration-frequency Curves for Precipitation in The Monsoon Area of Vietnam. Annuals of Disas, 93-103.

Nhat, L. M., Tachikawa, Y. & Takara, K. J. A. O. D. P. R. I. 2006b. Establishment of Intensity-duration-frequency Curves for Precipitation in The Monsoon Area of Vietnam. Prev. Res. Inst, 93-103.

Nile, B., Hassan, W. & Esmaeel, B. An Evaluation of Flood Mitigation Using a Storm Water Management Model [SWMM] In A Residential Area In Kerbala, Iraq. IOP Conference Series: Materials Science and Engineering, 2018. IOP Publishing, 012001.

Nile, B. K., Hassan, W. H., Alshama, G. A. J. A. J. O. E. & Sciences, A. 2019. Analysis of the Effect of Climate Change on Rainfall Intensity and Expected Flooding by Using ANN and SWMM Programs. Journal Of Engineering and Applied Sciences, 14, 974-984.

Nile, B. K. J. A. I. C. E. 2018. Effectiveness of Hydraulic and Hydrologic Parameters in Assessing Storm System Flooding. Advances In Civil Engineering, 2018.

Nirupama, N. and Simonovic, S.P., 2007. Increase of flood risk due to urbanisation: a Canadian example. Natural Hazards, 40(1), pp.25-41.

Obaid, H. A. 2015. Modelling Sewer Overflow of Karbala City with Large Floating Population. Universiti Teknologi Malaysia.

Obaid, H. A., Shahid, S., Basim, K. B. K. & Shreeshivadasan, C. J. M. J. O. C. E. 2014. Modeling Sewerage Overflow in an Urban Residential Area Using Storm Water Management Model. Malaysian Journal of Civil Engineering, 26.

Pennington, M. The Rational Method—frequently Used, Often Misused. Water New Zealand Stormwater Conference. Https://www. WaterNZ. Org. NZ/attachment, 2012.

Plenker, T. 2002. Computer Aided Decision Support on Choosing the Right Technology for Sewer Rehabilitation. Water Science and Technology, 46, 403-410.

Rabori, Moafi, A. & Ghazavi, R. 2018. Urban Flood Estimation and Evaluation of the Performance of an Urban Drainage System in a Semi-arid Urban Area Using SWMM. Water Environment Research, 90, 2075-2082.

Rangari, V. A., Prashanth, S. S., Umamahesh, N., Patel, A. K. J. A. J. O. E., A. 2018. Simulation of Urban Drainage System Using a Storm Water Management Model (SWMM). Sian Journal of Engineering and Applied Technology, 7, 710.

Rathnam, E. V., Jayakumar, K. & Cunnane, C. Runoff Computation in a Data Scarce Environment for Urban Stormwater Management-a Case

Study. Proceedings of the Congress-international Association for Hydraulic Research, 2001. 446-454.

Rawls, W. J., Brakensiek, D. L. & Miller, N. J. J. O. H. E. 1983. Green-Ampt Infiltration Parameters from Soils Data. Journal of Hydraulic Engineering, 109(1), 62–70., 109, 62-70.

Rossman, L. 2015. Storm Water Management Model User’s Manual, Version 5.1: National Risk Management Laboratory Office of Research and Development Us Environmental Protection Agency 26 Martin Luther King Drive Cincinnati. OH.

Rossman, L.A., 2010. Storm water management model user's manual, version 5.0 (p. 276). Cincinnati: National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

Rossman, L. A., Dickinson, R. E., Schade, T., Chan, C. C., Burgess, E., Sullivan, D. & Lai, F.-h. J. J. O. W. M. M. 2004. SWMM 5-the Next Generation Of EPA's Storm Water Management Model.

Selvalingam, S., Liong, S. & Manoharan, P. J. A. I. W. R. 1987. Use of RORB and SWMM Models to an Urban Catchment in Singapore. Advances in Water Resources 10, 78-86.

Shen, J. & Zhang, Q. J. E. P. 2014. Parameter Estimation Method for SWMM Under The Condition of Incomplete Information Based on GIS and RS. Electronic Journal of Geotechnical Engineering 20(14):6095-6108, 6095-6108.

Staufer, P., Scheidegger, A. & Rieckermann, J. J. W. R. 2012. Assessing the Performance of Sewer Rehabilitation on the Reduction of Infiltration and Inflow. Water Research, 46(16), 5185–5196. , 46, 5185-5196.

Simpson, M.G., 2010. Low impact development modeling to manage urban storm water runoff and restore predevelopment site hydrology (Doctoral dissertation, Colorado State University).

Nirupama, N. and Simonovic, S.P., 2007. Increase of flood risk due to urbanisation: a Canadian example. Natural Hazards, 40(1), pp.25-41.

Taatpour, F., Kouhanestani, Z. K., Armin, M. J. I. S. & Engineering 2019. Evaluating the Performance of Collection and Disposal of Surface Runoff Network Using SWMM Model (case Study: The City of Likak, Kohgiluyeh and Boyer Ahmad Province). Irrigation Sciences and Engineering, 42, 33-48.

Te, C. V., Maidment, D. R. & Mays, L. W. J. W. R. H. 1988. Applied Hydrology.

Young, C. B., Mcenroe, B. M. & Rome, A. C. J. J. O. H. E. 2009. Empirical Determination of Rational Method Runoff Coefficients. 14, 1283-1289.

Zaini, N., Malek, M. A. & Yusoff, M. 2015. Application of Computational Intelligence Methods in Modelling River Flow Prediction: A Review. International Conference on Computer, Communications, And Control Technology (i4ct), 2015. Ieee, 370-374.

Zhang, L., Ye, Z. & Shibata, S. 2020. Assessment of Rain Garden Effects for the Management of Urban Storm Runoff in Japan. Sustainability, 12.

Zhao, X., Yang, K., Peng, S., Xu, Q. & Meng, C. The Study of Urban Rainstorm Waterlogging Scenario Simulation Based on GIS and SWMM Model take the Example of Kunming Dongfeng East Road Catchment Area. 2013 21st International Conference on Geoinformatics, 2013. Ieee, 1-5.

Zwain, H. M., Nile, B. K., Faris, A. M., Vakili, M. & Dahlan, I. J. S. R. 2020. Modelling of Hydrogen Sulfide Fate and Emissions in Extended Aeration Sewage Treatment Plant Using Toxchem Simulations. Scientific Reports, 10, 1-11.

Waikar, M.L. and Namita, U., 2015. Urban flood modeling by using EPA SWMM 5. SRTM University's Research Journal of Science, 1, p.20.

Wu, J.Y., Thompson, J.R., Kolka, R.K., Franz, K.J. and Stewart, T.W., 2013. Using the Storm Water Management Model to predict urban headwater stream hydrological response to climate and land cover change. Hydrology and Earth System Sciences, 17(12), pp.4743-4758.

APPENDICES

Appendix (A): Flooding in Stormwater Sewer in the Studied Area

Figure A-1: Flooded area in Al-Soob Al-Kabeer Quarter (picture taken in Feb. 2021)

Figure A-2: Flooded area in A-lsoob Al-Kabeer Quarter (picture taken Feb. 2021)

Figure A-3: Flooded area in Al-soob Al-Kabeer Quarter (picture taken in Feb. 2021)

Appendix B-1

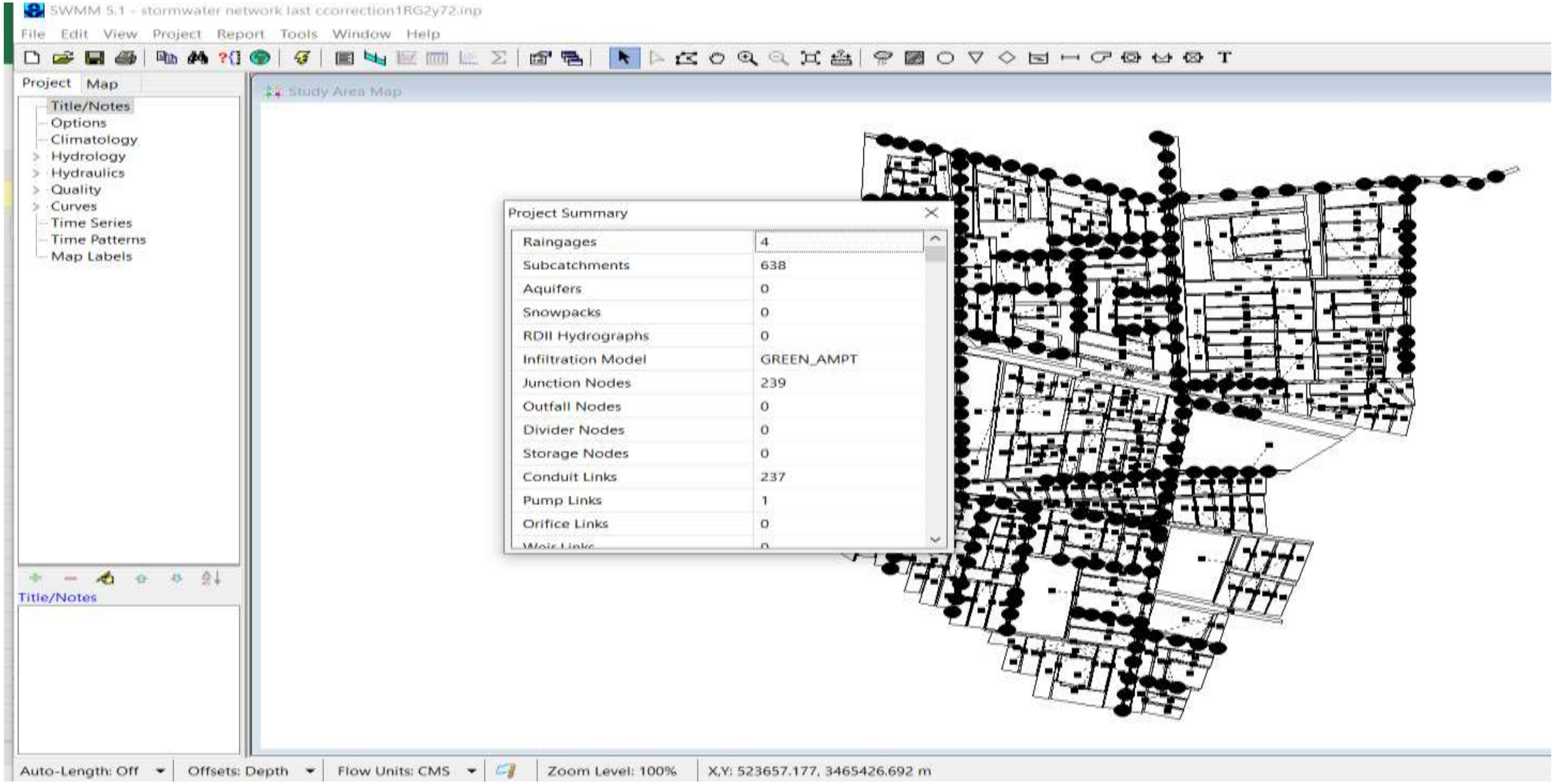


Figure B-1: Project Summery

Appendix B-2: Properties of sub-catchments

sub-catchment summary

Name	Area	Width	%Imper	%Slope	Rain Gage	Outlet
Sub-01	0.73	23.97	72.00	0.2550	Rain Gage-01	Sub-518
Sub-02	0.67	26.69	72.00	0.2550	Rain Gage-01	Sub-518
Sub-03	0.81	29.31	72.00	0.2550	Rain Gage-01	Sub-519
Sub-04	0.76	28.64	72.00	0.2550	Rain Gage-01	Sub-538
Sub-05	0.79	28.27	72.00	0.2550	Rain Gage-01	Sub-521
Sub-06	0.42	14.99	72.00	0.2550	Rain Gage-01	Sub-539
Sub-07	0.49	17.20	72.00	0.2550	Rain Gage-01	Sub-539
Sub-08	0.69	22.46	72.00	0.2550	Rain Gage-01	Sub-540
Sub-09	0.87	31.98	72.00	0.2550	Rain Gage-01	Sub-523
Sub-10	0.36	6.55	72.00	0.1300	Rain Gage-01	Sub-524
Sub-100	0.15	6.90	72.00	0.1300	Rain Gage-01	Sub-444
Sub-101	0.16	8.34	72.00	0.1300	Rain Gage-01	Sub-445
Sub-102	0.13	5.39	72.00	0.2550	Rain Gage-01	Sub-447
Sub-103	0.38	8.17	72.00	0.3800	Rain Gage-01	Sub-419
Sub-104	0.17	4.62	72.00	0.2550	Rain Gage-01	Sub-421
Sub-105	0.33	8.55	72.00	0.1300	Rain Gage-01	Sub-421
Sub-106	0.76	23.93	72.00	0.2550	Rain Gage-01	Sub-420
Sub-107	0.70	28.64	72.00	0.2550	Rain Gage-01	Sub-425
Sub-108	0.69	21.60	72.00	0.2550	Rain Gage-01	Sub-425
Sub-109	0.29	15.19	72.00	0.1300	Rain Gage-01	Sub-439
Sub-11	0.53	16.55	72.00	0.1300	Rain Gage-01	Sub-525
Sub-110	0.51	17.14	72.00	0.1300	Rain Gage-01	Sub-439

Sub-111	0.29	10.15	72.00	0.1300 Rain Gage-01	Sub-436
Sub-112	0.67	20.00	72.00	0.2900 Rain Gage-01	Sub-422
Sub-113	0.12	8.90	72.00	0.3800 Rain Gage-01	Sub-429
Sub-114	0.49	10.20	72.00	0.2550 Rain Gage-01	Sub-113
Sub-115	0.36	13.10	72.00	0.1300 Rain Gage-01	Sub-431
Sub-116	0.49	17.87	72.00	0.2550 Rain Gage-01	Sub-432
Sub-117	0.43	14.30	72.00	0.2550 Rain Gage-01	Sub-432
Sub-118	0.40	15.21	72.00	0.3800 Rain Gage-01	Sub-349
Sub-119	0.54	15.70	72.00	0.2550 Rain Gage-01	Sub-350
Sub-12	0.64	23.83	72.00	0.2550 Rain Gage-01	Sub-527
Sub-120	0.55	12.34	75.00	0.1300 Rain Gage-01	Sub-350
Sub-121	0.56	19.78	72.00	0.3800 Rain Gage-01	Sub-348
Sub-122	0.70	22.35	72.00	0.1300 Rain Gage-01	Sub-323
Sub-123	0.65	26.20	72.00	0.2550 Rain Gage-01	Sub-351
Sub-124	0.55	21.21	72.00	0.1300 Rain Gage-01	Sub-352
Sub-125	0.71	11.50	95.00	0.1300 Rain Gage-01	Sub-354
Sub-126	0.77	27.10	72.00	0.1300 Rain Gage-01	Sub-355
Sub-127	0.83	38.30	72.00	0.2550 Rain Gage-01	Sub-321
Sub-128	0.87	30.20	72.00	0.5100 Rain Gage-01	Sub-321
Sub-129	1.54	31.58	95.00	0.5100 Rain Gage-01	Sub-320
Sub-13	0.69	22.88	72.00	0.2550 Rain Gage-01	Sub-526
Sub-130	0.91	28.66	72.00	0.5100 Rain Gage-01	Sub-305
Sub-131	0.90	34.00	72.00	0.6300 Rain Gage-01	Sub-306
Sub-132	1.11	26.70	72.00	0.5100 Rain Gage-01	Sub-311
Sub-133	0.76	28.45	72.00	0.6300 Rain Gage-01	Sub-313
Sub-134	0.90	22.88	72.00	0.5100 Rain Gage-01	Sub-312

Sub-135	0.96	18.20	72.00	0.5100	Rain Gage-01	Sub-313
Sub-136	0.78	16.40	72.00	0.3800	Rain Gage-01	Sub-315
Sub-137	0.69	23.76	72.00	0.3800	Rain Gage-01	Sub-314
Sub-138	0.67	24.20	72.00	0.3800	Rain Gage-01	Sub-316
Sub-139	0.42	13.77	72.00	0.3800	Rain Gage-01	Sub-317
Sub-14	0.59	21.15	72.00	0.2550	Rain Gage-01	Sub-525
Sub-140	0.44	12.65	72.00	0.1300	Rain Gage-01	Sub-318
Sub-141	4.70	55.53	72.00	0.2550	Rain Gage-01	Sub-322
Sub-142	0.60	23.32	72.00	0.2550	Rain Gage-01	Sub-330
Sub-143	0.98	32.62	72.00	0.2550	Rain Gage-01	Sub-326
Sub-144	0.56	22.91	72.00	0.1300	Rain Gage-01	Sub-329
Sub-145	0.58	21.95	72.00	0.1300	Rain Gage-01	Sub-329
Sub-146	0.27	12.31	72.00	0.1300	Rain Gage-01	Sub-327
Sub-147	0.31	12.93	72.00	0.3800	Rain Gage-01	Sub-327
Sub-148	0.64	23.70	72.00	0.2550	Rain Gage-01	Sub-325
Sub-149	0.81	27.5	72.00	0.1300	Rain Gage-01	Sub-310
Sub-15	2.15	34.39	72.00	0.5100	Rain Gage-01	Sub-524
Sub-150	0.81	27.54	72.00	0.1300	Rain Gage-01	Sub-324
Sub-151	0.92	28.83	72.00	0.1300	Rain Gage-01	Sub-324
Sub-152	0.48	19.84	72.00	0.1300	Rain Gage-01	Sub-371
Sub-153	0.62	11.50	72.00	0.2550	Rain Gage-01	Sub-336
Sub-154	0.45	16.87	72.00	0.5100	Rain Gage-01	Sub-338
Sub-155	0.44	10.92	72.00	0.5100	Rain Gage-01	Sub-334
Sub-156	0.55	18.05	72.00	0.3800	Rain Gage-01	Sub-334
Sub-157	0.61	7.93	72.00	0.3800	Rain Gage-01	Sub-332
Sub-158	0.41	12.35	72.00	0.3800	Rain Gage-01	Sub-363

Sub-159	0.54	20.14	72.00	0.3800	Rain Gage-01	Sub-366
Sub-16	0.95	16.95	72.00	0.3800	Rain Gage-01	Sub-568
Sub-160	0.63	22.25	72.00	0.3800	Rain Gage-01	Sub-364
Sub-161	0.79	31.67	72.00	0.3800	Rain Gage-01	Sub-364
Sub-162	0.40	8.72	72.00	0.3800	Rain Gage-01	Sub-384
Sub-163	0.42	11.50	72.00	0.1300	Rain Gage-01	Sub-365
Sub-164	0.55	20.04	72.00	0.5500	Rain Gage-01	Sub-367
Sub-165	0.48	16.56	72.00	0.1300	Rain Gage-01	Sub-368
Sub-166	0.56	15.36	72.00	0.5100	Rain Gage-01	Sub-369
Sub-167	0.49	8.83	72.00	0.1300	Rain Gage-01	Sub-361
Sub-168	0.28	6.36	72.00	0.5000	Rain Gage-01	Sub-340
Sub-169	0.53	10.89	72.00	0.3800	Rain Gage-01	Sub-370
Sub-17	1.02	24.11	72.00	0.3800	Rain Gage-01	Sub-564
Sub-170	0.42	8.23	72.00	0.2550	Rain Gage-01	Sub-360
Sub-171	0.52	13.77	72.00	0.2550	Rain Gage-01	Sub-347
Sub-172	0.61	25.20	72.00	0.2550	Rain Gage-01	Sub-343
Sub-173	0.48	17.03	72.00	0.1300	Rain Gage-01	Sub-342
Sub-174	0.26	9.83	72.00	0.1300	Rain Gage-01	Sub-346
Sub-175	0.23	9.11	72.00	0.1300	Rain Gage-01	Sub-347
Sub-176	0.63	24.00	72.00	0.1300	Rain Gage-01	Sub-345
Sub-177	0.40	15.67	72.00	0.1300	Rain Gage-01	Sub-335
Sub-178	0.29	13.87	72.00	0.2550	Rain Gage-01	Sub-398
Sub-179	0.37	14.35	72.00	0.1300	Rain Gage-01	Sub-399
Sub-18	0.71	16.53	72.00	0.1300	Rain Gage-01	Sub-568
Sub-180	0.35	12.78	72.00	0.1300	Rain Gage-01	Sub-400
Sub-181	0.34	13.11	72.00	0.2550	Rain Gage-01	Sub-401

Sub-182	0.30	12.56	72.00	0.3800	Rain Gage-01	Sub-469
Sub-183	0.34	13.78	72.00	0.2550	Rain Gage-01	Sub-468
Sub-184	0.34	12.91	72.00	0.2550	Rain Gage-01	Sub-410
Sub-185	0.34	12.78	72.00	0.3800	Rain Gage-01	Sub-409
Sub-186	0.29	14.10	72.00	0.1300	Rain Gage-01	Sub-411
Sub-187	0.73	20.30	72.00	0.2550	Rain Gage-01	Sub-412
Sub-188	0.10	4.41	72.00	0.5100	Rain Gage-01	Sub-407
Sub-189	0.12	4.76	72.00	0.1300	Rain Gage-01	Sub-406
Sub-19	0.91	19.14	72.00	0.5100	Rain Gage-01	Sub-562
Sub-190	0.17	6.45	72.00	0.1300	Rain Gage-01	Sub-404
Sub-191	0.21	7.11	72.00	0.1300	Rain Gage-01	Sub-402
Sub-192	0.28	9.83	72.00	0.1300	Rain Gage-01	Sub-462
Sub-193	0.31	13.51	72.00	0.1300	Rain Gage-01	Sub-464
Sub-194	0.07	4.24	72.00	0.1300	Rain Gage-01	Sub-471
Sub-195	0.89	32.19	72.00	0.1300	Rain Gage-01	Sub-515
Sub-196	0.66	18.58	72.00	0.2550	Rain Gage-01	Sub-514
Sub-197	0.30	6.59	72.00	0.1300	Rain Gage-01	Sub-513
Sub-198	0.47	24.50	72.00	0.1300	Rain Gage-01	Sub-512
Sub-199	0.51	16.22	72.00	0.1300	Rain Gage-01	Sub-505
Sub-20	0.85	22.39	72.00	0.3800	Rain Gage-01	Sub-282
Sub-200	0.24	9.60	72.00	0.3800	Rain Gage-01	Sub-517
Sub-201	0.23	9.37	72.00	0.2550	Rain Gage-01	Sub-517
Sub-202	0.20	4.91	72.00	0.1300	Rain Gage-01	Sub-513
Sub-203	0.38	16.96	72.00	0.1300	Rain Gage-01	Sub-500
Sub-204	0.38	7.79	72.00	0.2550	Rain Gage-01	Sub-499
Sub-205	0.40	6.99	72.00	0.3800	Rain Gage-01	Sub-499

Sub-206	0.67	17.29	72.00	0.2550	Rain Gage-01	Sub-496
Sub-207	0.37	4.97	72.00	0.6300	Rain Gage-01	Sub-501
Sub-208	0.50	16.04	72.00	0.2550	Rain Gage-01	Sub-559
Sub-209	0.36	14.99	72.00	0.2550	Rain Gage-01	Sub-559
Sub-21	0.65	20.51	72.00	0.5100	Rain Gage-01	Sub-561
Sub-210	0.49	18.43	72.00	0.2550	Rain Gage-01	Sub-560
Sub-211	0.81	29.64	72.00	0.3800	Rain Gage-01	Sub-497
Sub-212	0.69	27.76	72.00	0.3800	Rain Gage-01	Sub-498
Sub-213	0.73	9.30	72.00	0.1300	Rain Gage-01	Sub-619
Sub-214	0.40	15.63	72.00	0.1300	Rain Gage-01	Sub-614
Sub-215	0.49	16.40	72.00	0.1300	Rain Gage-01	Sub-613
Sub-216	5.10	52.56	72.00	0.5100	Rain Gage-01	Sub-549
Sub-217	1.10	42.21	72.00	0.5100	Rain Gage-01	Sub-549
Sub-218	0.44	14.22	72.00	0.5100	Rain Gage-01	Sub-551
Sub-219	0.19	7.89	72.00	0.5100	Rain Gage-01	Sub-552
Sub-22	0.59	8.30	72.00	0.1300	Rain Gage-01	Sub-285
Sub-220	0.65	10.02	72.00	0.5100	Rain Gage-01	Sub-550
Sub-221	0.61	17.24	72.00	0.5100	Rain Gage-01	Sub-553
Sub-222	0.26	10.30	72.00	0.5100	Rain Gage-01	Sub-556
Sub-223	0.85	31.21	72.00	0.5100	Rain Gage-01	Sub-385
Sub-224	1.25	36.88	72.00	0.5100	Rain Gage-01	Sub-557
Sub-225	1.15	40.41	72.00	0.1300	Rain Gage-01	Sub-610
Sub-226	0.24	14.40	72.00	0.5100	Rain Gage-01	Sub-614
Sub-227	0.53	20.04	72.00	0.1300	Rain Gage-01	Sub-612
Sub-228	0.65	39.37	72.00	0.1300	Rain Gage-01	Sub-623
Sub-229	0.77	24.50	72.00	0.5100	Rain Gage-01	Sub-616

Sub-23	0.76	8.03	72.00	0.2550	Rain Gage-01	Sub-285
Sub-230	0.57	22.64	72.00	0.1300	Rain Gage-01	Sub-548
Sub-231	0.43	15.73	72.00	0.1300	Rain Gage-01	Sub-493
Sub-232	0.51	18.97	72.00	0.3800	Rain Gage-01	Sub-492
Sub-233	0.81	30.00	72.00	0.5100	Rain Gage-01	Sub-491
Sub-234	0.68	21.80	72.00	0.2550	Rain Gage-01	Sub-495
Sub-235	0.50	5.54	72.00	0.3800	Rain Gage-01	Sub-507
Sub-236	0.24	10.51	72.00	0.5100	Rain Gage-01	Sub-506
Sub-237	0.19	8.10	72.00	0.1300	Rain Gage-01	Sub-508
Sub-238	0.23	10.39	72.00	0.2550	Rain Gage-01	Sub-506
Sub-239	0.22	9.74	72.00	0.1300	Rain Gage-01	Sub-508
Sub-24	0.77	23.69	72.00	0.1300	Rain Gage-01	Sub-532
Sub-240	0.47	10.42	72.00	0.2550	Rain Gage-01	Sub-511
Sub-241	0.26	9.55	72.00	0.5100	Rain Gage-01	Sub-511
Sub-242	0.29	9.46	72.00	0.1300	Rain Gage-01	Sub-494
Sub-243	0.16	9.12	72.00	0.1300	Rain Gage-01	Sub-494
Sub-244	0.87	4.39	72.00	0.5100	Rain Gage-01	Sub-489
Sub-245	3.79	44.37	72.00	0.5100	Rain Gage-01	Sub-489
Sub-246	0.79	22.67	72.00	0.6300	Rain Gage-01	Sub-504
Sub-247	1.61	25.35	72.00	0.2550	Rain Gage-01	Sub-504
Sub-248	7.38	62.50	72.00	0.2550	Rain Gage-01	Sub-417
Sub-249	0.38	14.94	72.00	0.5000	Rain Gage-01	Sub-396
Sub-25	0.79	35.42	72.00	0.1300	Rain Gage-01	Sub-283
Sub-250	0.35	13.38	72.00	0.1300	Rain Gage-01	Sub-395
Sub-251	0.35	13.77	72.00	0.3800	Rain Gage-01	Sub-394
Sub-252	0.37	13.96	72.00	0.5100	Rain Gage-01	Sub-397

Sub-253	0.41	13.75	72.00	0.3800	Rain Gage-01	Sub-397
Sub-254	0.61	177.20	72.00	0.2550	Rain Gage-01	Sub-386
Sub-255	0.51	20.42	72.00	0.1300	Rain Gage-01	Sub-387
Sub-256	0.51	21.37	72.00	0.1300	Rain Gage-01	Sub-388
Sub-257	0.59	22.22	72.00	0.1300	Rain Gage-01	Sub-389
Sub-258	0.60	21.36	72.00	0.1300	Rain Gage-01	Sub-389
Sub-259	4.47	47.32	72.00	0.3800	Rain Gage-01	Sub-374
Sub-26	0.89	30.10	72.00	0.1300	Rain Gage-01	Sub-528
Sub-260	1.78	19.50	72.00	0.2550	Rain Gage-01	Sub-319
Sub-261	0.54	20.98	72.00	0.2550	Rain Gage-01	Sub-377
Sub-262	0.56	22.23	72.00	0.1300	Rain Gage-01	Sub-377
Sub-263	0.56	22.23	72.00	0.1300	Rain Gage-01	Sub-376
Sub-264	0.62	23.30	72.00	0.1300	Rain Gage-01	Sub-375
Sub-265	0.67	25.33	72.00	0.5100	Rain Gage-01	Sub-380
Sub-266	0.62	24.90	72.00	0.1300	Rain Gage-01	Sub-380
Sub-267	0.63	23.20	72.00	0.1300	Rain Gage-01	Sub-379
Sub-268	0.60	22.63	72.00	0.2550	Rain Gage-01	Sub-378
Sub-269	0.63	28.55	72.00	0.1300	Rain Gage-01	Sub-301
Sub-27	0.35	5.86	72.00	0.1300	Rain Gage-01	Sub-528
Sub-270	0.65	29.40	72.00	0.1300	Rain Gage-01	Sub-303
Sub-271	0.42	44.63	72.00	0.1300	Rain Gage-01	Sub-302
Sub-272	0.42	19.91	72.00	0.5100	Rain Gage-01	Sub-300
Sub-273	0.93	20.60	72.00	0.2550	Rain Gage-01	Sub-300
Sub-274	0.40	19.17	72.00	0.1300	Rain Gage-01	Sub-296
Sub-275	0.41	17.50	72.00	0.1300	Rain Gage-01	Sub-295
Sub-276	0.40	1.98	72.00	0.1300	Rain Gage-01	Sub-297

Sub-277	0.45	20.33	72.00	0.1300	Rain Gage-01	Sub-297
Sub-278	0.38	16.71	72.00	0.1300	Rain Gage-01	Sub-319
Sub-279	0.19	0.97	72.00	0.2550	Rain Gage-01	Sub-291
Sub-28	0.93	31.22	72.00	0.1300	Rain Gage-01	Sub-529
Sub-29	0.81	34.82	72.00	0.1300	Rain Gage-01	Sub-541
Sub-30	0.31	5.16	72.00	0.1300	Rain Gage-01	Sub-535
Sub-31	0.95	30.61	72.00	0.2550	Rain Gage-01	Sub-537
Sub-32	0.91	33.28	72.00	0.5100	Rain Gage-01	Sub-536
Sub-33	0.86	8.13	72.00	0.3800	Rain Gage-01	Sub-534
Sub-34	0.63	21.10	72.00	0.1300	Rain Gage-01	Sub-530
Sub-35	0.64	21.60	72.00	0.1300	Rain Gage-01	Sub-533
Sub-36	0.65	22.85	72.00	0.1300	Rain Gage-01	Sub-534
Sub-37	0.81	12.44	72.00	0.1300	Rain Gage-01	Sub-542
Sub-38	0.59	22.84	72.00	0.2550	Rain Gage-01	Sub-544
Sub-39	0.56	21.59	72.00	0.2550	Rain Gage-01	Sub-543
Sub-40	0.85	29.45	72.00	0.2550	Rain Gage-01	Sub-546
Sub-41	0.77	28.61	72.00	0.2550	Rain Gage-01	Sub-547
Sub-42	0.56	21.74	72.00	0.2550	Rain Gage-01	Sub-547
Sub-43	1.52	36.85	72.00	0.5100	Rain Gage-01	Sub-286
Sub-44	0.84	26.45	72.00	0.2550	Rain Gage-01	Sub-287
Sub-45	0.97	23.53	72.00	0.2550	Rain Gage-01	Sub-288
Sub-46	1.31	33.56	72.00	0.2550	Rain Gage-01	Sub-289
Sub-47	0.94	17.31	72.00	0.2550	Rain Gage-01	Sub-290
Sub-48	1.38	32.20	72.00	0.2550	Rain Gage-01	Sub-291
Sub-49	0.53	21.00	72.00	0.3800	Rain Gage-01	Sub-585
Sub-50	0.45	12.50	72.00	0.1300	Rain Gage-01	Sub-587

Sub-51	0.42	12.75	72.00	0.3800	Rain Gage-01	Sub-579
Sub-52	0.45	18.67	72.00	0.1300	Rain Gage-01	Sub-586
Sub-53	2.12	49.94	72.00	0.6300	Rain Gage-01	Sub-588
Sub-54	0.96	17.33	72.00	0.6300	Rain Gage-01	Sub-578
Sub-55	1.05	13.86	72.00	0.5100	Rain Gage-01	Sub-580
Sub-56	0.68	25.20	72.00	0.1300	Rain Gage-01	Sub-581
Sub-57	1.95	30.30	72.00	0.3800	Rain Gage-01	Sub-582
Sub-58	0.71	28.53	72.00	0.3800	Rain Gage-01	Sub-582
Sub-59	0.56	20.87	72.00	0.1300	Rain Gage-01	Sub-589
Sub-60	0.09	2.89	72.00	0.1300	Rain Gage-01	Sub-591
Sub-61	0.59	21.66	72.00	0.5100	Rain Gage-01	Sub-589
Sub-62	0.69	11.98	72.00	0.5100	Rain Gage-01	Sub-570
Sub-63	0.63	19.50	72.00	0.2550	Rain Gage-01	Sub-597
Sub-64	0.25	7.72	72.00	0.6300	Rain Gage-01	Sub-594
Sub-65	0.62	21.50	72.00	0.5100	Rain Gage-01	Sub-596
Sub-66	0.93	31.95	72.00	0.5100	Rain Gage-01	Sub-593
Sub-67	0.74	27.35	72.00	0.3800	Rain Gage-01	Sub-593
Sub-68	1.42	31.98	72.00	0.1300	Rain Gage-01	Sub-473
Sub-69	0.99	41.35	72.00	0.1300	Rain Gage-01	Sub-474
Sub-70	1.62	43.20	72.00	0.2550	Rain Gage-01	Sub-484
Sub-71	1.40	35.10	72.00	0.2550	Rain Gage-01	Sub-487
Sub-72	0.38	8.50	72.00	0.2550	Rain Gage-01	Sub-485
Sub-73	1.18	43.50	72.00	0.1300	Rain Gage-01	Sub-482
Sub-74	0.85	33.45	72.00	0.2550	Rain Gage-01	Sub-481
Sub-75	0.77	9.33	72.00	0.2550	Rain Gage-01	Sub-479
Sub-76	0.62	9.20	72.00	0.1300	Rain Gage-01	Sub-479

Sub-77	0.48	8.50	72.00	0.1300	Rain Gage-01	Sub-459
Sub-78	0.57	8.30	72.00	0.1300	Rain Gage-01	Sub-459
Sub-79	0.82	25.10	72.00	0.1300	Rain Gage-01	Sub-458
Sub-80	0.85	31.85	72.00	0.1300	Rain Gage-01	Sub-475
Sub-81	0.84	33.11	72.00	0.1300	Rain Gage-01	Sub-476
Sub-82	0.88	34.00	72.00	0.2550	Rain Gage-01	Sub-477
Sub-83	0.81	29.14	72.00	0.1300	Rain Gage-01	Sub-480
Sub-84	1.84	43.66	72.00	0.1300	Rain Gage-01	Sub-483
Sub-85	1.06	40.27	72.00	0.2550	Rain Gage-01	Sub-292
Sub-86	0.66	25.03	72.00	0.2550	Rain Gage-01	Sub-441
Sub-87	0.85	32.25	72.00	0.2550	Rain Gage-01	Sub-293
Sub-88	0.84	34.87	72.00	0.2550	Rain Gage-01	Sub-294
Sub-89	0.91	17.82	72.00	0.2550	Rain Gage-01	Sub-450
Sub-90	0.61	18.92	72.00	0.2550	Rain Gage-01	Sub-442
Sub-91	1.06	19.73	72.00	0.3800	Rain Gage-01	Sub-453
Sub-92	0.86	18.10	72.00	0.2550	Rain Gage-01	Sub-454
Sub-93	0.93	17.63	72.00	0.5000	Rain Gage-01	Sub-456
Sub-94	0.85	17.87	72.00	0.1300	Rain Gage-01	Sub-452
Sub-95	0.59	17.16	72.00	0.1300	Rain Gage-01	Sub-442
Sub-96	0.60	7.98	72.00	0.2550	Rain Gage-01	Sub-445
Sub-97	0.55	16.21	72.00	0.2550	Rain Gage-01	Sub-446
Sub-98	0.86	26.93	72.00	0.2550	Rain Gage-01	Sub-448
Sub-99	0.16	6.51	72.00	0.2550	Rain Gage-01	Sub-449

………….. to sub-catchment 640

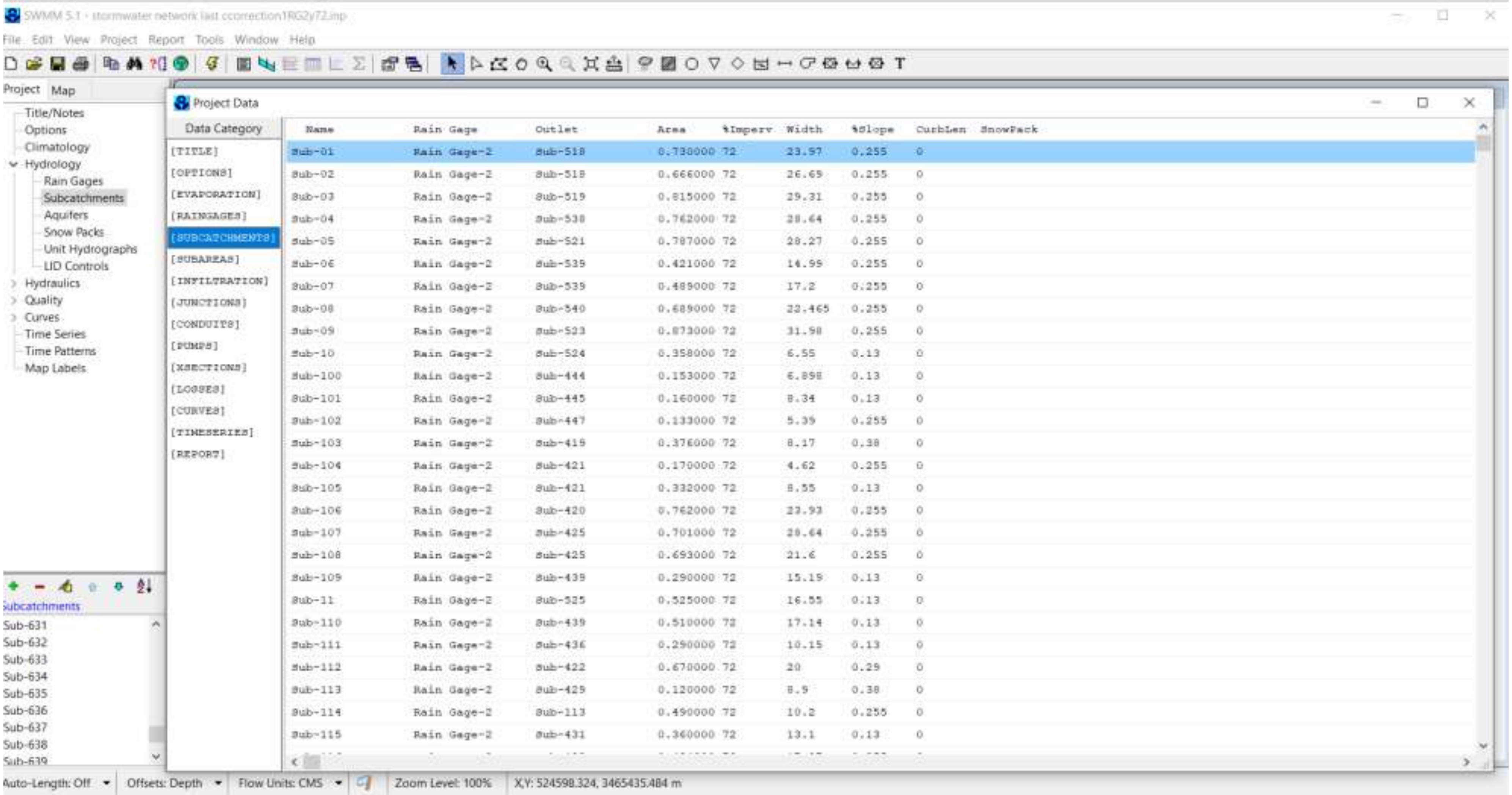


Figure B-2: Properties of sub-catchments.

Appendix B-3

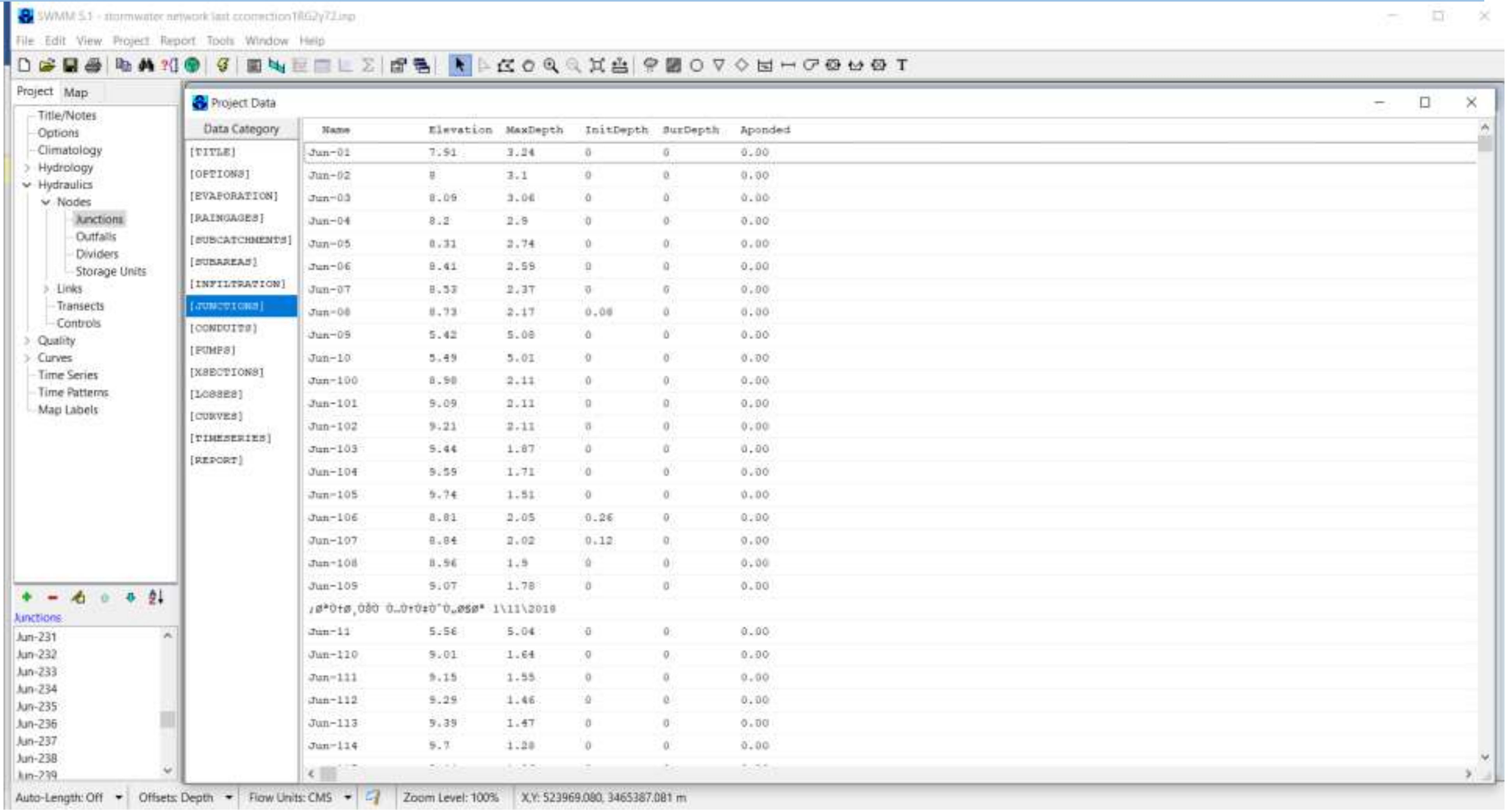


Figure B-3: Properties of the tested manholes.

Appendix B-4

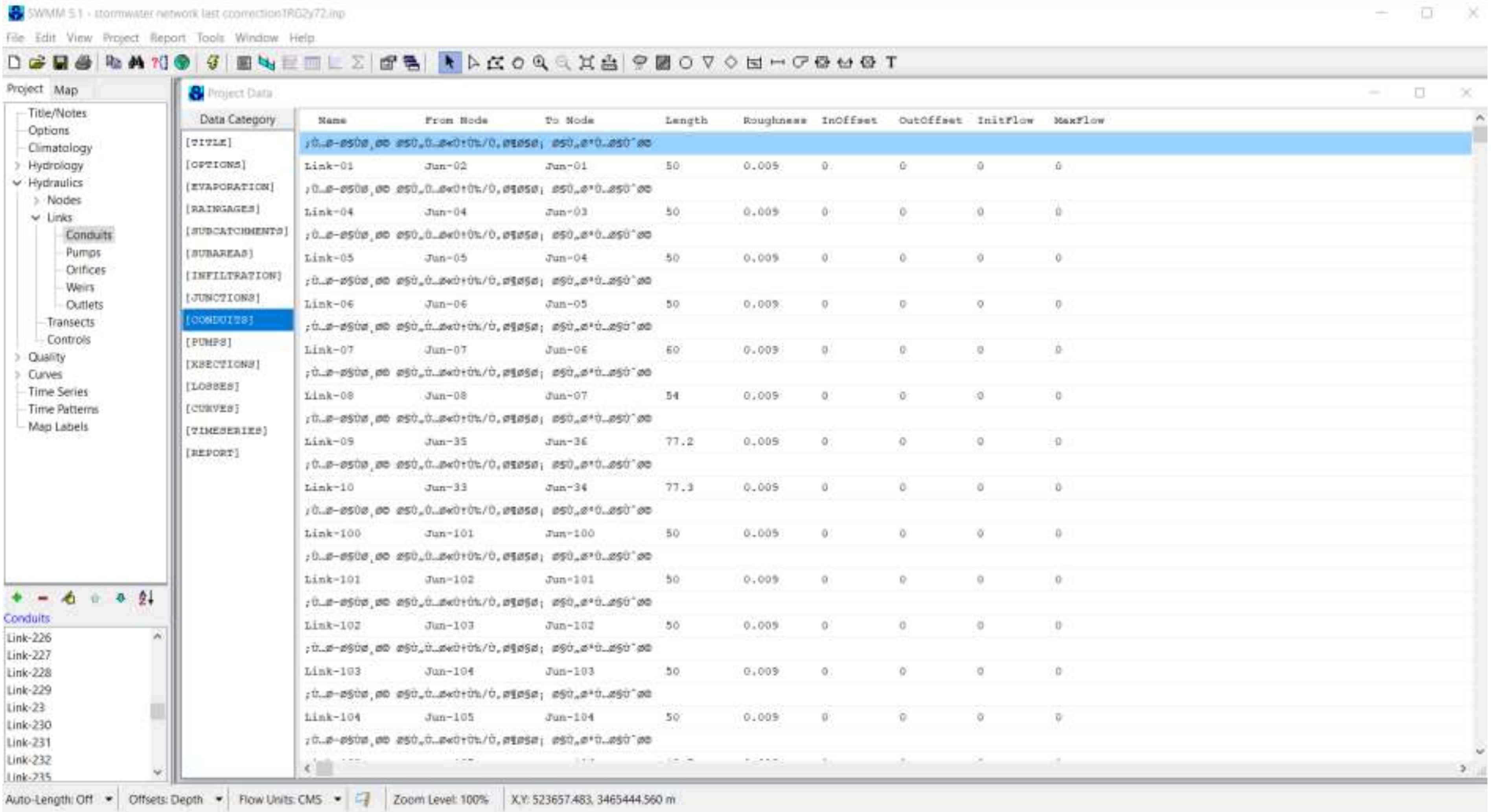


Figure B-3: Properties of links.

APPENDIX-C: The manning roughness coefficient for overland

The Conduit Material	Manning n
Closed Conduits	
- Asbestos-cement pipe	0.11-0.015
Brick	0.13-0.017
Cast iron pipe	
-Cement and seal-coated	0.011-0.015
Concrete (monolithic)	
-Smooth forms	0.012–0.014
- Rough forms	0.015–0.017
- Concrete pipe	0.011–0.015
Corrugated Metal Pipe	1/2 in. (13 mm) _ 22/3 in. (68 mm)
Corrugations	
- Plain	0.022–0.026
- Paved invert	0.018–0.022
- Spun asphalt	0.011–0.015
Plastic Pipe (Smooth)	0.011–0.015
Polyethylene	0.011–0.015
Polyvinyl Chloride	0.009b
Vitrified Clay Pipe	0.010b
Vitrified Clay	0.011–0.015
Liner Plates	0.011–0.020

Appendix-D: Input and output data for performed simulation in the SWMM.

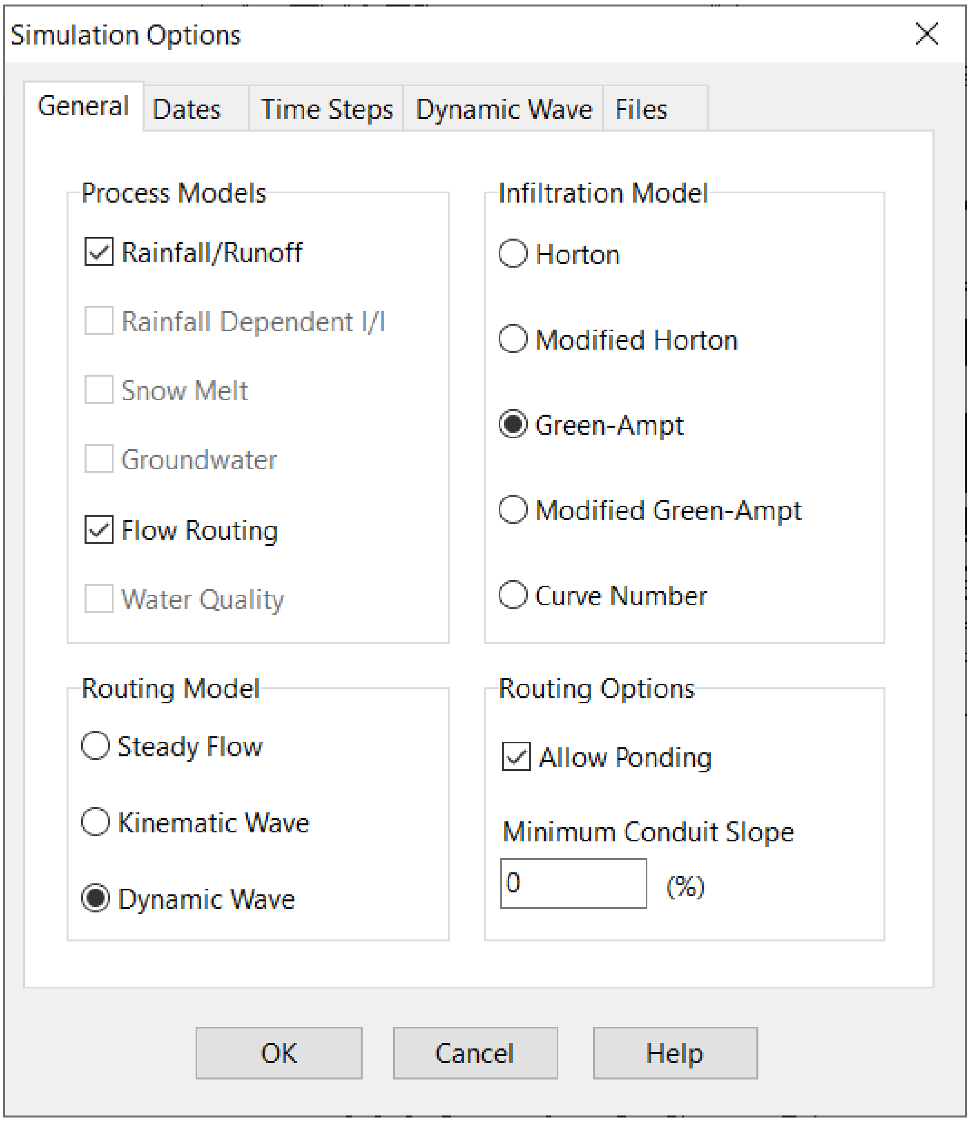


Figure D-1: Simulation options window from the SWMM, showing the general options.

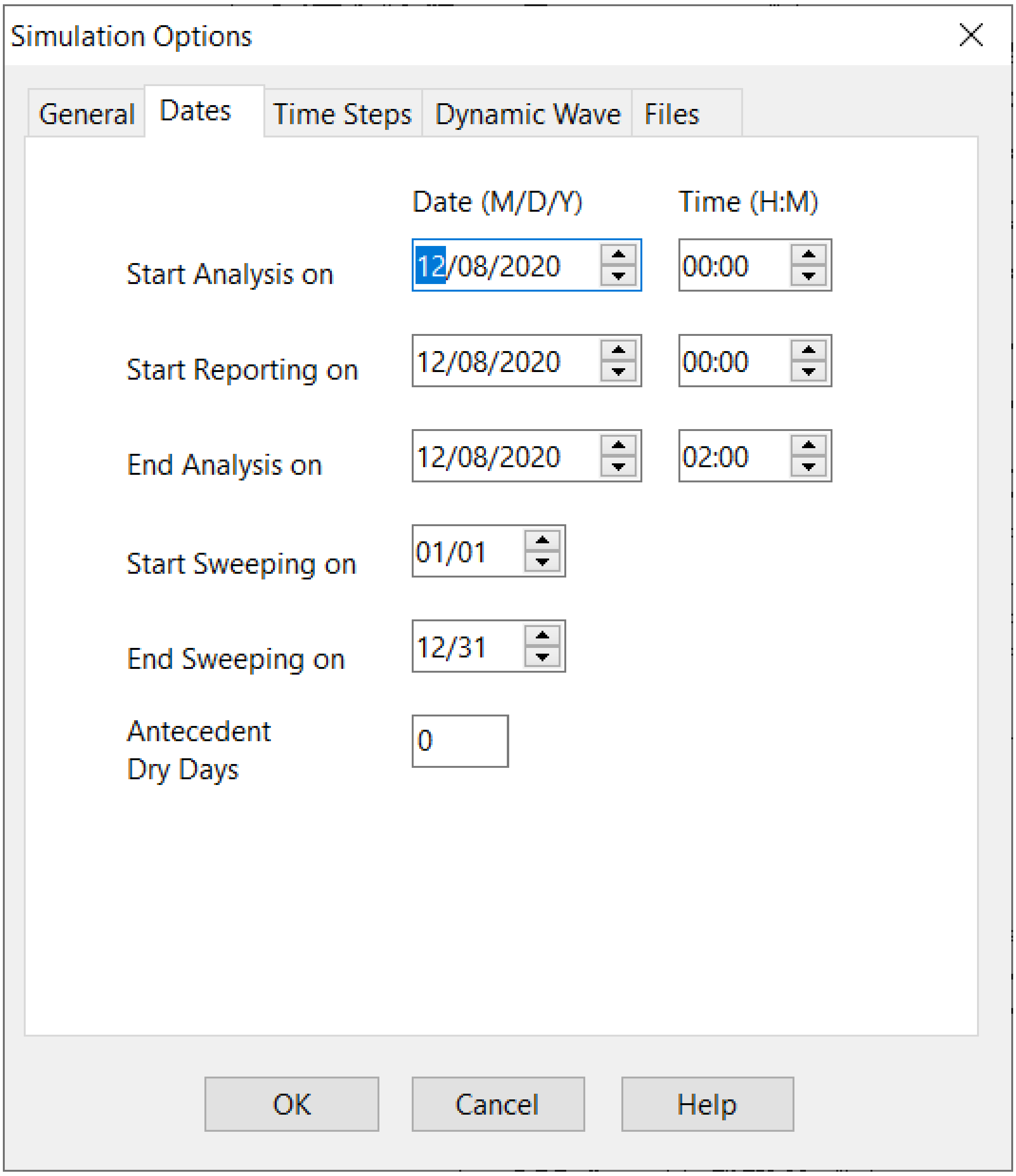


Figure D-2: Simulation options window from the SWMM, showing the date options..

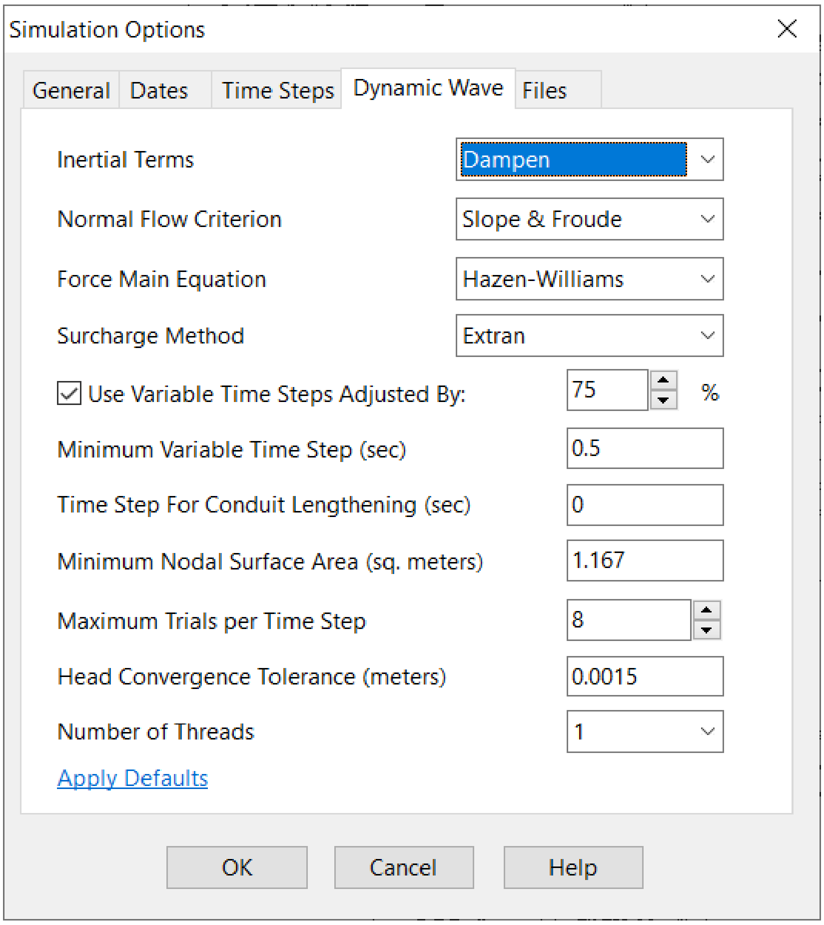


Figure D-3: Simulation options window from the SWMM, showing the dynamic wave options.

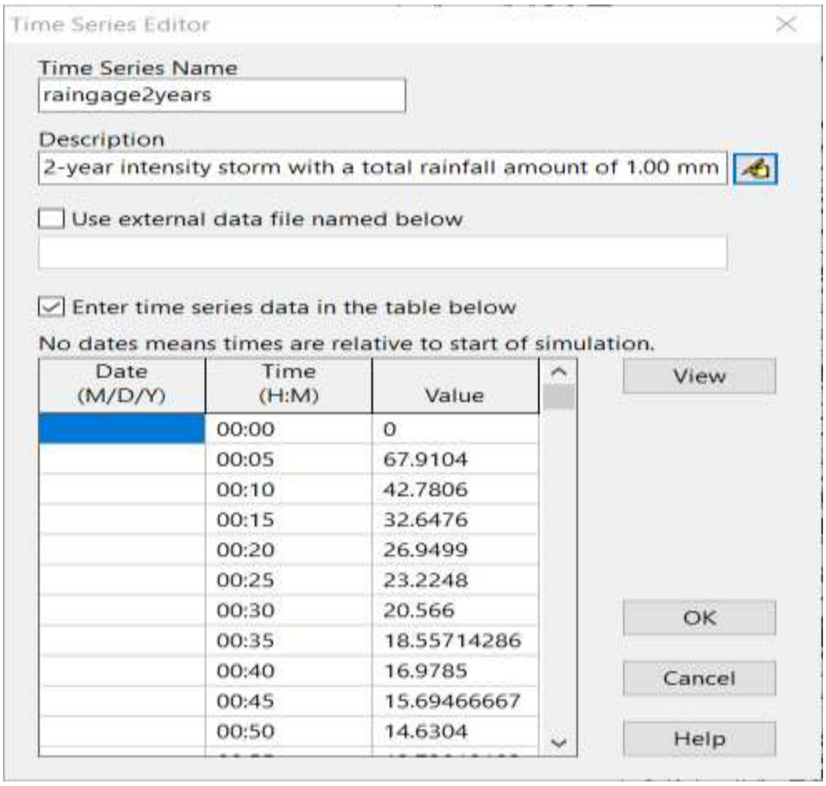


Figure D-4: Time series editor for 2 years return period.

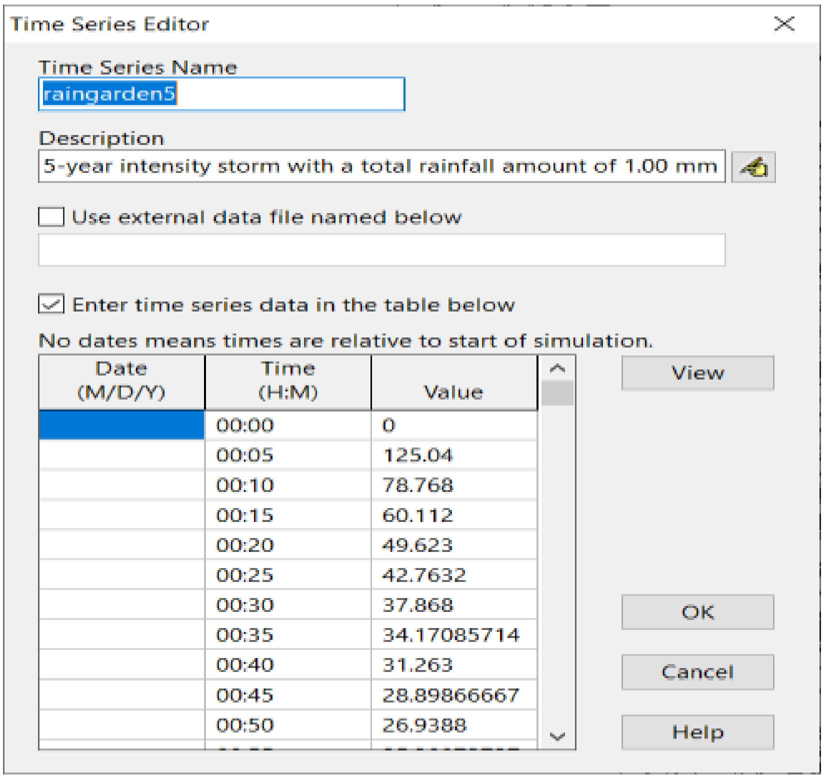


Figure D-5: Time series editor for 5 years return period.

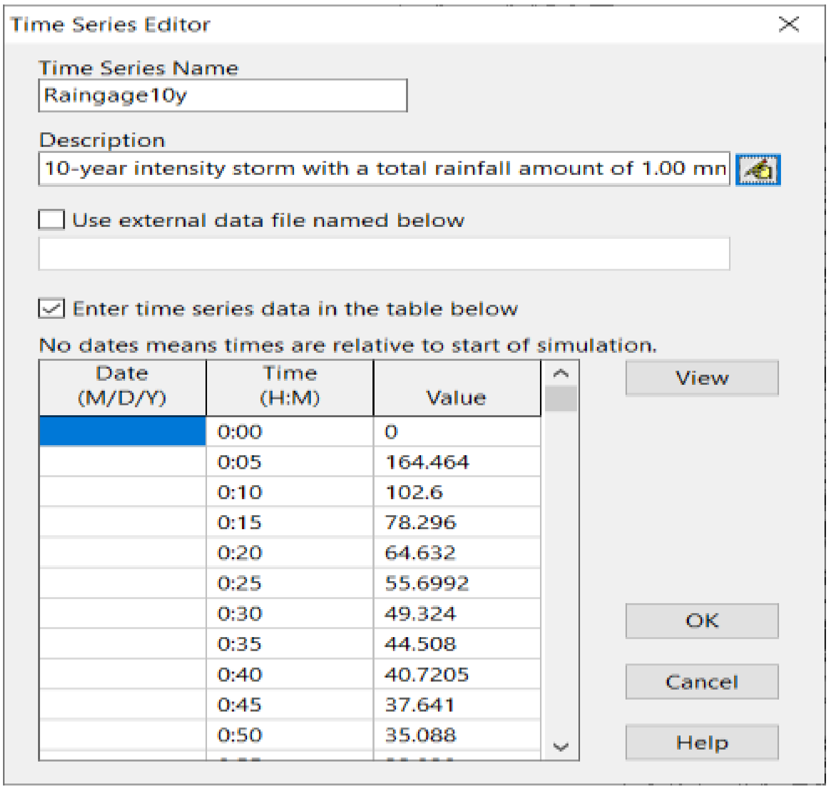


Figure D-6: Time series editor for 10 years return period.

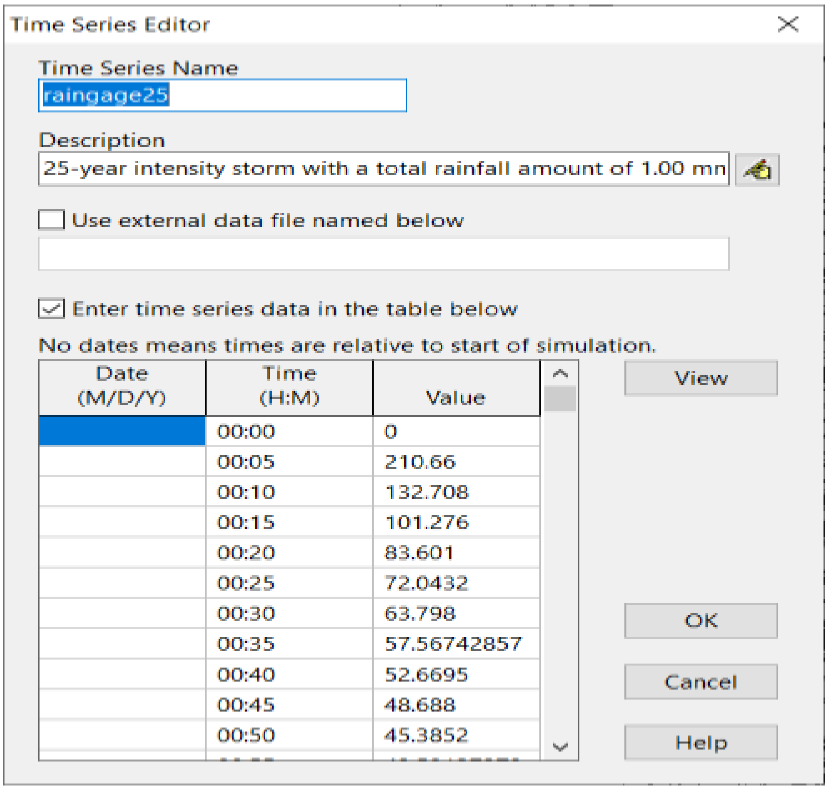


Figure D-7: Time series editor for 25 years return period.

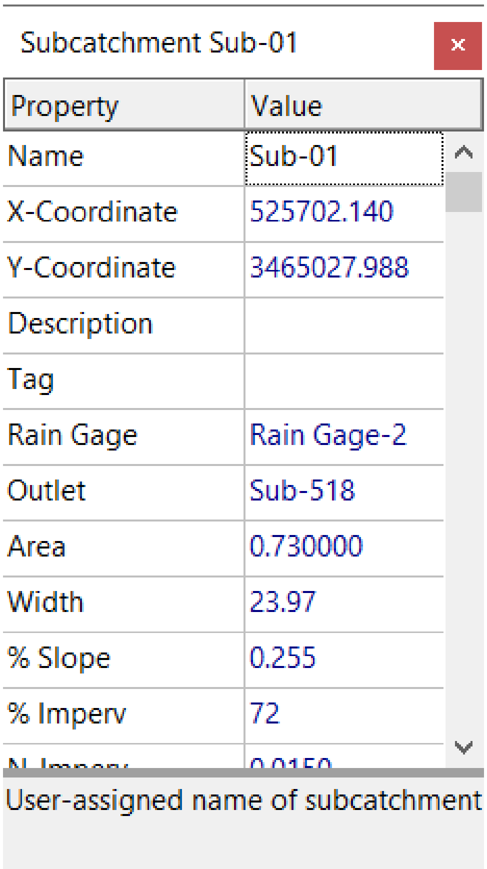
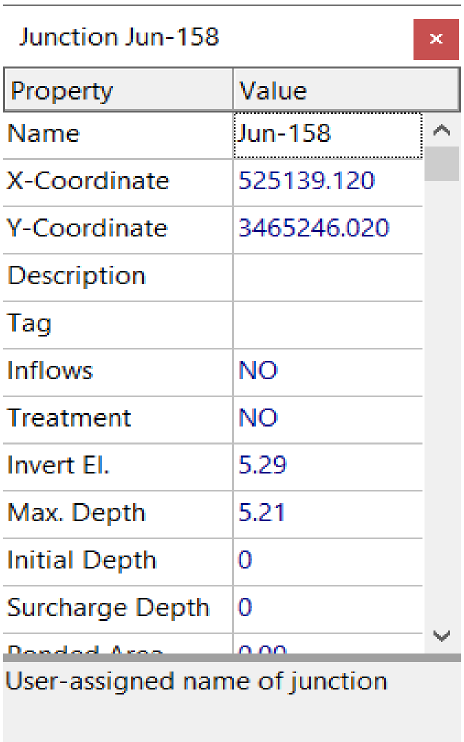


Figure D-8: Input properties of sub-catchment number 01.

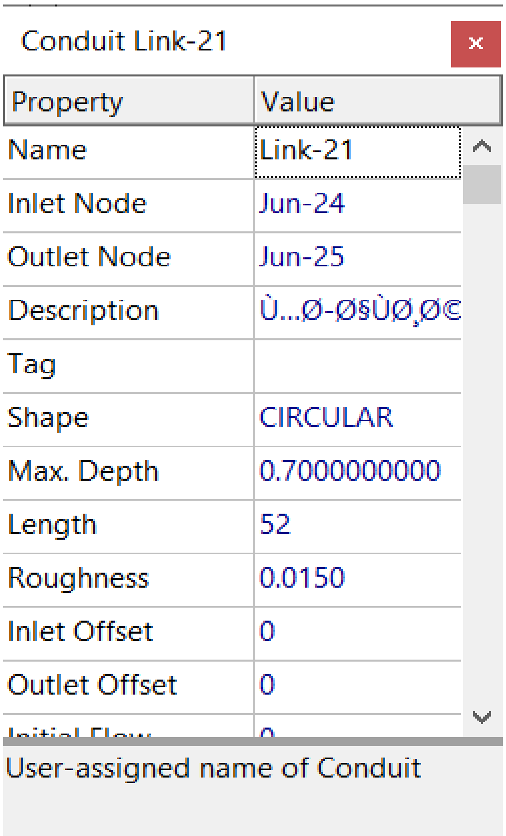


Junction Jun-158

Property	Value
Name	Jun-158
X-Coordinate	525139.120
Y-Coordinate	3465246.020
Description	
Tag	
Inflows	NO
Treatment	NO
Invert El.	5.29
Max. Depth	5.21
Initial Depth	0
Surcharge Depth	0
Ponded Area	0.00

User-assigned name of junction

Figure D-8: Input properties of manhole (Junction) Jun-158.

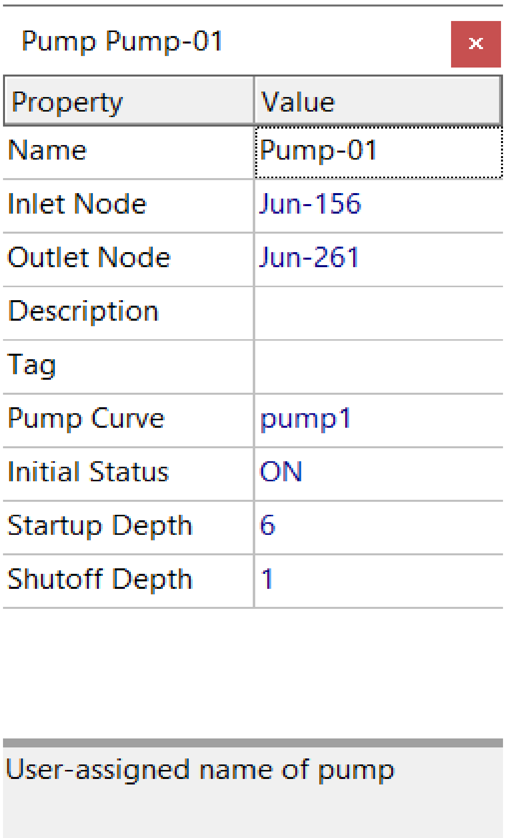


Conduit Link-21

Property	Value
Name	Link-21
Inlet Node	Jun-24
Outlet Node	Jun-25
Description	Ù…ØØ§ÙØ¸Ø©
Tag	
Shape	CIRCULAR
Max. Depth	0.7000000000
Length	52
Roughness	0.0150
Inlet Offset	0
Outlet Offset	0
Initial Flow	0

User-assigned name of Conduit

Figure D-8: Input properties of pipe (conduit) Link-158.



Pump Pump-01

Property	Value
Name	Pump-01
Inlet Node	Jun-156
Outlet Node	Jun-261
Description	
Tag	
Pump Curve	pump1
Initial Status	ON
Startup Depth	6
Shutoff Depth	1

User-assigned name of pump

Figure D-8: Input properties of pump-station, pump-01.

Appendix-E: Table of choosing the discharge depending on calculating the depth of runoff surface

Node-ID	Discharge flooding CMS	Volume 10^6 liter.	Volume m^3	Sub-id	Area m^2	Depth of runoff cm
jun-107	0.04	0.246	246	291	2100	11.71428571
Jun-108	0.008	0.018	18	416	2440	0.737704918
Jun-109	0.151	0.291	291	640	12456.87	2.336060343
Jun-117	0.005	0.001	1	416	2440	0.040983607
Jun-122	0.035	0.042	42	417	18100	0.232044199
Jun-125	0.022	0.02	20	640	12456	0.160565189
Jun-152	0.005	0.001	1	531	531	0.188323917
16-Jun	0.072	0.03	30	548	4100	0.731707317
Jun-189	0.058	0.056	56	563	2930	1.911262799
Jun-211	0.039	0.085	85	305	1390	6.115107914
Jun-216	0.004	0.001	1	323	3100	0.032258065
22-Jun	0.125	0.897	897	607	5140	17.45136187
Jun-218	0.015	0.005	5	331	1500	0.333333333
Jun-240	0.008	0.001	1	423	5120	0.01953125
Jun-109	0.151	0.291	291	640	12456	2.336223507

الخلاصة

لقد زاد الجريان السطحي و تدفقه الى انظمة الصرف الصحي مؤخرا بسبب التوسع الحضري و التغير المناخي و التقادم في البنى التحتية مما ادى الى حدوث فيضانات. تحدد هذه الدراسة استخدام برنامج SWMM للتنبؤ بكمية مياه الأمطار وكذلك تطبيق LID على شبكة تصريف مياه الامطار لمنطقة الدراسة في حي الصوب الكبير الناتج عن سطح الجريان السطحي لمياه الأمطار وتدفقها إلى نظام الصرف الصحي طوال مدة أحداث هطول الأمطار في فترات العودة المختلفة .تم تحديد نموذج الكمية يدويا عن طريق تغيير ميزات مستجمعات المياه الفرعية الفعالة باستخدام معدلات التدفق التصميمية و التدفق المحاكية لفترات العودة المختلفة. كان متوسط الخطأ التربيعي الطبيعي (NMSE) هو (١,٠١٤٥) و معامل الارتباط (R) هو (٠,٩٥٧) و ان هذه القيم ضمن الحدود المقبولة مما يؤكد صحة النموذج.

وأشارت نتائج تقييم النموذج الكمي إلى أن النظام حرج وغمرته المياه عند التدفق في فترة تساقط الامطار في العديد من مواقع غرف التفتيش. استجابة لحدث هطول الأمطار ، عندما زادت فترة العودة من ٢ إلى ٢٥ سنة أظهرت زيادة في حجم الفيضانات لشبكة الامطار ونسبة غرف التفتيش الفائضة من ١٤٦٦ m3 و ١٠ ٪ إلى ١٣٧٣١ m3 و ٤٢ ٪ ،بالتتابع.

وكان الحل المقترح باستخدام تقنية LID قد قلل من حجم الفيضانات في فترات العودة المختلفة ٢,٥,١٠ و ٢٥ إلى ٩٩٨ و ٢٢٩٢,٤ و ٧٩٥٩ و ١١٩٦٧ ، تم مقارنة النظام عن طريق تغيير قطر خط الجذع بدون تغيير الأقطار ، مما أدى إلى تقليل حجم الفيضان في فترات عودة مختلفة ٢,٥ و ١٠ و ٢٥ إلى ١٠٨٤,٥ و ٢٠٠٣ و ٧٣٧٥ و ١٢٥٤٦ على التوالي. عند المقارنة بين الحلين ، بالامكان إعطاء الأفضلية لـ LID تقنيًا وفي طريقة انشاءه في تقليل الفيضان.

جمهورية العراق

وزارة التعليم العالي و البحث العلمي

جامعة كربلاء

كلية الهندسة

قسم القندسة المدنية

تقييم استخدام البنية التحتية الخضراء لتحسين إدارة مياه الأمطار في محافظة المثنى

رسالة مقدمة الى مجلس كلية الهندسة / جامعة كربلاء وهي جزء من متطلبات نيل درجة الماجستير في علوم الهندسة المدنية

كتبت بواسطة:

افنان حسين منديل

بكالوريوس في الهندسة المدنية ٢٠١٦ / جامعة المثنى

باشراف :

أ.د. باسم خليل نايل

أ.د. عصام جواد الياسري

شوال - ١٤٤٣ أيار - ٢٠٢٢