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The Effect of Densely Populated Area on the Operation of the Combined Sewage System: Case Study, Al-Najaf City

A thesis submitted to the Department of Civil Engineering at the University of Kerbala in partial fulfilment for the degree of master of sciences in Civil Engineering.

By

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صَدَق الله العلي العَظيم

سورة طه {114}

Abstract

Flooding in the sewer systems may be caused by urbanization when increasing the impervious areas and decreasing infiltration rate, land-use changes, or climate change that cause increasing the rainfall intensity or the misuse of the inhabitants, all that affect the performance of these systems.

The present study aims to search the effect of a densely populated area on operating the combined sewage system under higher rainfall intensities using the Storm Water Management Model (SWMM) by simulating a future increase in rainfall intensities for reducing the combined sewage system overflow in the study area. The present study selected AL-Rashadiya quarter that locates in Najaf city, as a case study.

The first step in the present study was generating the Intensity-Duration-Frequency (IDF) curves by finding the empirical equations of these curves based on historical precipitation data of the interval from 1989 – 2018, three statistical distributions were used to predict the highest rainfall intensities for the return periods of 2, 5, 10, and 25 years. These distributions include Gumbel, Log Pearson, and Lognormal distribution, where the higher rainfall intensities obtained were by using Gumbel distribution, where these rainfall intensities have been used in the SWMM modelling to estimate the maximum flooding volumes in the sewer systems of the study area.

The available data represents only one event of precipitation, on 28/11/2020, which was used for calibration purposes of the quantity model, where the rainfall depth was 55 mm in Al-Najaf city.

Also, comparisons were conducted between the design flow rates, the event model flow rates and models flow rates using the different rainfall intensities, using the indicators of the Normalized Mean Square Error, coefficient of determination, and Root Mean Square Error. These indicators help to estimate the modelling performance and obtain the nearest rainfall intensity to the rainfall event, which was the rainfall intensity for the return

period of 5-years. This rainfall intensity was used in the SWMM modelling of stormwater quality in the study area to estimate the pollutants volumes.

The estimated flooding volumes in the modelling of the combined sewage system are 3817 m^3, 6912 m^3, 8929 m^3, and 13434 m^3, using the rainfall intensities for the return periods of 2, 5, 10 and 25 years, respectively. Obtained flooding quantities were utilized as an external flow rate from the combined sewage system nodes to the nearest nodes in the stormwater system.

The flooding result using the stormwater system modelling was 526 m^3, 2669 m^3, 3316 m^3, and 5568 m^3, using the rainfall intensities for the return periods of 2, 5, 10 and 25 years, respectively, where these flooding volumes were the final flooding volumes in the study area.

Also, laboratory tests were conducted on the stormwater at the disposal point at the end of the stormwater system in dry and wet weather. The obtained tests result during the rainfall event were used in the calibration process of the stormwater quality model to estimate the pollutants Buildup and Washoff factors in the study area.

The quantities of pollutants produced at the outfall point of the stormwater system were 1589.34 kg of TSS, 250.302 kg of BOD_5, 0.514 kg of Cu, 0.227 kg of Pb, 0.165 kg of Cr and 0.309 kg of Mn, by using simulation of the SWMM quality model for 2 hours.

The suggested scenarios include increasing diameters of some pipes in the combined sewage system, where the obtained results showed a flooding reduction percentage in the combined sewage system of 53.52 %, 39.65 %, 33.3 %, and 24.41 % from the total flooding, where this scenario an ability to reduce the pollutant quantity that comes from the combined sewage system overflow during the rainfall events when this overflow enters the stormwater system inlets.

The other scenario includes using a compact unit at the end of the stormwater system to treat pollutant stormwater, which considers an un-controlling problem, with a treatment capacity of 500 m^3/h.

Supervisor certificate

I certify that this thesis entitled "The Effect of Densely Populated Area on the Operation of the Combined Sewage System: Case Study, Al-Najaf City", which is prepared by "Ammar Rasheed Majeed", is under our supervision at University of Karbala in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering (Sanitary Engineering).

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Linguistic certificate

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Examination committee certification

We certify that we have read the thesis entitled "The Effect of Densely Populated Area on the Operation of the Combined Sewage System: Case Study, Al-Najaf City" and as an examining committee, we examined the student "Ammar Rasheed Majeed" in its content and in what is connected with it and that in our opinion it is adequate as a thesis for the degree of Master of Science in Civil Engineering (Sanitary Engineering).

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Dedication

I sincerely dedicate this work to the best persons and things I knew in my life:

The noble messenger Mohammed and his good and pure family ...

My immortal love, Iraq, and for everyone who sacrificed for it

My dears, father and mother, my bigger sister and wife, brothers and sons, for their honourable stand with me in all my life steps ...

Finally, All my friends who supported me ...

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List of Symbols

Title	Symbol
Environmental Protection Agency	EPA
US Environmental Protection Agency	USEPA
Combined Sewer Overflows systems	CSOs
Sewer systems Overflows	SSOs
Intensity-Duration-Frequency	IDF
Geographic Information System	GIS
Storm Water Management Model	SWMM
Municipality Directorate of AL-Najaf	DMN
Best Management Practice	BMPs
AL-Najaf Sewage Directorate	NSD
American Society of Civil Engineers	ASCE
Dry Weather Flow	DWF
Infiltration and inflow	I&I
Depression Storage	dp
Probability Density Function	PDF
Indian Meteorological Department	IMD
Log Pearson Type III distribution	LPT III
Kolmogorov-Smirnov test	KS
Power Function	POW
Expansional Function	EXP
Cubic Meter per Second	CMS
Biochemical Oxygen Demand	BOD_5
Chemical Oxygen Demand	COD
Total Suspended Solid	TSS
Nitrogen	N
Phosphor	P
Kingdom of Saudi Arabia	KSA
Source Water Management Strategies	SWMS
Advanced Simulation Capability for Environmental Management	ASCEM
Normalized mean square error	NMSE
Root mean square error	RMSE
Coefficient of determination	R^2

Low Impact Development	LID
Personal Computer of the Stormwater Management Model	PCSWMM
Event Mean Concentrations	EMC
Copper	Cu
Lead	Pb
Chrome	Cr
Manganese	Mn

Chapter One

Introduction

1.1. Background

The drainage systems have been used since the beginning of the third millennium BC. So, the studies of water transportation problems have used functional technological solutions. These studies have a long history and deep roots in ancient times begun with a merger of technology with philosophy and sciences that appeared in Mesopotamia, Egypt, India, Hellas, and China (Yannopoulos et al., 2015).

Densely population in urban areas is one of the several significant demographic's challenges of the 21st century. The dense growth of the population is at most concentrated in urban areas. In developing countries, the most growth of cities is unplanned, leading to rapid densification (Resnick, 1980). Sewerage networks in many cities are still not building properly (Burian & Edwards, 2002). In General, recent years showed that world cities are quickly vulnerable to the occurrence and effects of pluvial floods (Barredo, 2007).

There are four interrelated consequences of land-use changes on the hydrology of any area: changes in hydrological infrastructure, changes in overall drainage, changes in the characteristics of the peak flow, and changes in the quality of water. Of all the changes in hydrologic facilities that influence city hydrology, urbanization has the greatest effect (Leopold, 1968). The hydrologic characteristics of any area, determined through its climate and structure. Consequently, any change in the properties of these areas will affect their hydrology (Bryan, 1970).

To removal both the liquid and solid sewage from urban societies, sewerage systems are used (Metcalf & Eddy, 1981). The pollutants, in most cases, hitting the stormwater systems as sewage leaking result by infiltration or the un-legal cross-connections, where finally result in a direct discharge of untreated sewage at the rivers and streams (Sercu et al., 2011; Sauer et al., 2011). On the other hand, sewer systems can be inundated by the rainwater under severe precipitation events and cause sewer overflows (McLellan et al., 2007; Passerat et al., 2011). Also, untreated wastewater released from failed sewer infrastructure in urban areas can leach into soil and migrate to groundwater (Reynolds & Barrett, 2003; Gotkowitz et al., 2016), and drinking water distribution systems under reduced pressure conditions (Teunis et al., 2010).

The runoff problems persist due to the increase in world people also the rapid migration of rural populations to the outskirts of cities (Ho, 2000). Also, significant economic losses and human injuries are still caused by urban flooding during rainy weather (Jia, 2013).

In an urbanized sub-catchment, the regular direct delivery of pollutants and water from impervious surfaces to streams has a damaging effect on the stream's health. Modern studies of ecological range indicators have shown the direct links between the impervious surfaces and streams remain small. These hints help improving the health of streams in the regions that are subject to urbanization includes finding methods of lowering the effectiveness of water delivery of impervious surfaces (Ladson, 2006). Also, the runoff from most land-use kinds had a low concentration of dissolved oxygen, where the concentration condition of the nutrients and sediments are closely associated with land use (Graves, 2004).

The combined economic use of rainwater forms the basis for strategies that adapts to the water sector due to progressive climate change. Rainwater is a significant component of water supplies that ensures surface and groundwater renewal, so it should be protected from contamination and maintained and used in rainfall settings (Zdeb et al., 2018).

1.2. Problem Statement

The justifications of the present study came from the fact that sewage systems are a concern for environmental safety, protecting public health, and human comfort in different world countries. This concern is increased gradually for many reasons, such as precipitation increase due to climate change, population growth, and improving people's ability to mobility.

This study targeted Al-Rashadiya quarter, which is located in the district of Kufa to North-East of Najaf city, Iraq. The study area is high-populated, where the number of people in 2009 was 9187 people, and the yearly growth factor for Al Al-Najaf city during the previous decade is 3.5% (CSO, 2009; INPC, 2011). It is suffering from flooding of the combined sewer and stormwater systems during the rainy season. High rainfall intensities with the dense population area affect the combined system operation and cause the runoff of wastewater to the stormwater system inlets that essentially suffer from flooding during the rainy events.

The climate changes led to an increase in the quantity of rainfall to values higher than the design capacity values of the combined sewer system in the study area and cause flooding in the stormwater system, where the flooding leads to decrease drainage capacity of the stormwater system, due to the sedimentations on the pipes' walls. The combined sewer system flooding during the rainfall season of the study area caused the flooding in the stormwater system under the lowest intensity of rainfall, where these rainfall intensities exceeded the design rainfall intensity. And thus, leads to rainwater contamination at the disposal point.

1.3. Objectives of the study

The objectives of this study involving:

1) to predict the future rainfall intensities of AL-Najaf city by producing the Intensity-Duration-Frequency (IDF) curves.

2) to evaluate the effects of densely populated areas on the operation of the combined sewage system and stormwater drainage system and water quality of the rainwater disposal point under the influence of high rain intensities.
3) to determine the rate of the expected floods in the combined sewer system that inflow to the stormwater drainage system through the inlets.
4) to identify the impact of small areas with a high population on the quality of rainwater discharge by the stormwater system to the disposal point.

All the above is done by preparing the suitable simulation models through using of Geographic Information System (GIS), AutoCAD Civil 3D and Storm Water Management Model (SWMM) (v5.1) program.

1.4. Study Scopes

The following are the study scopes:

a. Drawn of IDF curves based on the maximum daily precipitation data of the 30-years that preceded this study. Then, the amounts of rainwater discharging in the stormwater network and the combined sewer network in the study area are adopt based on these curves.
b. The obtained results of the present study have been based on data included population, stormwater sewer system, combined sewer system, maximum daily precipitation.
c. The tests of rainwater characteristics directly discharged to the river were considered in this study. The rainwater characteristics tests involved the pH, Conductivity, TDS, Turbidity, Temperature, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Dissolve Oxygen (DO), and some of the Heavy metals.

The solutions to management, good planning and analysis are necessary within increasing degeneration to be considered, to avoid unexpected events, such as floods in the stormwater network and sewage network, and environmental pollution.

1.5. Methodology

The methodology can be reviewed in the following points:

1. Metrological data, for the study area, were collected from the Meteorology and Seismic Monitoring Authority of Iraq for the duration from 1989 to 2018. This data includes daily rainfall (mm).
2. Using the collected daily rainfall data to derive the rain Intensity-Duration-Frequency (IDF) curve relationship for Najaf city for different periods. Then, drawing these curves.
3. Collecting the population information from Directorate of Statistics of Najaf city.
4. Collecting the geographic information system (GIS) data from the Municipality Directorate of AL-Najaf (DMN) and AL-Najaf Sewage Directorate (NSD). The data include characteristics of the sectoral area, combined sewage system, and stormwater systems data, such as the parameters of a study area, pipes, junctions, and all appurtenances for the study area.
5. The predicted Rainfall Intensity Duration Frequency (IDF) curves, ArcGIS (v10.4), and Storm Water Management Model (SWMM v5.1) are used in the analysis of the combined sewage and stormwater systems for the study area to simulate and assess flooding.
6. Laboratory tests to determine and evaluate the effects of the densely populated and rainfall intensities during dry and wet weather have been conducted on the quality of rainwater discharged in the disposal point on the river by measuring some parameters of the rainwater characteristics.

1.6. Thesis structure

The thesis contains six chapters, which are:

- Chapter one, that appears background, problem statement, objectives of the study, study scopes, methodology of this thesis, and thesis structure.

- Chapter two, that contains the introduction and the literature reviews about the relationship of flooding with density population and urbanization, changes in the intensities of rainfall, the quality of rainwater, and the modelling by SWMM.
- Chapter three, which explains the used subjects and techniques include the introduction, study methodology, description of the study area, land use, general description of SWMM, surface runoff, the field data, the hydraulic data description, the hydrological data, and the time series and the intensity-duration-frequency (IDF) curves.
- Chapter four, that explains the pollutants modelling by SWMM and the stormwater quality characteristics.
- Chapter five, that presents the results of the flooding quantity in the combined sewage system using the SWMM modelling and the results of the SWMM quality modelling of the rainwater. Also, it presents suggested scenarios.
- Chapter six contains the conclusions and the recommendations for future works.

Chapter Two

Literature Review

2.1. Introduction

This chapter presents some of a previous studies related to factors that affect the floods occurring in the stormwater system and sewage system in urban areas. These factors involve the density population and urbanization and their relationship with occurrence of floods in stormwater and sewerage systems, climate changes and their relationship with the changes in the intensities of rainfall and development of IDF curves. Also, this chapter presents studies that dealt with the quality of rainwater which is discharged directly into waterways. Finally, it presents previous studies that be related to flooding modelling obtained by using SWMM software.

2.2. Effects of population density and urbanization on the occurrence of floods in sewerage systems

Cities are socialite centres, where living depends upon many functions and services, for example employment, education, provision stock water and energy, homes, transport links. The urban floods can cause a wide disruption into services to submit and an influence on people lives. Several examples were noted in the recently, including flooding in Brisbane in 2011 and diffused flooding in Thailand that flooded Bangkok in 2011 and the sudden flooding in Beijing in 2012 caused by increasing precipitation intensity.

Most predicts referred that the urban flooding problem will increase in future. The first explanation was the rapid growth of the city's population, where the world population become more urbanist. A report prepared by United Nations (2012) referred that the world population living in urban areas had exceeded the rural population. Also, in the interval from 2011 to 2050, the world population will rise about 2.3 billion (7-9.3 billion). The report expected that the people number lives in the urban regions would be risen by 2.7 billion in the same period, where it will be arrived at 6.3 billion people, where this growth represents a rise in the urban population from 51% (in 2011) to 68% (in 2050) compared with the total world population (United Nations Department of Economic and Social Affairs, 2012).

With further people moving to urban areas, they surely will increase the proportion of impervious areas on the ratio of the green regions and increases the quantities of runoff. The exposition to flood hazards in the urban areas will be risen with rising of people exist, particularly in the densely populated cities. Usually, these urban regions are founding in the low-lying coastal and plains area.

The second explanation trending that the possibility of climate change leads to a lot of rainfall, where several statistical scientific researches showed many high precipitation events happened in the previous hundred years, in North America (Peterson et al. 2008) and Denmark (Arnbjerg - Nielsen 2006).

Generally, most studies have concentrated on the factors and problems corresponding to water concerns, water management, and sewerage systems. According to Kundzewicz & Kowalczak (2009), the water problems classified into three major categories: "Too much", "Too little" or "Too dirty ."

According to Cooney (2012), the report of the intergovernmental panel on climate change (IPCC) stated that the hydrological disturbances remain too harmful to the human community, also the environment. Perhaps, these increase with urbanization extension and the possible climate changes.

Wagner & Breil (2013) mentioned that the natural cycles are modifying by the extension of urbanization, where the infrastructure is senile and stagnancy. For this, big residents’ numbers impacted in per unit area.

Obaid et al. (2014) stated that the studies of sewer overflow problems are needed because of the population increase, economic advancement, and people movement ability.

The study of Ward & Winter (2016) pointed out that traditionalistic drainage systems in urban spaces are build up to improve human dominance over the biophysical ecosystem that causes pollution surface runoff discharged in the urban waterways. The study pointed to most people miss the "connection" between their effects on the quality of river's water and runoff and between their activities on their property.

A study was conducted by Hassan et al. (2017) to identify the performance of stormwater systems to address risks related to climate change in the future. The study results showed that due to climate changes, the rainfall intensity has raised to 33.54 mm/h. This change caused flooding in 47% of the stormwater system manholes. The illegal sewage process will increase this flooding in the system to the percentage ranged 39% to 52% at this rainfall intensity.

The study of Petit (2017) indicated to the growth of world cities is associated with an increase in a demand for sewage and stormwater infrastructure in terms of the water cycle with the economic level, and associate the condition of this system in eco-urban areas is critical. Part of the existing sewage network requires an imminent renovation. At the same time, another network part must construct in the development area, where rainwater runoff becomes a threat in terms of flooding due to impermeable soil. In this part, the best practices aimed at reducing these issues were an environmental and economic point of view, identifying and innovative, and at the same time adapting cities to desired economic developments.

Gawi (2017) suggested that highly populated countries, like Iraq, face .many health problems caused by environmental pollution.

The study conducted by Rosburg et al. (2017) studied the urbanization impacts on duration and variation of the flow duration curve (FDC) within 8 water catchments that have different growth percentages. The results showed a rise in the curve's percentages with 34% in urban regions due to the conversion in the hydrological path and urbanization, where increases impervious area. At the same interval, the opposite happened in rural regions due to a drop in the groundwater level, where groundwater extracting for agriculture purposes.

The study by Salerno et al. (2018) studied the impacts of climate change and urbanization on the quality of water receivers in serviced areas via a combined sewage system. Study findings indicated that impenetrable urban surfaces and rainfall rates are important factors that affect the cumulative overflows of the combined sewer systems subsequently, the quality of water receivers. The scenarios of the year 2100 reflected the truth of the mixed impacts, which can lead to a significant decline of water quality by doubling the overall phosphorous load comparison to current loads. The reduction of the impervious area has been an effective method for responding to these scenarios by limiting new impermeable sub-catchments to be developed and decreasing existing watersheds by 15%.

According to Chang et al. (2018), the population growth and migration from rural to urban areas have resulted in the construction of grey cities mainly composed of impervious surfaces. Large amounts of rainwater, containing pollutants from grey cities, cause problems such as inland flooding and water pollution.

Rangari et al. (2019) concluded that the urban flood is self-invited, which means the human appetite for more land and unregulated infrastructure construction by changes in natural land use, land cover, and streamflow ways. A self-invited means the hazards tied for the tremendous property losses, in some cases life losses.

Mahaut & Andrieu (2019) investigated the connection between hydrological mechanisms and urban management, where the proportional impacts of population and climate change can be occurred. The obtained results explained that climate change has little impact on sewage systems flooding compared to population increasing and urban progression in particular scenarios. Also, the study supported the use of separated systems for the limitation of this sewer flooding.

2.3. Changes in the rainfall intensities and the development of Intensity–Duration–Frequency (IDF) curves

AlHassoun (2011) conducted a study in KSA, where developed an empirical equation for the rainfall intensity estimation by the precipitation frequencies analysis.

Westra et al. (2013) conducted a study that addressed, "Global increasing trends in annual maximum daily precipitation", the study showed an increase in the precipitation rate in certain areas due to climate change.

Kleidorfer et al.'s (2014) prepared a study entitled of “compared the effect of enhanced rainfall intensities and the urban area pavement" which is shown comparable to several results in both impacts. So, when attempting to forecast the potential success of combined sewage systems, it is necessary to look at all aspects.

De-Paola et al. (2014) conducted a study to forecasting IDF for a chain of data and climate predictions in three African towns. The study compared various techniques used in collecting data with recorded data to create a synthetic series of rainfall with statistical properties. The rainfall pattern of the three tested cities was analysed, and (IDF) curves were assessed. Also, a specific rainfall simulation to determine the impact of climate change on (IDF) for the period 2010 – 2050 was tried. The evaluation results of the (IDF) curves allowed framing the rainfall development of the three cases studied, initially using only the historical data set. Then, the climate predictions to check the changes in rainfall patterns were used. Finally, by using the same data and climate predictions, the study evaluated the probable maximum precipitation (PMP).

Al-Awadi (2016) studied the subject of assessment of Intensity-Duration-Frequency (IDF) models for Baghdad City, Iraq. Many utilized analysis methods have been developing the association among rainfall intensities, duration of the storm, and the return period by using rainfall data. Three common distributions were used to find IDF curves, which are Gumbel, LPT III, and Lognormal. Non-linear regression analysis has also been used in finding the (IDF) equations for different return periods. The obtained results showed no substantial variation between the three methods used where all distributions have located at an appropriate significance level, with a minor preference for the distribution of LPT III.

The study of Dakheel (2017) was conducted to draw (IDF) curves for Nasiriyah town, Iraq. The results showed that rainfall intensity increases with a storm duration decreases. Also, frequencies of rainfall for given durations become higher intensity if the return period is high too.

Al-Amri and Subyani (2017) have generated IDF for ungauged positions in an arid of the Kingdom of Saudi Arabia (KSA). The study developed configuration standards IDF for water schemes in non-gauged arid areas.

One of the conducted study results by Nile et al. (2018) was that the climate change and world warming impact the increased rainfall intensities to higher than the design capacity of current systems, where this problem caused these systems flooding. Also, excessive use of sewer systems, such as the extra sewage quantities that enter the sewerage system, and users closing the sewer inlets by throwing trash could be raising the flooding of these systems.

Kadhim's (2018) conducted a study about the evaluation of a maximum rainfall magnitude of the Mid-Mesopotamian plain using the frequency factors method; the results showed that the rainfall volume increases with the rising return time.

Basumatary & Sil's (2018) used in a study the statistical analysis methods, which are Lognormal, Gumbel and LPT III, to estimate the best fit amongst PDF. The study results indicated that goodness fit examinations using LPT III distribution was the more proper for the study region. Also, IDF curves have been developed for each location by producing the average values of (IDF) curves by using ArcGIS.

Kusumastuti et al. (2019) used the Rational Formula (Q = C*i*A), to measure the peak flood effluence in the sub-catchments, where design rainfall intensity was used. The study outcomes showed that the Rational Method approached offered the nearest volume of projected flood discharge compared to the measured streamflow value in the sub-watershed.

Parvez & Inayathulla (2019) study generated the IDF curves for Indian rural in Bangalore. The study recommended the necessity of depending on the rainfall characteristics to build up water systems and the significance of similar studies in identifying the potential impacts of climate change as one way to defeat urban flooding.

Al-Sudani (2019) investigated the effects of rainfall returns periods in Iraq, and he showed that the mean annual rainfall has an asymmetrical increasing trend from the south-west to the northeast, based on the increasing rainfall ratio in the northern region of Iraq.

Mahdi & Mohamedmeki (2020) conducted a study that used the analysis of precipitation frequency and PDF, based on Bernard equation, to predict various rainfall intensities and return period, where the result compared by utilizing the KS goodness of fit test. The results were close, accepted at the significant level of 10%.

2.4. The quality of rainwater

According to the study prepared by Koldabadi et al.'s (2012), it was found that the presence of heavy metal ions such as copper (Cu), chromium (Cr), lead (Pb), mercury (Hg), cadmium (Cd), nickel (Ni), zinc (Zn), and cobalt (Co) in the environment leads to affect the life and health of human because of their toxicity. Unlike other organic pollutants, these heavy metals will not degrade into simple end products, wherein disclose in the waste's streams from various industrial activities.

Copeland (2014) highlighted that most stormwater issues are due to the stormwater quantities flow with an excessive form on hard surfaces, such as rooftops, parking lots, and sidewalks. After that, this runoff flows through the stormwater sewer, carrying a high percentage of harmful materials to aquatic life and public health toward lakes and streams.

Hussein et al. (2015) studied a relationship between precipitation and the concentrations of TSS and BOD_5. The study results showed that BOD_5 and TSS significantly rise after the rainfall events in a study region.

According to Li et al.'s (2015) study, disposal of the volume of the runoff with percent equal to 0.4 removes loads equal to 0.53, 0.55, 0.61, and 0.58 for COD, TSS, P, and N, respectively based on the total event runoff.

The study of Jalliffier-Verne et al. (2015), showed that in addition to local land-use improvements, the Source Water Management Strategies (SWMS) should be considered the effects of climate change on contaminant dilution to protect or improve water quality.

Komínková et al. (2016) conducted study to assess the impact of the combined sewer and stormwater systems overflows on vitality metals in small rivers of urban. The results indicated that the type of urban sewer affects the vitality of metals, where the wastewater decreases the vitality metals, while the stormwater increases metals.

According to Walsh et al. (2016), urban runoff is the main cause of degrading flows of ecosystems on the global level.

Chen et al. (2016) studied the influence of land use on the quality of surface water. The result showed that this influence was highly on N, P, and COD concentration in very urbanized areas. On the other side, in the rural and suburban lands, agriculture was more impact in N, P, and COD, where these pollutants come from the runoff on the surfaces of the agricultural areas. Also, these impacts were of high levels in the very urbanized and suburban in the rainfall event, and in agricultural areas were more than these levels in the dry weather.

Madoux-Humery et al. (2016) studied the influence of overflows in the combined sewage system (CSOs) during rainfall events on the E-coli concentration in a river used as a source of drinking water. The results showed that most of the E. coli (about 80%) connected to CSOs are obtained when rainfall events are occurred with a depth of more than 10 millimetres and in the case of ice melt in the spring season.

According to studies conducted by Verhougstraete et al. (2015) and Sowah et al. (2017), it was found that in suburban and rural areas, leak from septic tank systems can contaminate groundwater or surface water as well as other sewer systems.

A conducted study by Alam et al. (2017), about the accumulation of wash-off solid wastes in sewer systems known as gross pollutants (GPs), showed a significant restriction for Best Management Practices (BMPs) of stormwater systems. The study results appeared that these GPs should be collected in their source before it blocks the inlets of drainage networks, where these materials affect the aquatic life of the receiving waters.

Zdeb et al. (2018) studied the physical and chemical quality of rainwater collected directly from precipitation. The study conducted tests of many characteristics such as PH, turbidity, permanganate, phosphorus, phosphate, oxygen, acid, base, conductivity, and hardness, heavy metals content. The study was conducted for the purpose that rainwater can be using for various economic purposes.

Atinkpahoun et al. (2018), conducted a study about the dynamic influent models to test strategies control using virtual WWTP. The study results showed that the changes in the flow rate of wastewater and pollutants (nitrogen, phosphorus, carbon, and heavy metals) were due to population fluctuations behaviours such as eating meals, voiding of the bladder, and washroom use, ..., etc.

Zhou's (2019) showed that stormwater quality and runoff are delimited by complicated biophysical means, with large determinations that noted for some land use between un-urban spatial size and the property.

2.5. The SWMM modelling

A study by Jang et al. (2007), considered the SWMM as a mechanism for hydrologic impacts evaluation. The study indicated that the hydrologic impacts are requisite for the design of detention storage of sewer systems in the planning stage of developing urban regions, where the purpose was to reduce the urbanization impacts. This evaluation has a high connection to pollutant concentrations produce from urban zones. The SWMM could use for both pre-development and post-development situations. SWMM results were compared with the past evaluations produced in the same regions, where the SWMM method solved the problems occurs with combined two diverse models, such as the longer time to peak flow and lowest peak flow. The use of SWMM enhanced the evaluation of the hydrologic impacts in the developing zone.

A conducted study by Park et al. (2008) about the effects of the division level and the spatial resolution of the sub-catchments on the surface level runoff and pollution using the SWMM modelling. The Scopes of their study has been done in Korea and carried out by applying GIS overlaying techniques. The division level considered the land-use forms, the slope of surfaces, and the flow directions in the stormwater drainage system. The results showed that the peak, the cumulative, and the total surface runoff had not been much affected by the sub-catchments division level, but the pollution loads were affected.

Wang et al. (2010) indicated that SWMM also classifies stormwater to both rainfall and runoff processes and provides better information support for flood risk assessment.

According to Guangtao et al. (2011), the primary aspects of flood modelling should consider the characteristics of urban flooding, the effects of heavy rainfall on urban catchment runoff, and the different socio-economic features.

Yan et al. (2011) indicated that the SWMM is an active method for both controlling and prevention against urban stormwater disasters, which is considered very important because of the significant threats to traffic, commerce, and characteristics of the growth of the population by stormwater disasters in recent years. It is one of the most successful applications in urban stormwater control researches.

Blansett (2011), pointed to the EPA SWMM v5.1 as is a physically and dynamically dependent model of the rainfall-runoff, used for stormwater-sewer discharge, velocity, surcharge, etc., to test the hydraulic and the hydrological output caused by the sewage network and rainfall-dependent inflow and infiltration (RDII) by simulation. The study pointed that SWMM v5.1 is used for the simulation of sewer and stormwater networks overflow with a high population and high rainfall intensities.

The study of Jiang et al. (2015) referred that the forecasting of floods is one of the methods used to mitigate floods and helps in reduce sub-catchment flooding, but not in urban areas. The SWMM employed in this study is the first overflows forecaster in the sewer systems scope for the design and the control purposes of sewer projects in urban regions. The study results of the simulation showed that using rainfall intensities for return period of one year, the study region did not suffer from flooding, but using rainfall intensities for more than 2-years (until 20 years) of return period, the study region will inundate. The study pointed that SWMM will remain the best in the forecasting of the flooding of the urban region. Only, routing problem of a runoff that makes the forecasting of flooding using the SWMM still un accurate.

Jefferson et al. (2017) stated that there are generally known harmful effects of urban stormwater. The regulations have been placed in many countries to enhance the standards of the water release to the water bodies. But usually, stormwater management, planning and engineering are carried out on small scales. To understand how to translate small-scale practices to keep urban river health, quantifying the cumulative efficacy of multiple stormwater management actions on a watershed scale is necessary.

A study was conducted by Thakali et al., (2018), to test the hydrological modelling and low-impact constructions techniques. The study results showed the ability to use the Storm Water Management Model (SWMM) and the low-impact constructions techniques, which are used to reduce the excess of surface runoff caused by climate change, such as the permeable pavement and the green roof. The approaches adopted successfully relieved the challenges presented by the climate change and the management of changes in urban stormwater volumes.

In a study conducted by Yang et al. (2020), the SWMM modelling outcomes (nodes overflow), from simulating the runoff and the rainfall in the urban environment, were used as a limit condition in overflow deluge modelling. The examination scenarios used different rainfall intensities and return period. The study results showed that nodes flooding, water depths, and region flooding increased proportionally with the return period. Also, results showed that the depths were surface and the flows were shallow, where generally occurring in the urban roadway, where these roadways are low in nature.

The study conducted by Behrouz et al. (2020), noted that the automagical process can use, which is called the Optimization Software Tool for Research Involving Computational Heuristics, or OSTRICH for the shortcut, in the calibration of the Storm Water Management Model (SWMM) to achieve individual and multi- goals. The new tool can give more accurate results from the models of SWMM. , Also, reduce the problems of calibration, which considers a complex process.

2.6. Summary

Chapter two were summarized the previous studies associated with some factors affecting the flooding of different kinds of sewer systems (separated and combined). These factors include effects of densely populated areas and urbanization, also the mechanisms and causes of flooding occurring in the sewer systems, such as the effects of land use and the impervious area on the stormwater systems and the combined sewer systems. In addition, the chapter reviewed the misuse of sewers systems and the climate changes impacts in the increase of rainfall intensities for different return periods, and the methods and the techniques that used in the deriving of intensity duration frequency (IDF) curves.

The previous studies about rainwater quality and the rainwater characteristics and pollution in the different areas are included in this chapter too. In addition, the modelling characteristics by using SWMM are also presented. Also, chapter two presented the purposes of using SWMM modelling in the analysis of various sewer systems and some of the SWMM outputs used in the flooding risk evaluation. Finally, the methods of assessment of SWMM results and the comparison of results with other evaluation methods were presented.

Chapter Three

Methodology and case study

3.1. Introduction

The sewer drainage networks setup and performance will be explained in this chapter through the study area modelling. The parameters of the hydraulic and the hydrological processes in the Storm Water Management Model (SWMM) will be discussed. The data of the sewage system and stormwater sewer system from sewer networks are critical for wastewater collection, protection of the aquatic environment and waterlogging control (Li et al., 2010; Yang et al., 2015).

The purpose of the profuse and accurate input data is to develop a rainfall-runoff model to get a proper, successful, and correct description of the relationship between the character of sub-catchment, sewers drainage, surface runoff and precipitation. Also, accurate input data consider an essential function in the modelling by SWMM to get the most practical simulation for the study area.

3.2. Study Methodology

The methodology is the guide of researchers to deal with the data collection, analysis, interpretation of the results, derivation of the conclusions, and suggestions proper recommendations in several steps. The purposes are:

1) Reviewing the data characteristics and methods used in the sewer systems modelling in the study area, where these systems including the combined sewage system and the stormwater drainage system.
2) Stimulating flow in the sewer systems and identifying the system's problems due to population dynamics and change in the rainfall events.

The methodology can be summarized in the chart shown in Figure 3.1.

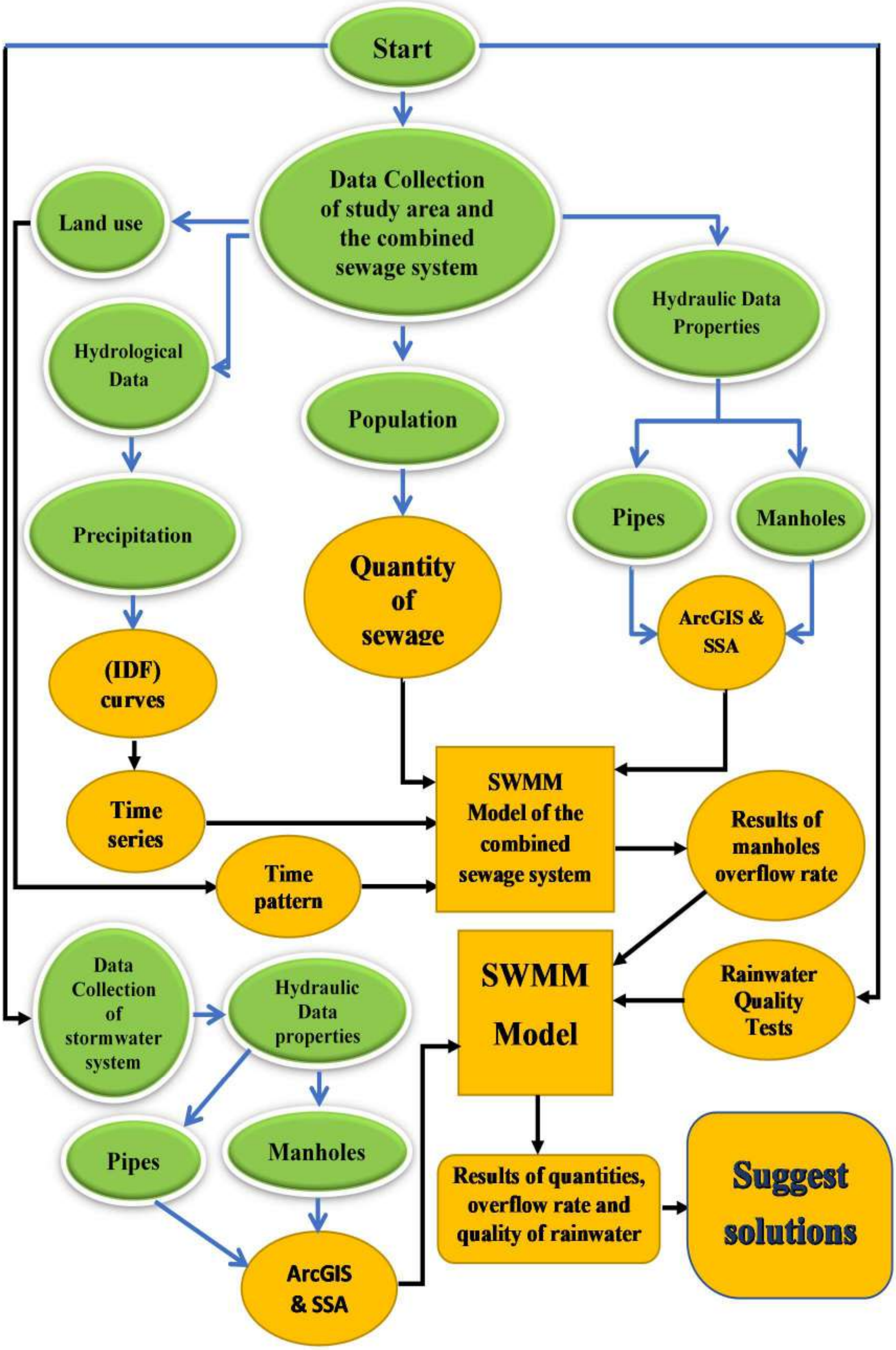


Figure 3.1: Study methodology flowchart.

3.3. Description of the study area

Al-Rashadiya quarter has been choosing as a study area. It locates on the AL-Kufa River to the North-East of AL-Najaf city (32°02'11.2"N, 44°24'30.5"E) that located about 160 km to the south-west of Baghdad, as shown in Figures 3.2 (Google earth, 2020) and 3.3 (Google Maps, 2020).

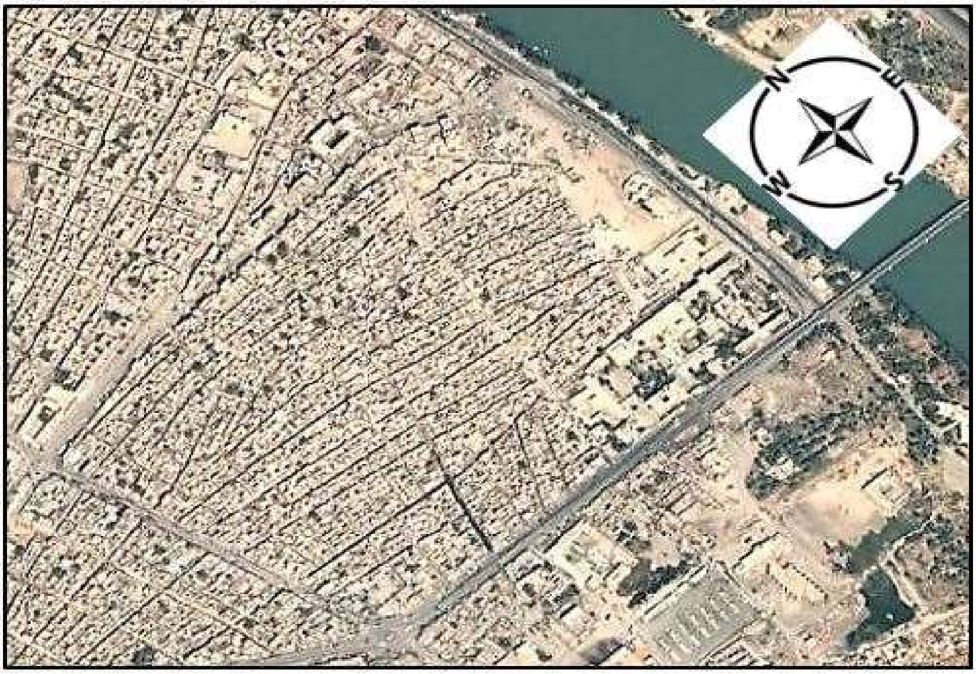


Figure 3.2: Study area (Google Earth, 2020).

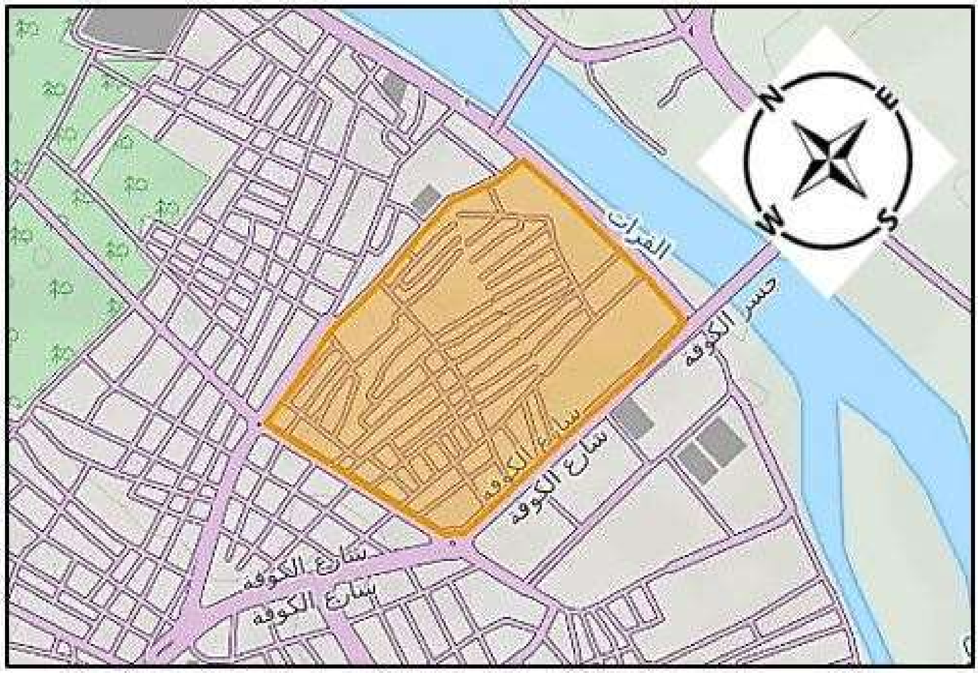


Figure 3.3: Study area location (Google Maps, 2020).

AL-Rashadiya quarter has serviced by two sewer systems which are:

1) A combined sewage system that covers all the area.
2) A stormwater sewer system that has a cross shape and cut the area into four sections.

The two systems are shown in Figures 3.4 and 3.5, these figures were prepared by ArcGIS.

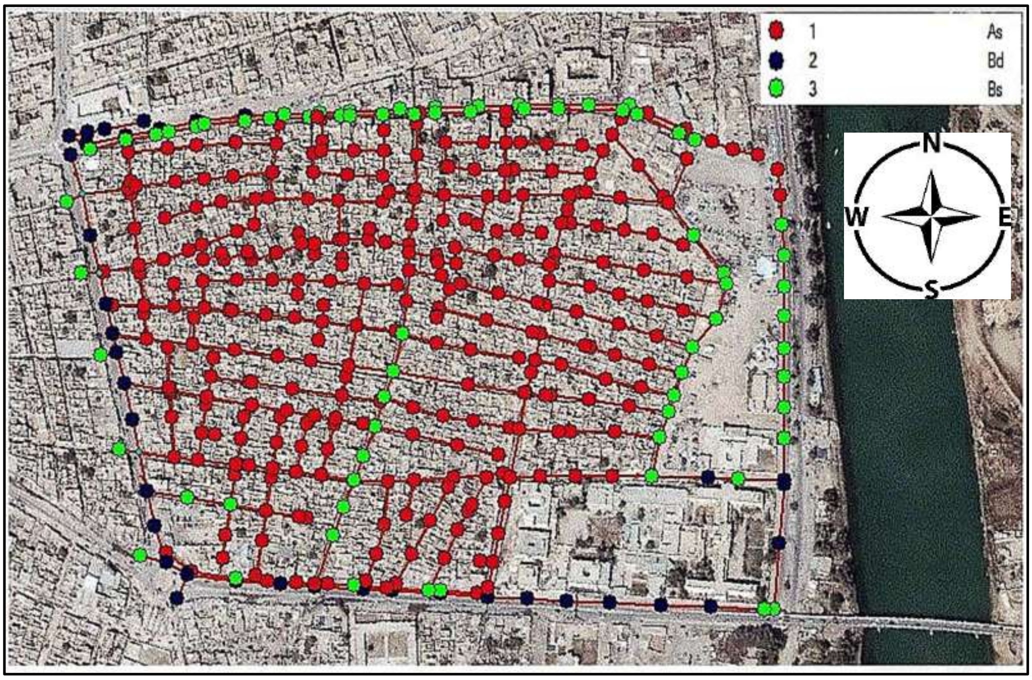


Figure 3.4: The combined sewage system of the study area prepared by ArcGIS.

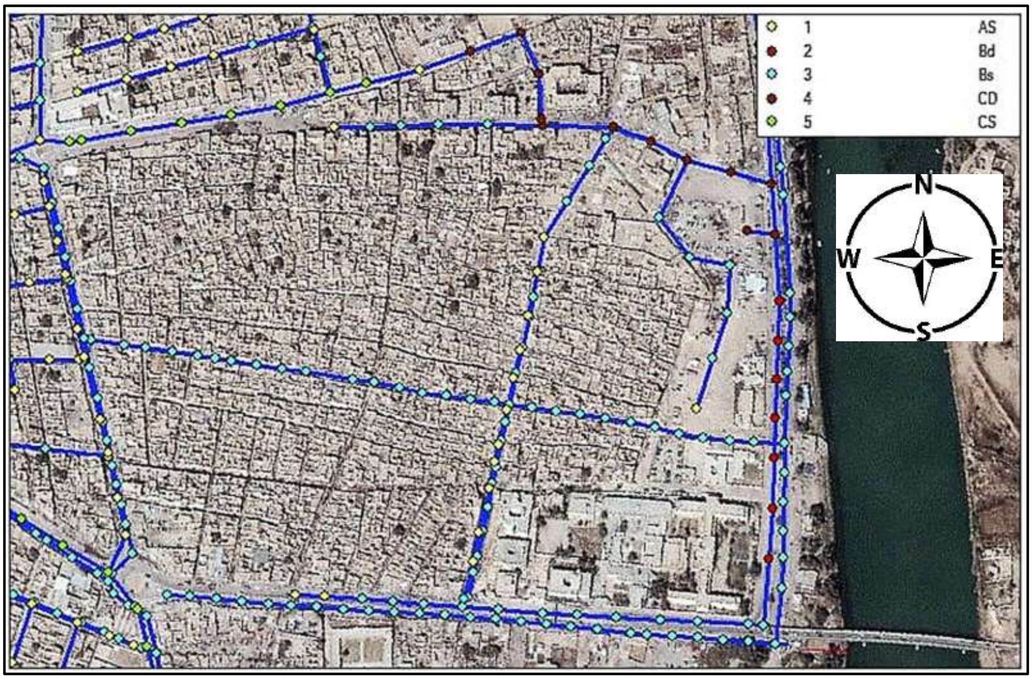


Figure 3.5: The stormwater sewer system of the study area prepared by ArcGIS.

All sub-catchments in the SWMM were linked directly to the combined sewage system to obtain the overflow in each node in this sewage system.

Second, this overflow use as a direct flow rate in the nearest node in the stormwater system to calculate the flooding in the stormwater sewer system nodes, as shown in Figure 3.6.

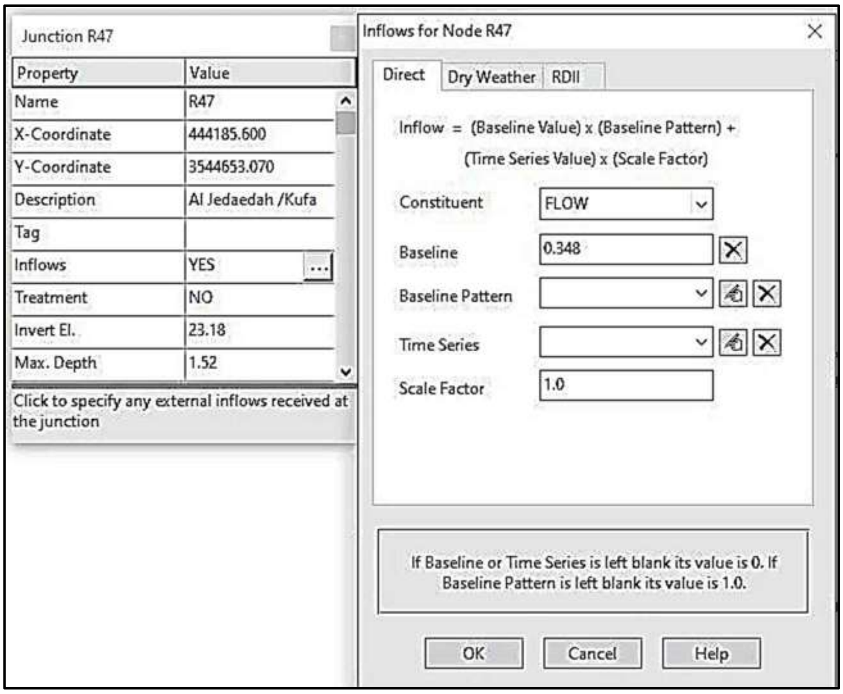


Figure 3.6: The dialogue editor of direct inflow in SWMM modelling.

3.3.1. Land use

The characteristics of the land use of the study area are essential in assigning the quantity and quality of produced surface water. Land-use of the study area divided into many parts: paved area (streets); commercial, religious, and public services buildings; and residences. The paved area (streets) occupied about 10% of the total land-use area. The commercial part occupies about 20% of the land-use area, consists of religious and service buildings, such as mosques, schools and a health centre, governmental buildings and two faculties, while the part of residences are formatting about 70% of the land-use in the study area. Figure 3.7 clarifies the land use of the chosen study area; supported by AL-Najaf Municipal Director (NMD, 2020).

This percentages of land-use (10% for street, 20% for commercial and 70% for residential) will be used in chapter four to the rainwater quality simulation by SWMM.

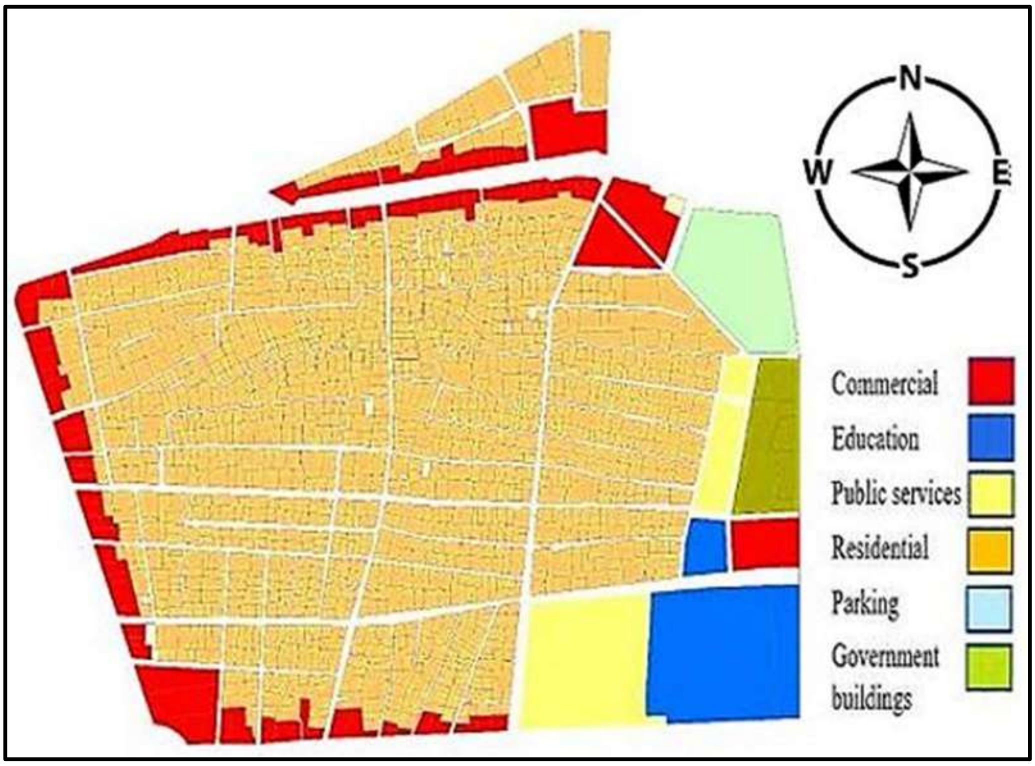


Figure 3.7: Land-use of the study area (NMD, 2020).

3.4. General description of SWMM

The SWMM is a full-wave, dynamic simulation modelling software utilised for an individual rainfall event or a long-dated simulation of the runoff quality and quantity. The SWMM has been used essentially in urban areas. New SWMM v5.1 is similar to the SWMM v5.0, and works with Microsoft Windows. The differences between them are that v5.1 can track the flow depth and rate, the generated runoff volume in an individual catchment, and the water quality in each pipe and channel at various run times of the simulation. SWMM gives an integrated ecosystem for the editing of data, running and simulations state of hydraulic and hydrologic of sewer systems, water quality and finally, shows the results (Rossman, 2010).

The SWMM modelling using to achieve national goals in obtaining the best stormwater management and reducing the surface runoff by many mechanisms, such as discharges retention and decrease infiltration methods, which cause the declining level of water bodies (Tsihrintzis and Hamid, 1997).

Long-term simulations enabled us to compare the benefits of different scenarios of the sewage treatment plant and storage capacities for the decrease of wastewater overflow. The benefits of reduction discharged TSS loads are similar to the benefits reduction of quantities of wastewater overflow (Cambez, 2008).

The modelling by SWMM represents the sewer network like the chain, where materials with the water are moving in between many main ecological parts, they named as following:

1. The atmosphere part, in which the rainfall falling and the pollutant is deposited onto part of land.
2. Land surface part, which represented by the sub-catchments.
3. The groundwater part receives the infiltration from the land surface part and transports a portion of inflow to the transport compartment.
4. The transport compartment contains a system of transportation, storage, regulation and treatment parts.

Rossman, (2010) stated that not all the environmental parts should appear in all models of SWMM.

3.4.1. The field data

The field data were collected for the study area as documents and as computer software files from AL-Najaf Sewage Directorate (NSD) and the Municipality Directorate of AL-Najaf (DMN), data included sub-catchments, pipes and nodes (manholes) properties. The collected data then plotted in ArcGIS, point and line shapefiles and export shapefiles were transferred to AutoCAD Civil 3D to combine all data in one file and export the last file which has (inp.) format to the SWMM program.

3.4.2. The surface runoff

Runoff has a fanciful look using the SWMM, as shown in Figure 3.8. Each sub-catchment surface is treated as a non-linear store by an indivisible inflow (rainfall). The surface runoff, filtering and evaporation were considered as outflows (Rossman, 2010).

The reservoir capacity (or dp), represented by ponds, wetting of the surface, and etc. (Lockie, 2009).

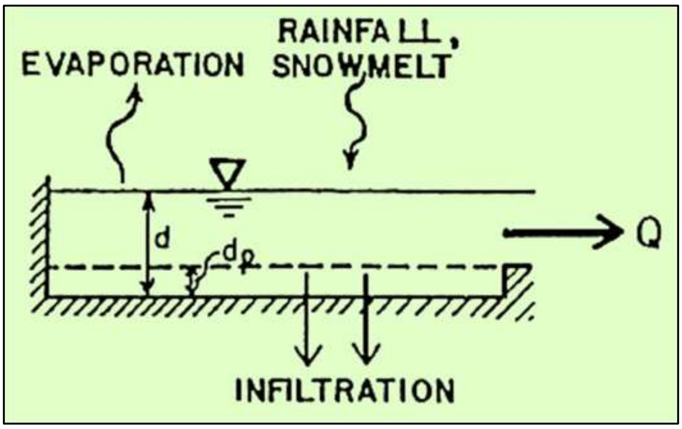


Figure 3.8: Non-linear reservoir representation of sub-catchment in SWMM (Rossman, 2010)

The surface runoff occurs when the water depth in the reservoir exceeds more than the extra storage of depression (Rossman, 2010).

The relationship between the inflow and outflow of the sub-catchment represents by the storage of the depression, which considers as a function for flow (in and out), as shown in the water balance equation 3.1.

$Q_{storage} = Q_{input} - Q_{output}$ ……. 3.1

where:

$Q_{storage}$: Is maximum depression storage from surface wetting (m^3 / sec).

Q_{input}: Is flow for individual catchment, involving that come from other sub-catchment flow and the precipitation (m^3 / sec).

Q_{output}: Is outflow includes infiltration, evaporation, and the surface runoff (m^3 / sec).

The water balance is either negative or positive. The negative balance occurs in drier seasons, where evaporation rate exceeds precipitation rate and the plants absorb the water stocks in the sub-catchment and causing the reduction in water. On the other hand, the positive balance occurs in the wet seasons where the precipitation rate higher than the evaporation rate, which creates the water excess convert to fill the sub-catchment storage and causing surface runoff and flooding.

3.4.3. Hydraulic data modelling

Hydraulic data were provided for the storm drainage system and the combined sewage system of AL-Rashadiya quarter regarding both the sub-catchments, nodes and pipes. These data included the area, width, type, depth, diameters, length, invert elevation, and etc.

3.4.3.1. Flow Routing

Flow routing in SWMM employs through the preservation of momentum and mass equation for slowly changing or the unsteady flow in one dimension (or sometimes known as the flow equations of Saint Venant).

SWMM gives three different levels of sophistication to resolve those equations as follows (Rossman, 2010):

1) Steady flow routing

Steady flow routing is the simplest type of routing potential by assuming the flow is uniform and steady. Steady flow routing translates the inflow hydrographs in conduit without changing in form and without retard. In this level, the Manning equation utilizes to correlate the flow area (or depth) to flow rate.

2) Kinematic routing

The continuity equation is solving for each conduit by a simple pattern of a momentum equation, where this requires that the water surface and the conduit is equalled in the slope.

3) Dynamic routing

The one-dimensional equations can be solved completely, so results are usually correct, in terms of theoretical calculations. The equations are the continuity equation of the volume in nodes and the momentum and continuity equations for pipes.

The dynamic routing is used in this study due to its capability to calculate the channel storage, pressurized flow, entrance/exit losses, flow reversal and backwater losses. So, the dynamic flow routing takes into consideration the most theoretically accurate results. In dynamic routing, filled pipe flow is imaged as pressurized.

Flow in sanitary sewage systems is unstable, but for some reasons and in some cases, maybe treated as a steady flow. However, in most cases, the rapid variations in sanitary drainage streams responding to the wet weather support the higher routing and static state analytical methods. (Rossman, 2010).

The dynamic flow routing is used Manning's equation to determine the flow rate (Q). Hazen Williams and Darcy Weisbach equations are used for circular force main shapes under pressurized flow (Rossman, 2010).

3.4.3.2. Pipes properties

The pipe is one of the sewer systems parts, used as a conduit to convey water between two nodes (the node is another part of the sewer system equipment). Pipes properties affect the flow in the sewer system. The pipe properties are the length, depth from ground level, diameter, slope, and these data provides an accurate simulation. For example, in SWMM modelling, the pipe length, upstream, and downstream data use to calculate the pipe slope to get the velocity and flow direction of fluids in the network, where the flow in the pipe can be calculated using Manning's equation. In this study, the pipes properties, locations and names of each sewer system in SWMM modelling are shown in Table 3.1 and Figures 3 and 5 in Appendix A.

Table 3.1: Pipes properties for sewerage systems in the study area (NSD, 2020).

Pipe Properties	The combined sewage system	The stormwater sewer system
No. of pipes in the system	408	149
Shape	Circular	Circular
Lengths range (m)	1 – 65	3.3 – 70
Diameters range (m)	0.25 – 0.6	0.315 – 0.5
Manning's Roughness	0.009	0.009
Pipe material type	PVC	PVC

The pipe properties dialogue editor in SWMM modelling is shown in Figure 3.9.

Figure 3.9: The pipe properties dialogue editor in SWMM modelling.

Chemically, the Polyvinyl Chloride material is resistant to bases, salts, acids, alcohols, and fats. It's also resistant to some solvents. Therefore, Polyvinyl Chloride is widely utilized in sewer pipes to resist the pipe corrosion effects.

According to the Water Environment Federation, Advanced Simulation Capability for Environmental Management (ASCEM) and Reports of Engineering (ASCE, 1982), Manning roughness coefficient values for the pipes is shown in Table M1 in Appendix A (Bizier, 2007).

For the pipes of sewer systems ,in this study, the value of the Manning roughness coefficient for the combined sewage system and stormwater drainage system pipes was 0.009, based on the pipes material type.

3.4.3.3. Manholes properties

The manholes are other parts of the sewer system used to access the sewer systems for inspection and maintenance. The construction of manholes has been improved, over time, regarding the materials used. Many improvements occurred on the manhole materials. One of these improvements is precast concrete materials which is utilized (Abbas et al., 2019).

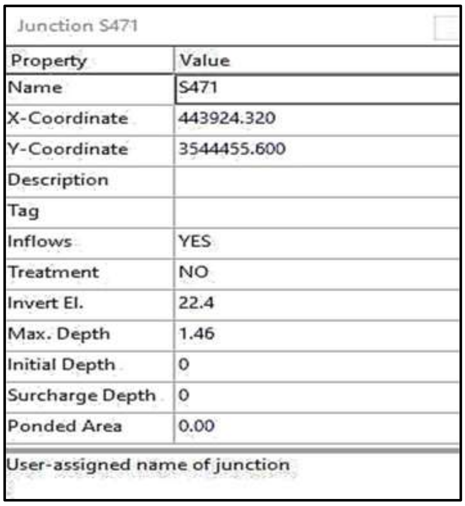
The manhole properties such as location, type, maximum depth, surcharge, invert elevation, ponded area and the external sources inflow that enter the sewer system (if existing) affect the flow rate and the overflows of the sewer system. Providing properties of the manholes is essential to obtain a more accurate simulation. For example, in SWMM modelling, the surcharge and the maximum depth affect the capacity of the manhole.

In this study, there are two sewer systems and the manholes properties in each sewer system are shown in Table 3.2. Also, the dialogue editor of the manhole properties in SWMM modelling is shown in Figure 3.10.

In this study, the manholes properties, locations and names of each sewer system in SWMM modelling are shown in Figures 2 and 4 in Appendix A.

Table 3.2: Manholes properties of the two systems in the study area (NSD, 2020).

Manholes Information	Combined system	Stormwater system
No. of Manholes	410	152
Manholes types	As, Bd, Bs	As, Bd, Bs, Cd & Cs
Manholes Materials	Reinforced concrete	Reinforced concrete
Maximum depth range (m)	0.92 - 4.67	0.6 – 5.08
Invert elevation range (m)	18.85 - 24.23	19 - 24.32
Normal ground level (NGL) (m)	24 - 29	
Ponded area	0	0



Junction S471

Property	Value
Name	S471
X-Coordinate	443924.320
Y-Coordinate	3544455.600
Description	
Tag	
Inflows	YES
Treatment	NO
Invert El.	22.4
Max. Depth	1.46
Initial Depth	0
Surcharge Depth	0
Ponded Area	0.00

User-assigned name of junction

Figure 3.10: The manholes properties dialogue editor in SWMM modelling.

3.4.3.3.1. External inflows of the study area

There are external inflows enter from adjacent districts to the sewer systems in the study area. Manning's equation (3.2) for full pipe flow has used to calculate these external inflows for insert these inflows in SWMM modelling.

$$Q_f = \frac{0.312}{n} * (D)^{\frac{8}{3}} * (S)^{\frac{1}{2}} \ldots\ldots\ldots \quad 3.2$$

Where:

Q_f: The full flow rate (m^3/sec)

D: The maximum depth (diameter) (m).

For the stormwater sewer system assumed the ratio of d/D = 0.78, and for the combined sewage system ratio of d/D = 0.65 (steel and McGhee, 1979; Metcalf & Eddy, 1981). Figure 3.11 shown partial full flow in pipe and Figure 3.12 shows the diagram of the partial flow curves Q & V (Metcalf & Eddy, 1981).

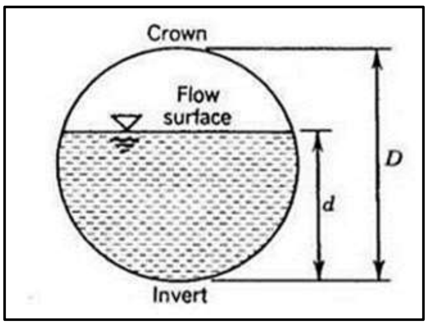


Figure 3.11: The maximum depth (D) and the partial depth (d) in the pipes.

Where:

D: The maximum depth (diameter), and

d: The partial depth.

Q_p: The partial flow rate,

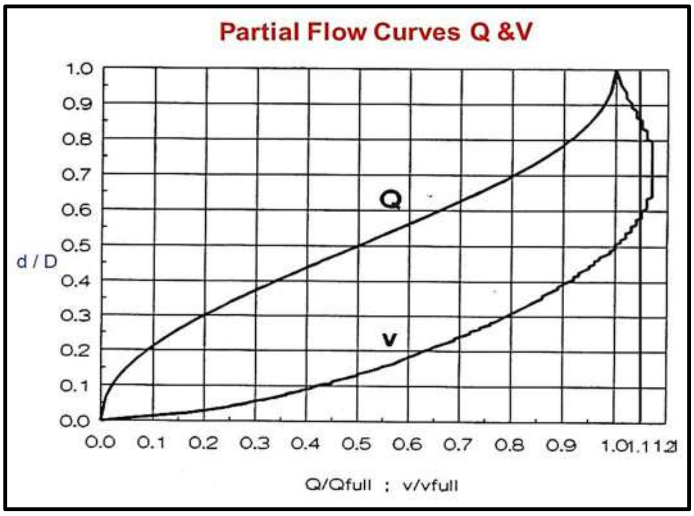


Figure 3.12: Diagram of the partial flow curves Q & V (Metcalf & Eddy, 1981).

3.4.3.3.2. Dry weather flow (DWF)

To modelling the combined sewage system by SWMM, dry weather wastewater flows will add to the appropriate conveyance nodes in this sewer system. The dry weather wastewater flows typically represents the locations where the collector sewage discharge to the trunk sewer. The number of these added flows depends on aggregation information using to couple the singular wastewater sources (businesses, homes, ... etc.) (Rossman, 2010).

3.4.3.3.2.1. Time pattern

Variation in sewage generation or time pattern is happening through the season, month, and day, this depends on water consumption rate. There is a wide variance of water quantity consumption because some months have a high consumption rate, at hot or warm months. The expected high demand for water supply can be on specific days, like Fridays and holidays. Also, the variation occurs in the same hours of the day, where the peak demand occurs through one day and its hour's occurrence depend on city characteristic and people habits.

The ratio between the wastewater generation to water consumption for each capita ranges from 70 to 100 % (steel and McGhee, 1979). In Najaf city, the average of this ratio is about 80% (NSD, 2020).

Usually, in the study area, the peak of water consumption occurs between (6 - 10) in the morning, when the people's activities beginning in the day, plus between (6 to 10) in the afternoon. The minimum water consumption always happens during midnight to 4 o'clock in the mornings. Also, peak water usage through the year increases through hot months than the cold months (NSD, 2020).

In the modelling of Time Patterns, the SWMM provides external DWFs, to differ periodically. Time Patterns in the SWMM modelling have applied correction factors, which considers as a set of multipliers of pollutants concentrations or as the DWF flow rates. The various Time Patterns kinds involve:

1) Monthly – 12 multiplier for the year (one for each month),
2) Daily - each weekday has one multiplier,
3) Hourly - each hour has one multiplier, between 12 A.M. to 11 P.M., and
4) Weekend - for weekend days has hourly multipliers.

Figure 3.13 is shown the dialogue editor of Time Pattern.

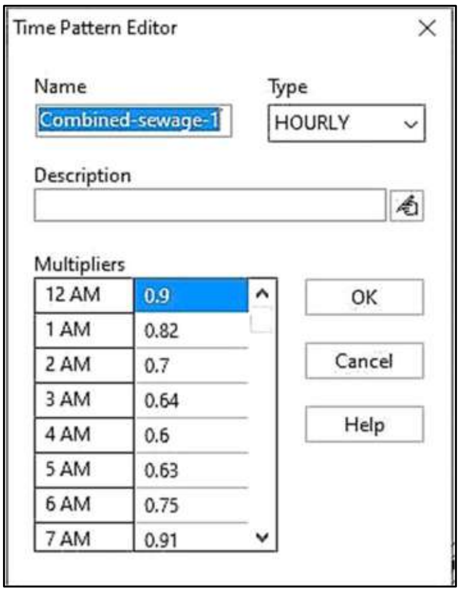


Figure 3.13: SWMM modelling editor of Time Pattern.

Choi (2016) has provided a particular pattern for the DWF shown in Table 3.3. The Hourly Pattern considers as a proper approximate and will use in this study in the combined sewage system modelling by SWMM.

Table 3.3: The type of pattern variation in the sewage sewer system (Choi., 2016).

Hourly pattern				Monthly pattern		Daily pattern	
A.M.	Pattern	P.M.	Pattern	Monthly	Pattern	Monthly	Pattern
12:00	0.9	12:00	1.17	January	1	Sunday	1.02
1:00	0.82	1:00	1.17	February	1	Monday	1
2:00	0.7	2:00	1.13	March	1	Tuesday	0.99
3:00	0.64	3:00	1.1	April	1	Wednesday	0.95
4:00	0.6	4:00	1.07	May	1	Thursday	0.94
5:00	0.63	5:00	1.08	Jun	1	Friday	1.1
6:00	0.75	6:00	1.1	Juley	1	Saturday	1
7:00	0.91	7:00	1.12	August	1		
8:00	1.06	8:00	1.12	September	1		
9:00	1.18	9:00	1.15	October	1		
10:00	1.23	10:00	1.11	November	1		
11:00	1.22	11:00	1.01	December	1		

3.4.3.3.2.2. Population forecasting and sewage generation

The average daily water consumption in Najaf city based on the available data from NSD is about 275 litres per capita per day.

3.4.4. Hydrological data modelling

The hydrological data modelling target represents the best presentation of the precipitation in the study area to estimate the water movement in sub-catchments, run-off and run-on.

In recent decades, hydrological research has devoted significant attention to improving the representation of precipitation fields in time and space. One of the most fundamental issues is the development of various multi-scaling and simple models. Therefore, rainfall modelling considers necessary. “All models are wrong; some are useful” That sentence is essential in the modelling of hydrological circumstances, which is based on data, because of the presence of un-solved questions and studied suppositions (Remesan and Mathew, 2016).

The hydrological data required in the SWMM modelling has many parameters such as Rain Gage, Sub-catchments, Aquifers, Snow Packs, Unit Hydrographs, and Low Impact Development (LID) Controls. The parameters of the Rain Gage and Sub-catchments will only be considered in the present study.

3.4.4.1. Rainfall Data in SWMM modelling

Rainfall considers the source of most runoff. The rainfall intensity has a wide range according to the geographic location and the seasons of the year. Sometimes, the rainfall intensity is very high and causes damages to facilities and human lives in the precipitation region, so it is a very concerning case.

Nowadays, there are many rainfalls models. Some models depend on the precipitation depth to estimate the runoff quantity through the relationship between the rainfall depth with area dimensions, while other models depend on rainfall intensities. Many questions must be answered before choosing rainfall model, such as:

1) What is the possibility of getting the rainfall data?
2) What are the sources of these data?
3) What is the range of data accuracy and their reliability?
4) What is the type of collected data?
5) What is the duration of data collected?
6) How are these data used?

All these questions will be answered in this study by using logical and statistical processes and analysis of the rainfall data; to get a proper choice with the best performance to the rainfall model.

3.4.4.1.1. The "Rain Gage"

Rain Gage provides one or more rainfall data for sub-catchment in the study region. These data come from an external file or a user-defined time series. Rain Gage input data of the rainfall properties involves (Rossman, 2010):

1) The rainfall data type (e.g., intensity, volume, or cumulative volume),
2) The recording time interval (e.g., hourly, 15-minute, 5-minute, etc.),
3) The source of the rainfall data (external file or input Time Series) and,
4) The name of rainfall data source.

Figure 3.14 represent the dialogue editor of the Rain Gage from the SWMM program. Table M2 in Appendix A represents the Rain Gage Properties in the SWMM modelling (Rossman, 2010).

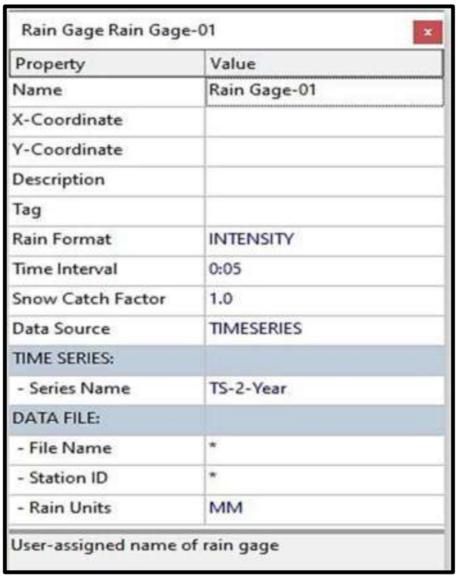


Figure 3.14: The dialogue editor of the Rain Gage from SWMM modelling.

3.4.4.2. Sub-catchment area properties

In the SWMM modelling, the sub-catchments are considered hydrologic units of the lands where the drainage system components and the topography of the sub-catchment are directing runoff to only a particular point, which use for runoff discharge. The user is accountable for identifying outlet points for the sub-catchments and dividing study land into the appropriate numbers of sub-catchments. The discharge outlets points can be either in other sub-catchments or directly in the drainage system nodes (Rossman, 2010).

The spatial distribution of the sub-catchments and the sub-catchments properties by GIS were provided from NSD in 2020 as an aerial image and shapefile for the study area, where available information assists in calculation the dimensions of sub-catchments.

Sub-catchment characteristics and their information include total and singular areas, width, permeability, slopes, and the drainage outlets for sub-catchment. Sub-catchment information is very important to obtain a higher accuracy when running the simulation, as it controls the amount and movement of surface runoff. In the present study, the area of the sub-catchments ranges from 0.01 to 0.45 hectares (from 100 to 450 m^2).

3.4.4.2.1. Width of sub-catchment

According to Cantone and Schmidt (2011), there is no real physical meaning to use sub-catchments width. The calculation of the width can be performed by dividing the sub-catchment surface area on the runoff length. The runoff length represents the longest surface flow route (Shen and Zhang, 2014). The width can be calculated by equation 3.3:

$$W = \frac{A}{L_{max}} \dots\dots 3.3$$

Where:

A: The area of the sub-catchment (m^2)

L_{max}: The maximum runoff length in the sub-catchment, which can be computed by equation 3.4:

$$L_{max} = (D_{p,pout})_{max} \dots\dots 3.4$$

$D_{p,pout}$: Distance between the farthest point of the sub-catchment outlet and another random vertex point of sub-catchment.

The width of each sub-catchment obtained by getting the value of the max runoff length by calculating the distance between outlet point and every vertex in the sub-catchment, as shown in Figure 3.15.

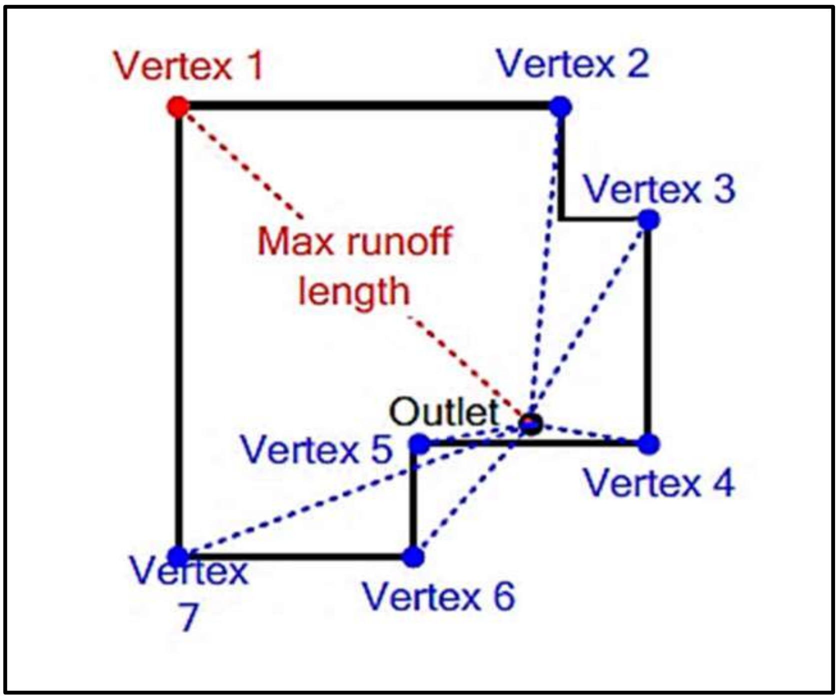


Figure 3.15: The maximum runoff length calculation (Shen and Zhang, 2014).

The range of the sub-catchment width in the study area is 18.86 - 170.03 m, according to an area of the sub-catchment.

3.4.4.2.2. Runoff on sub-catchments

The runoff can flow from sub-catchment to another sub-catchment and use it as a route, and the drainage of runoff from two sub-catchments to one outlet is also possible . The sub-watershed runoff and the wastewater generated in the urban areas are discharge by streams or network-connected pipes to one outlet (Rossman, 2010).

The sub-catchments area of the study region is about 0.3369 km^2 (33.69 hectares), and it divided into 1716 sub-catchments in the modelling by SWMM with ranged area from 0.01 to 0.45 hectares, as shown in Figure 3.16.

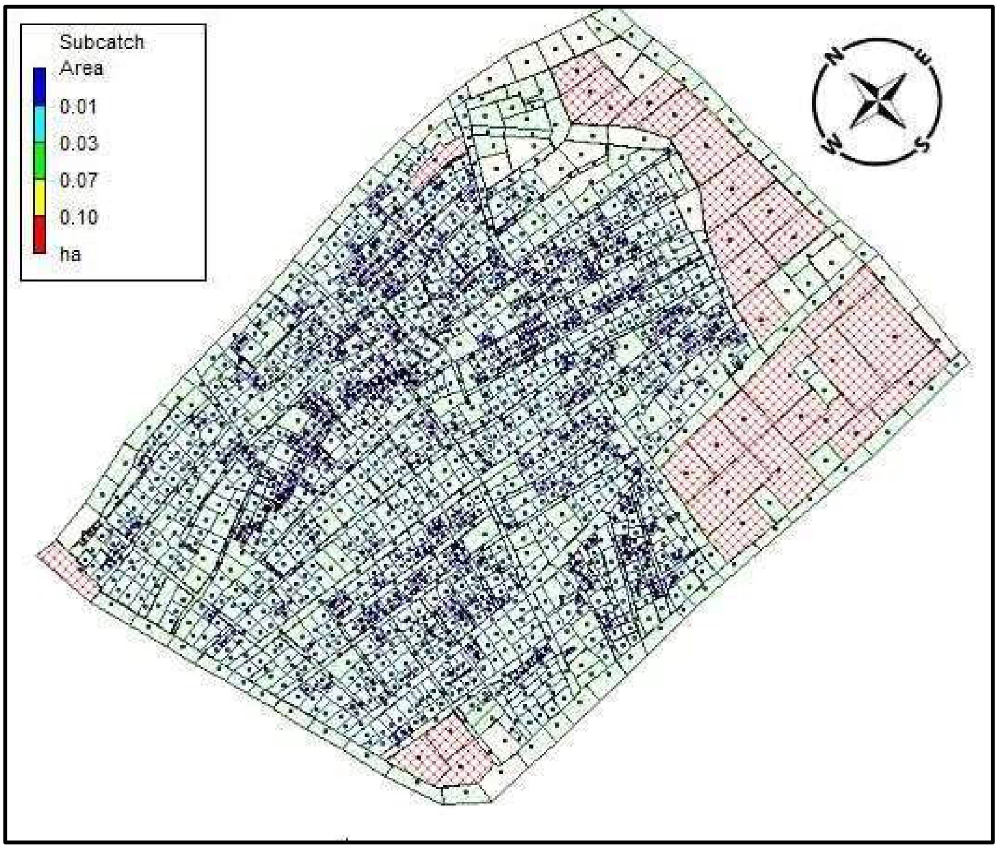


Figure 3.16: Study area sub-catchments from SWMM.

3.4.4.2.3. Infiltration/Inflow model

Infiltration and inflow (I&I) are external flow in a sewers system that products from groundwater and surface water. I&I can overload the sewer systems and wastewater treatment plants, and cause sewer systems overflow (SSOs) or the basement flooded. This flow value can be as far as ten times of dry weather flow (DWF), but the estimate of the peak and the volume of I&I includes a great deal of doubt.

Spatial and temporal variability of the I&I estimation makes it difficult to understand this phenomenon. Depending on the time range of various I&I processes, some sub-catchments features may only affect the particular I&I sources. For example, the geology of the sub-catchments and configuration of the sewer networks may affect slow and fast I&I processes in different methods (Choi, 2016).

Kufa city soils are classified as sandy silty soil, where this type of soil has a high ability to infiltrate (Ali & Fakhraldin, 2016).

In SWMM modelling, infiltration can be modelled in different formulas which are:

1) "Horton infiltration" (1940),
2) "Modified Horton infiltration" formula,
3) "Green-Ampt infiltration" (1911) formula,
4) "Modified Green-Ampt infiltration" formula, and
5) "Curve Number infiltration" formula.

For this present study, the model of Green-Ampt is used, where there is no favourite one way upon another way. But the Green-Ampt model is more physically-based (Gironás et al., 2009).

The Green-Ampt model is a simple empirical model to represent the process of infiltration and developed from the application of Darcy law and the law of conservation of mass. The Green-Ampt model will be employed as an infiltration model in SWMM modelling. It calculates the amount of rainfall infiltrated into an upper unsaturated region.

Green-Ampt formula supposes that existing a wetting face of soil column separated this face from the other soil, where the above wetting face is fully saturated, and the below is at the beginning moisture content (Rawls et al.,1983). The purpose of uses the Green-Ampt method is related to the soil suction head, soil's hydraulic conductivity, initial moisture deficit and soil porosity. Equations 3.5 and 3.6 are the general equations of the Green-Ampt (Rawls et al., 1983):

$$f = K * \left[\left(\frac{\Psi * N}{F}\right) + 1\right] \;\ldots\ldots 3.5$$

$$F = K_t + \Psi\, N * \ln\left[1 + \left(\frac{F}{\Psi * N}\right)\right] \;\ldots\ldots 3.6$$

Where:

f: Infiltration capacity, which measured in mm/hr.,

K: the saturated hydraulic conductivity, which measured in mm/hr.,

Ψ: head of suction, which measured in mm, N or $\Delta\mathbf{\Phi}$: Available porosity. It can be calculated by subtract wilting point from field capacity, and

F: Mass infiltration (mm).

A definition of the parameters of above equations according to Talebi & Pitt, (2011) study is:

f: Infiltration rate (cm/hr.).

K or Kt: Hydraulic conductivity (in/hr.).

Ψ: The initial Matric potential of the soil (in.).

N or ΔΦ: The difference of soil water content after infiltration with initial water content (in^3/in^3).

F: The cumulative infiltration at time t (in.).

Rawls et al., (1983) regarded these equations under the assumption that ponding depth is negligible on the soil surface and analysed approximately 5000 USA soils samples and published these analysed values for the Green-Ampt parameters, as shown in Table M3 in Appendix A.

In the present study, the infiltration equation of Green-Amtp will use in the SWMM modelling of the combined sewage system to estimate the infiltration values, where the values of the parameters of equation 3.5 will be taken from Table M3 based on the nearest soil type to the study area soil type, which is the sand-clay.

3.4.4.2.4. Pervious and impervious area

Every one of the sub-catchments in the SWMM modelling has two sub-area options, impervious option and a pervious option, appear in the catchment properties table with other options, such as sub-area routing and percent routed, as shown in Figure 3.17.

Subcatchment 95913

Property	Value
Name	95913
X-Coordinate	444338.902
Y-Coordinate	3544614.240
Description	
Tag	
Rain Gage	Rain Gage-01
Outlet	S267A2
Area	0.450480
Width	150
% Slope	0.2
% Imperv	75
N-Imperv	0.015
N-Perv	0.1
Dstore-Imperv	2.00
Dstore-Perv	5.00
%Zero-Imperv	25
Subarea Routing	OUTLET
Percent Routed	100
Infiltration Data	GREEN_AMPT
Groundwater	NO
Snow Pack	
LID Controls	0
Land Uses	0
Initial Buildup	NONE
Curb Length	0
N-Perv Pattern	
Dstore Pattern	
Infil. Pattern	

Figure 3.17: The sub-catchment properties table in SWMM modelling.

Three options existing in sub-area routing: Impervious, outlet option and pervious option. Figure 3.18 presents the typical effect on these three sub-area routing runoff methods when utilized to an individual sub-catchment.

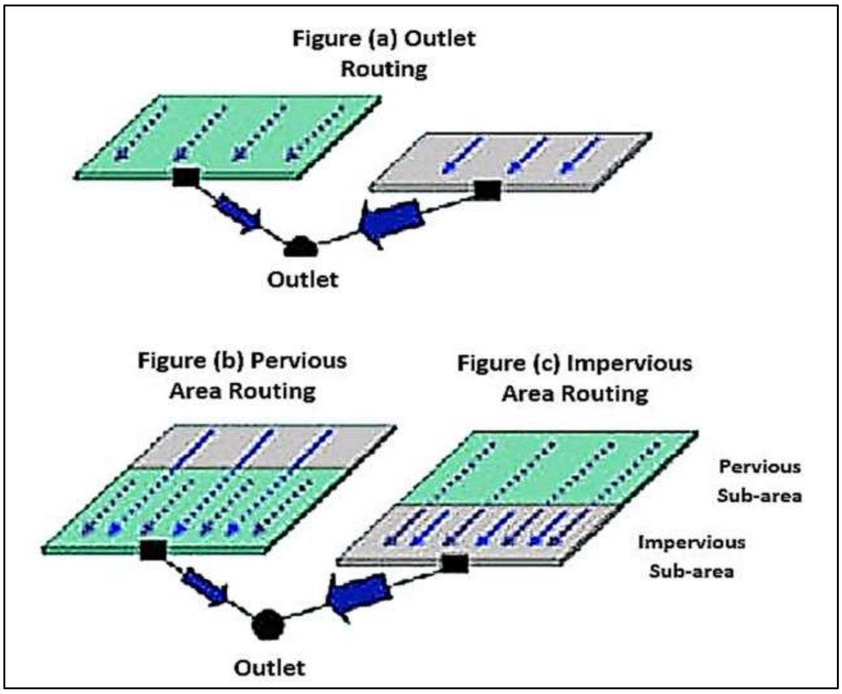


Figure 3.18: The sub-areas segments in SWMM (Gironás et al., 2009).

The outlet option is shown in Figure 3.18 (a), which route both sub-areas runoff directly to the outlet of the sub-catchment. Because the runoff is fully provided in the impervious area, the %zero-impervious value will be zero, and in this case, 100% will be routed to both the outlet or the Impervious area. The pervious option is shown in Figure 3.18 (b), which route the impervious sub-area runoff to the outlet across the pervious sub-area, where there are some of losing in the runoff in the infiltration and depression storage in the pervious area. Impervious option is shown in Figure 3.18 (c), which routes the runoff from pervious sub-area across the impervious sub-area after that to the outlet (Gironás et al., 2009).

The impervious area of individual sub-catchment was initial created based on soil occupation by roofs and pavements. So, the only losses used by SWMM for impervious areas are the depression storage (dp) losses.

Sub-catchments in Kufa city are divided according to the permeability, impervious sub-catchments and pervious sub-catchments. The impervious sub-catchments can be divided into two types of sub-catchments, including the sub-catchments have depression storage and sub-catchments that do not include depression storage. The pervious sub-catchment enables runoff to infiltrate toward the topsoil region.

The impervious area and pervious area have been chosen as 75% and 25% of the total study areas, respectively. The choice of the percent impervious and pervious areas was according to the type and the areas of cover land. Also, the impervious areas that have depression storage were taken as 25% of the total impervious areas. The depression storage depth of impervious area and the pervious areas took 5 mm and 2 mm, respectively.

3.4.4.2.5. Slope of study areas

The slope is essential to determine the runoff direction over the sub-catchment surface. The study area has a wide variation in the values of the slopes to many adjacent small regions. Sub-catchment slope of the streets can be calculated from the difference between the invert elevation of the nodes (manholes) and divide this difference values on the distances between nodes. Other sub-catchments slopes that inputted in the SWMM based on the information of study area sewer design taken from Iraq geological survey data in 2010 and NSD in 2020. The sub-catchments slopes of the study area ranged from 0.1 to 3.3 %.

3.4.4.2.6. Manning's roughness (n) of sub-catchment runoff

Hydraulic roughness coefficients have used in the analysis of shallow surface run-off in two principal ways. The first is in the hydrographs routing of surface run-off over the land surface for simulating storm hydrographs in urban hydrology and small watersheds. The second is in the direct calculations the velocities of overland flow, e.g., calculating the time of concentration T_c or travel times (Engman, 1986; ASCE, 1982).

Manning's roughness parameter is one of the most effective in hydrologic modelling. The values for each sub-catchment depend on the land use type. Manning's roughness coefficient for the different overland types shown in Table M4 of Appendix A (McCuen, 1989).

In the present study, the Manning's roughness coefficient of the study impervious area was in different values, where it takes equal to, 0.011 for external streets that paved with smooth asphalt, 0.013 for the interior roads that paved with the smooth brick concrete, and 0.014 for houses roofs that paved with the brick and cement mortar.

3.4.4.2.7. Depression storage (dp)

The depth of storage in the area or depression storage in SWMM modelling is an essential parameter for the impervious and pervious area. The values of depression storage in the present study area taken 2 mm for the impervious area and 5 mm for the pervious area based on Table 3.4 (Rossman, 2010).

Table 3.4: The depth of depression storage for the various land use (Rossman., 2010)

Type of surface	Depression depth
Impervious surfaces	0.05 - 0.10 inches (1.27 – 2.54 mm)
Lawns	0.10 - 0.20 inches (2.54 – 5.08 mm)
Pasture	0.2 inches (5.08 mm)
Forest litter	0.3 inches (7.62 mm)

3.4.5. Curves

Curves in SWMM modelling include Time Series, Time Patterns and Map Labels. Time Patterns were explained in the section (3.4.3.3.2.1.).

3.4.5.1. Time Series

The purpose of the Time Series is to describe how the particular object properties vary with time. It is able to explain and depict information of:

1) Rainfall.
2) Temperature.
3) Evaporation.
4) Hydrograph of inflows in each node.
5) Water-stage in outfall node.
6) Control settings of the flow regulators and pumps.
7) The external inflow of the pollutant-graphs at the nodes of the drainage system.

During the preparation stages of the Time Series a novel name for every Time Series was given. The Time Series can be specified either as an hour or absolute for the day's date and time. The rainfall amounts corresponding to the periods must be nonzero (Rossman, 2010).

In the present study, the Intensity-Duration-Frequency curves (IDF) will be utilized to predict the data of four Time-series taken for four high intensities of study area rainfall in four return periods 2, 5, 10 and 25 years.

3.4.6. Rainfall data collection

As responded in the Methodology (section 1.5.), the first step is to collect metrological data from the Meteorology and Seismic Monitoring Authority of Iraq. This data was collected from rainfall stations of Al-Najaf city and represents the daily precipitation for the period 1989 to 2018 and presented in Figure 3.19. The precipitation data were used in the development of IDF.

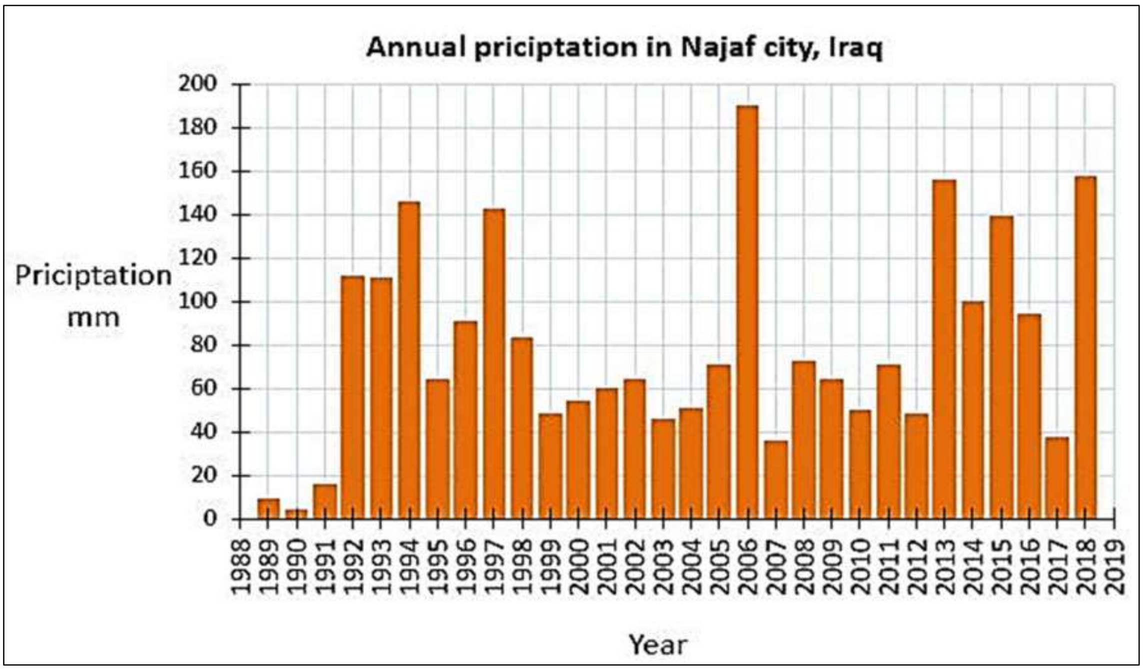


Figure 3.19: The annual rainfall (mm) of Al-Najaf city (based on the data of Meteorology and Seismic Monitoring Authority of Iraq, 2020).

3.4.6.1. IDF Curves

For delicate analysis of precipitation of fixed duration, it must obtain more best fit of the probability of the distribution. There are required steps that implemented to the development of any IDF curve, and as follows:

1) Evaluation of the rainfall data and chose the maximum daily rainfall in the year.

2) Development of the Probability Density Function (PDF) distributions and choose the best fit for available data.

3) Choose the best fit distribution, which gives the average to determine rainfall intensities for selected return period and the specific duration.

“Multi-collinearity” is a defect in data-based modelling. It is a statistical case from input variables presence or data series in an input structure, where this problem must be studying (Maier & Dandy, 2000).

The lack of a methodological approach in selecting the significant inputs may lead to the modelling issues listed below (Remesan & Mathew, 2016):

1) I ncrease in input dimensionality: when used all available inputs indiscriminately, this will cause computational complexity and memory insufficiency.
2) Presence of more local minima in the error surface due to the inclusion of irrelevant data points.
3) Early convergence and divergence due to accidental presence data: will lead to poorer model accuracy.

To construct rainfall Intensity-Duration-Frequency (IDF) curves, the maximum rainfall intensities historical series at a higher duration and an accurate time is needed. The before-mentioned data is possible to obtain by rainfall gage stations that consider rare and very few, where available data represent a cumulative depth of rainfall of one day (Nhat et al., 2006).

For estimation of the runoff, especially in urban areas having short-duration rainfall, rainfall measurement is necessary. In developing countries like Iraq, duration rainfall is short and available data is mostly for daily rainfall data. In such cases, the estimation of rainfall for sewer system design is indicated by the approximation, thus, leading to repeat failure in the drainage networks.

IDF is a common tool for various engineering projects that is used to estimated flooding. This relationship is very significant in most water resources engineering projects.

In the present study, the purpose of IDF curves generation is to develop empirical formulas to estimate the higher design rainfall intensities for the Al-Najaf city. Then, (IDF) data will be used in the Time series of SWMM modelling. This method allows for the estimation of the higher value of rainfall of chosen return periods 2, 5, 10, and 25 years and durations shorter than a day, every 5 minutes using only the daily data. The assumption of simple scaling implies the indirect relationships between the different return periods and the rainfall duration and can be used to derive the (IDF) relationships from long durations.

3.4.6.2. Generation of IDF Curves

In first SWMM modelling, the design storm intensity derives from the different return periods. Then, the storm intensity used to estimate the peak runoff from each sub-catchment and input parameters in the runoff simulation in SWMM modelling.

In the present study, the frequency analysis performed using the best-fitted distribution for the collected data was used. Climate Change report (Change, 2007) recommended choosing the raised-risk scenarios wisely, where a corresponding value (numerical) for these risks is necessary for any designing work. In the processing of rainfall data, Gumbel distribution maybe provides a better fit than the Log-Normal distributions based on the Kolmogorov-Smirnov test of goodness of fit.

3.4.6.2.1. Estimation of the short-duration rainfall

The rainfall intensities of the various durations derive from the daily maximum rainfall data using the Indian Meteorological Department (IMD) formula, also called the reduction formula. IMD used to estimate the short durations rainfall intensities according to the following equation (Jaleel & Farawn, 2013):

$$P_t = P_{24} * \left(\frac{t}{24}\right)^{\frac{1}{3}} \dots\dots\dots\dots 3.7$$

Where, P_t is the required rainfall depth in mm for the duration t in hours. P_{24} is the maximum depth of daily rainfall in mm, t is the duration in hours for the required rainfall depth and the constant value of 24 represents day hours.

3.4.6.2.2. Theory of distributions

A. Gumbel distribution theory

Gumbel distribution (EV-1, Generalized Extreme Values Distribution Type-I), is used to model the distribution of maximum (or the minimum) samples number of various distributions. It is a popularly used distribution in the estimation of IDF curves, where it has an agreement for maximum modelling. Gumbel distribution is almost easy and uses just events that classify as extreme. The maximum values mean the peak of the rainfalls (Lee, 2005).

For any duration, the maximum intensity and the statistical variables, which are the average and standard deviation, should be computed. Gumbel extreme values distribution is given by the following equation (Ahmed et al., 2012):

$$P_t = P_{avg} + K * S \; \ldots\ldots\ldots\ldots 3.8$$

Where

P_t: The precipitation frequency of every duration (in mm) with a particular return period (year),

P_{avg}: The average of maximum precipitation corresponding to specific durations and obtain from the following equation (Ahmed et al., 2012):

$$P_{avg} = \frac{1}{n}\sum_{i=1}^{n} P_i \; \ldots\ldots\ldots\ldots 3.9$$

P_i: An individual amount of rainfall extremist,

n: The events or record years,

K: Gumbel frequency factor, and it is a function of the sample size and the return period. It computes with the following equation (Ahmed et al., 2012):

$$K = -\frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left(\ln\frac{T}{T-1}\right)\right] \ldots\ldots\ldots\ldots.3.10$$

S: The standard deviation of the data (P_i), it is computed with the following equation (Ahmed et al., 2012):

$$S = \left[\frac{1}{n-1}\sum_{i=1}^{n}(P_i - P_{avg})^2\right]^{\frac{1}{2}} \ldots\ldots\ldots\ldots.3.11$$

Multiplied the frequency factor K by S provides the rainfall intensities of the desirable return period from an average data.

After above steps, the rainfall intensity (i) can obtain by the equation (Ahmed et al., 2012):

$$i = \frac{P_t}{T_d} \ldots\ldots\ldots\ldots.3.12$$

Where T_d is the duration measured by hours.

B. Log Pearson type III distribution (LPT III) theory

It is one of the Pearson distributions types. It is reviewed by USA Weather Resources Council in the year 1967, this type of log distribution transforms the volume of the water and thereafter its analysis the hydrologic frequency by the LPT III. Because it is fast in the calculation, it is used in computers with the frequency factors in an analysis of the frequency. Therefore, LPT III is significant and useful (Lee, 2005).

This probability model used to calculate the rainfall intensity for different return period and the durations of the rainfall for each station from the historical IDF curves. It involves logarithms of the measured values. The standard deviation and the mean are determined using the logarithmic transformed data. A simple definition for LPT III distribution is provided by the following equations (Elsebaie, 2012):

$$P = \log\ (P_i) \ldots\ldots\ldots\ldots.3.13$$

$$P_t = P_{avg} + K_t\, S \ldots\ldots\ldots\ldots.3.14$$

$$P_{avg} = \frac{1}{n}\sum_{i=1}^{n} P \ldots\ldots\ldots\ldots.3.15$$

$$S = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(P - P_{avg}\right)^2\right]^{\frac{1}{2}} \ldots\ldots\ldots\ldots.3.16$$

P_t, S and P_{avg} are defined as in Gumbel theory barring that they determine according to the logarithmically transformed values of P. The symbol K_t represents the Pearson frequency factor that builds on the return period (t). C_s represents the Coefficient of skewness, which is used for calculating a distribution frequency factor and determines by the equation (Elsebaie, 2012):

$$C_S = \frac{n\sum_{i=1}^{n}(P_i - P_{avg})^3}{(n-1)(n-2)(S)^3} \ldots\ldots\ldots\ldots.3.17$$

Many hydrology references have tables of K_T values, such as Chow (1988). Through knowing C_s and t, K_t for LPT III distribution can determine. The solution in equation (3.14) will be given the estimated maximum value for the specific return period.

C. Lognormal distribution theory

The Lognormal distribution assumes that the hydrologic quantity distribution forms a lognormal distribution. In the 1962, the Board of the Corps of Engineers in the U.S Army used this distribution. It had applied this method to California frequency analysis, and this method evaluated to a high degree. This method transforms the peak flow data with a logarithm. Then uses the normal distribution to examine the flood frequency of the transformed data. This method presents considerable good results (Lee, 2005).

Sometimes, variables obey an exponential relationship as x = exp (V). If the exponent is a random variable, such as V, the equation will be X = exp (V) which means a random variable equation. When V has a normal distribution, a particular case occurs, and the distribution of X is described as a lognormal distribution. For the transformation to Ln (X) = V, or in the present study Ln (P_i) = P, the logarithm of P_i will be normally distributed, and the random variable Pi will be lognormally distributed or as a random variable (Parvez and Inayathulla, 2019), the P-value is calculating by the following equation:

$$P = \text{Ln}\,(P_i) \dots\dots\dots\dots 3.18$$

It normally distributed, with the transformation of:

$$Z = \frac{P - a}{b} \dots\dots\dots\dots 3.19$$

The Lognormal distribution will be a standard normal distribution. The factor of frequency for the lognormal distribution is equivalent to the factor of frequency for the normal distribution, but it will be applicable for the variable logarithms. The arithmetic mean and the standard deviation of variables will be used in the following equation:

$$P_T = P_{avg} + K_T\, S_P \dots\dots\dots\dots 3.20$$

Where:

$$P_{avg} = \frac{1}{n}\sum_{i=1}^{n} P \dots\dots\dots\dots 3.21$$

3.4.6.2.3. Goodness of fit

It is a test used to compare goodness fit between the expected frequencies obtained from the hypothesized distribution and the frequency of occurrence observed in a sample. The Easy Fit (v5.5) software program is used to transform goodness tests using the Kolmogorov-Smirnov test. The minimum value gained from the test of Kolmogorov-Smirnov is considered the best fit of the chosen distributions.

3.4.6.2.4. Chi-square test

The Chi-Square test is commonly used to identify the best fit of the theoretical distribution for the available data, so it is powerful to do this test. The purpose of the Chi-Square test is to obtain a good fit between the predicted and the observed data. The following equation considers the best representation of the Chi-Square Test:

$$X^2 = \frac{\sum_{i=1}^{n}(O_i - E_i)^2}{E_i} \quad \dots\dots\dots\dots 3.22$$

Where O_i represents the observed frequencies, and E_i represents the predictable frequencies. If O_i is close corresponding to E_i, x^2 value will little, indicate the good fit; otherwise, it will be not (Stemmler, 2020).

3.4.6.2.5. Derivation of IDF equations

The IDF curves application builds up empirical equations that correlate a maximum rainfall intensity, frequency and duration of occurrence based on available rainfall data. These empirical equations represent the relationship between the parameters of rainfall duration. The frequencies can be considered as independent variables and the max rainfall as a dependent variable. There are several commonly used equations of hydrology applications found in the literature. The general forms of the four commonly equations that used to depict a correlation of the rainfall intensities with durations is briefed as follows (Chow, 1988):

1) Sherman's equation:

$$i = \frac{a}{(T + b)^c} \quad \dots\dots\dots\dots 3.23$$

2) Bernard's equation:

$$i = \frac{C * T^m}{d^e} \quad \dots\dots\dots\dots 3.24$$

3) Talbot's equation:

$$i = \frac{C * T^m}{d + b} \quad \dots\dots\dots\dots 3.25$$

4) Kimijima's equation:

$$i = \frac{C * T^m}{d^e + b} \quad \dots\dots\dots\dots 3.26$$

Where i represents rainfall intensity (mm/hour), d represents duration (minutes), and a, c, b, e and m are constant limitations associate with metrological conditions, T is the return period (year).

The four mentioned empirical equations proved that the rainfall intensities reduce with raised the durations of rainfall during a given return period.

In hydrology practical applications, these empirical equations have been widely used. In the present study, the Sherman equation was utilized to estimate the rainfall intensity for the specific return period.

Chapter Four

Pollutant Modelling

4.1. Introduction

Many urban cities witness speedy development all around the world, and the urbanization operation is obtaining more attention, and this adjusted the natural environment of these urban areas (Long et al., 2014). Expansion in the impervious area occurs due to urbanization, the pollutants that will be cumulated increasingly over the ground surface will happen.

During rainfall seasons, the rainwater runoff loading pollutants through the sewer systems and directs them to streams, and finally, the water quality will be deteriorated in these waterways (Wang et al., 2016; Zhang et al.,2018).

Stormwater quality modelling uses to forecast, analyse and manage pollution and urban water quality. The monitoring of the quality of urban runoff requires substantial resources. First, it must calibrate the stormwater quantity model, then the quality model when the urban stormwater is modelling. The calibration of stormwater quantity models is usually easier than quality models (Chen & Adams, 2006; Zhu et al., 2012).

SWMM modelling of the pollutants loads in the stormwater drainage system will be explained in this chapter. The required input parameters of the pollutants modelling using the Storm Water Management Model (SWMM) will be discussed. Also, some pollutants tests in the lab for the stormwater drainage system at the disposal point will be identified (see Figure 1 in Appendix A). These pollutants concentrations from the tests will be used in the inspection and calibration process when simulating the SWMM modelling for the pollutants loads.

Quality modelling of the urban stormwater usually focuses on pollution limitation and estimates the impacts resulting from these stormwaters. A lot of mechanisms can decide the stormwater quality. One of these is the buildup-washoff mechanism, which considers the most substantial of those mechanisms, which commonly assume that the quantities of pollutants are building up over the impervious surfaces of the sub-catchments urban area, and this usually occurs in dry weather.

This chapter aims to discuss the quality and characteristics of the rainwater discharged to the disposal point on Kufa river.

4.2. Pollutant modelling by SWMM

The sources of Kufa river pollutants in the study area come from two directions, which are:

1) The surface runoff due to human activities in a highly-populated area.
2) Domestic wastewater from nodes overflows of the combined sewage system.

SWMM is used to modelling stormwater quantity as well as stormwater quality. The SWMM modelling of stormwater quality required many parameters. Also, several procedures can be followed to complete the SWMM quality models, such as the initial buildup that relates to the land-use in the study area.

The land-use contains Build-up, Wash-off and the streets sweeping data. Both Build-up and Wash-off have different equations that depend on many factors. These factors make the calibration of the stormwater quality model is too hard without on-site data. The SWMM modelling of the stormwater quality equations is the exponential function, the power function, and the saturation equation (Rossman, 2010).

4.3. Assigns of the Land Uses

The editor of "Land Uses Assignment" in the SWMM modelling is used when starting with the property editing of the land-use in sub-catchments modelling. The editor purpose is to select the land use of a particular sub-catchment to simulate the model of water quality.

The percent of the ground area in a sub-catchment relate to every land use kind, where this percent enters alongside its land-use class. If there is no percent to the land-use, this blank is left. The percentages of land-uses do not inevitably have to arrive at 100% of the total area. Land-Use Assignment editor in the SWMM modelling is shown in Figure 4.1 (US EPA SWMM Software)

Figure 4.1: The Land-Use Assignment Editor (US EPA SWMM Software).

4.3.1. Land use classifications

Land uses classes are dedicated to the land surface characteristics or development activities assigned to sub-catchments, such as residential area, commercial area, undeveloped area, and industrial area. The characteristics of land surface might involve the paved roads, the rooftops, the yards, the natural or unexploited soils, etc. The Land uses option only used to identify the spatial difference in the rates of buildup and wash-off of pollutant inside the sub-catchments.

In the SWMM modelling of stormwater quality, there are many choices for identifying and assigning the land uses to the sub-catchment. One of these ways is to assign a mix of land uses for every one of the sub-catchments. It finally emerges in all land uses inside sub-catchment holding the same impervious and previous properties. The second followed way to identify the sub-catchments with an individual land-use classification with impervious and pervious properties, which reflect the class of these properties. The operations that can define the classification type for every one of the land uses are:

1) The pollutant buildup,
2) The pollutant washoff, and
3) The street sweeping.

4.3.2. Initial Buildup

The "Initial Buildup" property of the sub-catchment from the Property Editor designates the existing quantity of pollutant buildup found on the sub-catchment surface at the simulation beginning. This property contains an entry grid of data with double columns, named "Pollutant" and "Initial Buildup", as shown in Figure 4.2 (US EPA SWMM Software).

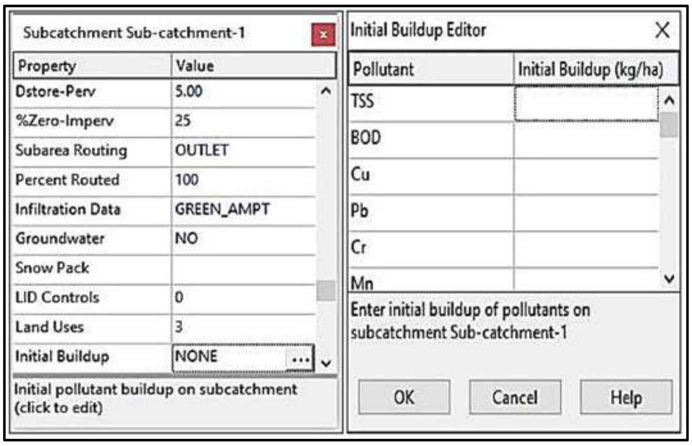


Figure 4.2: The Initial Buildup Editor (US EPA SWMM Software).

The column "Pollutant" represents the name of each entering pollutant in the project, such as TSS, BOD, Pb, Cu, etc. The column named "Initial Buildup" represents the initial buildup values of the pollutants, where these values entering in the corresponding boxes for these pollutants. If there is no buildup value for a specific pollutant, its buildup value supposes to be zero.

Entering a specified value for initial pollutant buildup in the blank of the "Antecedent Dry Days" parameter will cancel the computed Initial Buildup (Rossman, 2010).

The "Antecedent Dry Days", previous to the wet weather, of pollutant buildup in the present study area is five days per a week. The buildup units are either km/hectare when the metric units (SI) is used or Ib./acre when using the American (U.S.) units.

The selected pollutants for the present study, which was used in the SWMM modelling for stormwater quality, are TSS, BOD, Cu, Pb, Cr, and Mn, and the corresponding values of the initial buildup will equal to zero.

4.3.3. Land use in SWMM modelling

The Land-Use Editor in the SWMM modelling stormwater quality includes three classified characteristics pages of land uses. The first page, called 'General', provides the names of the land-uses and the streets sweeping parameters. The second page, called 'Buildup', showing the rate at which pollutant the buildup occurs.

Page three is called the 'Wash-off' page, which delimits the wash-off rate of occurrence pollutant (Rossman, 2010). Land-Use Editors of SWMM modelling is shown in Figure 4.3 (US EPA SWMM Software).

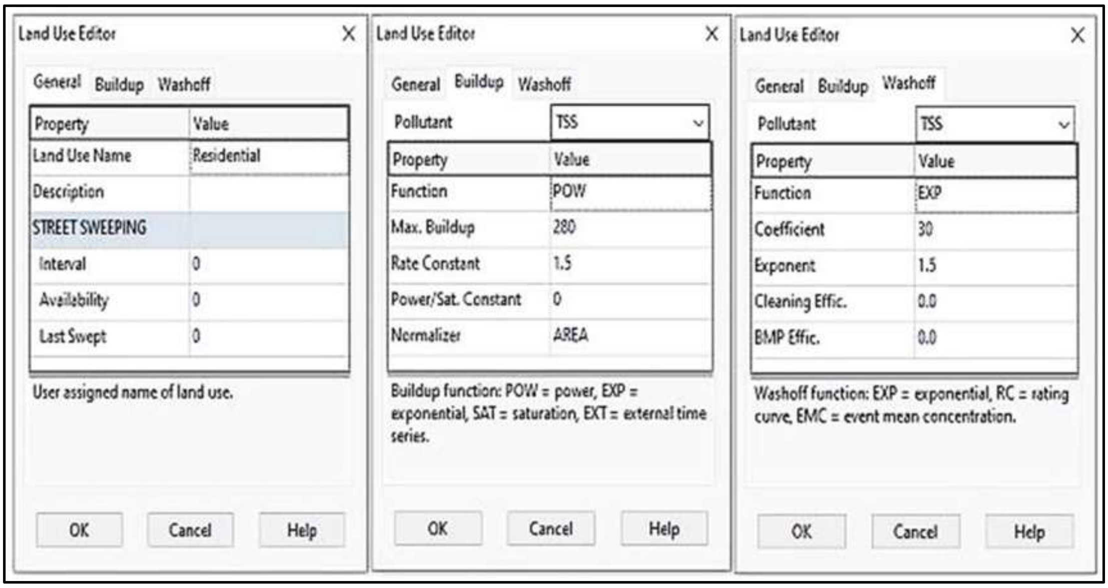


Figure 4.3: The Initial Buildup Editors (US EPA SWMM Software).

4.3.3.1. The General Page

This page is one of the editor pages of the land use, which depicts the specific land use class characteristics as following:

- "Land Use Name" is a name selected for any type of land use such as residential, commercial, street, etc.
- "Description" is a description or commentary of land use, it is optional.
- "Street Sweeping Interval" is the interval time between street sweeping for the specifics land in the land-use editor (in days).
- "Street Sweeping Availability" represents the ready part for removal in the sweeping process from the total buildup of pollutants.
- "Last Swept" indicates the total days from the latest sweeping operation until the simulation beginning.

If the sweeping of the street does not exist for the specific land uses, the last three characteristics blanks are left empty.

In this study, a corresponding blank for the "Land Use Name" will be filled with the name of the land-use class found in the study area, which Residential 70%, Commercial 20% and Streets 10%, see section 3.3.1, in chapter 3. Also, the blanks of "Street Sweeping Availability" will be left empty because street sweeping is not available for the study area.

4.3.3.2.1. Street Sweeping

Street sweeping can be utilized in every land-use class to minimize the accumulation of particular pollutants buildup. To describe streets sweeping, there are parameters included:

- The days which are divided between two sweeping processes,
- The interval time (in days), which is starting from the last street sweeping process until the simulation beginning.
- The whole of the available buildup fraction of pollutants which can remove by sweeping, and

- The buildup fraction for any given pollutant available for removal by sweeping process.

Note: the last parameter can differ with the type of pollutant. The above parameters can vary for every land-use type.

4.3.3.2. "Buildup" page

The page of the "Buildup" of the editor dialogue of Land Use depicts the characteristics correlated with the buildup of the pollutant overhead land through dry weather times and contains:

- "Pollutant" is a selected pollutant that wants to edit its buildup characteristic, such as TSS, BOD_5, etc.
- "Function" is the function type of the buildup, which used for the pollutant. More options are lied under the "Function" and as following:

1) "NONE", which means there are no buildup exists,
2) "POW" to the buildup of the power function,
3) "EXP" to the buildup of the exponential function,
4) "SAT" to the buildup of the saturation function, and
5) "EXT" means to provide an external time series for buildup.

The term "Max. Buildup" refers to the maximum buildup. It is a coefficient in kg (or lbs.) of the pollutant per unit of the measured variable such as litre.

4.3.3.2.1. Pollutant Buildup

The pollutant buildup within a land-use classification is the accumulative pollutant quantity describes by either a mass per unit length of the curb (Mass unit/Length unit) or mass per unit of sub-catchment area (Mass unit/Area unit). The mass expresses in kilograms (Kg) for metric units and pounds (Ib.) for US units. Pollutants buildup may be or not be associated with traffic flow, time, street sweeping and dry fallout (Chen, 2006).

The buildup amount (B) is a function shows the number of days, the days before the precipitation day or the days of dry weather, which can be calculated by utilizing one of the equations mentioned earlier in Build Up Page -"Functions", as follow (Rossman, 2010):

1) "Power Function" where the pollutant buildup (B) is proportional to time (t) that raises to some power until achieving the maximum limit,

$$B = min.(C_1, C_2, t^{C3}) \text{.........4.1}$$

Where,

B: The buildup amount, it is measured in kilograms per unit of area (or per curb length) for pollutants whose concentration units are either mg/L or µg/L. If the concentration units are counts/L, then the buildup is expressed as counts per unit of area (or per curb length).

C_1: The greatest buildup achievable, which is measured by mass unit/area unit or mass unit /length unit,

C_2: Constant of the buildup rating.

t: Antecedent dry days, and

C_3: The exponent of the time.

2) "Exponential Function" which reflects the curve of the exponential growth buildup that asymptotic the high limit approximately,

$$B = C_1(1 - e^{-C_2 t}) \text{.........4.2}$$

Where,

C_1: The potential greatest buildup, which is measured by mass unit/area unit or mass unit /length unit, and

C_2: The constant of the buildup rate ($\frac{1}{\text{days}}$).

3) "Saturation Function" where the buildup starts with a linear relationship and constant rate then decreases until reached saturation with time,

$$B = \frac{C_1 t}{C_2 + t} \text{.........4.3}$$

Where,

C_1: The potential greatest buildup, which is measured by mass unit/area unit or mass unit /length unit, and

C_2: A constant of the half-saturation (days until arriving at half-maximum buildup).

4) "External Time Series" is an optional option that allows the use of the time series for determining the daily buildup rate as a time function. Values of Time-Series that are assigned would have Mass units/Area units/day or Mass units/Length units/day. The "External Time Series" option can provide a maximum possible buildup. Also, it provides a scaling factor that doubles the values of the Time Series.

In the present study, "Power Function" (POW) was used for pollutants buildup.

4.3.3.3. “Washoff” Page

The page of the "Wash-off" of the editor dialogue of land use depicts the characteristics correlated with the wash-off of the pollutant located overhead land through wet weather events and contains (Rossman, 2010):

- "Pollutant" is a selected pollutant that wants to edit its wash-off characteristic, such as TSS, BOD_5, etc.
- "Function" is the function type of the wash-off, which is used for the pollutant. The "Function" has options which are:

1) "NONE", which means there are no wash-off exists,
2) "EXP" to the wash-off by the exponential function,
3) "RC" to the wash-off by the rating curve, and
4) "EMC" means the event-mean concentrations of the wash-off.

- "Coefficient" is the C_1 value in the rating curve equation and the exponential equation wash-off, or EMC.
- "Exponent" is the exponent that is used in the rating curve equation and the exponential equation wash-off.
- "Cleaning Efficiency" is the removal efficiency of the street cleaning (%) for the pollutant. It is a portion of the total pollutant amount that is

available to be removed from the land surface, which is the amount removed actually.

- "BMP Efficiency Removal" is the efficiency (%) connected with any of the "Best Management Practice" that may happen. The decreasing amount, at each time step, from the total calculated load of the wash-off.

4.3.3.3.1. Pollutant Washoff

During wet weather periods, the pollutant wash-off from a specific class of land-use occurs. One of the following means can express the pollutant wash-off:

1. "Exponential Washoff" or by the symbols (W), which is the wash-off loading measured in mass unit per hour, such as kg/hour, it is proportional to the quantity of remaining buildup and to the outcome of runoff. Also, it has some power,

$$W = C_1 q^{C_2} B \ldots\ldots\ldots 4.4$$

Where,

C_1: The coefficient of the wash-off,

C_2: The exponent of the wash-off,

q: The rate of the runoff per the unit of the area, such as inches/hour or millimetre/hour), and

B: The buildup of the pollutant (units of the mass).

B refer to the total net mass of the buildup, where the same units are used to express the concentration of pollutant mass in both the buildup process and the wash-off process, which is (µg, mg, or counts).

2. "Rating Curve Washoff" represents the rate of the washoff (W), which measured in (mass/sec.) which is commensurate with runoff rate that lifts to some of the power,

$$W = C_1 Q^{C_2} \ldots\ldots\ldots 4.5$$

Where,

C_1: Wash-off coefficient,

C_2: Wash-off exponent, and

Q: The runoff rate in units (m^3/sec or gallon/sec, etc.)

3. "Event Mean Concentration" it is a special case of Rating Curve Washoff where the exponent is 1.0 and the coefficient C_1 represents the washoff pollutant concentration in mass per litter.

In the present study, exponential washoff will be used for Washoff process.

The typical quality characteristics of the runoff water in the urban area based on the EMC function according to the U.S. Environment Protection Agency (USEPA, 1983) are listed in Table P1 of Appendix A.

4.4. Stormwater quality characteristics

After precipitation, the stormwater will washoff the pollutants from the sub-catchments surface. Then this stormwater enters the stormwater drainage system through the system inlets, and finally, will be disposed of at the disposal point directly in the river.

The purposes of the quality modelling are to obtain the coefficients of the buildup and washoff equations, where stormwater quality modelling requires many trials for getting these coefficients, which used to calculate the pollutants buildup.

Before modelling the stormwater quality by SWMM, stormwater characteristics should be tested in the stormwater drainage system in the laboratory for comparison and calibration purposes. Many stormwater characteristics can be tested in the laboratory, where could be utilized to identifying the method of dealing with the stormwater based on its type.

The stormwater can have surface water characteristics, which can be disposed directly to the streams without treatment or have wastewater characteristics, which must treat before disposal.

In the present study, the selected characteristics tests of the stormwater quality during dry weather shows in Table 4.1. In the modelling of the stormwater quality by SWMM, the selected characteristics for modelling was TSS, BOD and Heavy metals, which is Copper, Lead, Chromium and Manganese.

Table 4.1: The selected characteristics tests of the stormwater at a disposal point.

No.	Test type	No.	Test type
1	pH units	8	Total solid (TS)
2	Temperature (C)	9	TSS
3	Conductivity	10	BOD_5
4	Dissolved Oxygen (DO)	11	Copper (Cu)
5	Turbidity	12	Lead (Pb)
6	Chemical Oxygen Demand (COD)	13	Chromium (Cr)
7	Total Dissolve Solid (TDS)	14	Manganese (Mn)

According to Steel (1979) and Tebbutt (1998), the typical characteristics of domestic sewage and the surface water quality for drinking water are listed in Tables P2 and P3 of Appendix A, respectively.

Chapter Five

Results and Discussion

5.1. Introduction

Chapter five exhibits the results gained using the physically based and statistical models, where SWMM modelling results will introduce. These results analysed to achieve the objectives described in chapter one, which study the effect of densely populated area on the operation of the combined sewage system to obtain the overflows quantity of the combined sewage systems which enters the stormwater system and affects the rainwater quality at the disposal point.

5.2. Modelling of the rainfall intensities

The rainfall intensities data during wet weather for the different return periods and the different durations were estimated using statistical techniques of frequencies analysis.

5.2.1. IDF curves generation

Generating of the intensity-duration-frequency (IDF) curves were performed by using the frequency analysis steps by three different distributions, which are Gumbel, LPT III and Lognormal, as following:

1) Selecting the maximum daily rainfall from the collected daily rainfall data throughout the year. The maximum of the daily rainfalls data throughout the 30 years (1989-2018) from AL-Najaf city station shown in Table 5.1.

Table 5.1: The data of the maximum daily rainfall data for 30 years from AL-Najaf city stations (Meteorology and Seismic Monitoring Authority of Iraq).

Year	Maximum daily rainfall (mm)	Year	Maximum daily rainfall (mm)	Year	Maximum daily rainfall (mm)
1989	5	1999	8.2	2009	12.6
1990	12	2000	10.7	2010	10.9
1991	8.8	2001	17.3	2011	13.8
1992	16.2	2002	15.2	2012	18.2
1993	34.4	2003	19	2013	64.5
1994	42	2004	8.7	2014	22.2
1995	11.5	2005	27.7	2015	32.9
1996	17.9	2006	22.6	2016	26.6
1997	21.1	2007	12.8	2017	8.6
1998	12.4	2008	26.8	2018	19.3

The data tested with the Kolmogorov-Smirnov test, where this test provides a measurement of the divergence of the sample distribution from the normal distribution. The test result showed that data does not differ significantly from the data normally distributed, as shown in Table 5.2.

Table 5.2: Kolmogorov-Smirnov (KS) test results.

Distribution Summary	
Count	30
Mean	19.33
Median	16.75
Standard Deviation	12.171254
Skewness	2.047956
Kurtosis	5.639648
Count	30

The value of the K-S test statistic (D) is 0.16767.
The p-value is 0.33024 > 0.05, the data does not differ significantly from that which is normally distributed.

2) The results of the daily rainfall depth in (mm) for the duration of t minutes (5, 10, 20, 30, 60, and 120 minutes) by using IMD formula (3.7) is shown in Table 5.3.

Table 5.3: Maximum daily rainfall depth (mm) for the duration t-minutes.

YEAR	Duration (minutes)					
	5	10	20	30	60	120
1989	0.76	0.95	1.20	1.38	1.73	2.18
1990	1.82	2.29	2.88	3.30	4.16	5.24
1991	1.33	1.68	2.12	2.42	3.05	3.84
1992	2.45	3.09	3.89	4.46	5.62	7.08
1993	5.21	6.56	8.27	9.47	11.93	15.03
1994	6.36	8.01	10.10	11.56	14.56	18.35
1995	1.74	2.19	2.76	3.16	3.99	5.02
1996	2.71	3.42	4.30	4.93	6.21	7.82
1997	3.20	4.03	5.07	5.81	7.32	9.22
1998	1.88	2.37	2.98	3.41	4.30	5.42
1999	1.24	1.56	1.97	2.26	2.84	3.58
2000	1.62	2.04	2.57	2.94	3.71	4.67
2001	2.62	3.30	4.16	4.76	6.00	7.56
2002	2.30	2.90	3.65	4.18	5.27	6.64
2003	2.88	3.62	4.57	5.23	6.59	8.30
2004	1.32	1.66	2.09	2.39	3.02	3.80
2005	4.19	5.28	6.66	7.62	9.60	12.10
2006	3.42	4.31	5.43	6.22	7.84	9.87
2007	1.94	2.44	3.08	3.52	4.44	5.59
2008	4.06	5.11	6.44	7.37	9.29	11.71
2009	1.91	2.40	3.03	3.47	4.37	5.50
2010	1.65	2.08	2.62	3.00	3.78	4.76
2011	2.09	2.63	3.32	3.80	4.78	6.03
2012	2.76	3.47	4.37	5.01	6.31	7.95
2013	9.77	12.31	15.50	17.75	22.36	28.17
2014	3.36	4.24	5.34	6.11	7.70	9.70
2015	4.98	6.28	7.91	9.05	11.41	14.37
2016	4.03	5.07	6.39	7.32	9.22	11.62
2017	1.30	1.64	2.07	2.37	2.98	3.76
2018	2.92	3.68	4.64	5.31	6.69	8.43

3) Using the Easy-Fit 5.5 software program to estimate the probability of rainfall depth for each return period and duration based on the durations data from Table 5.3. Then, rank the program by Chi-Square test and chose one of the selected distributions, Gumbel max, LPT III, and Lognormal.

The rainfall probability calculations based on the following equation:

$$P(x) = 1 - \frac{1}{x} \dots \dots \dots 5.1$$

Where x the return period, 2, 5, 10 and 25 years. The result for each distribution is shown in Table 5.4.

Table 5.4: Rainfall depth using Easy-fit v5.5 and the selected distributions.

Distribution type	Return period (year)	Rainfall depth (mm)					
		Duration (minutes)					
		5	10	20	30	60	120
Gumbel distribution	2	2.62	3.31	4.17	4.77	6.01	7.57
	5	4.25	5.36	6.75	7.73	9.74	12.27
	10	5.33	6.72	8.46	9.69	12.21	15.38
	25	6.96	8.43	10.63	12.17	29.75	19.31
Log Pearson Type III distribution	2	2.45	3.08	3.89	4.45	5.61	7.06
	5	3.96	4.98	6.28	7.19	9.06	11.41
	10	5.16	6.50	8.19	9.37	11.81	14.88
	25	6.92	8.72	10.99	12.58	15.85	19.97
Lognormal distribution	2	2.51	3.16	3.99	4.56	5.75	7.24
	5	3.96	4.99	6.29	7.20	9.07	11.43
	10	5.02	6.33	7.98	9.13	11.51	14.50
	25	6.47	8.16	10.28	11.77	14.83	18.69

*The actual value in MSE is 2.6245 mm. Rounded up/down values were used in the presentation of tables, but not in the MSE, wherein the calculations took eight digits after the decimal point.

4) Converting the rainfall depth data (mm) in Table 5.4 to rainfall intensity, i (mm/hr.), via dividing the values of rainfall depth on the duration in hours, as shown in Table 5.5.

Table 5.5: Rainfall intensity for each distribution.

Distribution type	Return period (year)	Rainfall intensity (mm/hr.)					
		Duration (minutes)					
		5	10	20	30	60	120
Gumbel distribution	2	31.49	19.83	12.50	9.54	6.01	3.79
	5	51.04	32.15	20.25	15.46	9.74	6.13
	10	63.98	40.30	25.39	19.38	12.21	7.69
	25	83.58	50.61	31.88	24.33	29.75	9.66
Log Pearson Type III distribution	2	30.14	18.98	11.96	9.13	5.75	3.62
	5	47.52	29.93	18.86	14.39	9.07	5.71
	10	60.29	37.99	23.93	18.26	11.51	7.25
	25	77.70	48.97	30.84	23.53	14.83	9.34

Lognormal distribution	2	29.38	18.51	11.66	8.90	5.61	3.53
	5	47.46	29.90	18.84	14.37	9.06	5.71
	10	61.89	38.99	24.56	18.74	11.81	7.44
	25	83.09	52.32	32.96	25.17	15.85	9.98

5) The rainfall intensities empirical equations for different return periods and different durations in the present study are estimating based on Sherman's equation, where minimum value test considers the best fit of the chosen distributions. This test provided in the Solver tool in Microsoft Excel software.

Table 5.6 represents the estimated equations from the three distributions of the rainfall intensities for the return periods of 2, 5, 10, and 25 years and the duration of 5, 10, 20, 30, 60 and 120 minutes.

Table 5.6: The estimated rainfall intensities equations using the selected distributions.

Return period (year)	Estimated rainfall intensities equations using the selected distributions.		
	Gumbel Distribution	Log Pearson Type III Distribution	Lognormal Distribution
2	$i = \frac{92.27}{(T_c)^{0.667}}$	$i = \frac{86.31}{(T_c + 0.018)^{0.668}}$	$i = \frac{88.3}{(T_c)^{0.667}}$
5	$i = \frac{149.942}{(T_c + 0.017)^{0.668}}$	$i = \frac{139.537}{(T_c + 0.022)^{0.668}}$	$i = \frac{139.633}{(T_c + 0.019)^{0.668}}$
10	$i = \frac{187.1}{(T_c)^{0.667}}$	$i = \frac{181.899}{(T_c + 0.019)^{0.668}}$	$i = \frac{177.291}{(T_c + 0.023)^{0.668}}$
25	$i = \frac{214.627}{(T_c)^{0.603}}$	$i = \frac{243.458}{(T_c)^{0.668}}$	$i = \frac{228.714}{(T_c + 0.028)^{0.669}}$

Where i represents rainfall intensity (mm/hour), and Tc is the time of concentration.

6) The study assumed an intensity duration of 5 - 120 minutes with a time interval of 5 minutes and calculated the rainfall intensities (i) from the equations in Table 5.6 for the return periods of 2, 5, 10 and 25 years. The results of the rainfall intensities are shown in Table 5.7.

Table 5.7: The estimated rainfall intensities by using Gumbel, LPT III and Lognormal distributions.

Tc min.	rainfall intensities from Gumbel distribution (mm/hr.)				rainfall intensities from Log Pearson type III distribution (mm/hr.)				rainfall intensities from Lognormal distribution (mm/hr.)			
	2 years	5 years	10 years	25 years	2 years	5 years	10 years	25 years	2 years	5 years	10 years	25 years
5	31.54	51.05	63.95	81.32	29.38	47.48	61.92	83.08	30.18	47.53	60.32	77.93
10	19.86	32.17	40.28	53.54	18.52	29.93	39.02	52.29	19.01	29.95	38.02	49.01
15	15.16	24.55	30.73	41.93	14.13	22.84	29.77	39.88	14.50	22.86	29.01	37.37
20	12.51	20.26	25.37	35.25	11.66	18.85	24.57	32.91	11.97	18.86	23.95	30.83
25	10.78	17.45	21.86	30.81	10.05	16.24	21.17	28.35	10.32	16.25	20.63	26.55
30	9.55	15.45	19.36	27.60	8.90	14.38	18.75	25.10	9.14	14.39	18.27	23.50
35	8.61	13.94	17.47	25.15	8.03	12.97	16.91	22.65	8.24	12.98	16.48	21.20
40	7.88	12.75	15.98	23.21	7.34	11.87	15.47	20.71	7.54	11.88	15.08	19.39
45	7.28	11.79	14.77	21.62	6.79	10.97	14.30	19.15	6.97	10.98	13.94	17.92
50	6.79	10.99	13.77	20.29	6.32	10.22	13.33	17.84	6.50	10.23	12.99	16.70
55	6.37	10.31	12.92	19.15	5.93	9.59	12.51	16.74	6.10	9.60	12.19	15.67
60	6.01	9.73	12.19	18.17	5.60	9.05	11.80	15.80	5.75	9.06	11.50	14.78
65	5.70	9.22	11.56	17.32	5.31	8.58	11.19	14.98	5.45	8.59	10.90	14.01
70	5.42	8.78	11.00	16.56	5.05	8.17	10.65	14.25	5.19	8.17	10.38	13.33
75	5.18	8.38	10.51	15.89	4.82	7.80	10.17	13.61	4.96	7.81	9.91	12.73
80	4.96	8.03	10.06	15.28	4.62	7.47	9.74	13.04	4.75	7.48	9.49	12.19
85	4.77	7.71	9.66	14.73	4.44	7.17	9.35	12.52	4.56	7.18	9.11	11.71
90	4.59	7.42	9.30	14.23	4.27	6.91	9.00	12.05	4.39	6.91	8.77	11.27
95	4.43	7.16	8.97	13.78	4.12	6.66	8.68	11.62	4.23	6.67	8.46	10.87
100	4.28	6.92	8.67	13.36	3.98	6.44	8.39	11.23	4.09	6.44	8.18	10.50
105	4.14	6.69	8.39	12.97	3.85	6.23	8.12	10.87	3.96	6.23	7.92	10.17
110	4.01	6.49	8.14	12.61	3.74	6.04	7.87	10.54	3.84	6.04	7.67	9.85
115	3.90	6.30	7.90	12.28	3.63	5.86	7.64	10.23	3.73	5.87	7.45	9.57
120	3.79	6.12	7.68	11.97	3.52	5.70	7.43	9.94	3.62	5.70	7.24	9.30

7) Drawing the intensity duration frequency (IDF) curves for the selected distributions using the calculated rainfall intensities data in Table 5.7 for the specific return periods of 2, 5, 10 and 25 years and for the assumed durations, which are 5 - 120 minutes with a time interval of 5 minutes, as shown in Figures 5.1, 5.2 and 5.3.

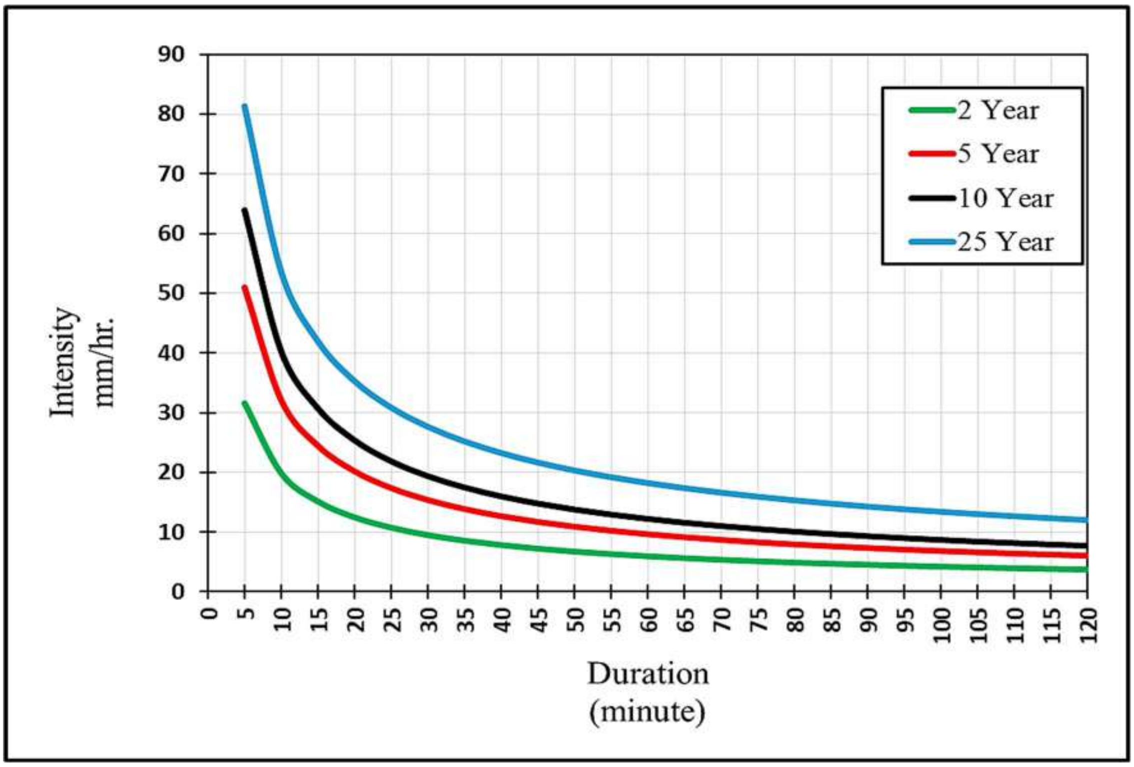


Figure 5.1: Intensity duration frequency (IDF) curves by using Gumbel distribution.

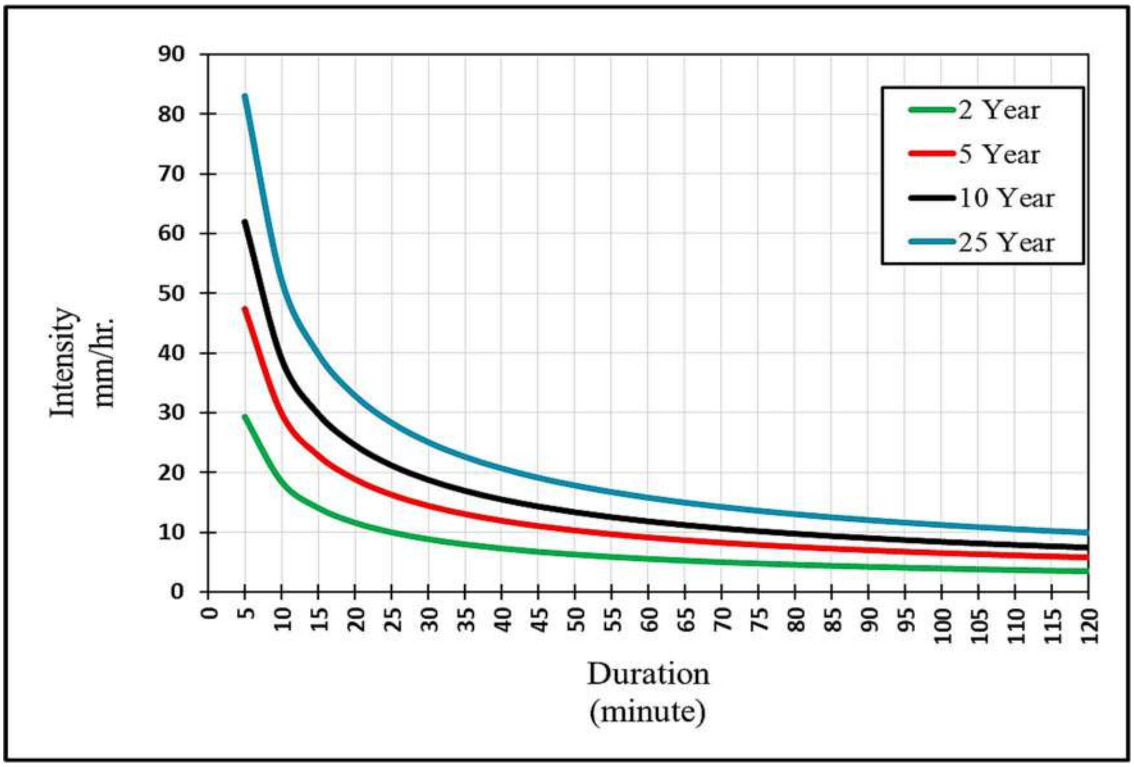


Figure 5.2: Intensity duration frequency (IDF) curves by using Log Pearson type III distribution.

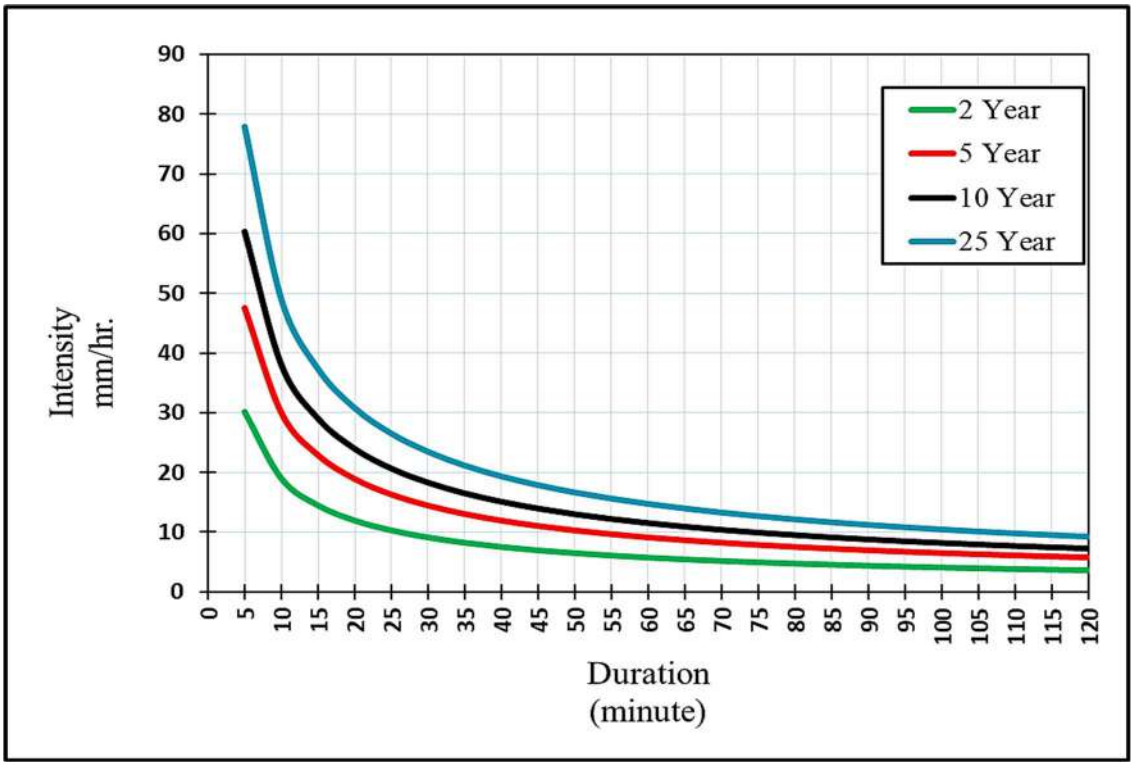
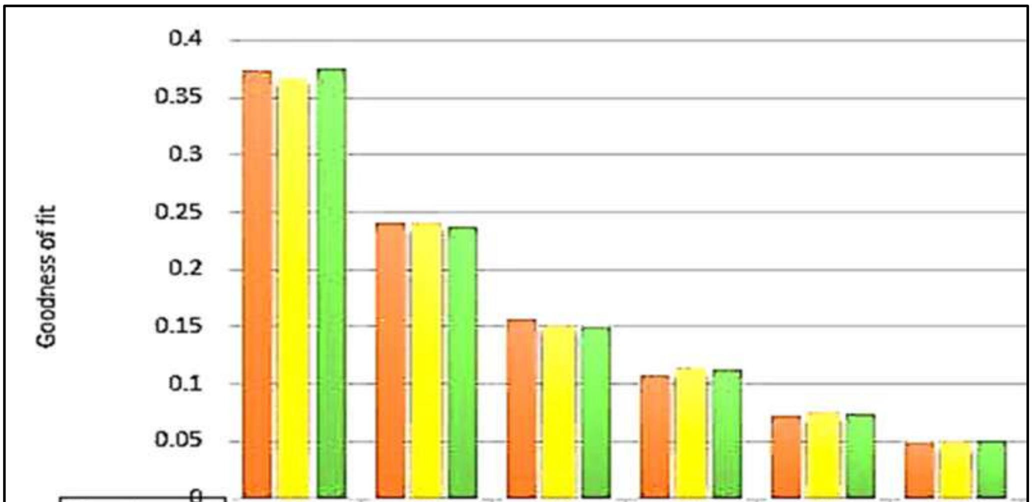


Figure 5.3: Intensity duration frequency (IDF) curves by using Lognormal distribution.

5.2.2. The Chi-square

The Chi-square goodness of fit test has been applied to the rainfall data. The Chi-square results do not show any priority for any method on the others and have a good agreement according to the Chi-square test, as shown in Figure 5.4.



Duration min	5	10	20	30	60	120
Gumbel	0.3735	0.241	0.1566	0.1084	0.0723	0.0482
Log Pearson	0.3671	0.2405	0.1519	0.1139	0.076	0.0506
Lognormal	0.375	0.2375	0.15	0.1125	0.075	0.05

Figure 5.4: Chi-square goodness of fit test results.

5.2.3. Selecting of the rainfall intensities for modelling

In the present study, the estimated equations of the IDF curves helps to calculate the rainfall intensity for any desired duration and for any return period in a short time. The rainfall intensities have been estimated in mm/hour for different return periods and different durations, in particular, with durations shorter than 24 hours, where durations used to estimate the rainfall intensities were from 5 to 120 minutes with a time interval of 5 minutes for return periods of 2, 5, 10 and 25 years.

The Gumbel distribution results provided the higher rainfall intensities values for the return periods of 2, 5, 10 and 25-year from other distributions. These results are the opposite of what Koutsoyiannis (2003) reported in his study where he stated that Gumbel distribution (EV1) is a model that produces the smallest possible design rainfall values in comparison to other distributions. But the findings are consistent with the study's findings of Elsebaie (2012) and Rasel and Islam (2015), where the results from the Gumbel method has given higher values of the rainfall intensities based on the yearly data of the precipitation in the study areas.

The calculated rainfall intensities using Gumbel distribution were utilized in the time series in the modelling by SWMM of the combined sewage system and the stormwater system, where the rainfall intensities that used in the SWMM provide the highest probabilities of flooding volumes.

5.3. SWMM Modelling of Combined Sewage System

The combined sewage system in the study area is already fully implemented and operated in 2011. During the rainfall period, the combined sewage overflow enters into the stormwater system that completed and implemented in 2010 and causes stormwater system overflow because of inadequate stormwater system capacity. Therefore, in the rainfall situation, all of the sewers systems deteriorated in the study area.

5.3.1. Forecasting of population

For the combined sewage system modelling purpose, the population number has been estimated for estimating sewage produced during dry weather, where the number of the residential units was 1716 units. The population growth was calculated in the study area until 2020 from the available population data in 2009 and Al-Najaf city growth population percentage (CSO, 2009; INPC, 2011), as shown in Figure 5.5.

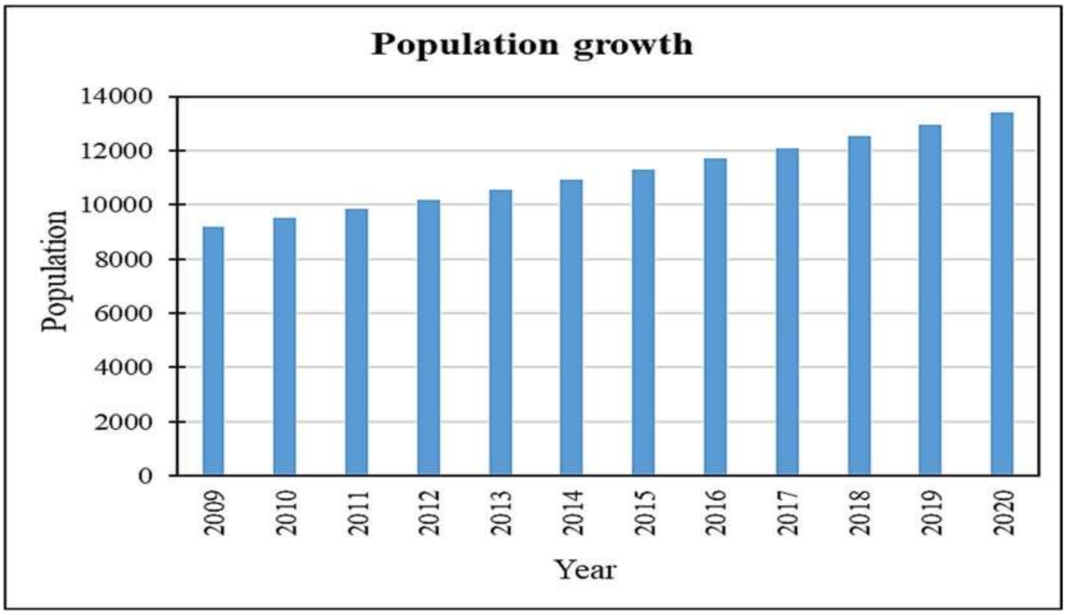


Figure 5.5: Forecasting of Al-Rashadiya quarter population (based on data from CSO, 2009; INPC, 2011).

The study assumed a rise in the number of populations of the study area from 9187 to 13413 people during 11 years (2009 to 2020), as shown in Figure 5.5. According to the number of the population in each residential unit, which is 1538 units (NSD, 2020), therefore, the equation of the number of the population in each residential will be:

$$\text{The number of the population in each residential} = \frac{\text{Population No.}}{\text{Residential units}} \quad \ldots\ldots 5.3$$

$$= \frac{13413 \text{ capita}}{1538 \text{ units}} = 8.72 \frac{\text{capita}}{\text{residential unit}} \approx 9 \frac{\text{capita}}{\text{residential unit}}$$

The population number in each residential unit showed an increase in the population concentration in each residential unit of the study area more than in other Al-Najaf city areas, where the number of residential units in the study area has remained fixed during the last 30 years (NSD, 2020). The estimated population in each residential unit was used for all units' types based on the modelling divides, which number was 1716 units.

5.3.2. Forecasting dry weather flow (DWF)

The average generation of the sewage flow from all units (residential, commercial, etc.) can be determined from the daily water consumption for each capita by using the formula (steel and McGhee, 1979):

$Q_{Avg} = P * G$ ……5.4

where:

Q_{Avg}: The average sewage generation for each unit (litter/day).

P: Population number (in thousand).

G: Daily water consumption per capita (litter/capita/day).

The sewage generation flow rate per each capita per day was calculated by assuming's that the daily sewage generation is 80% of the daily water consumption for each capita, which is 275 litres/capita/day (NSD, 2020), as shown in the following equation:

$Q_{sewage} = 275 * 0.8 = 220$ litter / capita / day … 5.5

The calculated sewage produced by the population number in each unit in the study area is shown in the following equation:

$$Q_{\text{sewage from each unit}} = \frac{\left(9\ \frac{\text{capita}}{\text{residential unit}}\ \text{x}\ 220\ \frac{\text{litter}}{\frac{\text{capita}}{\text{day}}}\right)}{\left(60 * 60 * 24\ \frac{\text{sec.}}{\text{day}}\right) \text{x} \left(1000\ \frac{\text{litter}}{\text{m}^3}\right)} \ \ldots\ 5.6$$

$$= 23\ \text{x}\ 10^{-5}\ \frac{\frac{\text{m}^3}{\text{sec.}}}{\text{residential unit}}$$

5.3.3. External inflows calculation of the study area

Table 5.8 shows the initial flow of the sewer systems pipes in the study area, which have external inflows values that were used in the modelling. The names and locations of these pipes in Al-Rashadiya sewer systems are shown in Figures 3 and 4 of Appendix A.

Table 5.8: The external inflows in the sewer systems pipes used in SWMM modelling.

No.	Pipe ID	Sewer system type	Q_p (m^3/sec)
1	4	Stormwater	0.147
2	9	Stormwater	0.321
3	16	Stormwater	0.159
4	25	Stormwater	0.125
5	14	Stormwater	0.193
6	24	Stormwater	0.185
7	42	Stormwater	0.226
8	1	Stormwater	0.524
9	28	Stormwater	0.261
10	50	Combined	0.114
11	45	Combined	0.175
12	34	Combined	0.163
13	21	Combined	0.176
14	4	Combined	0.197
15	95	Combined	0.182

5.3.4. The models performance

To obtain the best results, the simulation time of the SWMM modelling continued for 3:00 hours, which is more than the rainfall intensity duration time, which is 2:00 hours, and this will help to estimate enough time for flooding volumes discharge and the infiltration.

There was a lack of data required for calibration and validation of the SWMM modelling. In the present study, the relationships between the results by using the indicators of the Normalized mean square error (NMSE), the Root mean square error (RMSE), and the Coefficient of determination (R^2)

were used to evaluate SWMM modelling performance, where these indicators were used in studies conducted by Zaini et al. (2015), Badieizadeh et al. (2016), Kourtis et al. (2017), Taatpour et al. (2019) and Hendrawan (2020).

Firstly, the relationships between the design flow rates and the obtained flow rates from the SWMM modelling of the combined sewage system for 215 pipes were conducted by using the NMSE, R^2 and RMSE indicators to evaluate the SWMM modelling performance. The results of these relationships are shown in Table 5.9 and Figure 5.6, 5.7, 5.8, and 5.9.

Table 5.9: The relationships result by using NMSE and RMSE indicators.

Rainfall intensity return period	Normalized Mean Square Error (NMSE)	Root Mean Square Error (RMSE)
2	0.6970	0.0363
5	0.3038	0.0281
10	0.2317	0.0255
25	0.1930	0.0241

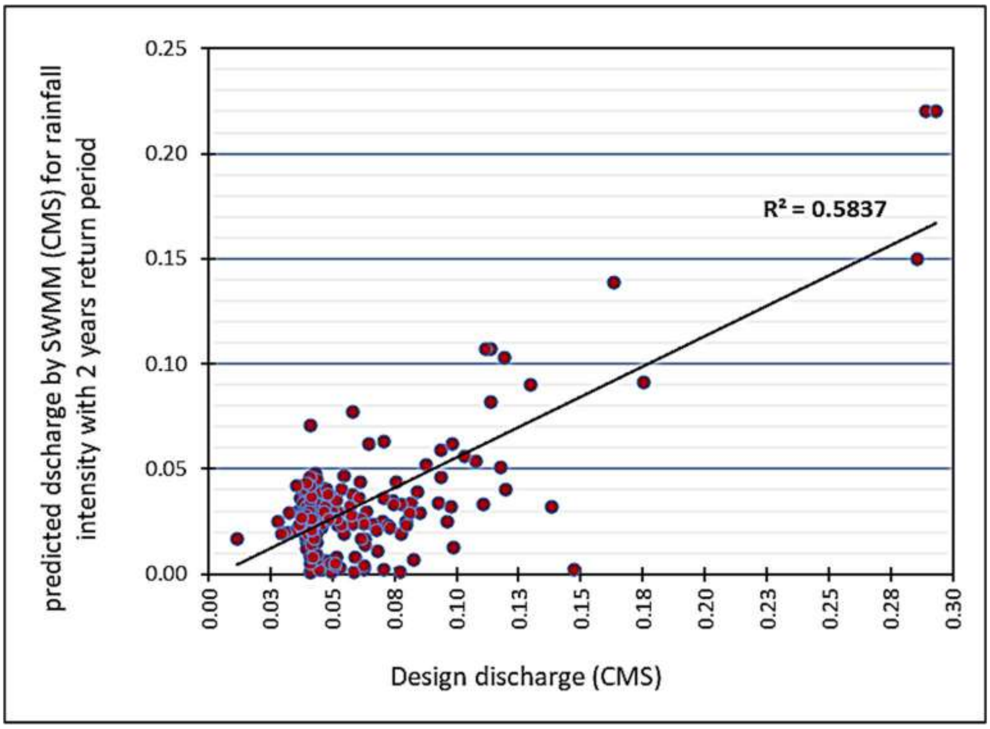


Figure 5.6: The relationship between the design flow rates and max flow rates obtained from the SWMM using rainfall intensity with 2 years return period by using the coefficient of determination (R^2).

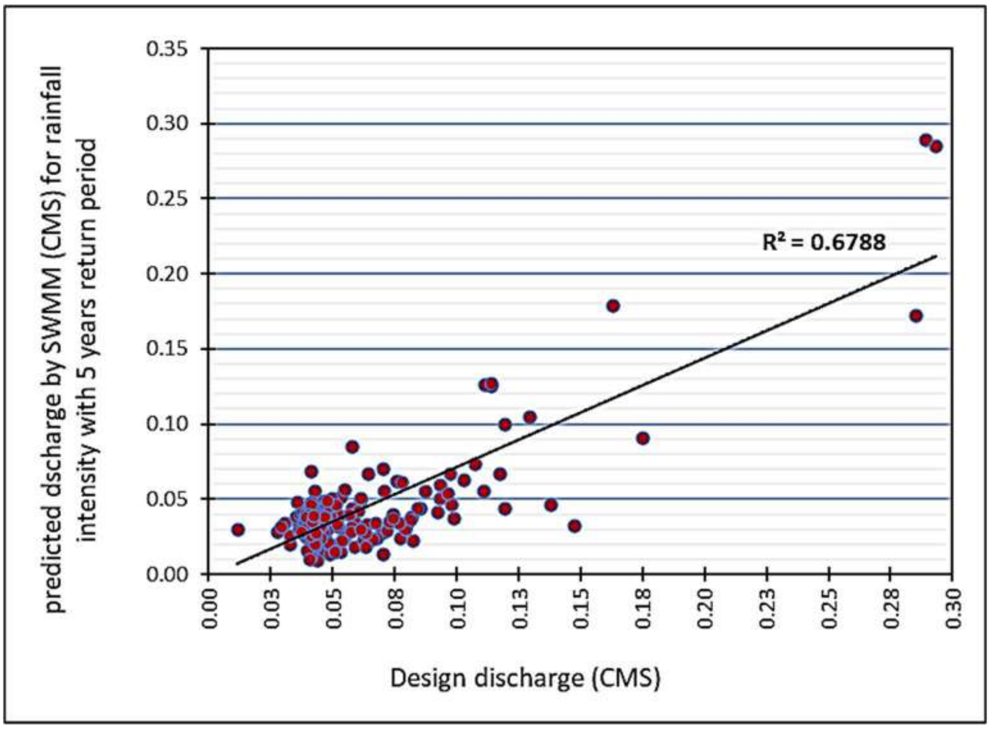


Figure 5.7: The relationship between the design flow rates and max flow rates obtained from the SWMM using rainfall intensity with 5 years return period by using the coefficient of determination (R^2).

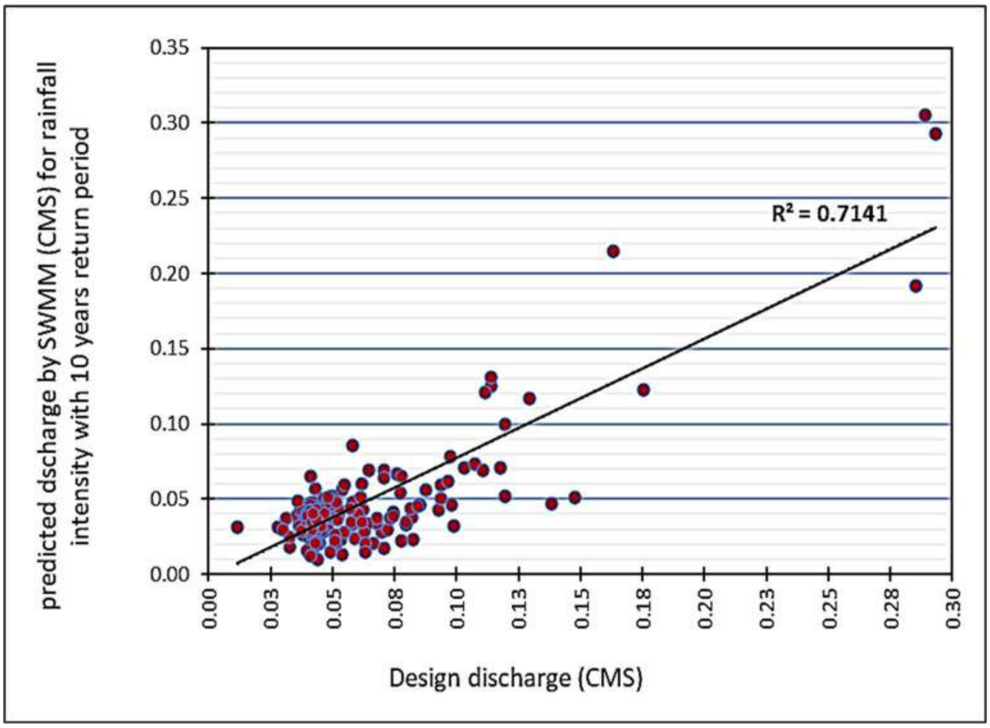


Figure 5.8: The relationship between the design flow rates and max flow rates obtained from the SWMM using rainfall intensity with 10 years return period by using the coefficient of determination (R^2).

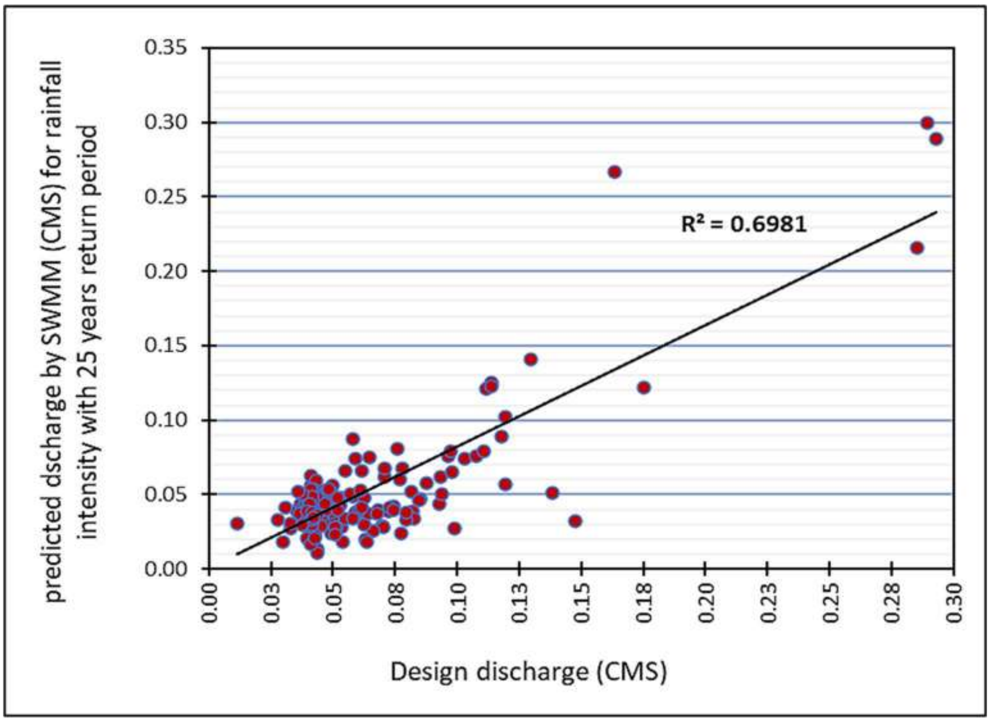


Figure 5.9: The relationship between the design flow rates and max flow rates obtained from the SWMM using rainfall intensity with 25 years return period by using the coefficient of determination (R^2).

Table 5.9 and Figures 5.6 to 5.9 represent the results of the indicators used. The values approach each other at the start of the simulation time, where these values refer to a decrease in the flow rates in existing pipes at the beginning of the combined sewage system. Other values, that have high flow rates, referred to the pipes at the end of the system, where the flow rates increase gradually because of the cumulating of the flow and increased of pipes diameters.

The values of NMSE ranged between (0.1930- 0.6970) using the rainfall intensities with the different return periods, where the results showed that for the rainfall intensity with 25 years return period model gave the minimum NMSE value. The NMSE results appear that the best performance by the SWMM was by using the rainfall intensity with 25 years return period.

The values of RMSE were close to zero for all models by SWMM for the different return periods, were ranged from (0.0241- 0.0363). The results of RMSE showed that the model of the rainfall intensity with 25 years return period, the SWMM gave a better performance.

The coefficient of determination (R^2) ranged between (58.37% - 71.41%) for the different return periods. The results showed that the SWMM modelling for the rainfall intensity with a return period of 10 years gave the best performance, where max flow rates values in pipes obtained from the model were close to the maximum design flow rates.

The three used methods in the comparison showed suitable and good performance of the SWMM, and this has an agreement with the results obtained by studies of Zaini et al. (2015), Badieizadeh et al. (2016), Kourtis et al. (2017), Taatpour et al. (2019) and Hendrawan (2020).

The results of using indicators between the design flow rates and max flow rates of the models by SWMM, using the three methods, have listed in Tables 1-5 in Appendix A.

One rainfall event has happened during the study interval on 28/11/2020, where the rainfall depth of the event was 55 mm with 120 minutes of duration (local government in Al-Najaf). The event's data was used as an accumulative value in the time series of the event modelling by SWMM. The relationships between the max pipes flow rates in the combined sewage system (for all system pipes) using the event modelling with the max pipes flow rates in the models by SWMM using the different intensities was applied. The RMSE and R2 indicators were used in the construction of the relationships. The results are shown in Table 5.10 and Figures 5.10, 5.11, 5.12, and 5.13.

Table 5.10: The results of the relationships using the RMSE indicator between max flow rates in the pipes of the event model and max flow rates in pipes obtained from the models using the rainfall intensities for the selected return periods.

Return period	RMSE
2	0.0505
5	0.0392
10	0.0575
25	0.0615

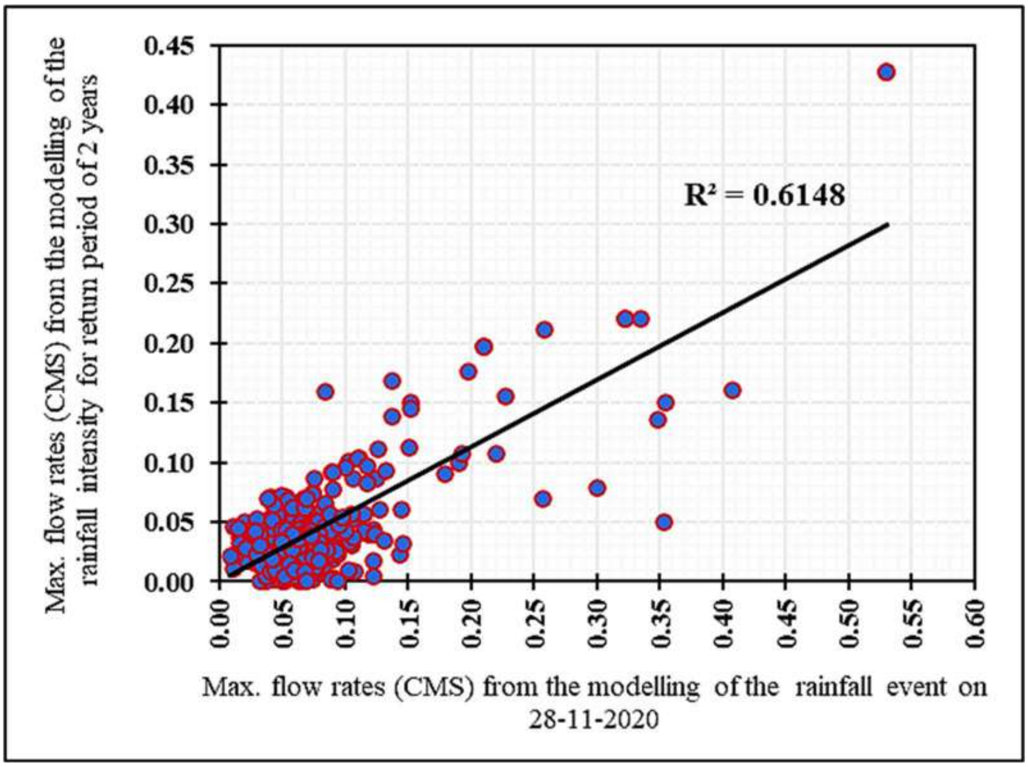


Figure 5.10: The results of using the R^2 indicator between max flow rates in the pipes of the event model and max flow rates in pipes obtained from the modelling using the rainfall intensity for the 2 years return period.

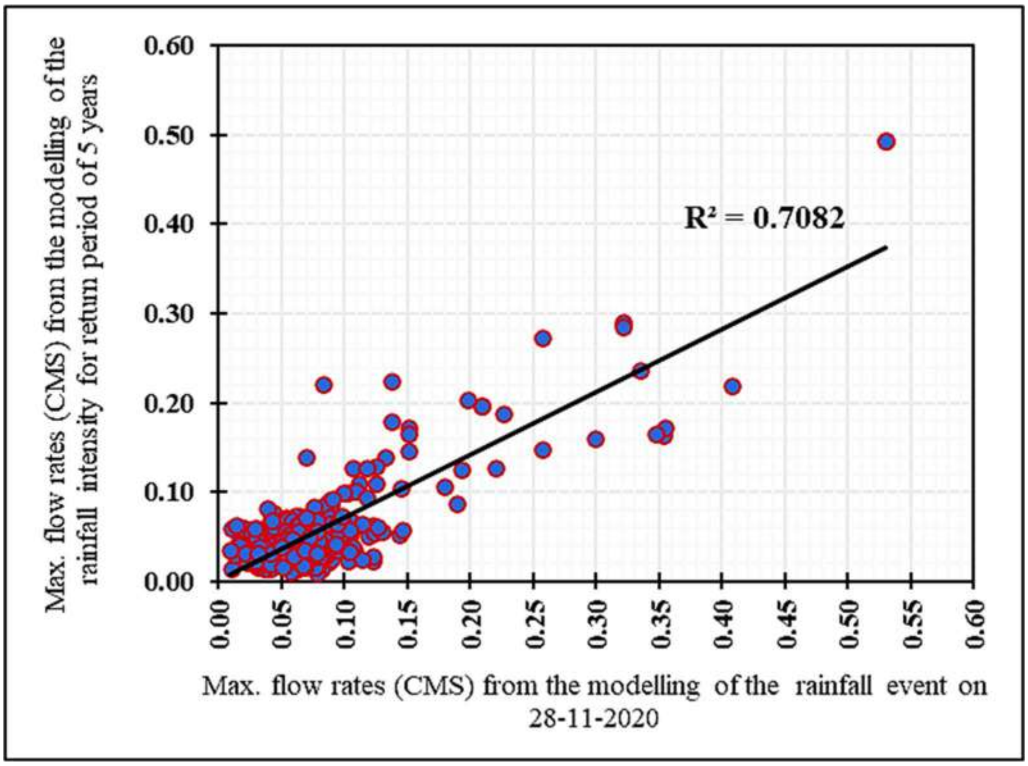


Figure 5.11: The results of using the R^2 indicator between max flow rates in the pipes of the event model and max flow rates in pipes obtained from the modelling using the rainfall intensity for the 5 years return period.

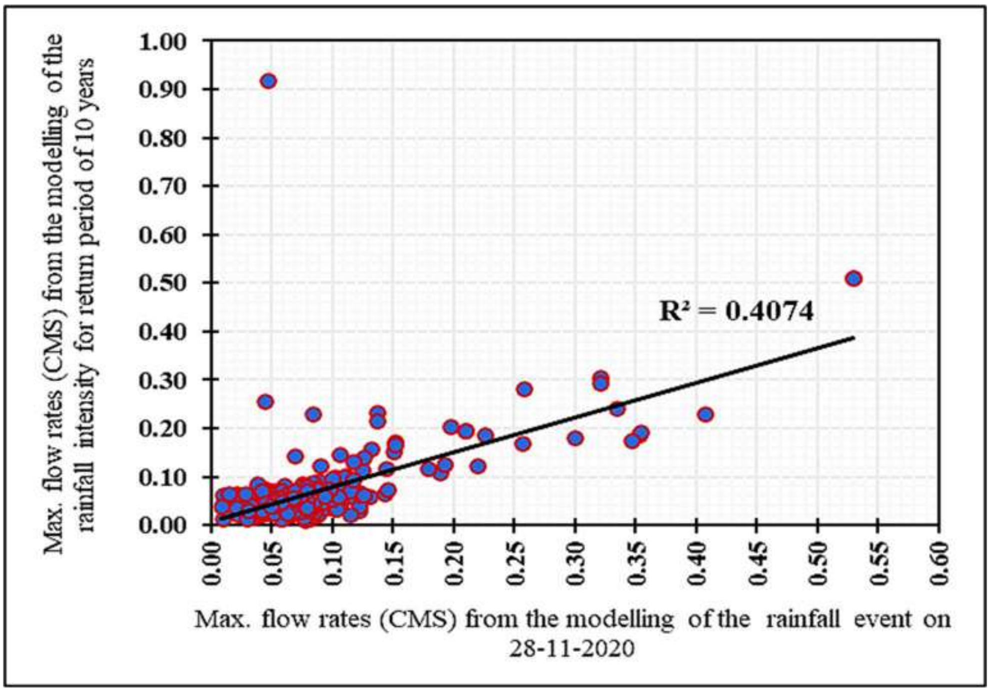


Figure 5.12: The results of using the R^2 indicator between max flow rates in the pipes of the event model and max flow rates in pipes obtained from the modelling using the rainfall intensity for the 10 years return period.

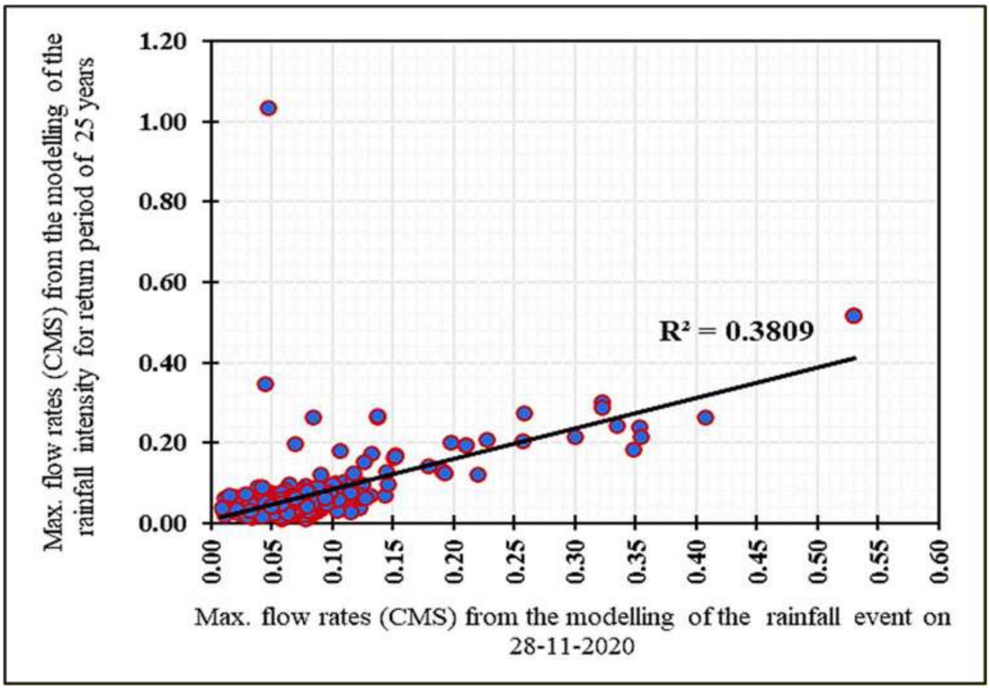


Figure 5.13: The results of using the R^2 indicator between max flow rates in the pipes of the event model and max flow rates in pipes obtained from the modelling using the rainfall intensity for the 25 years return period.

Table 5.10 and figures 5.10, 5.11, 5.12, and 5.13 present the results of the use of RMSE and R^2 indicators to predict the modelling performance by the relationships between the maximum flow rates from the event model and the maximum flow rates from the modelling of the rainfall intensities for the selected return periods. The obtained results by using the RMSE method showed low values for the relationship between the pipes flow rate of the rainfall event model and flow rate from models by SWMM using rainfall intensities with different return periods. The RMSE value using the rainfall intensity with 5-years, which is 0.0392, was close to zero where it is the best-obtained result. Also, the best result of R^2 was is 70.82% using the rainfall intensity for the return period of 5-years. The indicators result indicates that there is a convergence between the data of the rainfall event and the rainfall intensity for the return period of 5-years. The results by using the RMSE indicator are list in Table 6 in Appendix A.

5.3.5. The infiltration

The infiltration rate in the soil of the study area was obtained by entering the parameters data of Green-Ampt equation (equation 3.5) in the SWMM modelling. According to Rawls (1983), these parameters values depend on the soil type in the study area. For the present study the type of soil is sandy clay, where the required parameters, according to Rawls (1983), will be:

1) The saturated hydraulic conductivity (k) = 0.02 inch./hr.,
2) The suction head (Ψ) = 9.45 inch., and
3) The cumulative infiltration at the time t (F) = 0.321 inch.
4) The fraction (Φ) = 0.43.

The obtained results of the models by SWMM showed that the infiltration rate at the start of the simulation increase when the return period increased. The infiltration rate starts with high values of 0.89 (mm/hr.) for the rainfall intensity with a 2-years return period and 0.9 (mm/hr.) with the rainfall intensities for 5, 10, and 25 years return periods. The infiltration rate continues in the decreasing with various rates for each rainfall intensities until minute 140 of the simulation time (Total simulation time 180 minutes).

For the remaining time of the simulation (from the minute of 145 to 180), the infiltration rate starts equally reduces in all models of the SWMM until the simulation time end.

The results of the infiltration rate from the SWMM modelling for the selected rainfall intensities for the different return periods are shown in Figures 5.14, 5.15, 5.16, and 5.17 and in Table 7, see, Appendix A.

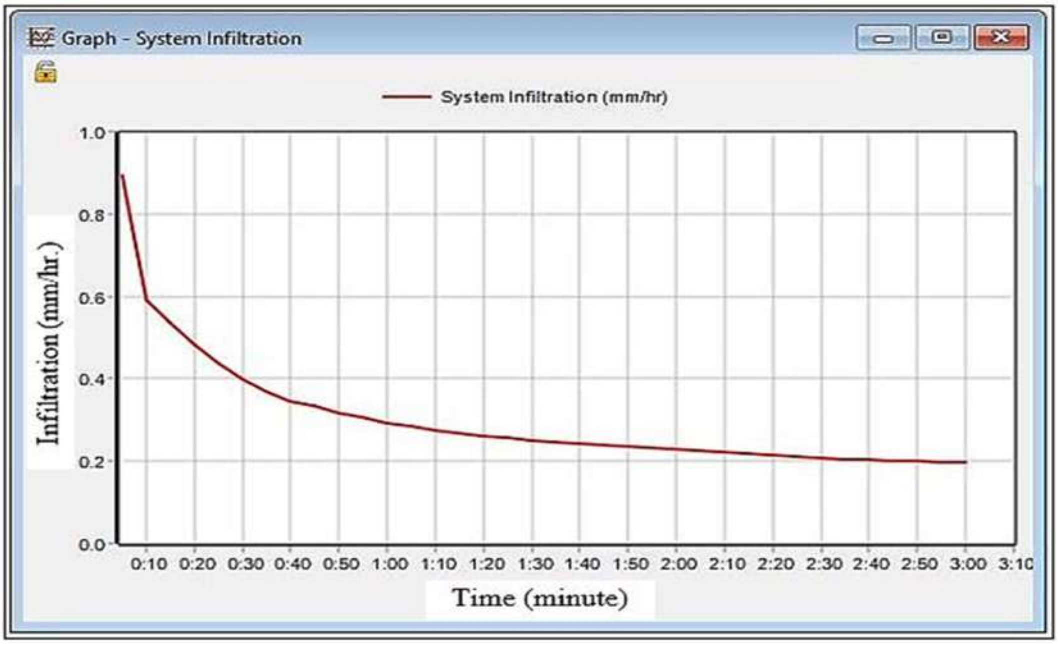


Figure 5.14: The infiltration rate from the SWMM modelling using rainfall intensity with 2 years return period.

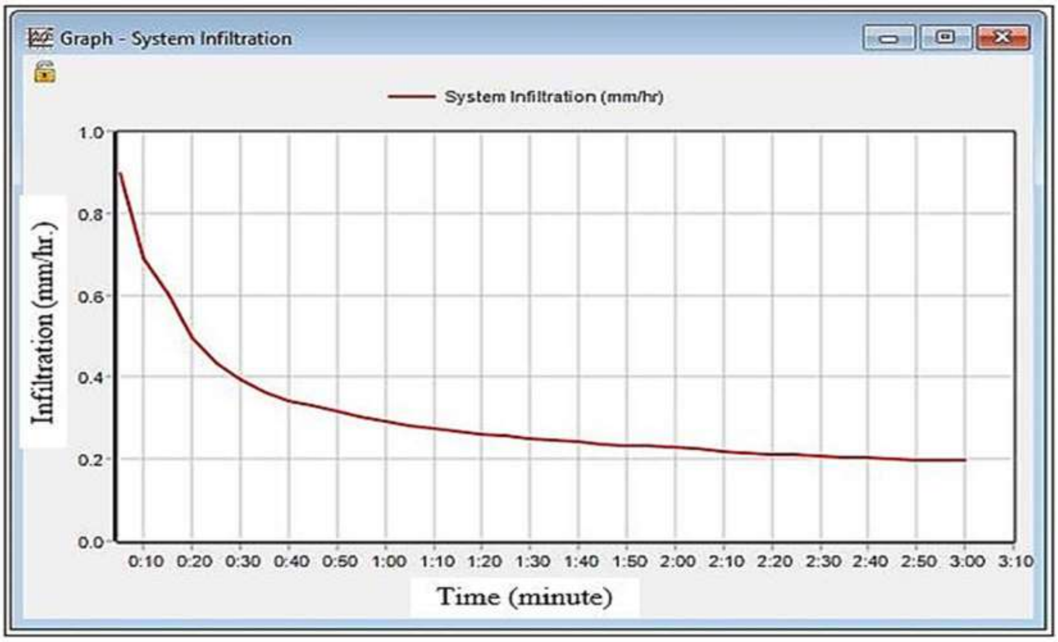


Figure 5.15: The infiltration rate from the SWMM modelling using rainfall intensity with 5 years return period.

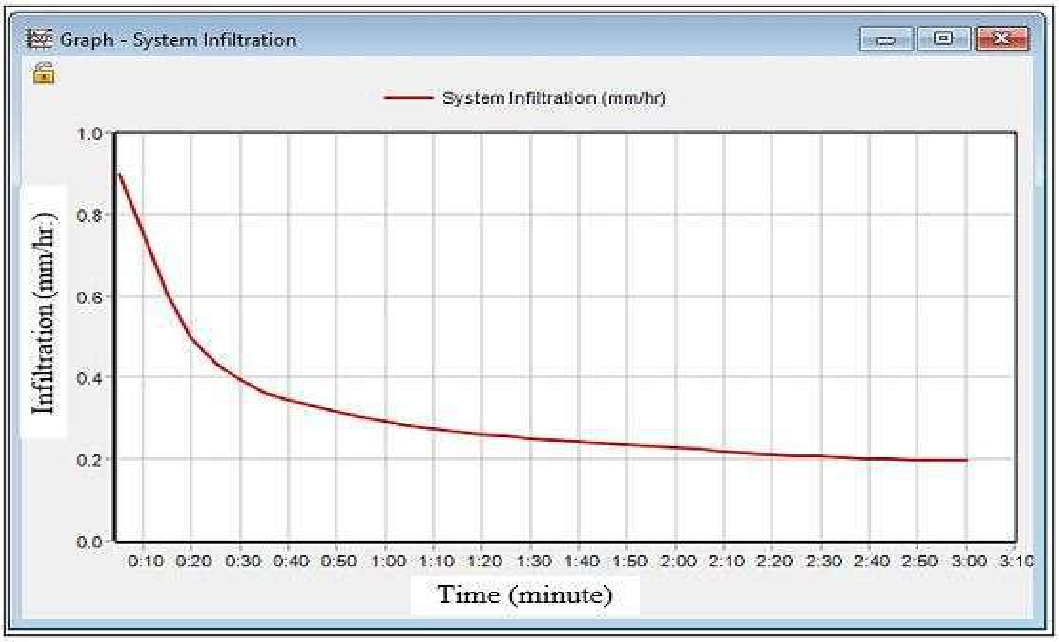


Figure 5.16: The infiltration rate from the SWMM modelling using rainfall intensity with 10 years return period.

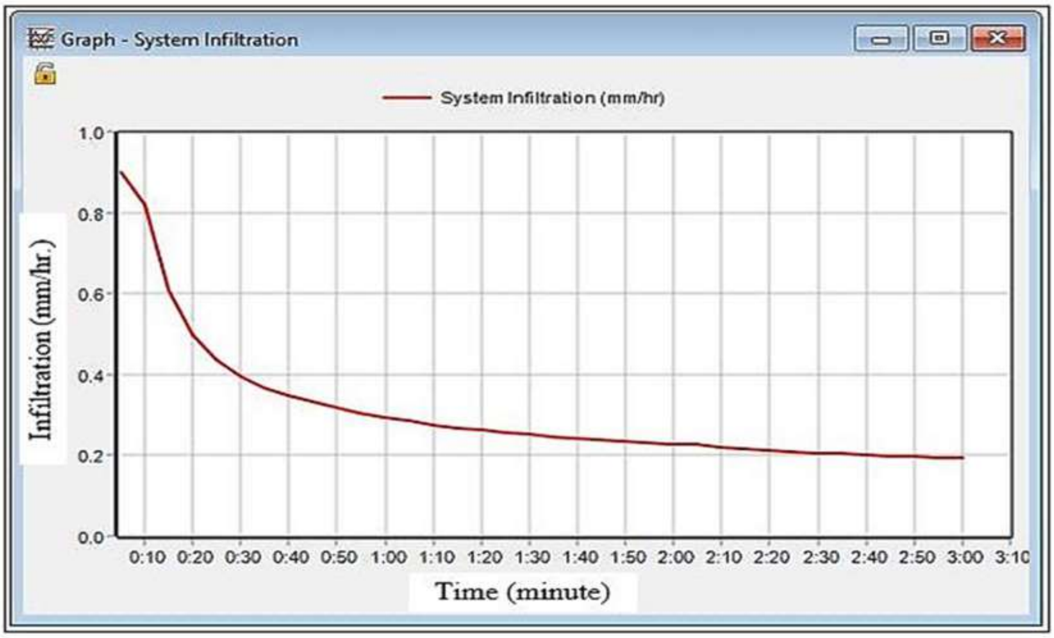


Figure 5.17: The infiltration rate from the SWMM modelling using rainfall intensity with 25 years return period.

5.3.6. Flooding volumes from SWMM modelling

In the SWMM modelling process for the combined sewage system, there are two sources of wastewater, the first from the volumes of the run-off on the sub-catchments due to the rainfall, and the second, the volumes of the produced wastewater that come from domestic uses.

In the case of arriving of these volumes to levels that exceed the design capacity of the sewer system, floods might occur in the nodes of the sewage system; this what happened within varying percentages in the combined sewage system of the study area when using the different rainfall intensities for different return periods.

The node flooding, in most cases, is caused by the unregular distribution of sewage quantity in the combined sewage system in the study area, where the flooding in some nodes is occurred by exceeding in criteria of the sewer system design. For example, nodes flooding occurs due to the direct connections of the home sewers to the nodes, not on houses connections (sewer pipes). The remaining volume of the runoff distributes between infiltration in the soil, depression storage, and the sewage liquids volume discharged by the combined sewage system. Table 5.11 listed The results obtained from the combined sewage system models.

Table 5.11: The results obtained from the SWMM modelling of the combined sewage system using the different rainfall intensities for different return periods.

Return period years	Total Runoff m^3	Total Nodes Flooding m^3	Remaining volume m^3	Percentage of flooding nodes to the total system nodes
2	5090	3817	1273	(36/410) ≈ 9%
5	10670	6912	3758	(83/410) ≈ 20%
10	14410	8929	5481	(106/410) ≈ 26%
25	23450	13434	10016	(138/410) ≈ 34%

The results in Table 5.11 appear that the total of the over sub-catchments runoff, nodes flooding volume and the remaining from the total runoff volume increased with the increase of the rainfall intensity having a high return period, where the rainfall intensity with the return period of 25 years, has recorded the higher value. The results showed increasing in nodes flooding volume with the higher rainfall intensity having the higher return period. The results in Table 5.11 agree with the results obtained by other researchers, for example, Nile et al. (2019), Hassan et al. (2017) and Nile (2018).

5.3.7. Flooding flow rates from SWMM modelling

The flooding flow rate obtained from SWMM modelling is varying based on the rainfall intensity. Figures 5.18, 5.19, 5.20, and 5.21 represent the flooding flow rate hydrographs from SWMM during 3 hours simulation time for the used rainfall intensities. Also, the values and the time of the maximum flooding rate occurring from SWMM modelling for the combined sewage system using the four rainfall intensities are listed in Table 5.12.

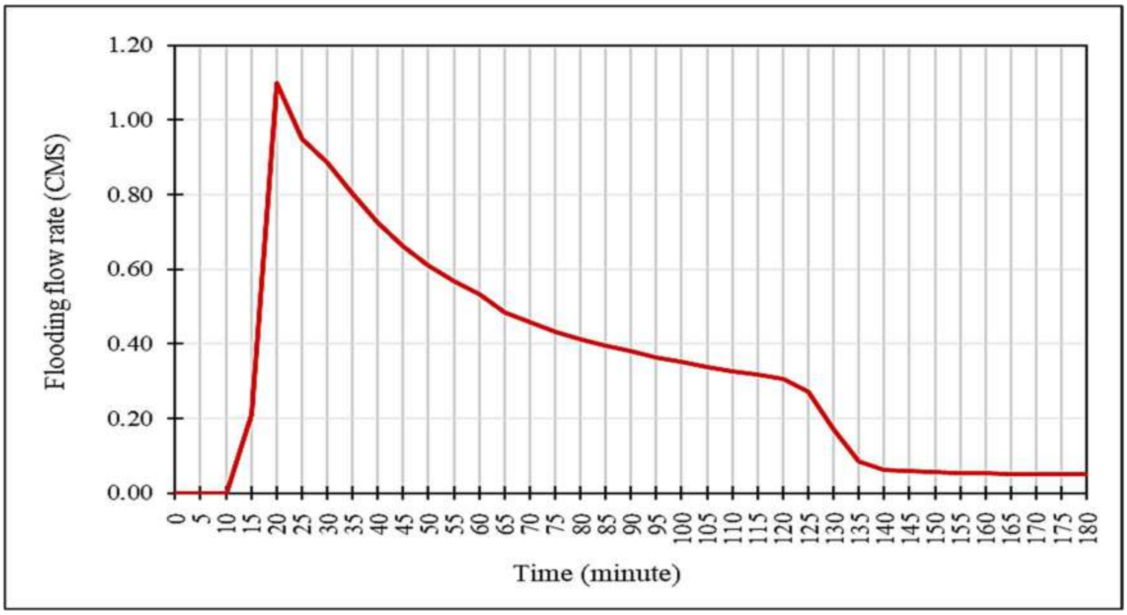


Figure 5.18: Flood flow rate from SWMM modelling for the combined sewage system using rainfall intensity for the return period of 2 years.

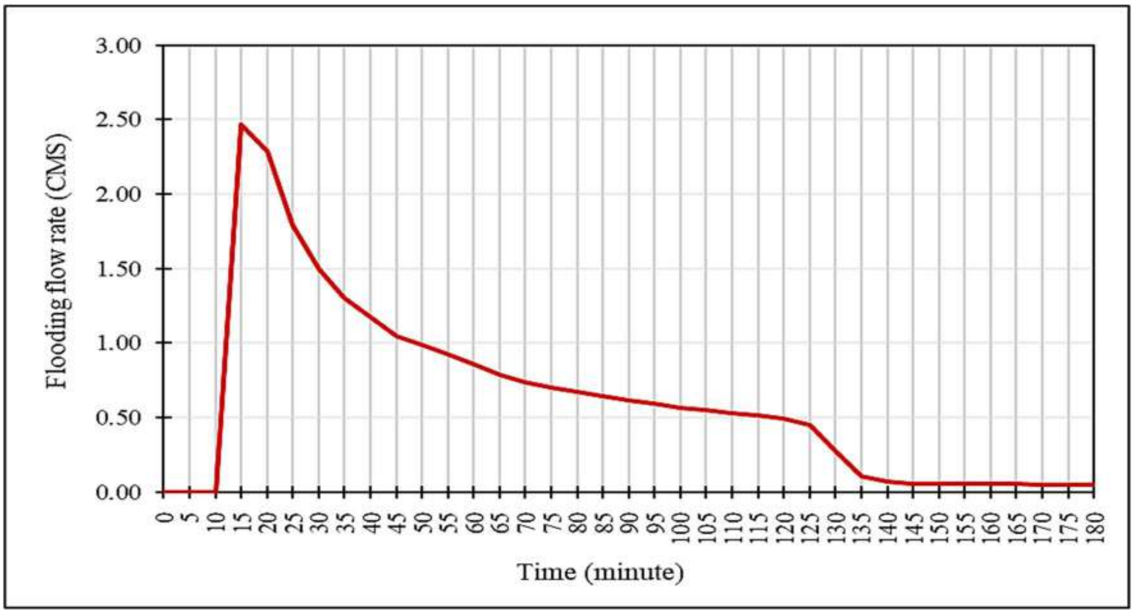


Figure 5.19: Flood flow rate from SWMM modelling for the combined sewage system using rainfall intensity for the return period of 5 years.

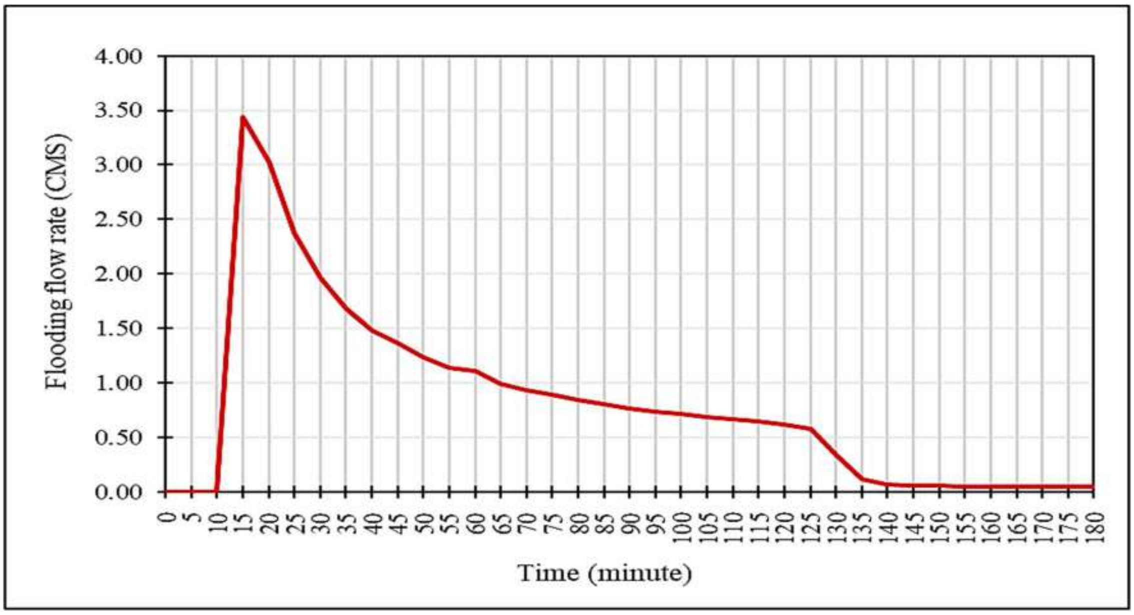


Figure 5.20: Flood flow rate from SWMM modelling for the combined sewage system using rainfall intensity for the return period of 10 years.

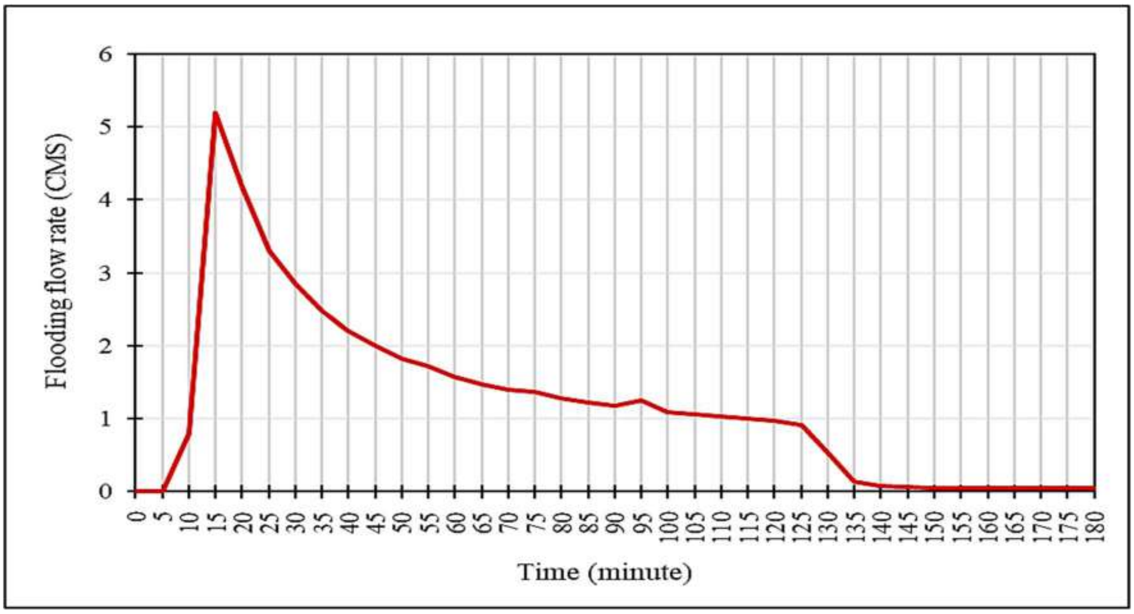


Figure 5.21: Flood flow rate from SWMM modelling for the combined sewage system using rainfall intensity for the return period of 25 years.

Table 5.12: The times and values of the maximum flooding rate from the SWMM modelling of the combined sewage system using different rainfall.

Return period (years)	Time of the maximum flooding rate (minutes)	The values of the maximum flooding rate (CMS)	The flooding rate (CMS) at min. 120	The flooding rate (CMS) at min. 180
2	20	1.098	0.305	0.050
5	15	2.467	0.495	0.051
10	15	3.441	0.623	0.051
25	15	5.192	0.980	0.051

As shown from the above hydrographs represented in Figures 5.18 to 5.21, the flooding flow begins after 10 minutes from the simulation start when using all the rainfall intensities for the return periods of 2, 5 and 10 years, while, the flooding flow begins after 5 minutes from the simulation start when using the rainfall intensity for the return periods of 25 years. Also, the maximum flooding rate occurs in late time using the rainfall intensity with a return period of 2-years than when using the other rainfall intensities. When using the rainfall intensity for the return period for 2-years, the flooding start time was after 20 minutes from simulation started and was 15 minutes when using the rainfall intensities for the return periods of 5, 10, and 25-years.

The late time of node flooding when using the rainfall intensity for the return period for 2-years (20 minutes) return to the estimated low values of the rainfall intensity for this return period which is less than other rainfall intensities for the return periods of 5, 10, and 25-years.

The maximum value that showed in Figure 5.18 of the flooding flow rate, about 1.098 CMS, by using the rainfall intensity for the return period of 2 years considered the lowest value among the maximum flow rates values obtained from the simulation of the three other rainfall intensities for the 5, 10, and 25-years of return periods, which are 2.467, 3.441, and 5.192 CMS, respectively.

At the minute of 150, all models show approximately equal values of the flow rates, which equal to 0.05 CMS, after that time, the values continue to decrease until the flooding stops when the wastewater flow rate declines to the design capacity of the system.

Figures 5.22, 5.23, 5.24, and 5.25 show the flooded nodes and their flow rate when the occurring time of the maximum flooding flow rate in SWMM modelling for the combined sewage system for all rainfall intensities that used.

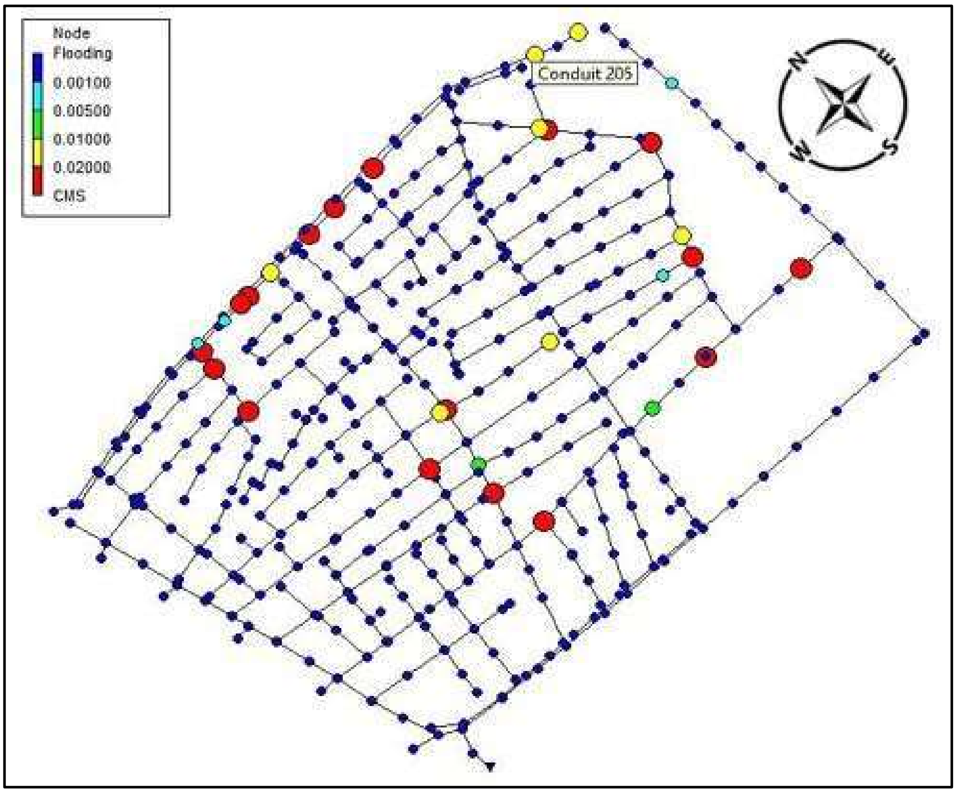


Figure 5.22: The flooded nodes after 20 minutes from the simulation starts (start of rainfall) in the SWMM modelling using rainfall intensity for the return period of 2 years.

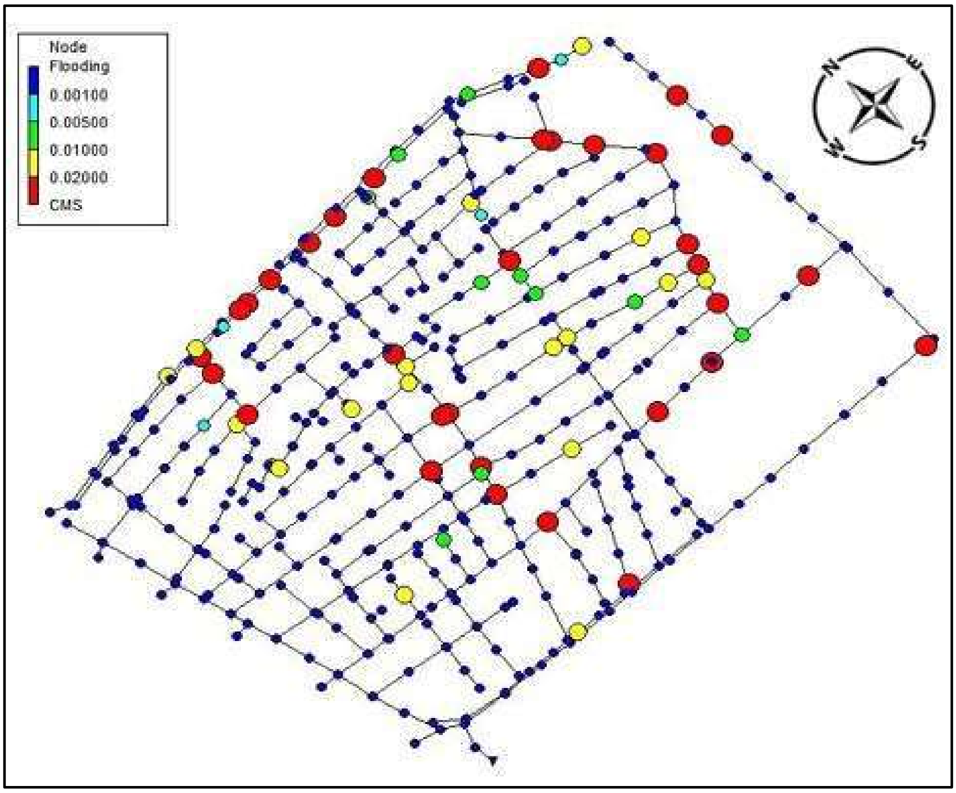


Figure 5.23: The flooded nodes after 15 minutes from the simulation starts (start of rainfall) in the SWMM modelling using rainfall intensity for the return period of 5 years.

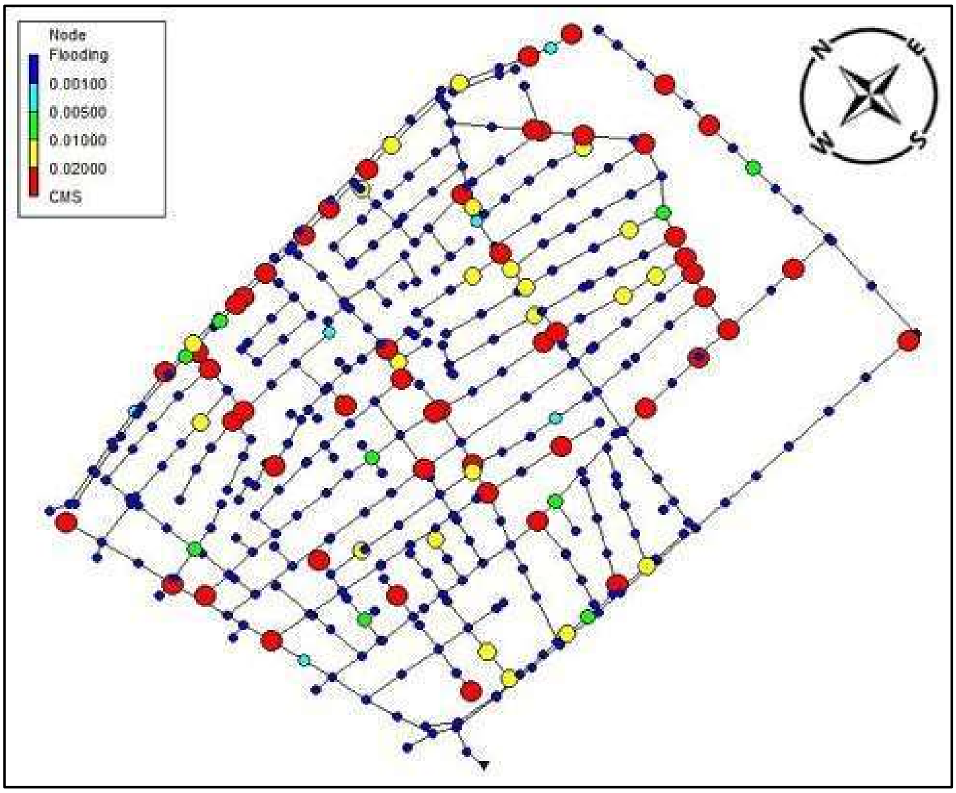


Figure 5.24: The flooded nodes after 15 minutes from the simulation starts (start of rainfall) in the SWMM modelling using rainfall intensity for the return period of 10 years.

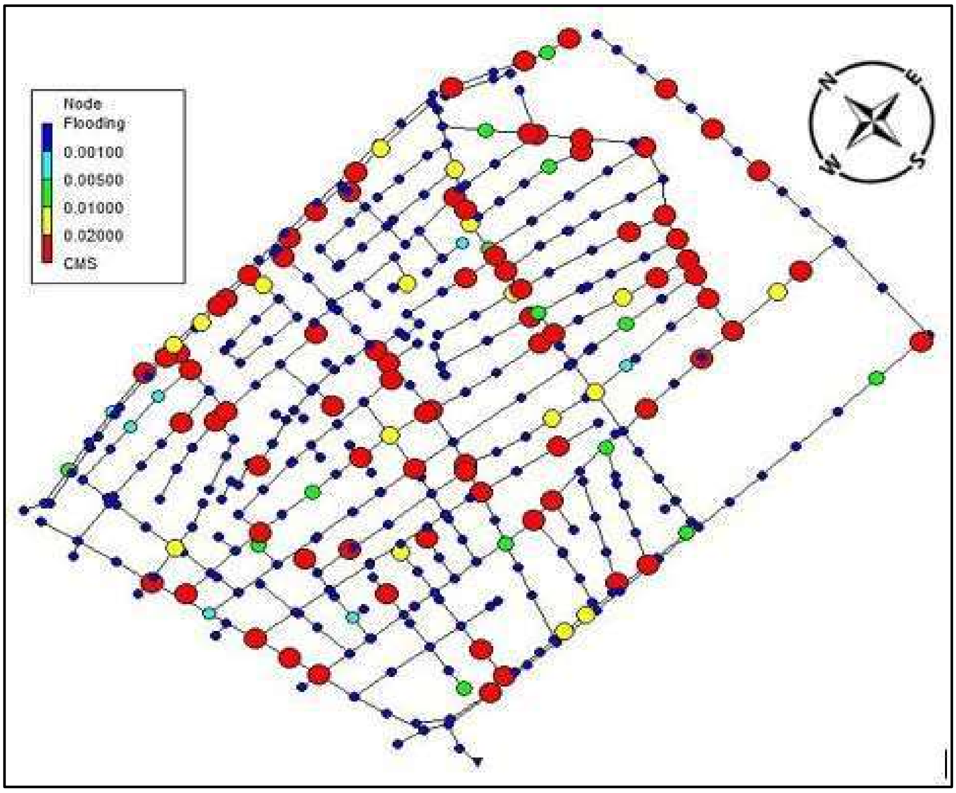


Figure 5.25: The flooded nodes after 15 minutes from the simulation starts (start of rainfall) in the SWMM modelling using rainfall intensity for the return period of 25 years.

Figures 5.22, 5.23, 5.24, and 5.25 represent the flooded nodes in the combined sewage system taken from the modelling by SWMM at the occurring time of the maximum flooding flow rate for the used rainfall intensities.

The blue colour points represent the unflooded nodes, and the points highlighted by other colours (i.e., cyan, green, yellow, and red) represent the flooded nodes which follow the different values of the flooding rate, see, the maps' key.

The maximum flooding flow rate occurs at minute 20 for the rainfall intensity for the 2-years return period and minute 15 for rainfall intensities for 5, 10, and 25-years return periods.

The SWMM models that using the different RIs and different return periods can estimate the values of flooding rate for all nodes in the combined sewage system of the study area.

The data of flooding rate in all flooded nodes for all rainfall intensities is listed in Tables 8 – 11, see, Appendix A.

Table 5.13 shows the results of the average flow, the maximum flow, and the total volume loading at the end of the combined sewage system from SWMM modelling by using the four rainfall intensities for the return periods of 2, 5, 10, and 25 years.

Table 5.13: The outfall loading from SWMM modelling of the combined sewage system using rainfall intensities for 2, 5, 10, and 25 years return periods.

Return period	Average flow rate (CMS)	Maximum flow rate (CMS)	Total discharged volume (CM)
2	0.274	0.427	3096
5	0.291	0.492	3566
10	0.294	0.510	3775
25	0.289	0.518	4143

Table 5.13 appears that all values of the average flow, the maximum flow and the total discharged volume increase when the rainfall intensity

increase, which increases with the return period, except in the case of using the model with the rainfall intensity for the return period of 25 years, where the average flow decreased.

In the SWMM modelling, the use of the rainfall intensities for the return period of 25 years, showed the maximum values in the maximum flow and total discharged volume, except the average flow value was less than the value obtained from SWMM modelling using the rainfall intensities for the return period of 10 years, which represents the higher average flow rate between the other average flow rates.

5.4. SWMM modelling of the stormwater system

The flooding volumes from the combined sewage system nodes using the four rainfall intensities were converted to average flow rate and used as a direct flow to nearest nodes in the stormwater system to estimate the flooding volumes in these nodes. Results of the total flooding volumes of the stormwater system nodes are shown in Table 5.14.

Table 5.14: The total of the nodes flooding volumes from the SWMM modelling of the stormwater system using rainfall intensities for 2, 5, 10, and 25 years return periods.

Return period	Total Nodes Flooding Volume (CM)	Percentage of flooding nodes / total nodes in the stormwater system
2	526	$(5/152) \approx 3\%$
5	2669	$(7/152) \approx 5\%$
10	3316	$(8/152) \approx 5\%$
25	5568	$(12/152) \approx 8\%$

The results shown in Table 5.14 appear that the total nodes flooding volume and the number of flooded nodes rising with the increase of the rainfall intensities.

The total flooding volumes from the stormwater system nodes using the different intensities and different return periods represent the ultimate flooding volume in the study area, where these flooding used as base data in suggested scenarios.

The flooded nodes results obtained from SWMM modelling of the stormwater system using the different rainfall intensities have listed in Table 12, see, Appendix A.

5.4.1. Effects of population activities on Al-Rashadiya sewer systems

The sewer flooding volumes are submissive to the increase due to population activities, behaviours and habits. The population behaviours affect in different ways, for example, the misuse and the un-legal sewers connections, closing the inlets of sewer systems by the rubbish, the wastes from the commercial activities, the spill of the untreated liquid and solid wastes, such as cars oils, butchers waste and food industries such as vinegar and vegetable market waste, etc., all of these reasons the overflows of the sewage systems during dry and rainy weather are occurred. Therefore, pollution in the rainwater during the rainy weather can be happened, which finally deposits in Kufa River; these results coincide with other researchers' findings, see, for example, Sercu et al., 2011, Sauer et al., 2011, Obaid et al. (2014), Ward and Winter (2016), Hassan et al. (2017) and Salerno et al. (2018).

The shortage in the periodic maintenance of the sewer systems, insufficient municipal services in waste collection and the significant increase in population growth in the study area, increase the stress on the sewer systems.

Figure 5. 26 shows the flooding locations (red points) and the effects of population activities (yellow arrow) on the sewer systems during dry and rainy weather in the study area; see, Figure 6, Appendix A.

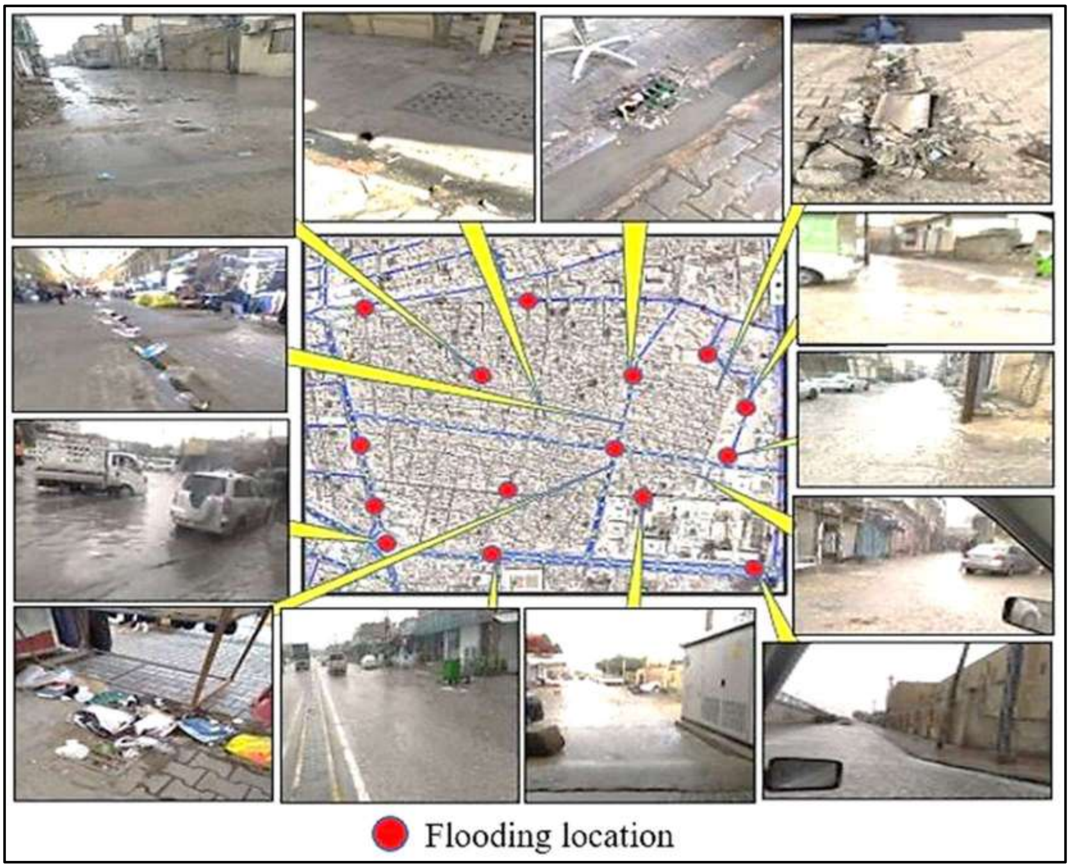


Figure 5.26: Flooding locations and the effects of population activities on the sewer systems during dry and rainy weather.

5.4.2. The stormwater quality

The stormwater system quality, in the dry weather and the rainwater quality in the rainy weather, was tested in the laboratory during the study interval from August 2020 to March 2021. Also, the rainwater quality was modelled by SWMM.

5.4.2.1. The stormwater system quality in dry weather

The stormwater quality was tested at the disposal point that located in the end of the stormwater system, the node R313A (See Figure 4 in Appendix A), by using laboratory tests during the dry weather during the study interval to measure some of the physical properties, chemical properties and pollutant concentration. The average tests result in the month for 3 samples are show in Table 5.15, Table 5.16 and Figures 5.27, 5.28, and 5.29.

Table 5.15: Physical and chemical properties of the stormwater system at disposal point during dry weather.

No	Test	Average of outlet results of stormwater system samples								Limitations	
		August 2020	September 2020	October 2020	November 2020	December 2020	January 2021	February 2021	March 2021	In Drinking Water	In WW
1	pH units	7.4	7.6	7.3	7.3	6.8	7	6.9	7.2	6.5 – 8.5[a]	6.5 – 8.5
2	Temperature (C°)	39.6	29	34.2	25.9	19.5	18.4	17.8	18.1	22 – 25[a]	30 – 35
3	Conductivity (µs/cm)	2900	2830	2960	2140	1200	1280	1190	1310	1000 [a]	
4	Dissolve Oxygen (DO) (% saturation)	5.6	5.2	6.3	5.8	8.1	7.3	6.9	6.8	7.92	
5	COD (mg/l)	262	227	251	293	275	272	255	245	30[a]	175 – 600[b]
6	Turbidity (NTU)	36.5	39.2	32.47	41.2	132	142	98	68	4 NTU [c]	
7	Total Dissolve Solids TDS (mg/l)	1270	1130	1200	990	1000	990	1140	1110	500[a]	< 1000
8	Total solid TS (mg/l)	1700	2390	2750	2067	2121	1920	2053	2122	-	

[a] Tebbutt, 1997, [b] McGhee & Steel, 1991, [C] WHO, 2017, GL: Guide Level, and MAC: Maximum Allowable Concentration.

Table 5.16: The wastewater and heavy metals tests in the dry weather of the stormwater system at the disposal point.

Date	TSS (mg/l)	BOD_5 (mg/l)	Cu (mg/l)	Pb (mg/l)	Cr (mg/l)	Mn (mg/l)
August 2020	1260	140	0.3421	0.1519	0.1354	0.1403
September 2020	1360	110	0.3055	0.1579	0.1687	0.1635
October 2020	1422	135	0.3726	0.0581	0.0978	0.0599
November 2020	1180	150	0.3647	0.0843	0.0581	0.0981
December 2020	851	160	0.3025	0.0978	0.0379	0.0689
January 2021	832	150	0.3147	0.1316	0.0000	0.0564
February 2021	988	140	0.3120	0.1328	0.0451	0.0615
March 2021	890	135	0.3035	0.1298	0.0506	0.0592

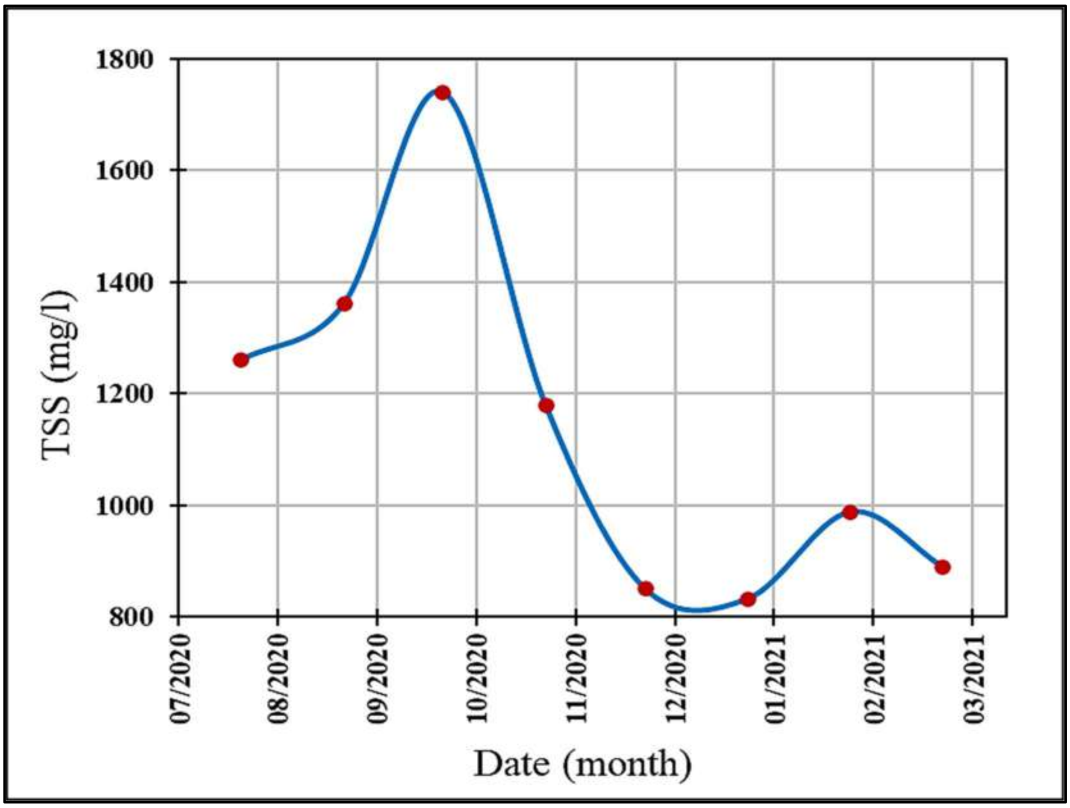


Figure 5.27: TSS test result of the stormwater at disposal point.

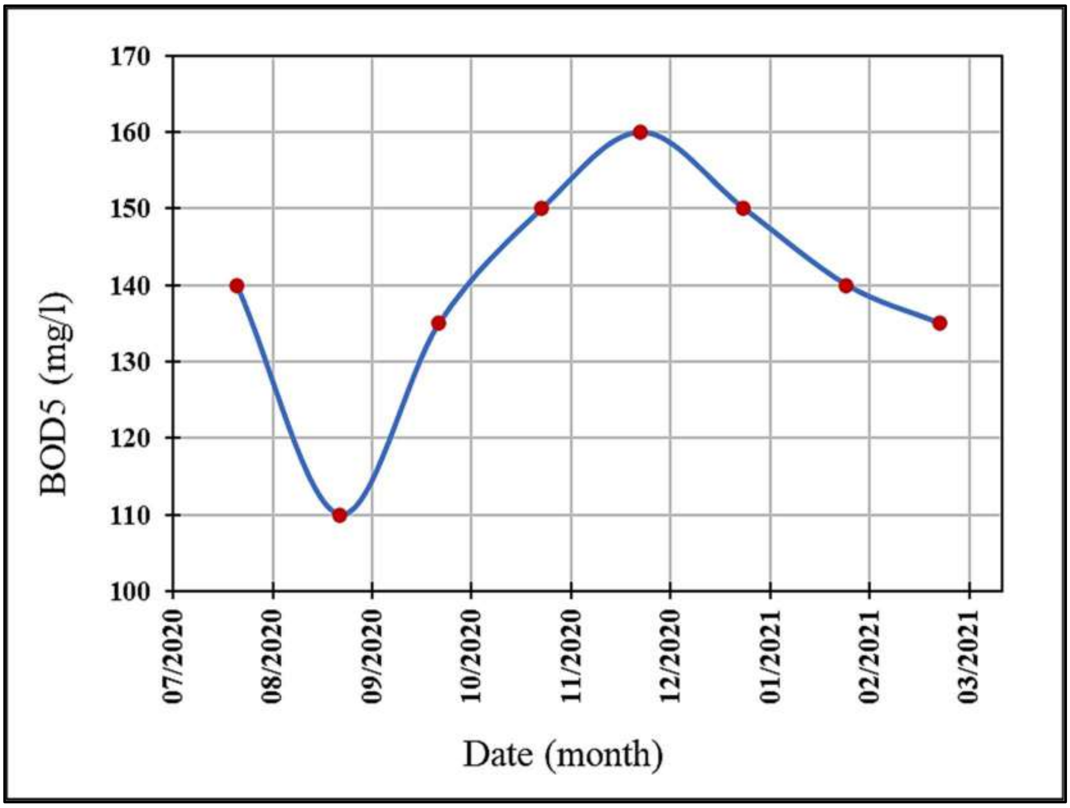


Figure 5.28: BOD_5 test result of the stormwater at disposal point.

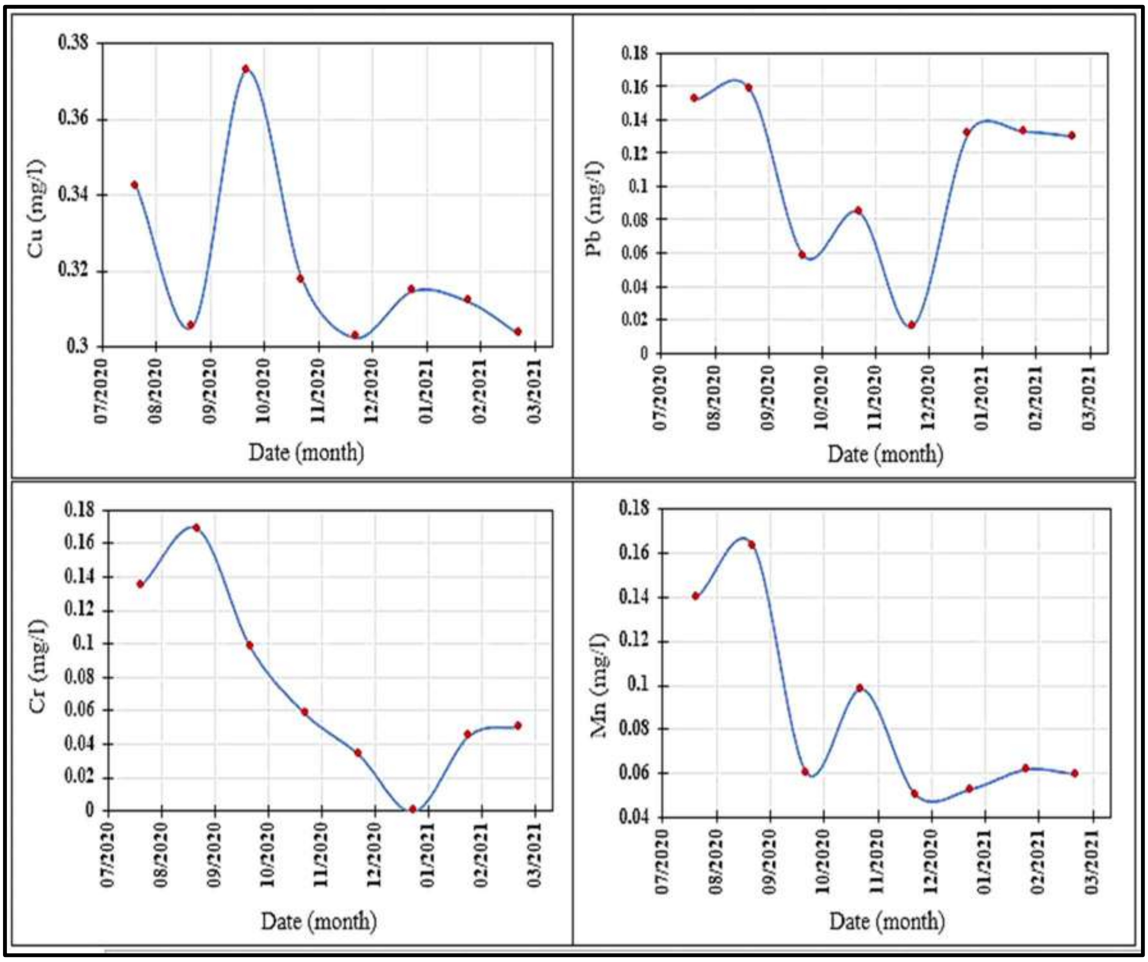


Figure 5.29: Heavy metals test result of the stormwater at disposal point.

Figures 5.27, 5.28 and 5.29 show the monthly results of the average laboratory tests for three samples for measuring the suspended solids (TSS), biochemical oxygen demand (BOD_5) and heavy metals concentrations in the stormwater, respectively. These diagrams appear wide variations in the results of the monthly tests during the study interval.

Figure 5.27 represents the TSS tests results, which increase in the hot months (because of high consumption of water) and decrease in the cold months (because of low consumption of water), which cause the precipitation of the suspended solids in the stormwater system. Also, the TSS values increase in the temperate months and the rainy season due to the rise in the flow rates in the rainwater system, which causes the agitation of these suspended solids and increases their concentrations in the samples.

Figure 5.28 show the opposite case, which occurs in the results of the BOD_5 tests, where the BOD_5 concentrations decrease in the hot months (because of an increase in the stormwater flow rates in the stormwater system), and increases in the cold months (because the decrease of the stormwater flows rates in the stormwater system).

As shown in Figure 5.29, there is no specific pattern has discovered in the behaviours of the heavy metal concentration during the dry weather, but its concentrations were more than the acceptable limits.

The variations in the values of TSS, BOD_5 and the heavy metals, may follow three sides, the first is the properties of the liquids that flow in the stormwater system during the dry weather, which produces from the untrue uses and un-legal abuses of sewer that connects directly to the stormwater system, where this side have a relation with the population and their daily habits and activities (domestic and commercial).

The second side is the sewage nodes overflows from the combined sewage system during the rainy weather, which enters the stormwater system and affects the stormwater system capacity and the disposal rainwater quality, finally causes pollution in the Kufa river.

The third side is the climate changes effects, where the precipitation frequency decreases because of the global warming phenomena, which affect the concentration of TSS, BOD_5 and heavy metals.

Table 5.17 shows the physical and chemical properties of the rainwater at the disposal point of the stormwater system after 20 minutes from the start of the rainfall event, which was on 28-11-2020.

Table 5.17: Physical and chemical properties of the rainwater at disposal point during the rainfall event on 28-11-2020.

No	Test	Rainwater properties
1	pH units	6.2
2	Temperature (C°)	21.1
3	Conductivity (µs/cm)	1380
4	Dissolve Oxygen (DO) (% saturation)	28.5
5	COD (mg/l)	515
6	Turbidity (NTU)	248
7	Total Dissolve Solids TDS (mg/l)	1900
8	Total solid TS (mg/l)	2700
9	Total suspended solid TSS	1740
10	BOD_5	240
11	Cu	0.2903
12	Pb	0.1143
13	Cr	0.0254
14	Mn	0.1107

The values of the stormwater properties in dry and wet weather presented in Tables 5.15 and 5.16 show that the pH units are within the acceptable range limit. The temperature shows a wide variety according to the season of the year, where it in some months arrives to lower and above the acceptable limits. The dissolved oxygen (DO) always was less than the minimum required limit, only in the rainy weather was exceed the acceptable limit. Also, the chemical oxygen demand (COD) was within the acceptable limit.

The conductivity, turbidity, total dissolved solids (TDS) and total solids (TS) always were above the limits. Some of the heavy metal's concentrations in the wet weather, which is Cu, Pb and Mn, were more than the acceptable limits, except the Cr was less than the acceptable limit.

5.4.2.2. Rainwater quality modelling results

The rainwater quality was modelled by SWMM using the rainfall intensity for a 5-years return period. The rainfall intensity was chosen due to its flow rates were more correlated with flow rates of the event in 28-11-2020 (coefficient of determination (R^2) equal to 70.82%, see section 5.3.4.). The pollutant tests' data of the event rainfall can be used in the manual calibration process of the SWMM quality model for the stormwater.

5.4.2.3. Rainwater quality tests results for the model calibration

The stormwater quality was tested after 20, 30, 60, and 120 minutes from the start time of the rainfall event on 28-11-2020, the aim of these tests was to identify the rainwater characteristics in the stormwater system at the disposal point, which will be used in the calibration of the stormwater quality model, the results of laboratory tests of the rainwater are shown in Table 5.18.

Table 5.18: The tests result of the rainwater characteristics.

Sample No.	Time of the sample took (minute)	TSS (mg/l)	BOD_5 (mg/l)	Cu (mg/l)	Pb (mg/l)	Cr (mg/l)	Mn (mg/l)
1	20	1740	240	0.2903	0.1143	0.0254	0.1107
2	30	1060	205	0.3177	0.1000	0.0383	0.1316
3	60	619	90	0.1254	0.0158	0.0327	0.0525
4	120	423	45	0.0547	0.0105	0.0339	0.0499

The results in Table 5.18 show the following points:

1) TSS, BOD5, and Pb values decreased from the rainfall start time with various proportions until the time ended of rainfall (2 hours).
2) Cu, Cr, and Mn values increased with various proportions from the rainfall starts time until the minute of 30, then these values start decreasing until the time ended of rainfall.

The cause of the variations of the results depending on many factors, such as the productivity rate of these materials, their distribution, the build-up rates of these materials in the study area, topography, the rainfall intensity, the runoff rates, the flow rates in the stormwater system, the samples handling, and tests circumstances, etc. The changes in pollutants concentrations in SWMM modelling during simulation times were listed in Table 13 of Appendix A.

The calibration of the stormwater modelling by SWMM is a complex process, where the SWMM calibrates through a repeated process until obtained a proper result that agrees with the laboratory tests results. The functions used in the calibration process were "Power Function" to the Buildup of pollutants and "Exponential Function" to pollutants Wash-off. The empirical coefficients of the Functions (C) that used in the quality model calibration are listed in Table 5.19.

Table 5.19: The empirical coefficients used in the calibration of the stormwater quality model by SWMM.

No.	Pollutant	Land use type	Buildup using POW Fun.		Washoff using EXP Fun.	
			C_1	C_2	C_1	C_2
1	TSS	Residential	87	0.8	12	0.06
		Commercial	79	0.6	10	0.08
		Street	62	0.4	8	0.02
2	BOD_5	Residential	15	0.1	7	0.004
		Commercial	14	0.2	7	0.008
		Street	10	0.2	8	0.009
3	Cu	Residential	0.08	0.1	0.1	0.1
		Commercial	0.11	0.05	1	1.2
		Street	0.1	0.1	0.1	0.005
4	Pb	Residential	0.06	0.1	0.1	0.1
		Commercial	0.03	0.02	1	1.5
		Street	0.1	0.1	0.1	0.05
5	Cr	Residential	0.15	0.09	0.062	0.02
		Commercial	0.25	0.1	0.015	0.07
		Street	0.21	0.09	0.01	0.02
6	Mn	Residential	0.06	0.04	0.2	0.08
		Commercial	0.031	0.02	1.4	1
		Street	0.11	0.1	0.1	0.06

The differences between the coefficient's values refer to the variation of the Buildup and the Wash-off of the pollutant's ratios based on the types of land uses and the activities that occur in these lands.

The validation of the calibrated model shows the model performance wherefrom the accuracy. In the present study, the coefficient of determination (R^2) was used for this purpose.

The obtained (R^2) values ranged between 95.36% to 99.64%, which indicate the high and perfect performance of the quality modelling by SWMM of the study area. The obtained results from the quality model agreed with other researchers' findings, such as Temprano et al. (2006), Chow et al. (2012) and Hussein et al. (2015).

Figures 5.30, 5.31, 5.32, 5.33, 5.34, and 5.35, show the values of the coefficient of determination (R^2) between the laboratory tests' results and the quality modelling results for the selected pollutants.

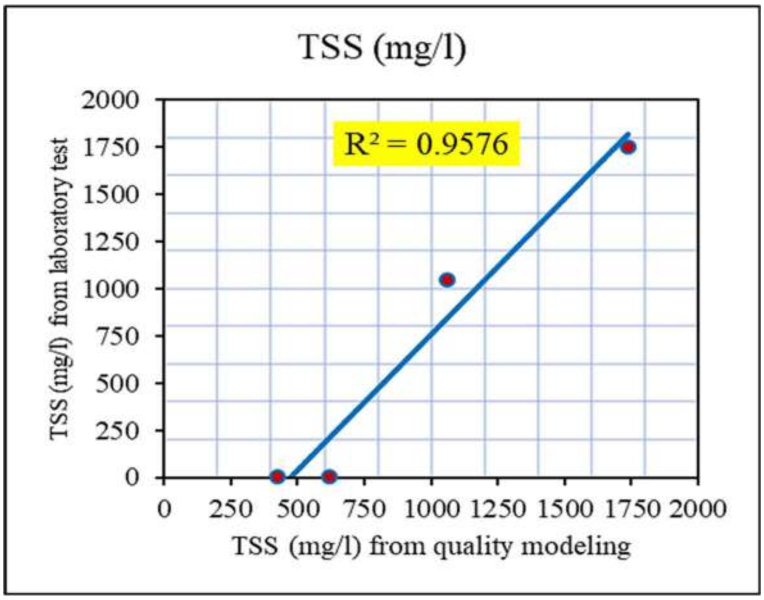


Figure 5.30: The coefficient of determination between TSS values.

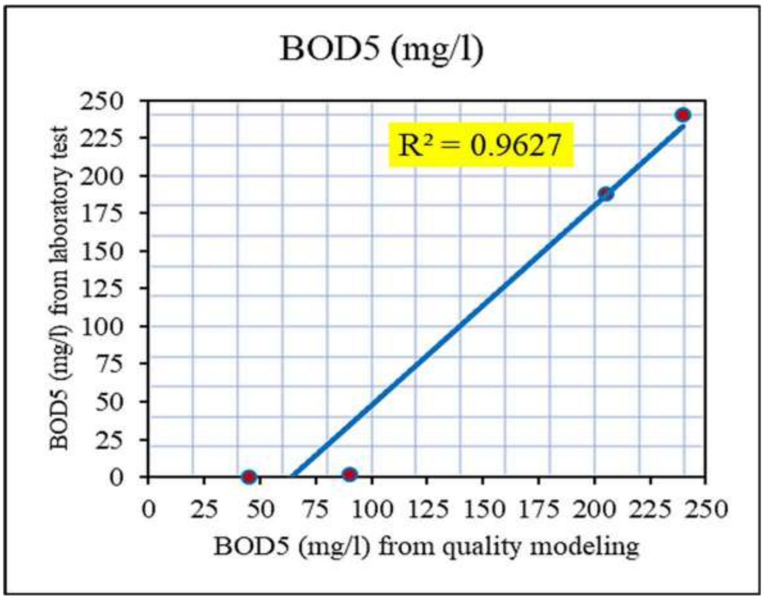


Figure 5.31: The coefficient of determination between BOD_5 values.

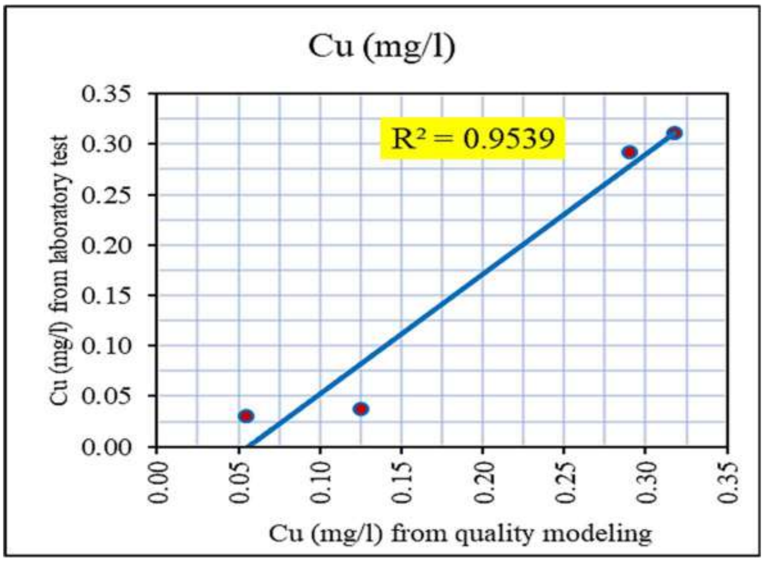


Figure 5.32: The coefficient of determination between Cu values.

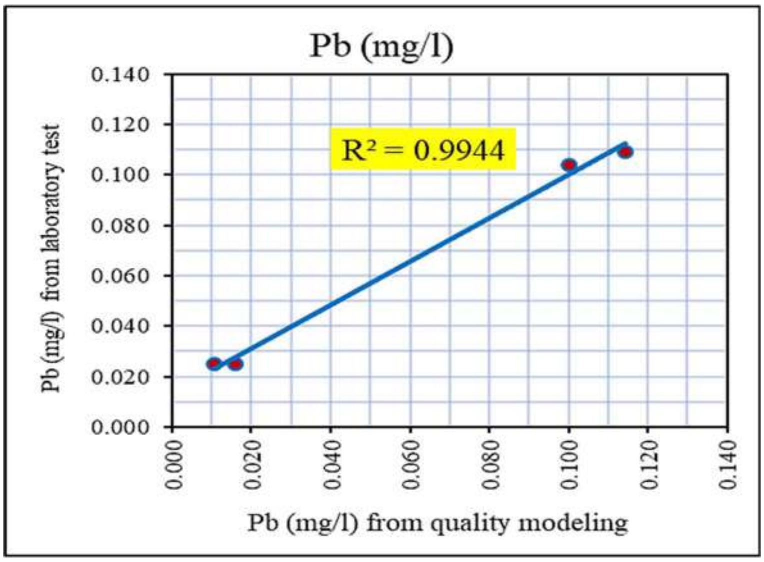


Figure 5.33: The coefficient of determination between Pb values.

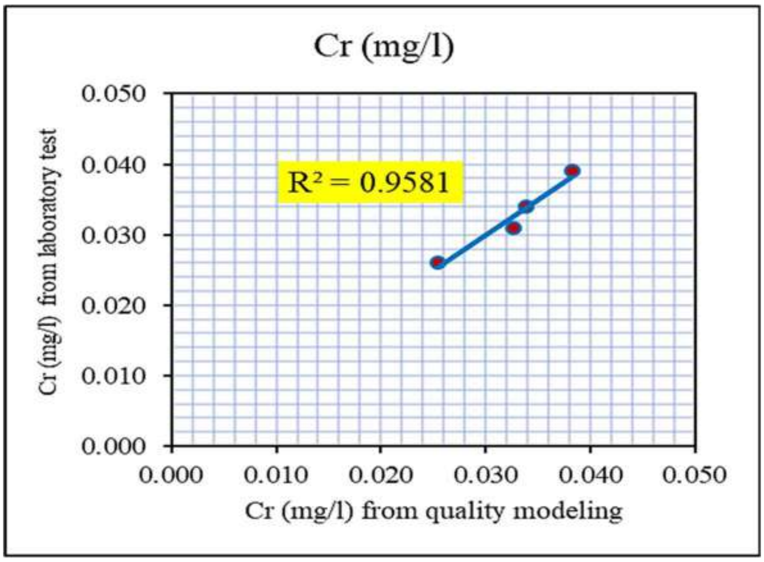


Figure 5.34: The coefficient of determination between Cr values.

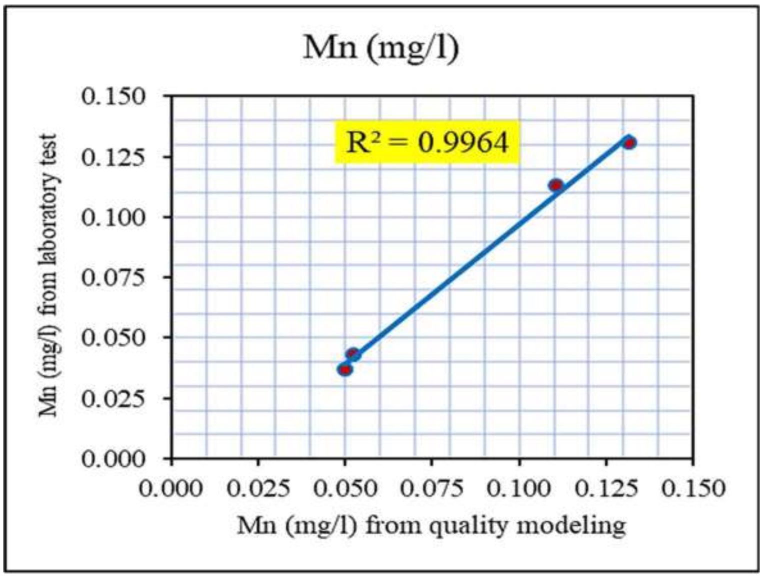


Figure 5.35: The coefficient of determination between Mn values.

The coefficients in Figures 5.31 to 5.36 show the highest match of the simulation of TSS, BOD_5, Cu, Pb, Cr, and Mn loading with the loading of the tests, where these results also indicate the SWMM effectiveness of the stormwater system quality simulation in the study area.

5.4.2.4. The pollutant loading at the outfall

The model also used to simulate the loading of pollutants in the study area. Table 5.20 show the pollutants loadings in the outfall point of the study area using the rainfall intensity for the return period of 2-years using simulation time 2 hours.

Table 5.20: Loadings of the pollutants in the outfall point of the study area (SWMM modelling).

Outfall loading						
Total discharge (m^3)	Total TSS kg	Total BOD_5 kg	Total Cu kg	Total Pb kg	Total Cr kg	Total Mn kg
5321	1589.34	250.302	0.514	0.227	0.165	0.309

The results in Table 5.20 show that all pollutant loading was increased after the rainfall in the study area. Also, the TSS loading was high compared to BOD_5 loading, and Cu loading was the highest compared to other heavy metals.

The present simulation of the pollutants loading using the SWMM stormwater system modelling in the rainy weather emphasizes deciding there is a need for rainwater treatments before disposals. The present study results of the pollutants loading can help in identifying required stages in the wastewater treatment plant for the reduction purpose of the pollutants directly discharged to Kufa river from the study area stormwater system.

5.5. The suggested scenarios:

Two suggesting scenarios that can be used to solve the sewer system problems of the study area are as follow:

5.5.1. Scenario number one:

The change of pipe diameter scenario has been used before in the study of Li et al. (2010) as one of the solutions for reducing the overflows in the sewer systems.

This scenario involves increasing the diameters of the pipes in some pipelines in the combined sewage system, which is the pipelines that involve some pipes that have diameters of 0.25, 0.4, and 0.5 m. The targeted pipelines collect rainwater either from large space areas or from other sewage pipelines that come from the sub streets, which have similar diameters to the diameters of the targeted pipelines. This causes a slow discharge of the sewage in these pipelines, therefore, presses on the targeted pipelines nodes and causes nodes overflow. This scenario has two targets, as described in the following:

1) The first target is to reduce the overflows quantities from the nodes of the combined sewage system produce during rainfall events, therefore, reduce the flooding volume in the study area.
2) The second target of this scenario is to decrease pollutants concentrations on the study area that come from the combined sewage system nodes

overflow, where these pollutants inflow to the stormwater system by the runoff during the rainy weather.

Figure 5.36 shows the mechanism of applying the scenario on the pipelines of the combined sewage system. The pipelines with blue colour represent the lines that need to change their pipes diameters from 0.25 m to 0.4 m, and the pipelines with yellow colour represent the lines that need to change their pipes diameters from 0.4 m to 0.5 m. Also, lines with red colour represent the lines that need to change their pipes diameters from 0.5 m to 0.6 m.

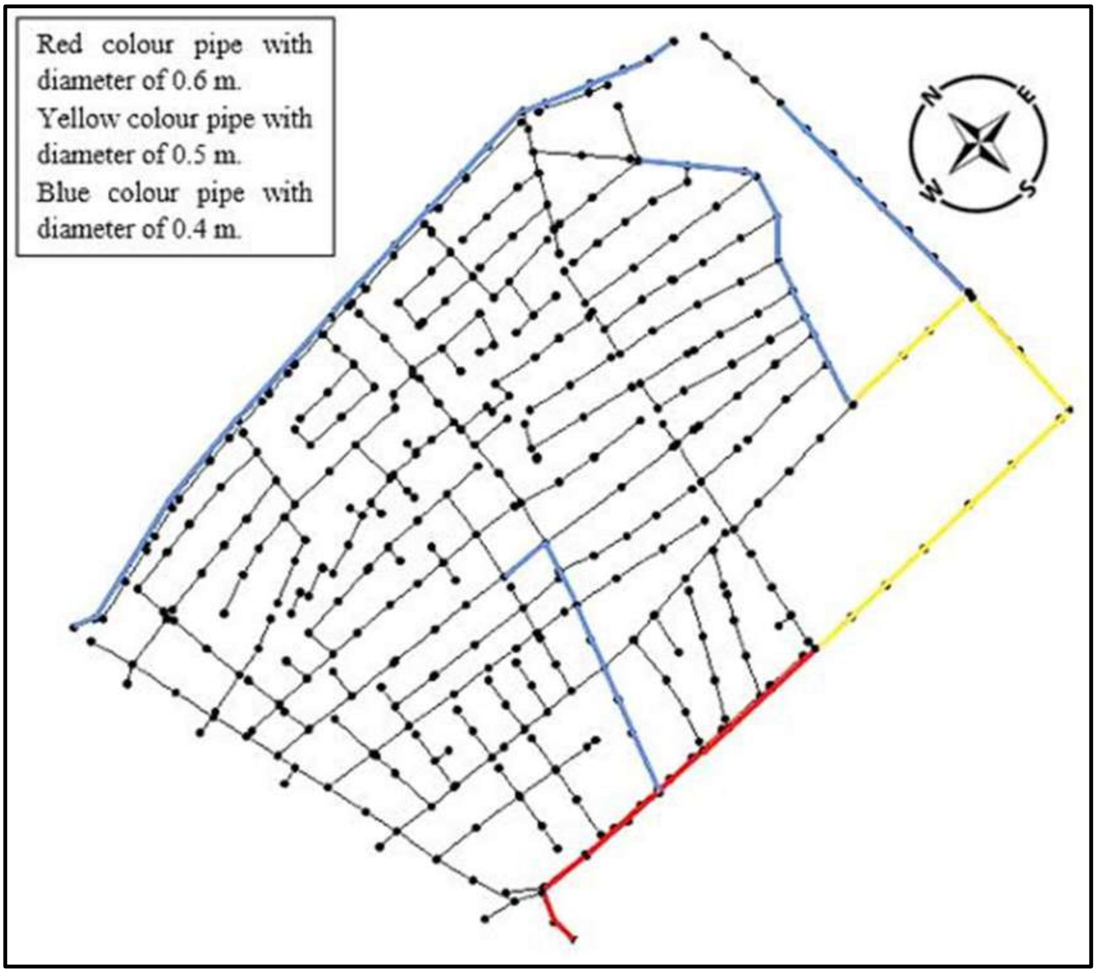


Figure 5.36: The combined sewage system pipelines which diameters changed.

Table 5.21 shows the results obtained from using this scenario in SWMM modelling to reduce the total flooding volumes in the combined sewage system nodes using different rainfall intensities for the different return periods.

Table 5.21: Flooding reduced values and scenario efficiency in the combined sewage system after pipes diameter increase.

Return period of the RI	Total flooding volume before pipes diameter change (m^3)	Total flooding volume after pipes diameter change (m^3)	Percentage of flooding reduction efficiency (%)
2	3817	1774	53.52
5	6912	4171	39.65
10	8929	5955	33.3
25	13434	10154	24.41

The results in Table 5.21 presents the efficiency of using the first scenario in reducing the combined sewage system flooding, where the results appear that the scenario efficiency in the flooding reduction was of higher value, when using the model of the rainfall intensity for a 2-years return period, than the other models of the rainfall intensities, which was 53.52%. Also, these results showed that the scenario efficiency has a negative relationship with the return period of the rainfall intensity. In other words, the scenario efficiency decreases with the increase of the rainfall intensity return period because of the increase in the runoff produced by the high rainfall intensities.

5.5.2. Scenario number two:

The second scenario targets to solve the stormwater quality problem at the disposal point, where considers a good and practical solution for the pollutants problem in the stormwater system. At present-day and based on the obtained data from NSD, the stormwater discharge operation continues for 3 to 4 hours in the day in dry weather, where the daily discharge of the stormwater at the disposal point is equal to 432 m^3/hr. (or 1728 m^3/day). The scenario suggests a compact unit installation with a capacity of 500 cubic meters per hour at the end of the stormwater system before the disposal point, which is equal to 2000 cubic meters per day, which is the capacity needed for disposal from the pollutants in the stormwater system for Al-Rashadiya quarter in dry weather.

In the wet weather, the compact unit will treat the quantity of the stormwater based on its capacity, and the overflowing stormwater quantity will be deposed in a by-pass to Kufa River.

This scenario helps in improving the quality of the flowed liquids in the stormwater system during dry weather and reduces pollutants that are thrown into the Kufa River. There are many causes of rainwater pollution, the first one is the misuse of the stormwater system, which considers not under controlling problem, such as the daily activities of the population and the second cause is the illegal connection, etc. This scenario has many benefits, which are:

1) The compact unit can be used to treat polluted water during dry and wet weathers. In dry weather, the concentration of pollutants in the stormwater will be little after used the compact unit (at disposal point). In rainy weather, the use of the compact unit will decrease pollutants concentration in rainwater. While the remaining quantities (untreated quantities which come from by-pass way) will be in a dilution state. Then, the stormwater from both directions will meet at the disposal point and convey directly into the Kufa River.
2) The small required space for the instillation of the compact unit agreed with the study area requirements.
3) The compact unit has a low cost when compared with other methods.
4) The compact unit maintenance considers easy.

So, the present study recommends using this scenario, because it is practical and applicable in the study area.

Chapter six

Conclusions and recommendations

6.1. Conclusions

The most important conclusion of the present study can be summarized as follows:

1) Three commonly statistical methods were used to derive the empirical equations of the rainfall intensities for different return periods to obtain the higher values of rainfall intensities, which were used in the quantity modelling by SWMM of the combined sewage system and quality modelling by SWMM of the stormwater system.
2) The Storm Water Management Model (SWMM v5.1) was used to simulate the hydraulic performance of the combined sewage system in AL-Rashadiya quarter, Al-Najaf city. The obtained results of the flow rates of the models were compared with the design flow rates using three indicators, the Normalized mean square error (NMSE), the coefficient of determination (R^2), and Root mean square error (RMSE). The comparison, between the design flow rates and the predicted flow rates, showed that the obtained values of NMSE ranged between 0.1930 and 0.6970, the obtained values of R^2 ranged between 58.37% and 71.41%, and the values of RMSE ranged between 0.0241 and 0.0363. Also, the comparison, between the design flow rates and the rainfall event flow rates on 28-11-2020, using the Normalized mean square error (NMSE), coefficient of determination (R^2), showed that the obtained values of NMSE ranged between 0.0392 and 0.0615, and the values of the coefficient of determination ranged between 38.09% and 70.82%.
3) The results of nodes flooding flow rates from the combined sewage system modelling were used as direct inflows to the near nodes in the stormwater system in the stormwater quality modelling to obtain the

flooding volumes and quality of the pollutants produced from the study area. The obtained results of the final flooding volumes from the stormwater system modelling were 526 m^3, 2669 m^3, 3316 m^3, and 5568 m^3 for rainfall intensities with return periods of 2, 5, 10, and 25 years, respectively.

4) The monthly laboratory tests were conducted on the stormwater at the disposal point of the stormwater system in the dry weather to identify the pollutants that was used in SWMM modelling of the stormwater system quality, which were TSS, BOD_5, Cu, Pb, Cr, and Mn.
5) Also, results of the conducted laboratory test during the rainfall event time were used in the calibration process of SWMM quality modelling. The coefficient of determination (R^2) between the laboratory tests results and the obtained results from modelling, showed that the values of R^2 were 95.76%, 96.27%, 95.39%, 99.44%, 95.81%, and 99.64% for TSS, BOD_5, Cu, Pb, Cr, and Mn, respectively.
6) The total pollutants quantities at outfall (disposal point) after 2 hours of the stormwater model simulation were 1589.54 kg of TSS, 250.302 kg of BOD_5, 0.514 kg of Cu, 0.227 kg of Pb, 0.165 kg of Cr, and 0.309 kg of Mn. Also, this study estimates the equations calibration factors of the buildup and the washoff for the selected pollutants in the study area.
7) This study suggests two different scenarios for solving the sewer system problems of the study area. The first scenario applied for reducing the flooding quantities from the combined sewage system nodes by increasing diameters of some pipes in the combined sewage system, the total flooding volumes reduced by 53.52%, 39.65%, 33.3%, and 24.41% using the rainfall intensities with return periods of 2, 5, 10, and 25 years, respectively. The second scenario used a compact unit with a treating capacity of 500 cubic meters per hour at the disposal point in the

stormwater system to reduce the quantity of pollutants amount in the stormwater before disposal, in both dry and wet weather.

6.2. Recommendations for the operational staff in Al-Najaf Sewerage Directorate:

1) The present study provided details about the quantity performance of the combined sewage system and the stormwater drainage system in a densely populated area, which is Al-Rashadiya quarter in Al-Najaf city. The outputs of this study can be used to improve the performance and reduce the floods that occur in these systems, especially during the rainy season.
2) The results of the quality of the liquids drained from the stormwater drainage system during the dry weather and the stormwater in the rainy seasons were presented, and classifies based on their laboratory tests characteristics as wastewater,
3) Also, the study results contributed to measuring the concentrations and quantities of pollutants that discharge to Kufa river directly, which can be helped in the identification of the required treats.
4) The pollution of the stormwater during the rainy season was, almost, due to the population activities in the study area during the dry season.
5) Two scenarios were suggested to solve the problems of the combined sewage system, stormwater system and the rainwater quality, the first was to reduce the flooding volumes from the combined sewage system, which has a great role in the flooding of the stormwater drainage system, which finally causes flooding and pollution in the study area. The causes of these floods were the low design capacity of the combined sewage system, in addition to the people's habits and activities that have harmed and affected the operation of these systems. The present study can help by using the SWMM program output to guide the users and operators of

sewer systems to protect and deal with these systems according to the design and operation criteria. The second scenario recommended was using a compact unit with a capacity of 500 cubic meters per hour before the disposal point in the stormwater system to reduce the pollutant amount that is disposed to Kufa river.

6.3. Recommendations for future works

1) Conduct long term observation and studies on sewer discharge pipes that are released directly from the districts located on the Kufa river banks to the river stream.
2) The performance of SWMM modelling was encouraging in this study where can apply to other regions in Najaf city.
3) Search and use new programs, such as Personal Computer Storm Water Management Model (PCSWMM), to identify the sewer systems problems with providing the essential parameters for the best operation of these programs.
4) Using scenarios closer to reality to reduce sewer overflow that causes pollution, such as the LID techniques, change the diameters of the sewer pipes and increase the networks pipelines.

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Appendix A

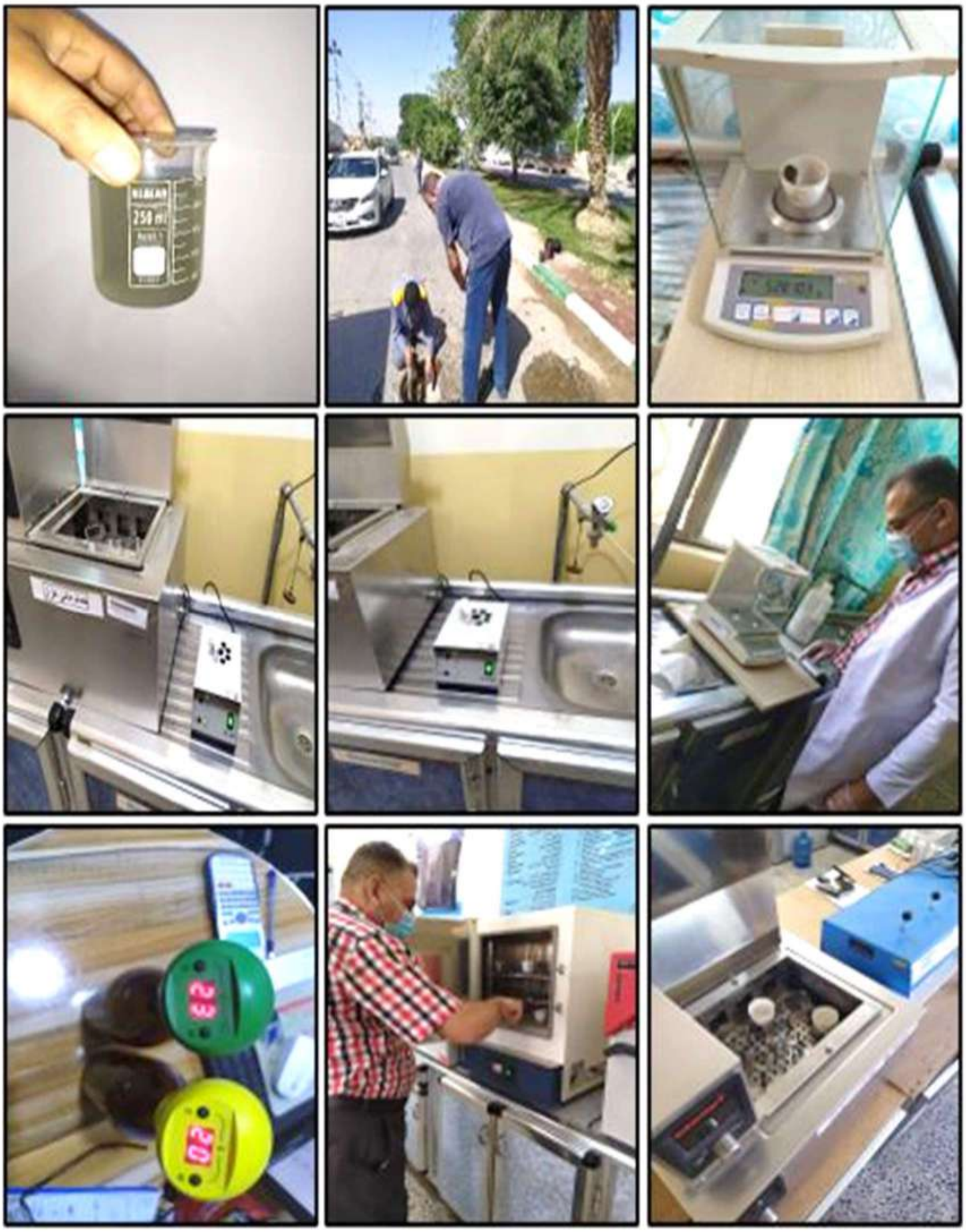

Figure 1: Pictures that show some stages of conducted laboratory tests on the stormwater samples from the study area.

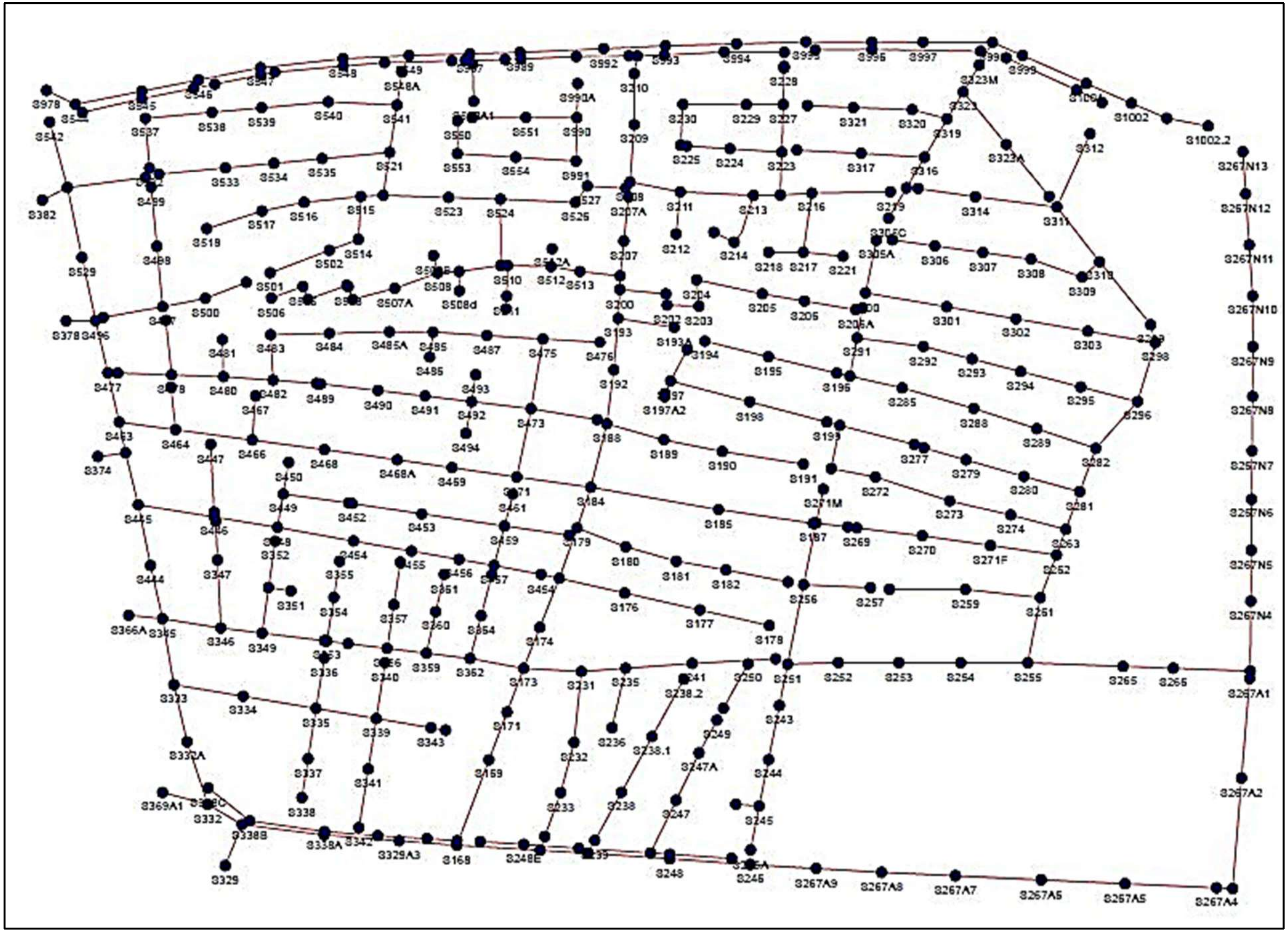

Figure 2: Manholes ID number of the combined sewage system.

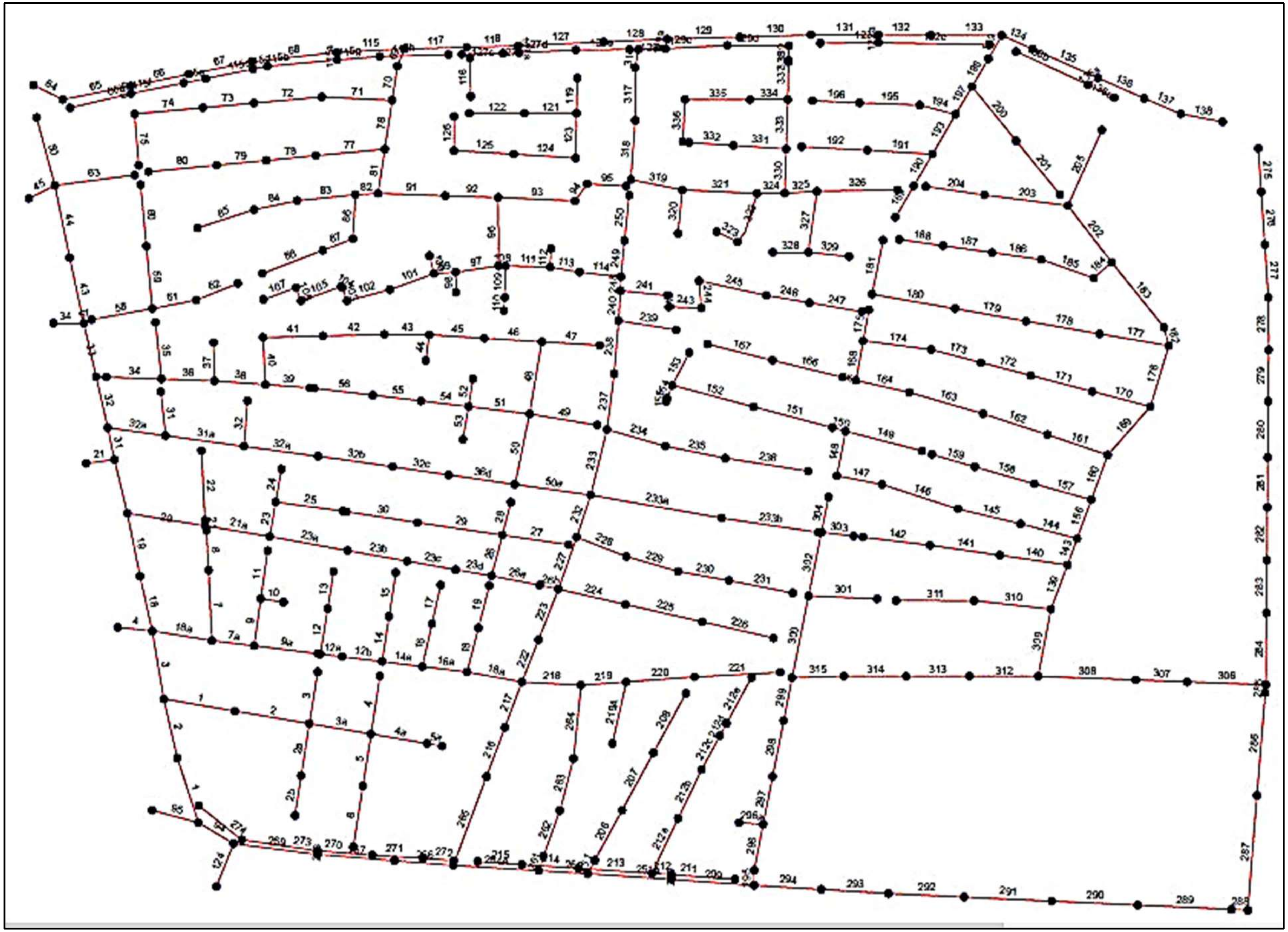

Figure 2: Pipes ID of the combined sewage system.

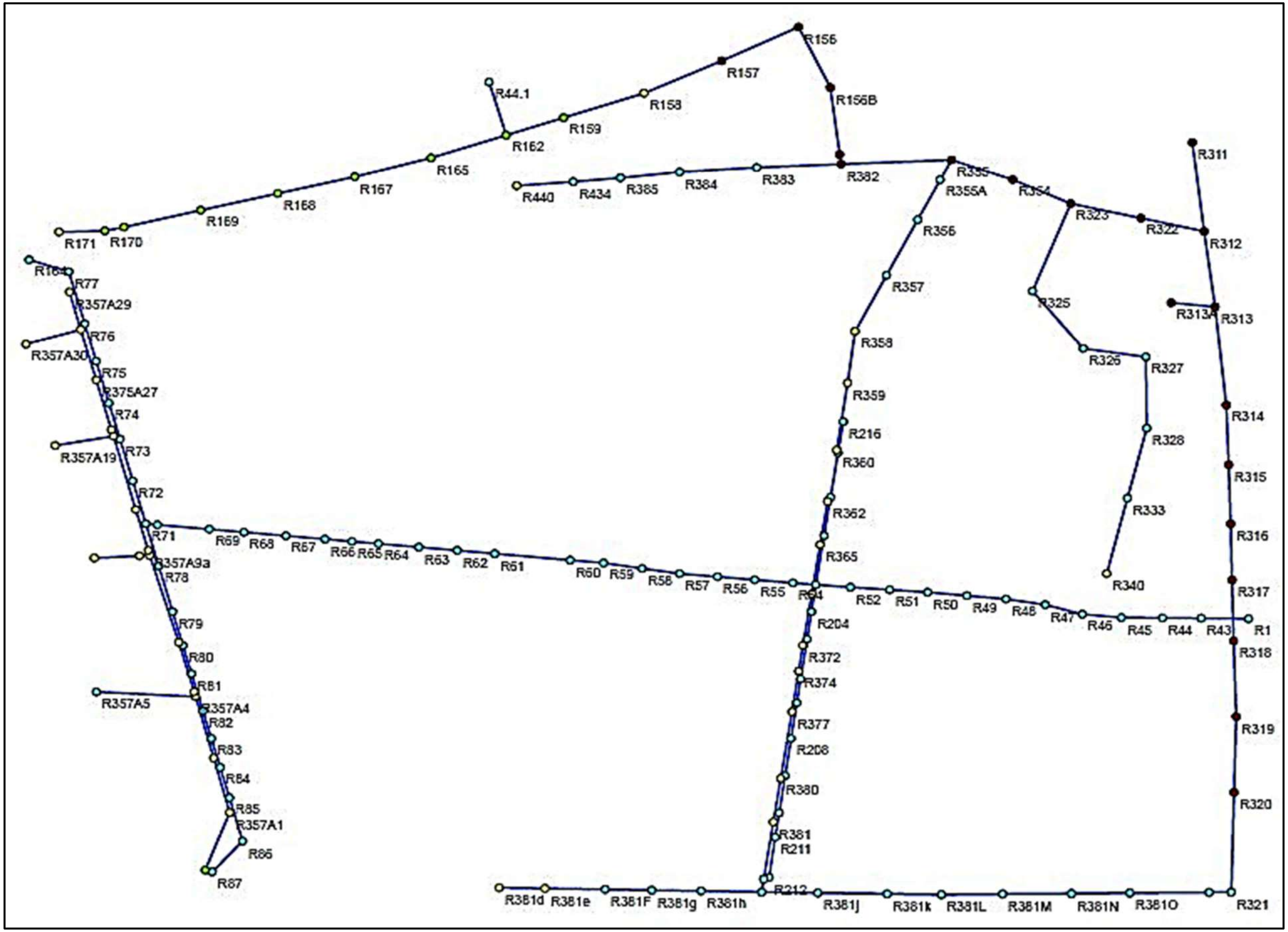

Figure 2: Manholes ID number of the stormwater system.

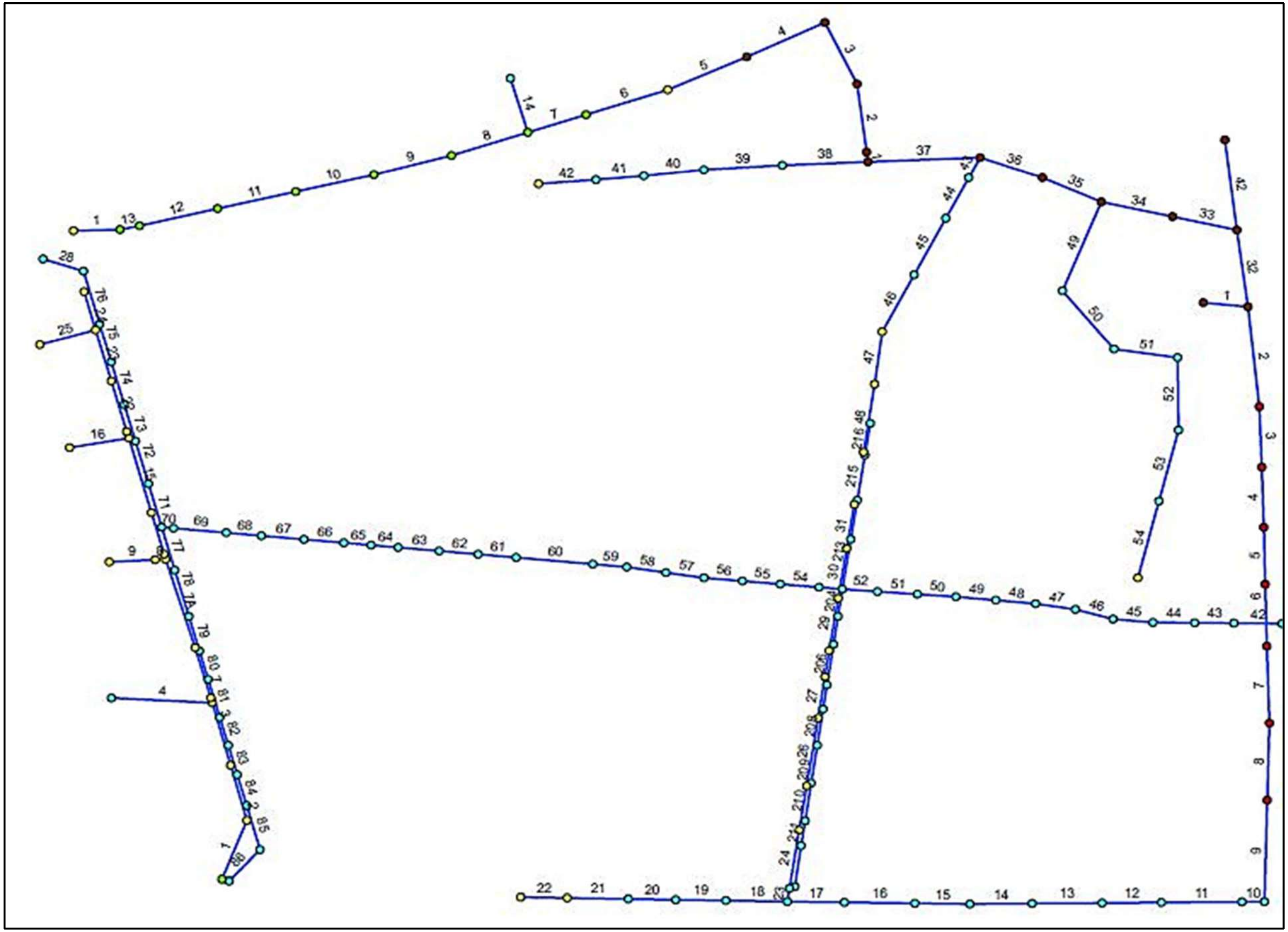

Figure 2: Pipes ID of the stormwater system.

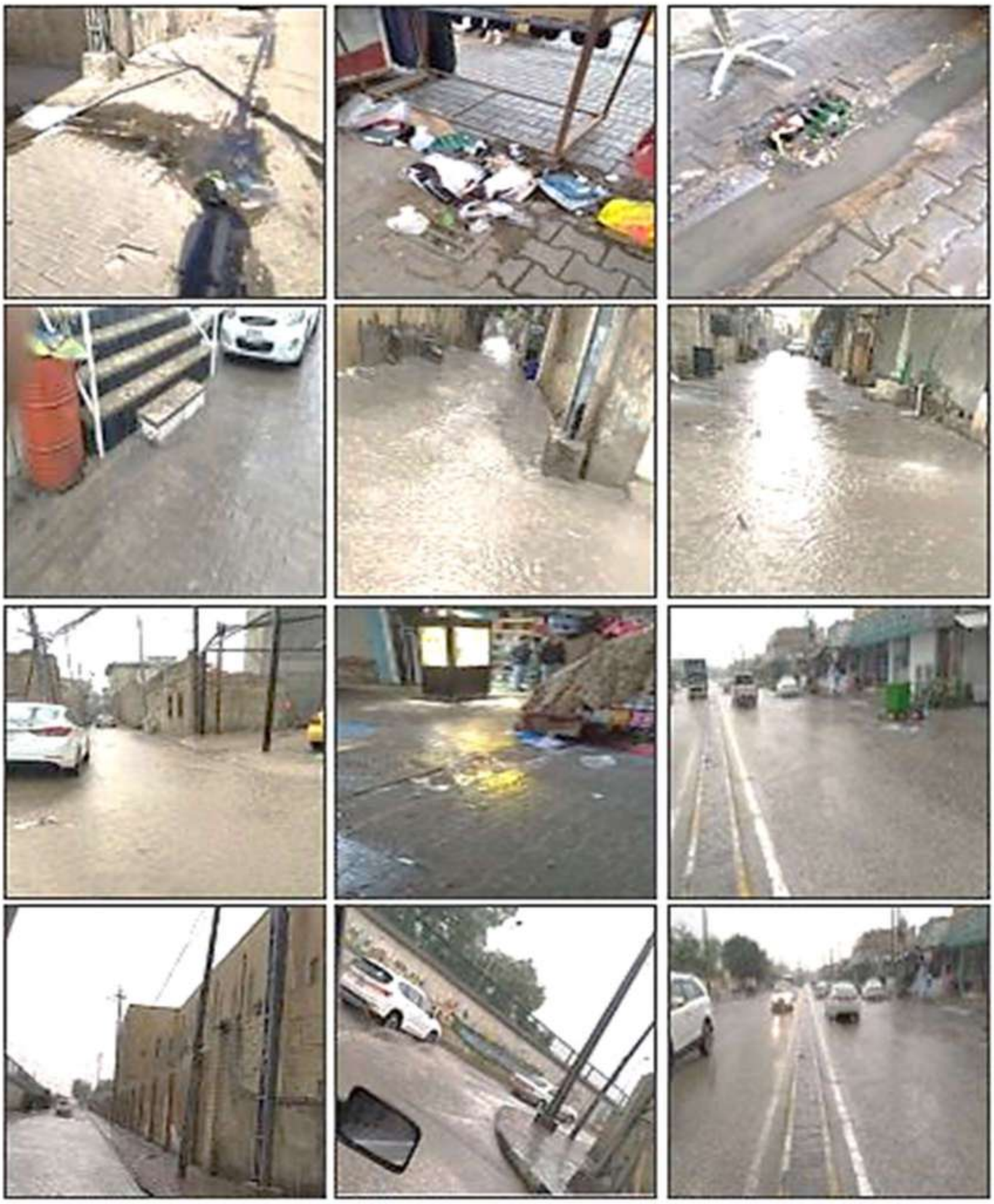

Figure 6: The sewer overflows during the dry weather and rainfall event in the study area.

Table M1: Typical Values of Manning coefficient n for various materials (Bizier, 2007).

The Conduit Material	Manning n[a]
Closed Conduits - Asbestos-cement pipe - Brick Cast iron pipe - Cement and seal-coated	 0.11–0.015 0.13–0.017 0.011–0.015
Concrete (monolithic) - Smooth forms - Rough forms - Concrete pipe	 0.012–0.014 0.015–0.017 0.011–0.015
Corrugated Metal Pipe 1/2 in. (13 mm) _ 22/3 in. (68 mm) Corrugations - Plain - Paved invert - Spun asphalt	0.022–0.026 0.018–0.022 0.011–0.015
Plastic Pipe (Smooth)	0.011–0.015
Polyethylene	0.011–0.015
Polyvinyl Chloride	0.009[b]
Vitrified Clay Pipe	0.010[b]
Vitrified Clay Liner Plates	0.011–0.015 0.011–0.020
Open Channels—lined - Asphalt - Brick - Concrete	 0.013–0.017 0.012–0.018 0.011–0.020

[a] Modified from American Society of Civil Engineers (ASCE). (1982). "Gravity sewer design and construction." ASCE Manual and Reports of Engineering Practice No. 60, ASCE, Reston, Va., unless otherwise noted.
[b] French, R. H. (2001). "Hydraulics of open channel flow." Stormwater collection systems design handbook, L. W. Mays, ed., McGraw-Hill, New York, with permission.

Table M2: The Rain Gage Properties in the SWMM modelling (Rossman, 2010).

Name	User-assigned rain gage name.
X-Coordinate	Horizontal location of the rain gage on the Study Area Map.
Y-Coordinate	Vertical location of the rain gage on the Study Area Map.
Description	Rain gage description (optional).
Tag	Optional label used to categorize or classify the rain gage.
Rain Format	Format in which the rain data are supplied: **INTENSITY:** each rainfall value is an average rate in inches/hour (or mm/hour) over the recording interval, **VOLUME:** each rainfall value is the volume of rain that fell in the recording interval (in inches or millimeters),

	CUMULATIVE: each rainfall value represents the cumulative rainfall that has occurred since the start of the last series of non-zero values (in inches or millimeters).
Rain Interval	Recording time interval between gage readings in either decimal hours or hours: minutes format.
Snow Catch Factor	Factor that corrects gage readings for snowfall.
Data Source	Source of rainfall data; either TIMESERIES for user-supplied Time Series data or FILE for an external data file.
Time Series	
- Series Name	Name of Time Series with rainfall data if Data Source selection was TIMESERIES; leave blank otherwise.
Data File	
- File Name	Name of external file containing rainfall data.
- Station No.	Recording gage station number.
- Rain Units	Depth units (in. or mm) for rainfall values in user-prepared files (other standard file formats have fixed units depending on the format).

Table M3: Parameters of Green-Ampt for different soil type, (Rawls et al., 1983)

Soil texture class	K (in./hr.)	Ψ (in.)	Φ	FC (in.)	WP wilting point
Sand	4.47	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
Sandy Clay Loam	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

K: The hydraulics conductivity of (in./hr.),
ψ: The suction head (in.),
Φ: fraction,
FC: The field capacity, fraction, and
WP: The wilting point, fraction.

Table M4: Manning's Roughness Coefficient (n) for Overland and Sheet Flow (McCuen, 1989).

Surface type	Manning coefficient n	Surface type		Manning coefficient n
Smooth asphalt	0.011	Cultivated soils	Residue cover ≤ 20%	0.06
Smooth concrete	0.012		Residue cover > 20%	0.17
Ordinary concrete lining	0.013		Range (natural)	0.13
Good wood	0.014	Grass	Short, prairie	0.15
Brick with cement mortar	0.014		Dense	0.24
Vitrified clay	0.015		Bermuda grass	0.41
Fallow (no residue)	0.05	Woods	Light underbrush	0.4
			Dense underbrush	0.8

Table P1: Some typical characteristics of water quality of urban runoff (US EPA, 1983).

Water Quality Characteristics of Urban Runoff	
Constituent	Event Mean Concentrations
TSS (mg/L)	180 - 548
BOD (mg/L)	12 - 19
COD (mg/L)	82 - 178
Total P (mg/L)	0.42 - 0.88
Soluble P (mg/L)	0.15-0.28
TKN (mg/L)	1.90 - 4.18
NO2/NO3-N (mg/L)	0.86 -2.2
Total Cu (µg/L)	43 - 118
Total Pb (µg/L)	182 - 443
Total Zn (µg/L)	202 - 633

Table P2: Typical domestic sewage characteristics (Steel, 1979).

Parameter	Weak	Medium	Strong
Total Suspended Solid (TSS)	100	200	350
Volatile Suspended Solid (VSS)	75	135	210
Biochemical Oxygen Demand (BOD)	100	200	400
Chemical Oxygen Demand (COD)	175	300	600
Total Organic Carbon (TOC)	100	200	400
Ammonia-N	5	10	20
Organic-N	8	20	40
PO_4-P	7	10	20

Table P3: The surface water quality for drinking water abstraction (Tebbutt, 1998).

Treatment type	A1	A1	A2	A2	A3	A3
Parameter (mg/l unless noted)	GL	MAC	GL	MAC	GL	MAC
pH units	6.5-8.5		5.5-9.0		5.5-9.0	
Color units	10	20	50	100	50	200
SS	25					
Temperature (°C)	22	25	22	25	22	25
Conductivity (µs/cm)	1000		1000		1000	
Odor (TON)	3		10		20	
Nitrate (NO3)	25	50		50		50
Fluoride	0.7-1	1.5	0.7-1.7		0.7-1.7	
Iron (soluble)	0.1	0.3	1	2	1	
Manganese	0.05		0.1		1	
Copper	0.02	0.05	0.05		1	
Zinc	0.5	3	1	0.05	1	0.05
Boron	1		1		1	
Arsenic	0.01	0.05		0.05	0.05	0.1
Cadmium	0.001	0.005	0.001	0.005		0.05
Chromium (total)		0.05		0.05		0.05
Lead		0.05		0.05		0.05
Selenium	0.01		0.01		0.01	
Mercury	0.0005	0.001	0.0005	0.001	0.0005	0.001
Barium		0.1		1		1
Cyanide		0.05		0.05		0.05
Sulphate	150	250	150	250	150	250
Chloride	200		200		200	
MBAS	0.2		0.2		0.5	
Phosphate (P2O5)	0.4		0.7		0.7	
Phenol		0.001	0.001	0.005	0.01	0.1
Hydrocarbons		0.05		0.2	0.5	1
PAH		0.0002		0.0002		0.001
Pesticides		0.001		0.0025		0.005
COD					30	
BOD (ATU)	<3		<5		<7	
DO (% saturation)	>70		>50		>30	
Kjeldahl nitrogen	1		2		3	
Ammonium (NH4)	0.05		1	1.5	2	4
Total coliforms/100 ml	50		5000		50000	
Faecal coliforms/100 ml	20		2000		20000	
Faecal streptococci/100 ml	20		1000		10000	
Salmonella	Absent in 5 ltr.		Absent in 1 ltr.			

A1: Simple physical treatment and disinfection,
A2: Normal full physical and chemical treatment with disinfection,
A3: Intensive physical and chemical treatment with disinfection.
MAC compliance is at 95 percentile level with the non-compliant 5 percentile not exceeding 150 per cent of the MAC level.
GL, guide level,
MAC, maximum allowable concentration,
ATU = allylthiourea,
MBAS = methylene blue active substance, and
TON = threshold odour number.

Table 1: NMSE analysis data between the design discharge and predicted discharge from SWMM for the combined sewage system using rainfall intensity-2 years return period.

Pipe No.	Design flow rate Co	Max. flow rate with 2 years return period Po	Co-Coavg	Cp-Cpavg	(Co-Coavg) * (Cp-Cpavg)	(Co-Cp)^2
2	0.0758	0.0440	-0.0037	0.0020	0.0000	0.0010
5	0.0589	0.0080	-0.0206	-0.0340	0.0007	0.0026
6	0.0413	0.0010	-0.0382	-0.0410	0.0016	0.0016
7	0.0467	0.0030	-0.0329	-0.0390	0.0013	0.0019
8	0.0461	0.0020	-0.0334	-0.0400	0.0013	0.0019
9	0.0464	0.0060	-0.0332	-0.0360	0.0012	0.0016
12	0.0327	0.0200	-0.0469	-0.0220	0.0010	0.0002
13	0.0776	0.0190	-0.0020	-0.0230	0.0000	0.0034
14	0.0707	0.0630	-0.0089	0.0210	-0.0002	0.0001
16	0.0743	0.0350	-0.0053	-0.0070	0.0000	0.0015
18	0.0700	0.0250	-0.0096	-0.0170	0.0002	0.0020
19	0.0383	0.0250	-0.0412	-0.0170	0.0007	0.0002
20	0.1383	0.0320	0.0587	-0.0100	-0.0006	0.0113
22	0.0533	0.0030	-0.0263	-0.0390	0.0010	0.0025
23	0.0413	0.0140	-0.0382	-0.0280	0.0011	0.0007
24	0.0424	0.0050	-0.0371	-0.0370	0.0014	0.0014
26	0.0363	0.0300	-0.0433	-0.0120	0.0005	0.0000
29	0.0579	0.0380	-0.0216	-0.0040	0.0001	0.0004
31	0.0624	0.0020	-0.0171	-0.0400	0.0007	0.0037
32	0.0413	0.0010	-0.0382	-0.0410	0.0016	0.0016
35	0.0448	0.0020	-0.0347	-0.0400	0.0014	0.0018
36	0.0354	0.0210	-0.0441	-0.0210	0.0009	0.0002
37	0.0705	0.0020	-0.0090	-0.0400	0.0004	0.0047
38	0.0116	0.0170	-0.0679	-0.0250	0.0017	0.0000
39	0.0589	0.0010	-0.0207	-0.0410	0.0008	0.0033
40	0.0681	0.0110	-0.0115	-0.0310	0.0004	0.0033
41	0.0481	0.0060	-0.0314	-0.0360	0.0011	0.0018
42	0.0498	0.0010	-0.0297	-0.0410	0.0012	0.0024
44	0.0926	0.0340	0.0130	-0.0080	-0.0001	0.0034
45	0.0438	0.0400	-0.0357	-0.0020	0.0001	0.0000
46	0.0818	0.0340	0.0023	-0.0080	0.0000	0.0023
47	0.0413	0.0170	-0.0382	-0.0250	0.0010	0.0006
48	0.0413	0.0260	-0.0382	-0.0160	0.0006	0.0002
49	0.0413	0.0210	-0.0382	-0.0210	0.0008	0.0004
51	0.0407	0.0220	-0.0388	-0.0200	0.0008	0.0004
54	0.0394	0.0150	-0.0401	-0.0270	0.0011	0.0006
55	0.0392	0.0180	-0.0403	-0.0240	0.0010	0.0005
59	0.0515	0.0080	-0.0280	-0.0340	0.0010	0.0019
60	0.0492	0.0050	-0.0304	-0.0370	0.0011	0.0019
61	0.0827	0.0070	0.0031	-0.0350	-0.0001	0.0057
62	0.0625	0.0040	-0.0170	-0.0380	0.0006	0.0034
63	0.1475	0.0020	0.0679	-0.0400	-0.0027	0.0212
64	0.0419	0.0110	-0.0377	-0.0310	0.0012	0.0010
65	0.0413	0.0300	-0.0382	-0.0120	0.0005	0.0001
66	0.0416	0.0420	-0.0379	0.0000	0.0000	0.0000
71	0.0522	0.0230	-0.0273	-0.0190	0.0005	0.0009
72	0.0396	0.0270	-0.0399	-0.0150	0.0006	0.0002
73	0.0471	0.0300	-0.0324	-0.0120	0.0004	0.0003
76	0.0581	0.0770	-0.0214	0.0350	-0.0007	0.0004
77	0.0548	0.0190	-0.0247	-0.0230	0.0006	0.0013
78	0.0406	0.0220	-0.0389	-0.0200	0.0008	0.0003
79	0.0389	0.0250	-0.0406	-0.0170	0.0007	0.0002
80	0.0450	0.0270	-0.0345	-0.0150	0.0005	0.0003
81	0.0936	0.0590	0.0140	0.0170	0.0002	0.0012
82	0.0536	0.0400	-0.0259	-0.0020	0.0001	0.0002
83	0.0411	0.0270	-0.0385	-0.0150	0.0006	0.0002
84	0.0385	0.0290	-0.0411	-0.0130	0.0005	0.0001
85	0.0413	0.0290	-0.0382	-0.0130	0.0005	0.0002
86	0.0639	0.0300	-0.0156	-0.0120	0.0002	0.0011

87	0.0371	0.0360	-0.0424	-0.0060	0.0003	0.0000
93	0.0527	0.0290	-0.0269	-0.0130	0.0003	0.0006
94	0.0440	0.0330	-0.0355	-0.0090	0.0003	0.0001
95	0.0384	0.0290	-0.0412	-0.0130	0.0005	0.0001
96	0.0428	0.0320	-0.0367	-0.0100	0.0004	0.0001
97	0.0424	0.0330	-0.0371	-0.0090	0.0003	0.0001
98	0.0404	0.0190	-0.0391	-0.0230	0.0009	0.0005
99	0.0405	0.0360	-0.0390	-0.0060	0.0002	0.0000
100	0.0396	0.0270	-0.0399	-0.0150	0.0006	0.0002
108	0.0327	0.0290	-0.0469	-0.0130	0.0006	0.0000
110	0.0483	0.0320	-0.0312	-0.0100	0.0003	0.0003
111	0.0411	0.0200	-0.0384	-0.0220	0.0008	0.0004
112	0.0437	0.0230	-0.0358	-0.0190	0.0007	0.0004
118	0.0413	0.0710	-0.0382	0.0290	-0.0011	0.0009
122	0.0413	0.0310	-0.0382	-0.0110	0.0004	0.0001
123	0.0436	0.0220	-0.0360	-0.0200	0.0007	0.0005
124	0.0413	0.0260	-0.0382	-0.0160	0.0006	0.0002
125	0.0433	0.0220	-0.0362	-0.0200	0.0007	0.0005
126	0.0436	0.0270	-0.0359	-0.0150	0.0005	0.0003
127	0.0413	0.0410	-0.0382	-0.0010	0.0000	0.0000
128	0.0462	0.0410	-0.0333	-0.0010	0.0000	0.0000
130	0.0413	0.0460	-0.0382	0.0040	-0.0002	0.0000
131	0.0411	0.0410	-0.0384	-0.0010	0.0000	0.0000
134	0.0463	0.0390	-0.0332	-0.0030	0.0001	0.0001
135	0.0388	0.0390	-0.0408	-0.0030	0.0001	0.0000
136	0.0413	0.0380	-0.0382	-0.0040	0.0002	0.0000
145	0.0443	0.0390	-0.0353	-0.0030	0.0001	0.0000
146	0.0380	0.0340	-0.0416	-0.0080	0.0003	0.0000
147	0.0494	0.0320	-0.0301	-0.0100	0.0003	0.0003
149	0.0436	0.0300	-0.0359	-0.0120	0.0004	0.0002
150	0.0456	0.0390	-0.0339	-0.0030	0.0001	0.0000
151	0.0429	0.0480	-0.0366	0.0060	-0.0002	0.0000
158	0.0663	0.0240	-0.0133	-0.0180	0.0002	0.0018
159	0.0409	0.0280	-0.0386	-0.0140	0.0005	0.0002
161	0.0937	0.0460	0.0142	0.0040	0.0001	0.0023
162	0.0477	0.0400	-0.0319	-0.0020	0.0001	0.0001
163	0.0383	0.0340	-0.0412	-0.0080	0.0003	0.0000
164	0.0407	0.0390	-0.0389	-0.0030	0.0001	0.0000
168	0.0468	0.0250	-0.0328	-0.0170	0.0006	0.0005
169	0.0380	0.0300	-0.0416	-0.0120	0.0005	0.0001
174	0.0397	0.0320	-0.0398	-0.0100	0.0004	0.0001
175	0.0422	0.0250	-0.0374	-0.0170	0.0006	0.0003
176	0.0436	0.0450	-0.0360	0.0030	-0.0001	0.0000
177	0.0617	0.0260	-0.0179	-0.0160	0.0003	0.0013
179	0.0455	0.0220	-0.0340	-0.0200	0.0007	0.0006
180	0.0391	0.0290	-0.0404	-0.0130	0.0005	0.0001
181	0.0398	0.0320	-0.0397	-0.0100	0.0004	0.0001
182	0.0604	0.0360	-0.0191	-0.0060	0.0001	0.0006
183	0.0383	0.0210	-0.0412	-0.0210	0.0009	0.0003
184	0.0797	0.0250	0.0002	-0.0170	0.0000	0.0030
185	0.0457	0.0260	-0.0338	-0.0160	0.0005	0.0004
186	0.0397	0.0300	-0.0398	-0.0120	0.0005	0.0001
187	0.0420	0.0330	-0.0375	-0.0090	0.0003	0.0001
188	0.0500	0.0300	-0.0295	-0.0120	0.0004	0.0004
191	0.0707	0.0360	-0.0088	-0.0060	0.0001	0.0012
192	0.0569	0.0320	-0.0226	-0.0100	0.0002	0.0006
205	0.0413	0.0170	-0.0382	-0.0250	0.0010	0.0006
208	0.0405	0.0220	-0.0390	-0.0200	0.0008	0.0003
218	0.0778	0.0330	-0.0018	-0.0090	0.0000	0.0020
219	0.0492	0.0270	-0.0304	-0.0150	0.0005	0.0005
220	0.0420	0.0210	-0.0376	-0.0210	0.0008	0.0004
221	0.0418	0.0270	-0.0377	-0.0150	0.0006	0.0002
224	0.0721	0.0230	-0.0074	-0.0190	0.0001	0.0024
225	0.0401	0.0260	-0.0395	-0.0160	0.0006	0.0002
226	0.0428	0.0270	-0.0368	-0.0150	0.0006	0.0002
228	0.0797	0.0230	0.0002	-0.0190	0.0000	0.0032
229	0.0420	0.0270	-0.0376	-0.0150	0.0006	0.0002

230	0.0413	0.0300	-0.0382	-0.0120	0.0005	0.0001
231	0.0429	0.0340	-0.0366	-0.0080	0.0003	0.0001
234	0.0628	0.0240	-0.0167	-0.0180	0.0003	0.0015
235	0.0403	0.0210	-0.0392	-0.0210	0.0008	0.0004
236	0.0435	0.0150	-0.0361	-0.0270	0.0010	0.0008
237	0.0875	0.0520	0.0080	0.0100	0.0001	0.0013
238	0.0410	0.0460	-0.0386	0.0040	-0.0002	0.0000
240	0.0391	0.0400	-0.0405	-0.0020	0.0001	0.0000
241	0.0731	0.0220	-0.0065	-0.0200	0.0001	0.0026
243	0.0379	0.0280	-0.0416	-0.0140	0.0006	0.0001
244	0.0442	0.0300	-0.0353	-0.0120	0.0004	0.0002
245	0.0473	0.0320	-0.0322	-0.0100	0.0003	0.0002
246	0.0402	0.0190	-0.0393	-0.0230	0.0009	0.0005
247	0.0438	0.0070	-0.0357	-0.0350	0.0013	0.0014
250	0.0580	0.0240	-0.0215	-0.0180	0.0004	0.0012
262	0.0988	0.0130	0.0193	-0.0290	-0.0006	0.0074
264	0.0853	0.0290	0.0057	-0.0130	-0.0001	0.0032
265	0.1194	0.1030	0.0399	0.0610	0.0024	0.0003
271	0.0413	0.0130	-0.0382	-0.0290	0.0011	0.0008
272	0.0433	0.0100	-0.0362	-0.0320	0.0012	0.0011
274	0.0413	0.0090	-0.0382	-0.0330	0.0013	0.0010
276	0.0413	0.0050	-0.0382	-0.0370	0.0014	0.0013
277	0.0413	0.0310	-0.0382	-0.0110	0.0004	0.0001
278	0.0413	0.0350	-0.0382	-0.0070	0.0003	0.0000
279	0.0414	0.0370	-0.0382	-0.0050	0.0002	0.0000
280	0.0413	0.0420	-0.0382	0.0000	0.0000	0.0000
284	0.1032	0.0560	0.0237	0.0140	0.0003	0.0022
285	0.2854	0.1500	0.2059	0.1080	0.0222	0.0183
290	0.1633	0.1390	0.0837	0.0970	0.0081	0.0006
294	0.1296	0.0900	0.0500	0.0480	0.0024	0.0016
297	0.0548	0.0470	-0.0248	0.0050	-0.0001	0.0001
301	0.0464	0.0250	-0.0331	-0.0170	0.0006	0.0005
303	0.0647	0.0620	-0.0149	0.0200	-0.0003	0.0000
304	0.0496	0.0370	-0.0300	-0.0050	0.0002	0.0002
310	0.0981	0.0620	0.0186	0.0200	0.0004	0.0013
313	0.0452	0.0230	-0.0343	-0.0190	0.0007	0.0005
314	0.0279	0.0250	-0.0516	-0.0170	0.0009	0.0000
317	0.0963	0.0250	0.0168	-0.0170	-0.0003	0.0051
319	0.0437	0.0190	-0.0359	-0.0230	0.0008	0.0006
320	0.0632	0.0170	-0.0163	-0.0250	0.0004	0.0021
321	0.0428	0.0160	-0.0368	-0.0260	0.0010	0.0007
322	0.0397	0.0120	-0.0399	-0.0300	0.0012	0.0008
323	0.0409	0.0080	-0.0386	-0.0340	0.0013	0.0011
325	0.0426	0.0240	-0.0370	-0.0180	0.0007	0.0003
326	0.0417	0.0140	-0.0379	-0.0280	0.0011	0.0008
327	0.0413	0.0270	-0.0382	-0.0150	0.0006	0.0002
329	0.0468	0.0300	-0.0328	-0.0120	0.0004	0.0003
330	0.0417	0.0250	-0.0378	-0.0170	0.0006	0.0003
331	0.0420	0.0190	-0.0376	-0.0230	0.0009	0.0005
333	0.0406	0.0300	-0.0390	-0.0120	0.0005	0.0001
335	0.0428	0.0170	-0.0367	-0.0250	0.0009	0.0007
129b	0.0976	0.0320	0.0181	-0.0100	-0.0002	0.0043
129c	0.0365	0.0230	-0.0430	-0.0190	0.0008	0.0002
132a	0.1177	0.0510	0.0382	0.0090	0.0003	0.0045
136a	0.0574	0.0280	-0.0221	-0.0140	0.0003	0.0009
136b	0.0397	0.0280	-0.0398	-0.0140	0.0006	0.0001
136c	0.0634	0.0140	-0.0161	-0.0280	0.0005	0.0024
14a	0.0395	0.0430	-0.0400	0.0010	0.0000	0.0000
212a	0.0814	0.0290	0.0018	-0.0130	0.0000	0.0027
212b	0.0415	0.0210	-0.0380	-0.0210	0.0008	0.0004
212c	0.0418	0.0260	-0.0377	-0.0160	0.0006	0.0002
219A	0.0538	0.0230	-0.0257	-0.0190	0.0005	0.0009
21a	0.0311	0.0200	-0.0485	-0.0220	0.0011	0.0001
23b	0.0518	0.0260	-0.0277	-0.0160	0.0004	0.0007
23c	0.0613	0.0440	-0.0183	0.0020	0.0000	0.0003
23d	0.1197	0.0400	0.0401	-0.0020	-0.0001	0.0063
2b	0.0510	0.0040	-0.0286	-0.0380	0.0011	0.0022

36d	0.0844	0.0390	0.0048	-0.0030	0.0000	0.0021
3a	0.0487	0.0260	-0.0308	-0.0160	0.0005	0.0005
5a	0.0511	0.0050	-0.0285	-0.0370	0.0011	0.0021
66b	0.0296	0.0190	-0.0499	-0.0230	0.0011	0.0001
7a	0.0435	0.0090	-0.0360	-0.0330	0.0012	0.0012
Link-03	0.2892	0.2200	0.2097	0.1780	0.0373	0.0048
Link-09	0.1139	0.1070	0.0343	0.0650	0.0022	0.0000
Link-10	0.1116	0.1070	0.0321	0.0650	0.0021	0.0000
Link-11	0.1139	0.0820	0.0343	0.0400	0.0014	0.0010
Link-14	0.1752	0.0910	0.0956	0.0490	0.0047	0.0071
Link-17	0.2932	0.2200	0.2136	0.1780	0.0380	0.0054
Link-19	0.1075	0.0540	0.0280	0.0120	0.0003	0.0029
Link-23	0.1108	0.0330	0.0313	-0.0090	-0.0003	0.0061
Link-24	0.0422	0.0080	-0.0374	-0.0340	0.0013	0.0012
Link-28	0.0517	0.0350	-0.0279	-0.0070	0.0002	0.0003
Link-29	0.0358	0.0420	-0.0437	0.0000	0.0000	0.0000
Link-30	0.0374	0.0270	-0.0421	-0.0150	0.0006	0.0001
Link-31	0.0480	0.0380	-0.0315	-0.0040	0.0001	0.0001
Link-32	0.0771	0.0010	-0.0025	-0.0410	0.0001	0.0058
Link-35	0.0616	0.0170	-0.0179	-0.0250	0.0004	0.0020
Link-37	0.0744	0.0330	-0.0051	-0.0090	0.0000	0.0017
Link-39	0.0676	0.0210	-0.0119	-0.0210	0.0003	0.0022
Average	**0.0583**	**0.0315**	**-4.5715**	**-2.2598**	**0.0010**	**0.0013**
S.D.	**0.0369**	**0.0279**				
R =	**0.9779**	**NMSE =**	**0.6970**			

Table 2: NMSE analysis data between the design discharge and predicted discharge from SWMM for the combined sewage system using rainfall intensity-5 years return period.

Pipe No.	Design flow rate Co	Max. flow rate with 2 years return period Po	Co-Coavg	Cp-Cpavg	(Co-Coavg) * (Cp-Cpavg)	(Co-Cp)^2
2	0.0758	0.0620	-0.0037	0.0200	-0.0001	0.0002
5	0.0589	0.0350	-0.0206	-0.0070	0.0001	0.0006
6	0.0413	0.0360	-0.0382	-0.0060	0.0002	0.0000
7	0.0467	0.0250	-0.0329	-0.0170	0.0006	0.0005
8	0.0461	0.0230	-0.0334	-0.0190	0.0006	0.0005
9	0.0464	0.0310	-0.0332	-0.0110	0.0004	0.0002
12	0.0327	0.0200	-0.0469	-0.0220	0.0010	0.0002
13	0.0776	0.0240	-0.0020	-0.0180	0.0000	0.0029
14	0.0707	0.0700	-0.0089	0.0280	-0.0002	0.0000
16	0.0743	0.0400	-0.0053	-0.0020	0.0000	0.0012
18	0.0700	0.0270	-0.0096	-0.0150	0.0001	0.0018
19	0.0383	0.0330	-0.0412	-0.0090	0.0004	0.0000
20	0.1383	0.0460	0.0587	0.0040	0.0002	0.0085
22	0.0533	0.0150	-0.0263	-0.0270	0.0007	0.0015
23	0.0413	0.0300	-0.0382	-0.0120	0.0005	0.0001
24	0.0424	0.0240	-0.0371	-0.0180	0.0007	0.0003
26	0.0363	0.0330	-0.0433	-0.0090	0.0004	0.0000
29	0.0579	0.0440	-0.0216	0.0020	0.0000	0.0002
31	0.0624	0.0310	-0.0171	-0.0110	0.0002	0.0010
32	0.0413	0.0440	-0.0382	0.0020	-0.0001	0.0000
35	0.0448	0.0140	-0.0347	-0.0280	0.0010	0.0010
36	0.0354	0.0380	-0.0441	-0.0040	0.0002	0.0000
37	0.0705	0.0130	-0.0090	-0.0290	0.0003	0.0033
38	0.0116	0.0300	-0.0679	-0.0120	0.0008	0.0003
39	0.0589	0.0180	-0.0207	-0.0240	0.0005	0.0017
40	0.0681	0.0240	-0.0115	-0.0180	0.0002	0.0019
41	0.0481	0.0300	-0.0314	-0.0120	0.0004	0.0003
42	0.0498	0.0390	-0.0297	-0.0030	0.0001	0.0001
44	0.0926	0.0410	0.0130	-0.0010	0.0000	0.0027
45	0.0438	0.0460	-0.0357	0.0040	-0.0001	0.0000
46	0.0818	0.0380	0.0023	-0.0040	0.0000	0.0019
47	0.0413	0.0240	-0.0382	-0.0180	0.0007	0.0003
48	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
49	0.0413	0.0430	-0.0382	0.0010	0.0000	0.0000

51	0.0407	0.0400	-0.0388	-0.0020	0.0001	0.0000
54	0.0394	0.0260	-0.0401	-0.0160	0.0006	0.0002
55	0.0392	0.0250	-0.0403	-0.0170	0.0007	0.0002
59	0.0515	0.0190	-0.0280	-0.0230	0.0006	0.0011
60	0.0492	0.0130	-0.0304	-0.0290	0.0009	0.0013
61	0.0827	0.0220	0.0031	-0.0200	-0.0001	0.0037
62	0.0625	0.0220	-0.0170	-0.0200	0.0003	0.0016
63	0.1475	0.0320	0.0679	-0.0100	-0.0007	0.0133
64	0.0419	0.0130	-0.0377	-0.0290	0.0011	0.0008
65	0.0413	0.0310	-0.0382	-0.0110	0.0004	0.0001
66	0.0416	0.0420	-0.0379	0.0000	0.0000	0.0000
71	0.0522	0.0310	-0.0273	-0.0110	0.0003	0.0005
72	0.0396	0.0340	-0.0399	-0.0080	0.0003	0.0000
73	0.0471	0.0380	-0.0324	-0.0040	0.0001	0.0001
76	0.0581	0.0850	-0.0214	0.0430	-0.0009	0.0007
77	0.0548	0.0250	-0.0247	-0.0170	0.0004	0.0009
78	0.0406	0.0280	-0.0389	-0.0140	0.0005	0.0002
79	0.0389	0.0320	-0.0406	-0.0100	0.0004	0.0000
80	0.0450	0.0350	-0.0345	-0.0070	0.0002	0.0001
81	0.0936	0.0590	0.0140	0.0170	0.0002	0.0012
82	0.0536	0.0510	-0.0259	0.0090	-0.0002	0.0000
83	0.0411	0.0280	-0.0385	-0.0140	0.0005	0.0002
84	0.0385	0.0310	-0.0411	-0.0110	0.0005	0.0001
85	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
86	0.0639	0.0330	-0.0156	-0.0090	0.0001	0.0010
87	0.0371	0.0400	-0.0424	-0.0020	0.0001	0.0000
93	0.0527	0.0390	-0.0269	-0.0030	0.0001	0.0002
94	0.0440	0.0430	-0.0355	0.0010	0.0000	0.0000
95	0.0384	0.0360	-0.0412	-0.0060	0.0002	0.0000
96	0.0428	0.0340	-0.0367	-0.0080	0.0003	0.0001
97	0.0424	0.0370	-0.0371	-0.0050	0.0002	0.0000
98	0.0404	0.0150	-0.0391	-0.0270	0.0011	0.0006
99	0.0405	0.0400	-0.0390	-0.0020	0.0001	0.0000
100	0.0396	0.0410	-0.0399	-0.0010	0.0000	0.0000
108	0.0327	0.0260	-0.0469	-0.0160	0.0008	0.0000
110	0.0483	0.0210	-0.0312	-0.0210	0.0007	0.0007
111	0.0411	0.0240	-0.0384	-0.0180	0.0007	0.0003
112	0.0437	0.0210	-0.0358	-0.0210	0.0008	0.0005
118	0.0413	0.0680	-0.0382	0.0260	-0.0010	0.0007
122	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
123	0.0436	0.0330	-0.0360	-0.0090	0.0003	0.0001
124	0.0413	0.0320	-0.0382	-0.0100	0.0004	0.0001
125	0.0433	0.0310	-0.0362	-0.0110	0.0004	0.0002
126	0.0436	0.0360	-0.0359	-0.0060	0.0002	0.0001
127	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
128	0.0462	0.0490	-0.0333	0.0070	-0.0002	0.0000
130	0.0413	0.0450	-0.0382	0.0030	-0.0001	0.0000
131	0.0411	0.0440	-0.0384	0.0020	-0.0001	0.0000
134	0.0463	0.0280	-0.0332	-0.0140	0.0005	0.0003
135	0.0388	0.0400	-0.0408	-0.0020	0.0001	0.0000
136	0.0413	0.0410	-0.0382	-0.0010	0.0000	0.0000
145	0.0443	0.0440	-0.0353	0.0020	-0.0001	0.0000
146	0.0380	0.0410	-0.0416	-0.0010	0.0000	0.0000
147	0.0494	0.0380	-0.0301	-0.0040	0.0001	0.0001
149	0.0436	0.0360	-0.0359	-0.0060	0.0002	0.0001
150	0.0456	0.0430	-0.0339	0.0010	0.0000	0.0000
151	0.0429	0.0550	-0.0366	0.0130	-0.0005	0.0001
158	0.0663	0.0230	-0.0133	-0.0190	0.0003	0.0019
159	0.0409	0.0260	-0.0386	-0.0160	0.0006	0.0002
161	0.0937	0.0500	0.0142	0.0080	0.0001	0.0019
162	0.0477	0.0460	-0.0319	0.0040	-0.0001	0.0000
163	0.0383	0.0340	-0.0412	-0.0080	0.0003	0.0000
164	0.0407	0.0410	-0.0389	-0.0010	0.0000	0.0000
168	0.0468	0.0400	-0.0328	-0.0020	0.0001	0.0000
169	0.0380	0.0270	-0.0416	-0.0150	0.0006	0.0001
174	0.0397	0.0390	-0.0398	-0.0030	0.0001	0.0000
175	0.0422	0.0370	-0.0374	-0.0050	0.0002	0.0000

176	0.0436	0.0390	-0.0360	-0.0030	0.0001	0.0000
177	0.0617	0.0490	-0.0179	0.0070	-0.0001	0.0002
179	0.0455	0.0240	-0.0340	-0.0180	0.0006	0.0005
180	0.0391	0.0340	-0.0404	-0.0080	0.0003	0.0000
181	0.0398	0.0380	-0.0397	-0.0040	0.0002	0.0000
182	0.0604	0.0420	-0.0191	0.0000	0.0000	0.0003
183	0.0383	0.0270	-0.0412	-0.0150	0.0006	0.0001
184	0.0797	0.0330	0.0002	-0.0090	0.0000	0.0022
185	0.0457	0.0320	-0.0338	-0.0100	0.0003	0.0002
186	0.0397	0.0410	-0.0398	-0.0010	0.0000	0.0000
187	0.0420	0.0480	-0.0375	0.0060	-0.0002	0.0000
188	0.0500	0.0500	-0.0295	0.0080	-0.0002	0.0000
191	0.0707	0.0550	-0.0088	0.0130	-0.0001	0.0002
192	0.0569	0.0400	-0.0226	-0.0020	0.0000	0.0003
205	0.0413	0.0240	-0.0382	-0.0180	0.0007	0.0003
208	0.0405	0.0390	-0.0390	-0.0030	0.0001	0.0000
218	0.0778	0.0610	-0.0018	0.0190	0.0000	0.0003
219	0.0492	0.0460	-0.0304	0.0040	-0.0001	0.0000
220	0.0420	0.0320	-0.0376	-0.0100	0.0004	0.0001
221	0.0418	0.0350	-0.0377	-0.0070	0.0003	0.0000
224	0.0721	0.0290	-0.0074	-0.0130	0.0001	0.0019
225	0.0401	0.0330	-0.0395	-0.0090	0.0004	0.0001
226	0.0428	0.0380	-0.0368	-0.0040	0.0001	0.0000
228	0.0797	0.0300	0.0002	-0.0120	0.0000	0.0025
229	0.0420	0.0340	-0.0376	-0.0080	0.0003	0.0001
230	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
231	0.0429	0.0410	-0.0366	-0.0010	0.0000	0.0000
234	0.0628	0.0270	-0.0167	-0.0150	0.0003	0.0013
235	0.0403	0.0240	-0.0392	-0.0180	0.0007	0.0003
236	0.0435	0.0230	-0.0361	-0.0190	0.0007	0.0004
237	0.0875	0.0550	0.0080	0.0130	0.0001	0.0011
238	0.0410	0.0460	-0.0386	0.0040	-0.0002	0.0000
240	0.0391	0.0400	-0.0405	-0.0020	0.0001	0.0000
241	0.0731	0.0350	-0.0065	-0.0070	0.0000	0.0014
243	0.0379	0.0310	-0.0416	-0.0110	0.0005	0.0000
244	0.0442	0.0330	-0.0353	-0.0090	0.0003	0.0001
245	0.0473	0.0390	-0.0322	-0.0030	0.0001	0.0001
246	0.0402	0.0270	-0.0393	-0.0150	0.0006	0.0002
247	0.0438	0.0090	-0.0357	-0.0330	0.0012	0.0012
250	0.0580	0.0310	-0.0215	-0.0110	0.0002	0.0007
262	0.0988	0.0370	0.0193	-0.0050	-0.0001	0.0038
264	0.0853	0.0440	0.0057	0.0020	0.0000	0.0017
265	0.1194	0.1000	0.0399	0.0580	0.0023	0.0004
271	0.0413	0.0260	-0.0382	-0.0160	0.0006	0.0002
272	0.0433	0.0180	-0.0362	-0.0240	0.0009	0.0006
274	0.0413	0.0120	-0.0382	-0.0300	0.0011	0.0009
276	0.0413	0.0460	-0.0382	0.0040	-0.0002	0.0000
277	0.0413	0.0380	-0.0382	-0.0040	0.0002	0.0000
278	0.0413	0.0290	-0.0382	-0.0130	0.0005	0.0002
279	0.0414	0.0240	-0.0382	-0.0180	0.0007	0.0003
280	0.0413	0.0330	-0.0382	-0.0090	0.0003	0.0001
284	0.1032	0.0630	0.0237	0.0210	0.0005	0.0016
285	0.2854	0.1720	0.2059	0.1300	0.0268	0.0129
290	0.1633	0.1790	0.0837	0.1370	0.0115	0.0002
294	0.1296	0.1050	0.0500	0.0630	0.0032	0.0006
297	0.0548	0.0560	-0.0248	0.0140	-0.0003	0.0000
301	0.0464	0.0390	-0.0331	-0.0030	0.0001	0.0001
303	0.0647	0.0670	-0.0149	0.0250	-0.0004	0.0000
304	0.0496	0.0450	-0.0300	0.0030	-0.0001	0.0000
310	0.0981	0.0460	0.0186	0.0040	0.0001	0.0027
313	0.0452	0.0320	-0.0343	-0.0100	0.0003	0.0002
314	0.0279	0.0280	-0.0516	-0.0140	0.0007	0.0000
317	0.0963	0.0540	0.0168	0.0120	0.0002	0.0018
319	0.0437	0.0390	-0.0359	-0.0030	0.0001	0.0000
320	0.0632	0.0180	-0.0163	-0.0240	0.0004	0.0020
321	0.0428	0.0190	-0.0368	-0.0230	0.0008	0.0006
322	0.0397	0.0160	-0.0399	-0.0260	0.0010	0.0006

323	0.0409	0.0100	-0.0386	-0.0320	0.0012	0.0010
325	0.0426	0.0320	-0.0370	-0.0100	0.0004	0.0001
326	0.0417	0.0220	-0.0379	-0.0200	0.0008	0.0004
327	0.0413	0.0270	-0.0382	-0.0150	0.0006	0.0002
329	0.0468	0.0380	-0.0328	-0.0040	0.0001	0.0001
330	0.0417	0.0310	-0.0378	-0.0110	0.0004	0.0001
331	0.0420	0.0300	-0.0376	-0.0120	0.0005	0.0001
333	0.0406	0.0400	-0.0390	-0.0020	0.0001	0.0000
335	0.0428	0.0200	-0.0367	-0.0220	0.0008	0.0005
129b	0.0976	0.0670	0.0181	0.0250	0.0005	0.0009
129c	0.0365	0.0290	-0.0430	-0.0130	0.0006	0.0001
132a	0.1177	0.0670	0.0382	0.0250	0.0010	0.0026
136a	0.0574	0.0280	-0.0221	-0.0140	0.0003	0.0009
136b	0.0397	0.0310	-0.0398	-0.0110	0.0004	0.0001
136c	0.0634	0.0270	-0.0161	-0.0150	0.0002	0.0013
14a	0.0395	0.0380	-0.0400	-0.0040	0.0002	0.0000
212a	0.0814	0.0360	0.0018	-0.0060	0.0000	0.0021
212b	0.0415	0.0260	-0.0380	-0.0160	0.0006	0.0002
212c	0.0418	0.0350	-0.0377	-0.0070	0.0003	0.0000
219A	0.0538	0.0220	-0.0257	-0.0200	0.0005	0.0010
21a	0.0311	0.0340	-0.0485	-0.0080	0.0004	0.0000
23b	0.0518	0.0330	-0.0277	-0.0090	0.0003	0.0004
23c	0.0613	0.0500	-0.0183	0.0080	-0.0001	0.0001
23d	0.1197	0.0440	0.0401	0.0020	0.0001	0.0057
2b	0.0510	0.0150	-0.0286	-0.0270	0.0008	0.0013
36d	0.0844	0.0440	0.0048	0.0020	0.0000	0.0016
3a	0.0487	0.0450	-0.0308	0.0030	-0.0001	0.0000
5a	0.0511	0.0150	-0.0285	-0.0270	0.0008	0.0013
66b	0.0296	0.0310	-0.0499	-0.0110	0.0006	0.0000
7a	0.0435	0.0270	-0.0360	-0.0150	0.0005	0.0003
Link-03	0.2892	0.2890	0.2097	0.2470	0.0518	0.0000
Link-09	0.1139	0.1250	0.0343	0.0830	0.0028	0.0001
Link-10	0.1116	0.1260	0.0321	0.0840	0.0027	0.0002
Link-11	0.1139	0.1270	0.0343	0.0850	0.0029	0.0002
Link-14	0.1752	0.0910	0.0956	0.0490	0.0047	0.0071
Link-17	0.2932	0.2850	0.2136	0.2430	0.0519	0.0001
Link-19	0.1075	0.0730	0.0280	0.0310	0.0009	0.0012
Link-23	0.1108	0.0550	0.0313	0.0130	0.0004	0.0031
Link-24	0.0422	0.0390	-0.0374	-0.0030	0.0001	0.0000
Link-28	0.0517	0.0460	-0.0279	0.0040	-0.0001	0.0000
Link-29	0.0358	0.0480	-0.0437	0.0060	-0.0003	0.0001
Link-30	0.0374	0.0280	-0.0421	-0.0140	0.0006	0.0001
Link-31	0.0480	0.0490	-0.0315	0.0070	-0.0002	0.0000
Link-32	0.0771	0.0340	-0.0025	-0.0080	0.0000	0.0019
Link-35	0.0616	0.0300	-0.0179	-0.0120	0.0002	0.0010
Link-37	0.0744	0.0370	-0.0051	-0.0050	0.0000	0.0014
Link-39	0.0676	0.0340	-0.0119	-0.0080	0.0001	0.0011
Average	**0.0583**	**0.0412**	**-4.5715**	**-0.1698**	**0.0010**	**0.0007**
S.D.	**0.0369**	**0.0325**				
R =	**0.8341**	**NMSE =**	**0.3038**			

Table 3: NMSE analysis data between the design discharge and predicted discharge from SWMM for the combined sewage system using rainfall intensity-10 years return period.

Pipe No.	Design flow rate Co	Max. flow rate with 2 years return period Po	Co-Coavg	Cp-Cpavg	(Co-Coavg) * (Cp-Cpavg)	(Co-Cp)^2
2	0.0758	0.0670	-0.0037	0.0250	-0.0001	0.0001
5	0.0589	0.0480	-0.0206	0.0060	-0.0001	0.0001
6	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
7	0.0467	0.0340	-0.0329	-0.0080	0.0003	0.0002
8	0.0461	0.0340	-0.0334	-0.0080	0.0003	0.0001
9	0.0464	0.0400	-0.0332	-0.0020	0.0001	0.0000
12	0.0327	0.0180	-0.0469	-0.0240	0.0011	0.0002
13	0.0776	0.0220	-0.0020	-0.0200	0.0000	0.0031
14	0.0707	0.0690	-0.0089	0.0270	-0.0002	0.0000

16	0.0743	0.0410	-0.0053	-0.0010	0.0000	0.0011
18	0.0700	0.0280	-0.0096	-0.0140	0.0001	0.0018
19	0.0383	0.0340	-0.0412	-0.0080	0.0003	0.0000
20	0.1383	0.0470	0.0587	0.0050	0.0003	0.0083
22	0.0533	0.0230	-0.0263	-0.0190	0.0005	0.0009
23	0.0413	0.0330	-0.0382	-0.0090	0.0003	0.0001
24	0.0424	0.0310	-0.0371	-0.0110	0.0004	0.0001
26	0.0363	0.0340	-0.0433	-0.0080	0.0003	0.0000
29	0.0579	0.0480	-0.0216	0.0060	-0.0001	0.0001
31	0.0624	0.0430	-0.0171	0.0010	0.0000	0.0004
32	0.0413	0.0450	-0.0382	0.0030	-0.0001	0.0000
35	0.0448	0.0210	-0.0347	-0.0210	0.0007	0.0006
36	0.0354	0.0390	-0.0441	-0.0030	0.0001	0.0000
37	0.0705	0.0170	-0.0090	-0.0250	0.0002	0.0029
38	0.0116	0.0310	-0.0679	-0.0110	0.0007	0.0004
39	0.0589	0.0240	-0.0207	-0.0180	0.0004	0.0012
40	0.0681	0.0340	-0.0115	-0.0080	0.0001	0.0012
41	0.0481	0.0350	-0.0314	-0.0070	0.0002	0.0002
42	0.0498	0.0460	-0.0297	0.0040	-0.0001	0.0000
44	0.0926	0.0430	0.0130	0.0010	0.0000	0.0025
45	0.0438	0.0470	-0.0357	0.0050	-0.0002	0.0000
46	0.0818	0.0380	0.0023	-0.0040	0.0000	0.0019
47	0.0413	0.0260	-0.0382	-0.0160	0.0006	0.0002
48	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
49	0.0413	0.0470	-0.0382	0.0050	-0.0002	0.0000
51	0.0407	0.0440	-0.0388	0.0020	-0.0001	0.0000
54	0.0394	0.0340	-0.0401	-0.0080	0.0003	0.0000
55	0.0392	0.0270	-0.0403	-0.0150	0.0006	0.0001
59	0.0515	0.0210	-0.0280	-0.0210	0.0006	0.0009
60	0.0492	0.0150	-0.0304	-0.0270	0.0008	0.0012
61	0.0827	0.0230	0.0031	-0.0190	-0.0001	0.0036
62	0.0625	0.0290	-0.0170	-0.0130	0.0002	0.0011
63	0.1475	0.0510	0.0679	0.0090	0.0006	0.0093
64	0.0419	0.0130	-0.0377	-0.0290	0.0011	0.0008
65	0.0413	0.0310	-0.0382	-0.0110	0.0004	0.0001
66	0.0416	0.0420	-0.0379	0.0000	0.0000	0.0000
71	0.0522	0.0390	-0.0273	-0.0030	0.0001	0.0002
72	0.0396	0.0360	-0.0399	-0.0060	0.0002	0.0000
73	0.0471	0.0420	-0.0324	0.0000	0.0000	0.0000
76	0.0581	0.0860	-0.0214	0.0440	-0.0009	0.0008
77	0.0548	0.0280	-0.0247	-0.0140	0.0003	0.0007
78	0.0406	0.0280	-0.0389	-0.0140	0.0005	0.0002
79	0.0389	0.0330	-0.0406	-0.0090	0.0004	0.0000
80	0.0450	0.0400	-0.0345	-0.0020	0.0001	0.0000
81	0.0936	0.0590	0.0140	0.0170	0.0002	0.0012
82	0.0536	0.0560	-0.0259	0.0140	-0.0004	0.0000
83	0.0411	0.0360	-0.0385	-0.0060	0.0002	0.0000
84	0.0385	0.0320	-0.0411	-0.0100	0.0004	0.0000
85	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
86	0.0639	0.0340	-0.0156	-0.0080	0.0001	0.0009
87	0.0371	0.0420	-0.0424	0.0000	0.0000	0.0000
93	0.0527	0.0420	-0.0269	0.0000	0.0000	0.0001
94	0.0440	0.0470	-0.0355	0.0050	-0.0002	0.0000
95	0.0384	0.0430	-0.0412	0.0010	0.0000	0.0000
96	0.0428	0.0350	-0.0367	-0.0070	0.0003	0.0001
97	0.0424	0.0370	-0.0371	-0.0050	0.0002	0.0000
98	0.0404	0.0140	-0.0391	-0.0280	0.0011	0.0007
99	0.0405	0.0410	-0.0390	-0.0010	0.0000	0.0000
100	0.0396	0.0340	-0.0399	-0.0080	0.0003	0.0000
108	0.0327	0.0250	-0.0469	-0.0170	0.0008	0.0001
110	0.0483	0.0300	-0.0312	-0.0120	0.0004	0.0003
111	0.0411	0.0240	-0.0384	-0.0180	0.0007	0.0003
112	0.0437	0.0200	-0.0358	-0.0220	0.0008	0.0006
118	0.0413	0.0650	-0.0382	0.0230	-0.0009	0.0006
122	0.0413	0.0360	-0.0382	-0.0060	0.0002	0.0000
123	0.0436	0.0400	-0.0360	-0.0020	0.0001	0.0000
124	0.0413	0.0350	-0.0382	-0.0070	0.0003	0.0000

125	0.0433	0.0330	-0.0362	-0.0090	0.0003	0.0001
126	0.0436	0.0370	-0.0359	-0.0050	0.0002	0.0000
127	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
128	0.0462	0.0500	-0.0333	0.0080	-0.0003	0.0000
130	0.0413	0.0440	-0.0382	0.0020	-0.0001	0.0000
131	0.0411	0.0470	-0.0384	0.0050	-0.0002	0.0000
134	0.0463	0.0280	-0.0332	-0.0140	0.0005	0.0003
135	0.0388	0.0440	-0.0408	0.0020	-0.0001	0.0000
136	0.0413	0.0410	-0.0382	-0.0010	0.0000	0.0000
145	0.0443	0.0440	-0.0353	0.0020	-0.0001	0.0000
146	0.0380	0.0420	-0.0416	0.0000	0.0000	0.0000
147	0.0494	0.0380	-0.0301	-0.0040	0.0001	0.0001
149	0.0436	0.0380	-0.0359	-0.0040	0.0001	0.0000
150	0.0456	0.0440	-0.0339	0.0020	-0.0001	0.0000
151	0.0429	0.0570	-0.0366	0.0150	-0.0005	0.0002
158	0.0663	0.0210	-0.0133	-0.0210	0.0003	0.0020
159	0.0409	0.0260	-0.0386	-0.0160	0.0006	0.0002
161	0.0937	0.0500	0.0142	0.0080	0.0001	0.0019
162	0.0477	0.0490	-0.0319	0.0070	-0.0002	0.0000
163	0.0383	0.0330	-0.0412	-0.0090	0.0004	0.0000
164	0.0407	0.0410	-0.0389	-0.0010	0.0000	0.0000
168	0.0468	0.0390	-0.0328	-0.0030	0.0001	0.0001
169	0.0380	0.0260	-0.0416	-0.0160	0.0007	0.0001
174	0.0397	0.0370	-0.0398	-0.0050	0.0002	0.0000
175	0.0422	0.0480	-0.0374	0.0060	-0.0002	0.0000
176	0.0436	0.0410	-0.0360	-0.0010	0.0000	0.0000
177	0.0617	0.0600	-0.0179	0.0180	-0.0003	0.0000
179	0.0455	0.0280	-0.0340	-0.0140	0.0005	0.0003
180	0.0391	0.0360	-0.0404	-0.0060	0.0002	0.0000
181	0.0398	0.0390	-0.0397	-0.0030	0.0001	0.0000
182	0.0604	0.0400	-0.0191	-0.0020	0.0000	0.0004
183	0.0383	0.0320	-0.0412	-0.0100	0.0004	0.0000
184	0.0797	0.0330	0.0002	-0.0090	0.0000	0.0022
185	0.0457	0.0380	-0.0338	-0.0040	0.0001	0.0001
186	0.0397	0.0360	-0.0398	-0.0060	0.0002	0.0000
187	0.0420	0.0450	-0.0375	0.0030	-0.0001	0.0000
188	0.0500	0.0520	-0.0295	0.0100	-0.0003	0.0000
191	0.0707	0.0640	-0.0088	0.0220	-0.0002	0.0000
192	0.0569	0.0440	-0.0226	0.0020	0.0000	0.0002
205	0.0413	0.0300	-0.0382	-0.0120	0.0005	0.0001
208	0.0405	0.0340	-0.0390	-0.0080	0.0003	0.0000
218	0.0778	0.0650	-0.0018	0.0230	0.0000	0.0002
219	0.0492	0.0510	-0.0304	0.0090	-0.0003	0.0000
220	0.0420	0.0450	-0.0376	0.0030	-0.0001	0.0000
221	0.0418	0.0370	-0.0377	-0.0050	0.0002	0.0000
224	0.0721	0.0300	-0.0074	-0.0120	0.0001	0.0018
225	0.0401	0.0370	-0.0395	-0.0050	0.0002	0.0000
226	0.0428	0.0430	-0.0368	0.0010	0.0000	0.0000
228	0.0797	0.0350	0.0002	-0.0070	0.0000	0.0020
229	0.0420	0.0350	-0.0376	-0.0070	0.0003	0.0000
230	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
231	0.0429	0.0440	-0.0366	0.0020	-0.0001	0.0000
234	0.0628	0.0280	-0.0167	-0.0140	0.0002	0.0012
235	0.0403	0.0250	-0.0392	-0.0170	0.0007	0.0002
236	0.0435	0.0250	-0.0361	-0.0170	0.0006	0.0003
237	0.0875	0.0560	0.0080	0.0140	0.0001	0.0010
238	0.0410	0.0460	-0.0386	0.0040	-0.0002	0.0000
240	0.0391	0.0400	-0.0405	-0.0020	0.0001	0.0000
241	0.0731	0.0370	-0.0065	-0.0050	0.0000	0.0013
243	0.0379	0.0340	-0.0416	-0.0080	0.0003	0.0000
244	0.0442	0.0360	-0.0353	-0.0060	0.0002	0.0001
245	0.0473	0.0410	-0.0322	-0.0010	0.0000	0.0000
246	0.0402	0.0290	-0.0393	-0.0130	0.0005	0.0001
247	0.0438	0.0100	-0.0357	-0.0320	0.0011	0.0011
250	0.0580	0.0330	-0.0215	-0.0090	0.0002	0.0006
262	0.0988	0.0320	0.0193	-0.0100	-0.0002	0.0045
264	0.0853	0.0460	0.0057	0.0040	0.0000	0.0015

265	0.1194	0.1000	0.0399	0.0580	0.0023	0.0004
271	0.0413	0.0310	-0.0382	-0.0110	0.0004	0.0001
272	0.0433	0.0220	-0.0362	-0.0200	0.0007	0.0005
274	0.0413	0.0160	-0.0382	-0.0260	0.0010	0.0006
276	0.0413	0.0430	-0.0382	0.0010	0.0000	0.0000
277	0.0413	0.0340	-0.0382	-0.0080	0.0003	0.0001
278	0.0413	0.0260	-0.0382	-0.0160	0.0006	0.0002
279	0.0414	0.0200	-0.0382	-0.0220	0.0008	0.0005
280	0.0413	0.0320	-0.0382	-0.0100	0.0004	0.0001
284	0.1032	0.0710	0.0237	0.0290	0.0007	0.0010
285	0.2854	0.1920	0.2059	0.1500	0.0309	0.0087
290	0.1633	0.2150	0.0837	0.1730	0.0145	0.0027
294	0.1296	0.1170	0.0500	0.0750	0.0038	0.0002
297	0.0548	0.0590	-0.0248	0.0170	-0.0004	0.0000
301	0.0464	0.0430	-0.0331	0.0010	0.0000	0.0000
303	0.0647	0.0690	-0.0149	0.0270	-0.0004	0.0000
304	0.0496	0.0460	-0.0300	0.0040	-0.0001	0.0000
310	0.0981	0.0460	0.0186	0.0040	0.0001	0.0027
313	0.0452	0.0320	-0.0343	-0.0100	0.0003	0.0002
314	0.0279	0.0310	-0.0516	-0.0110	0.0006	0.0000
317	0.0963	0.0620	0.0168	0.0200	0.0003	0.0012
319	0.0437	0.0430	-0.0359	0.0010	0.0000	0.0000
320	0.0632	0.0210	-0.0163	-0.0210	0.0003	0.0018
321	0.0428	0.0220	-0.0368	-0.0200	0.0007	0.0004
322	0.0397	0.0160	-0.0399	-0.0260	0.0010	0.0006
323	0.0409	0.0120	-0.0386	-0.0300	0.0012	0.0008
325	0.0426	0.0370	-0.0370	-0.0050	0.0002	0.0000
326	0.0417	0.0290	-0.0379	-0.0130	0.0005	0.0002
327	0.0413	0.0280	-0.0382	-0.0140	0.0005	0.0002
329	0.0468	0.0400	-0.0328	-0.0020	0.0001	0.0000
330	0.0417	0.0330	-0.0378	-0.0090	0.0003	0.0001
331	0.0420	0.0330	-0.0376	-0.0090	0.0003	0.0001
333	0.0406	0.0420	-0.0390	0.0000	0.0000	0.0000
335	0.0428	0.0210	-0.0367	-0.0210	0.0008	0.0005
129b	0.0976	0.0780	0.0181	0.0360	0.0007	0.0004
129c	0.0365	0.0320	-0.0430	-0.0100	0.0004	0.0000
132a	0.1177	0.0710	0.0382	0.0290	0.0011	0.0022
136a	0.0574	0.0350	-0.0221	-0.0070	0.0002	0.0005
136b	0.0397	0.0340	-0.0398	-0.0080	0.0003	0.0000
136c	0.0634	0.0150	-0.0161	-0.0270	0.0004	0.0023
14a	0.0395	0.0390	-0.0400	-0.0030	0.0001	0.0000
212a	0.0814	0.0440	0.0018	0.0020	0.0000	0.0014
212b	0.0415	0.0300	-0.0380	-0.0120	0.0005	0.0001
212c	0.0418	0.0350	-0.0377	-0.0070	0.0003	0.0000
219A	0.0538	0.0130	-0.0257	-0.0290	0.0007	0.0017
21a	0.0311	0.0370	-0.0485	-0.0050	0.0002	0.0000
23b	0.0518	0.0360	-0.0277	-0.0060	0.0002	0.0002
23c	0.0613	0.0510	-0.0183	0.0090	-0.0002	0.0001
23d	0.1197	0.0520	0.0401	0.0100	0.0004	0.0046
2b	0.0510	0.0260	-0.0286	-0.0160	0.0005	0.0006
36d	0.0844	0.0450	0.0048	0.0030	0.0000	0.0015
3a	0.0487	0.0480	-0.0308	0.0060	-0.0002	0.0000
5a	0.0511	0.0220	-0.0285	-0.0200	0.0006	0.0008
66b	0.0296	0.0300	-0.0499	-0.0120	0.0006	0.0000
7a	0.0435	0.0360	-0.0360	-0.0060	0.0002	0.0001
Link-03	0.2892	0.3050	0.2097	0.2630	0.0551	0.0002
Link-09	0.1139	0.1250	0.0343	0.0830	0.0028	0.0001
Link-10	0.1116	0.1210	0.0321	0.0790	0.0025	0.0001
Link-11	0.1139	0.1310	0.0343	0.0890	0.0031	0.0003
Link-14	0.1752	0.1230	0.0956	0.0810	0.0077	0.0027
Link-17	0.2932	0.2930	0.2136	0.2510	0.0536	0.0000
Link-19	0.1075	0.0730	0.0280	0.0310	0.0009	0.0012
Link-23	0.1108	0.0690	0.0313	0.0270	0.0008	0.0017
Link-24	0.0422	0.0400	-0.0374	-0.0020	0.0001	0.0000
Link-28	0.0517	0.0480	-0.0279	0.0060	-0.0002	0.0000
Link-29	0.0358	0.0490	-0.0437	0.0070	-0.0003	0.0002
Link-30	0.0374	0.0290	-0.0421	-0.0130	0.0005	0.0001

Link-31	0.0480	0.0510	-0.0315	0.0090	-0.0003	0.0000
Link-32	0.0771	0.0540	-0.0025	0.0120	0.0000	0.0005
Link-35	0.0616	0.0350	-0.0179	-0.0070	0.0001	0.0007
Link-37	0.0744	0.0390	-0.0051	-0.0030	0.0000	0.0013
Link-39	0.0676	0.0370	-0.0119	-0.0050	0.0001	0.0009
Average	**0.0582**	**0.0442**	**-4.5678**	**0.4702**	**0.0010**	**0.0006**
S.D.	**0.0370**	**0.0347**				
R =	**0.8043**	**NMSE =**	**0.2317**			

Table 4: NMSE analysis data between the design discharge and predicted discharge from SWMM for the combined sewage system using rainfall intensity-25 years return period.

Pipe No.	Design flow rate Co	Max. flow rate with 2 years return period Po	Co-Coavg	Cp-Cpavg	(Co-Coavg) * (Cp-Cpavg)	(Co-Cp)^2
2	0.0758	0.0810	-0.0037	0.0390	-0.0001	0.0000
5	0.0589	0.0740	-0.0206	0.0320	-0.0007	0.0002
6	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
7	0.0467	0.0410	-0.0329	-0.0010	0.0000	0.0000
8	0.0461	0.0370	-0.0334	-0.0050	0.0002	0.0001
9	0.0464	0.0370	-0.0332	-0.0050	0.0002	0.0001
12	0.0327	0.0270	-0.0469	-0.0150	0.0007	0.0000
13	0.0776	0.0240	-0.0020	-0.0180	0.0000	0.0029
14	0.0707	0.0620	-0.0089	0.0200	-0.0002	0.0001
16	0.0743	0.0420	-0.0053	0.0000	0.0000	0.0010
18	0.0700	0.0290	-0.0096	-0.0130	0.0001	0.0017
19	0.0383	0.0370	-0.0412	-0.0050	0.0002	0.0000
20	0.1383	0.0510	0.0587	0.0090	0.0005	0.0076
22	0.0533	0.0280	-0.0263	-0.0140	0.0004	0.0006
23	0.0413	0.0350	-0.0382	-0.0070	0.0003	0.0000
24	0.0424	0.0220	-0.0371	-0.0200	0.0007	0.0004
26	0.0363	0.0410	-0.0433	-0.0010	0.0000	0.0000
29	0.0579	0.0490	-0.0216	0.0070	-0.0002	0.0001
31	0.0624	0.0480	-0.0171	0.0060	-0.0001	0.0002
32	0.0413	0.0560	-0.0382	0.0140	-0.0005	0.0002
35	0.0448	0.0310	-0.0347	-0.0110	0.0004	0.0002
36	0.0354	0.0390	-0.0441	-0.0030	0.0001	0.0000
37	0.0705	0.0280	-0.0090	-0.0140	0.0001	0.0018
38	0.0116	0.0310	-0.0679	-0.0110	0.0007	0.0004
39	0.0589	0.0380	-0.0207	-0.0040	0.0001	0.0004
40	0.0681	0.0400	-0.0115	-0.0020	0.0000	0.0008
41	0.0481	0.0470	-0.0314	0.0050	-0.0002	0.0000
42	0.0498	0.0350	-0.0297	-0.0070	0.0002	0.0002
44	0.0926	0.0440	0.0130	0.0020	0.0000	0.0024
45	0.0438	0.0480	-0.0357	0.0060	-0.0002	0.0000
46	0.0818	0.0390	0.0023	-0.0030	0.0000	0.0018
47	0.0413	0.0380	-0.0382	-0.0040	0.0002	0.0000
48	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
49	0.0413	0.0500	-0.0382	0.0080	-0.0003	0.0001
51	0.0407	0.0470	-0.0388	0.0050	-0.0002	0.0000
54	0.0394	0.0420	-0.0401	0.0000	0.0000	0.0000
55	0.0392	0.0290	-0.0403	-0.0130	0.0005	0.0001
59	0.0515	0.0280	-0.0280	-0.0140	0.0004	0.0006
60	0.0492	0.0240	-0.0304	-0.0180	0.0005	0.0006
61	0.0827	0.0340	0.0031	-0.0080	0.0000	0.0024
62	0.0625	0.0380	-0.0170	-0.0040	0.0001	0.0006
63	0.1475	0.0320	0.0679	-0.0100	-0.0007	0.0133
64	0.0419	0.0200	-0.0377	-0.0220	0.0008	0.0005
65	0.0413	0.0320	-0.0382	-0.0100	0.0004	0.0001
66	0.0416	0.0410	-0.0379	-0.0010	0.0000	0.0000
71	0.0522	0.0460	-0.0273	0.0040	-0.0001	0.0000
72	0.0396	0.0410	-0.0399	-0.0010	0.0000	0.0000
73	0.0471	0.0470	-0.0324	0.0050	-0.0002	0.0000
76	0.0581	0.0870	-0.0214	0.0450	-0.0010	0.0008
77	0.0548	0.0340	-0.0247	-0.0080	0.0002	0.0004
78	0.0406	0.0330	-0.0389	-0.0090	0.0004	0.0001

79	0.0389	0.0360	-0.0406	-0.0060	0.0002	0.0000
80	0.0450	0.0450	-0.0345	0.0030	-0.0001	0.0000
81	0.0936	0.0620	0.0140	0.0200	0.0003	0.0010
82	0.0536	0.0480	-0.0259	0.0060	-0.0002	0.0000
83	0.0411	0.0490	-0.0385	0.0070	-0.0003	0.0001
84	0.0385	0.0340	-0.0411	-0.0080	0.0003	0.0000
85	0.0413	0.0420	-0.0382	0.0000	0.0000	0.0000
86	0.0639	0.0370	-0.0156	-0.0050	0.0001	0.0007
87	0.0371	0.0440	-0.0424	0.0020	-0.0001	0.0000
93	0.0527	0.0430	-0.0269	0.0010	0.0000	0.0001
94	0.0440	0.0480	-0.0355	0.0060	-0.0002	0.0000
95	0.0384	0.0480	-0.0412	0.0060	-0.0002	0.0001
96	0.0428	0.0370	-0.0367	-0.0050	0.0002	0.0000
97	0.0424	0.0330	-0.0371	-0.0090	0.0003	0.0001
98	0.0404	0.0190	-0.0391	-0.0230	0.0009	0.0005
99	0.0405	0.0370	-0.0390	-0.0050	0.0002	0.0000
100	0.0396	0.0420	-0.0399	0.0000	0.0000	0.0000
108	0.0327	0.0310	-0.0469	-0.0110	0.0005	0.0000
110	0.0483	0.0390	-0.0312	-0.0030	0.0001	0.0001
111	0.0411	0.0200	-0.0384	-0.0220	0.0008	0.0004
112	0.0437	0.0130	-0.0358	-0.0290	0.0010	0.0009
118	0.0413	0.0630	-0.0382	0.0210	-0.0008	0.0005
122	0.0413	0.0320	-0.0382	-0.0100	0.0004	0.0001
123	0.0436	0.0490	-0.0360	0.0070	-0.0003	0.0000
124	0.0413	0.0370	-0.0382	-0.0050	0.0002	0.0000
125	0.0433	0.0370	-0.0362	-0.0050	0.0002	0.0000
126	0.0436	0.0410	-0.0359	-0.0010	0.0000	0.0000
127	0.0413	0.0340	-0.0382	-0.0080	0.0003	0.0001
128	0.0462	0.0530	-0.0333	0.0110	-0.0004	0.0000
130	0.0413	0.0430	-0.0382	0.0010	0.0000	0.0000
131	0.0411	0.0510	-0.0384	0.0090	-0.0003	0.0001
134	0.0463	0.0310	-0.0332	-0.0110	0.0004	0.0002
135	0.0388	0.0480	-0.0408	0.0060	-0.0002	0.0001
136	0.0413	0.0390	-0.0382	-0.0030	0.0001	0.0000
145	0.0443	0.0440	-0.0353	0.0020	-0.0001	0.0000
146	0.0380	0.0420	-0.0416	0.0000	0.0000	0.0000
147	0.0494	0.0380	-0.0301	-0.0040	0.0001	0.0001
149	0.0436	0.0390	-0.0359	-0.0030	0.0001	0.0000
150	0.0456	0.0430	-0.0339	0.0010	0.0000	0.0000
151	0.0429	0.0590	-0.0366	0.0170	-0.0006	0.0003
158	0.0663	0.0260	-0.0133	-0.0160	0.0002	0.0016
159	0.0409	0.0320	-0.0386	-0.0100	0.0004	0.0001
161	0.0937	0.0500	0.0142	0.0080	0.0001	0.0019
162	0.0477	0.0530	-0.0319	0.0110	-0.0003	0.0000
163	0.0383	0.0370	-0.0412	-0.0050	0.0002	0.0000
164	0.0407	0.0410	-0.0389	-0.0010	0.0000	0.0000
168	0.0468	0.0390	-0.0328	-0.0030	0.0001	0.0001
169	0.0380	0.0300	-0.0416	-0.0120	0.0005	0.0001
174	0.0397	0.0360	-0.0398	-0.0060	0.0002	0.0000
175	0.0422	0.0540	-0.0374	0.0120	-0.0004	0.0001
176	0.0436	0.0430	-0.0360	0.0010	0.0000	0.0000
177	0.0617	0.0660	-0.0179	0.0240	-0.0004	0.0000
179	0.0455	0.0360	-0.0340	-0.0060	0.0002	0.0001
180	0.0391	0.0440	-0.0404	0.0020	-0.0001	0.0000
181	0.0398	0.0470	-0.0397	0.0050	-0.0002	0.0001
182	0.0604	0.0400	-0.0191	-0.0020	0.0000	0.0004
183	0.0383	0.0370	-0.0412	-0.0050	0.0002	0.0000
184	0.0797	0.0330	0.0002	-0.0090	0.0000	0.0022
185	0.0457	0.0460	-0.0338	0.0040	-0.0001	0.0000
186	0.0397	0.0390	-0.0398	-0.0030	0.0001	0.0000
187	0.0420	0.0460	-0.0375	0.0040	-0.0001	0.0000
188	0.0500	0.0560	-0.0295	0.0140	-0.0004	0.0000
191	0.0707	0.0680	-0.0088	0.0260	-0.0002	0.0000
192	0.0569	0.0500	-0.0226	0.0080	-0.0002	0.0000
205	0.0413	0.0340	-0.0382	-0.0080	0.0003	0.0001
208	0.0405	0.0430	-0.0390	0.0010	0.0000	0.0000
218	0.0778	0.0680	-0.0018	0.0260	0.0000	0.0001

219	0.0492	0.0510	-0.0304	0.0090	-0.0003	0.0000
220	0.0420	0.0500	-0.0376	0.0080	-0.0003	0.0001
221	0.0418	0.0410	-0.0377	-0.0010	0.0000	0.0000
224	0.0721	0.0390	-0.0074	-0.0030	0.0000	0.0011
225	0.0401	0.0450	-0.0395	0.0030	-0.0001	0.0000
226	0.0428	0.0470	-0.0368	0.0050	-0.0002	0.0000
228	0.0797	0.0380	0.0002	-0.0040	0.0000	0.0017
229	0.0420	0.0380	-0.0376	-0.0040	0.0002	0.0000
230	0.0413	0.0410	-0.0382	-0.0010	0.0000	0.0000
231	0.0429	0.0470	-0.0366	0.0050	-0.0002	0.0000
234	0.0628	0.0300	-0.0167	-0.0120	0.0002	0.0011
235	0.0403	0.0280	-0.0392	-0.0140	0.0006	0.0002
236	0.0435	0.0290	-0.0361	-0.0130	0.0005	0.0002
237	0.0875	0.0580	0.0080	0.0160	0.0001	0.0009
238	0.0410	0.0460	-0.0386	0.0040	-0.0002	0.0000
240	0.0391	0.0400	-0.0405	-0.0020	0.0001	0.0000
241	0.0731	0.0410	-0.0065	-0.0010	0.0000	0.0010
243	0.0379	0.0370	-0.0416	-0.0050	0.0002	0.0000
244	0.0442	0.0390	-0.0353	-0.0030	0.0001	0.0000
245	0.0473	0.0400	-0.0322	-0.0020	0.0001	0.0001
246	0.0402	0.0310	-0.0393	-0.0110	0.0004	0.0001
247	0.0438	0.0110	-0.0357	-0.0310	0.0011	0.0011
250	0.0580	0.0340	-0.0215	-0.0080	0.0002	0.0006
262	0.0988	0.0270	0.0193	-0.0150	-0.0003	0.0052
264	0.0853	0.0470	0.0057	0.0050	0.0000	0.0015
265	0.1194	0.1020	0.0399	0.0600	0.0024	0.0003
271	0.0413	0.0460	-0.0382	0.0040	-0.0002	0.0000
272	0.0433	0.0320	-0.0362	-0.0100	0.0004	0.0001
274	0.0413	0.0240	-0.0382	-0.0180	0.0007	0.0003
276	0.0413	0.0540	-0.0382	0.0120	-0.0005	0.0002
277	0.0413	0.0440	-0.0382	0.0020	-0.0001	0.0000
278	0.0413	0.0360	-0.0382	-0.0060	0.0002	0.0000
279	0.0414	0.0280	-0.0382	-0.0140	0.0005	0.0002
280	0.0413	0.0310	-0.0382	-0.0110	0.0004	0.0001
284	0.1032	0.0740	0.0237	0.0320	0.0008	0.0009
285	0.2854	0.2160	0.2059	0.1740	0.0358	0.0048
290	0.1633	0.2670	0.0837	0.2250	0.0188	0.0108
294	0.1296	0.1410	0.0500	0.0990	0.0050	0.0001
297	0.0548	0.0660	-0.0248	0.0240	-0.0006	0.0001
301	0.0464	0.0460	-0.0331	0.0040	-0.0001	0.0000
303	0.0647	0.0750	-0.0149	0.0330	-0.0005	0.0001
304	0.0496	0.0490	-0.0300	0.0070	-0.0002	0.0000
310	0.0981	0.0650	0.0186	0.0230	0.0004	0.0011
313	0.0452	0.0290	-0.0343	-0.0130	0.0004	0.0003
314	0.0279	0.0330	-0.0516	-0.0090	0.0005	0.0000
317	0.0963	0.0760	0.0168	0.0340	0.0006	0.0004
319	0.0437	0.0480	-0.0359	0.0060	-0.0002	0.0000
320	0.0632	0.0200	-0.0163	-0.0220	0.0004	0.0019
321	0.0428	0.0230	-0.0368	-0.0190	0.0007	0.0004
322	0.0397	0.0210	-0.0399	-0.0210	0.0008	0.0003
323	0.0409	0.0170	-0.0386	-0.0250	0.0010	0.0006
325	0.0426	0.0350	-0.0370	-0.0070	0.0003	0.0001
326	0.0417	0.0490	-0.0379	0.0070	-0.0003	0.0001
327	0.0413	0.0290	-0.0382	-0.0130	0.0005	0.0002
329	0.0468	0.0440	-0.0328	0.0020	-0.0001	0.0000
330	0.0417	0.0300	-0.0378	-0.0120	0.0005	0.0001
331	0.0420	0.0370	-0.0376	-0.0050	0.0002	0.0000
333	0.0406	0.0440	-0.0390	0.0020	-0.0001	0.0000
335	0.0428	0.0210	-0.0367	-0.0210	0.0008	0.0005
129b	0.0976	0.0790	0.0181	0.0370	0.0007	0.0003
129c	0.0365	0.0370	-0.0430	-0.0050	0.0002	0.0000
132a	0.1177	0.0890	0.0382	0.0470	0.0018	0.0008
132c	0.0376	0.0500	-0.0420	0.0080	-0.0003	0.0002
136b	0.0397	0.0330	-0.0398	-0.0090	0.0004	0.0000
136c	0.0634	0.0180	-0.0161	-0.0240	0.0004	0.0021
14a	0.0395	0.0390	-0.0400	-0.0030	0.0001	0.0000
212a	0.0814	0.0520	0.0018	0.0100	0.0000	0.0009

212b	0.0415	0.0330	-0.0380	-0.0090	0.0003	0.0001
212c	0.0418	0.0380	-0.0377	-0.0040	0.0002	0.0000
219A	0.0538	0.0180	-0.0257	-0.0240	0.0006	0.0013
21a	0.0311	0.0410	-0.0485	-0.0010	0.0000	0.0001
23b	0.0518	0.0400	-0.0277	-0.0020	0.0001	0.0001
23c	0.0613	0.0530	-0.0183	0.0110	-0.0002	0.0001
23d	0.1197	0.0570	0.0401	0.0150	0.0006	0.0039
2b	0.0510	0.0280	-0.0286	-0.0140	0.0004	0.0005
36d	0.0844	0.0460	0.0048	0.0040	0.0000	0.0015
3a	0.0487	0.0520	-0.0308	0.0100	-0.0003	0.0000
5a	0.0511	0.0230	-0.0285	-0.0190	0.0005	0.0008
66b	0.0296	0.0180	-0.0499	-0.0210	0.0010	0.0001
7a	0.0435	0.0360	-0.0360	-0.0060	0.0002	0.0001
Link-03	0.2892	0.3000	0.2097	0.2580	0.0541	0.0001
Link-09	0.1139	0.1250	0.0343	0.0830	0.0028	0.0001
Link-10	0.1116	0.1210	0.0321	0.0790	0.0025	0.0001
Link-11	0.1139	0.1230	0.0343	0.0810	0.0028	0.0001
Link-14	0.1752	0.1220	0.0956	0.0800	0.0076	0.0028
Link-17	0.2932	0.2890	0.2136	0.2470	0.0528	0.0000
Link-19	0.1075	0.0760	0.0280	0.0340	0.0010	0.0010
Link-23	0.1108	0.0790	0.0313	0.0370	0.0012	0.0010
Link-24	0.0422	0.0350	-0.0374	-0.0070	0.0003	0.0001
Link-28	0.0517	0.0480	-0.0279	0.0060	-0.0002	0.0000
Link-29	0.0358	0.0520	-0.0437	0.0100	-0.0004	0.0003
Link-30	0.0374	0.0300	-0.0421	-0.0120	0.0005	0.0001
Link-31	0.0480	0.0540	-0.0315	0.0120	-0.0004	0.0000
Link-32	0.0771	0.0600	-0.0025	0.0180	0.0000	0.0003
Link-35	0.0616	0.0410	-0.0179	-0.0010	0.0000	0.0004
Link-37	0.0744	0.0400	-0.0051	-0.0020	0.0000	0.0012
Link-39	0.0676	0.0370	-0.0119	-0.0050	0.0001	0.0009
Average	**0.0582**	**0.0480**	**-4.5913**	**1.2922**	**0.0010**	**0.0005**
S.D.	**0.0369**	**0.0360**				
R =	**0.7348**	**NMSE =**	**0.1930**			

Table 5: RMSE analysis data between the design discharge and predicted discharge from SWMM for the combined sewage system using rainfall intensity-25 years return period.

N0.	Pipe No.	Co	RMSE for rainfall intensity with 2-year return period		RMSE for rainfall intensity with 5-year return period		RMSE for rainfall intensity with 10-year return period		RMSE for rainfall intensity with 25-year return period	
			Cp	(Cp-Co)^2	Cp	(Cp-Co)^2	Cp	(Cp-Co)^2	Cp	(Cp-Co)^2
1	2	0.0758	0.0440	0.0010	0.0620	0.0002	0.0670	0.0001	0.0810	0.0000
2	5	0.0589	0.0080	0.0026	0.0350	0.0006	0.0480	0.0001	0.0740	0.0002
3	6	0.0413	0.0010	0.0016	0.0360	0.0000	0.0390	0.0000	0.0390	0.0000
4	7	0.0467	0.0030	0.0019	0.0250	0.0005	0.0340	0.0002	0.0410	0.0000
5	8	0.0461	0.0020	0.0019	0.0230	0.0005	0.0340	0.0001	0.0370	0.0001
6	9	0.0464	0.0060	0.0016	0.0310	0.0002	0.0400	0.0000	0.0370	0.0001
7	12	0.0327	0.0200	0.0002	0.0200	0.0002	0.0180	0.0002	0.0270	0.0000
8	13	0.0776	0.0190	0.0034	0.0240	0.0029	0.0220	0.0031	0.0240	0.0029
9	14	0.0707	0.0630	0.0001	0.0700	0.0000	0.0690	0.0000	0.0620	0.0001
10	16	0.0743	0.0350	0.0015	0.0400	0.0012	0.0410	0.0011	0.0420	0.0010
11	18	0.0700	0.0250	0.0020	0.0270	0.0018	0.0280	0.0018	0.0290	0.0017
12	19	0.0383	0.0250	0.0002	0.0330	0.0000	0.0340	0.0000	0.0370	0.0000
13	20	0.1383	0.0320	0.0113	0.0460	0.0085	0.0470	0.0083	0.0510	0.0076
14	22	0.0533	0.0030	0.0025	0.0150	0.0015	0.0230	0.0009	0.0280	0.0006
15	23	0.0413	0.0140	0.0007	0.0300	0.0001	0.0330	0.0001	0.0350	0.0000
16	24	0.0424	0.0050	0.0014	0.0240	0.0003	0.0310	0.0001	0.0220	0.0004
17	26	0.0363	0.0300	0.0000	0.0330	0.0000	0.0340	0.0000	0.0410	0.0000
18	29	0.0579	0.0380	0.0004	0.0440	0.0002	0.0480	0.0001	0.0490	0.0001
19	31	0.0624	0.0020	0.0037	0.0310	0.0010	0.0430	0.0004	0.0480	0.0002

20	32	0.0413	0.0010	0.0016	0.0440	0.0000	0.0450	0.0000	0.0560	0.0002
21	35	0.0448	0.0020	0.0018	0.0140	0.0010	0.0210	0.0006	0.0310	0.0002
22	36	0.0354	0.0210	0.0002	0.0380	0.0000	0.0390	0.0000	0.0390	0.0000
23	37	0.0705	0.0020	0.0047	0.0130	0.0033	0.0170	0.0029	0.0280	0.0018
24	38	0.0116	0.0170	0.0000	0.0300	0.0003	0.0310	0.0004	0.0310	0.0004
25	39	0.0589	0.0010	0.0033	0.0180	0.0017	0.0240	0.0012	0.0380	0.0004
26	40	0.0681	0.0110	0.0033	0.0240	0.0019	0.0340	0.0012	0.0400	0.0008
27	41	0.0481	0.0060	0.0018	0.0300	0.0003	0.0350	0.0002	0.0470	0.0000
28	42	0.0498	0.0010	0.0024	0.0390	0.0001	0.0460	0.0000	0.0350	0.0002
29	44	0.0926	0.0340	0.0034	0.0410	0.0027	0.0430	0.0025	0.0440	0.0024
30	45	0.0438	0.0400	0.0000	0.0460	0.0000	0.0470	0.0000	0.0480	0.0000
31	46	0.0818	0.0340	0.0023	0.0380	0.0019	0.0380	0.0019	0.0390	0.0018
32	47	0.0413	0.0170	0.0006	0.0240	0.0003	0.0260	0.0002	0.0380	0.0000
33	48	0.0413	0.0260	0.0002	0.0370	0.0000	0.0370	0.0000	0.0390	0.0000
34	49	0.0413	0.0210	0.0004	0.0430	0.0000	0.0470	0.0000	0.0500	0.0001
35	51	0.0407	0.0220	0.0004	0.0400	0.0000	0.0440	0.0000	0.0470	0.0000
36	54	0.0394	0.0150	0.0006	0.0260	0.0002	0.0340	0.0000	0.0420	0.0000
37	55	0.0392	0.0180	0.0005	0.0250	0.0002	0.0270	0.0001	0.0290	0.0001
38	59	0.0515	0.0080	0.0019	0.0190	0.0011	0.0210	0.0009	0.0280	0.0006
39	60	0.0492	0.0050	0.0019	0.0130	0.0013	0.0150	0.0012	0.0240	0.0006
40	61	0.0827	0.0070	0.0057	0.0220	0.0037	0.0230	0.0036	0.0340	0.0024
41	62	0.0625	0.0040	0.0034	0.0220	0.0016	0.0290	0.0011	0.0380	0.0006
42	63	0.1475	0.0020	0.0212	0.0320	0.0133	0.0510	0.0093	0.0320	0.0133
43	64	0.0419	0.0110	0.0010	0.0130	0.0008	0.0130	0.0008	0.0200	0.0005
44	65	0.0413	0.0300	0.0001	0.0310	0.0001	0.0310	0.0001	0.0320	0.0001
45	66	0.0416	0.0420	0.0000	0.0420	0.0000	0.0420	0.0000	0.0410	0.0000
46	71	0.0522	0.0230	0.0009	0.0310	0.0005	0.0390	0.0002	0.0460	0.0000
47	72	0.0396	0.0270	0.0002	0.0340	0.0000	0.0360	0.0000	0.0410	0.0000
48	73	0.0471	0.0300	0.0003	0.0380	0.0001	0.0420	0.0000	0.0470	0.0000
49	76	0.0581	0.0770	0.0004	0.0850	0.0007	0.0860	0.0008	0.0870	0.0008
50	77	0.0548	0.0190	0.0013	0.0250	0.0009	0.0280	0.0007	0.0340	0.0004
51	78	0.0406	0.0220	0.0003	0.0280	0.0002	0.0280	0.0002	0.0330	0.0001
52	79	0.0389	0.0250	0.0002	0.0320	0.0000	0.0330	0.0000	0.0360	0.0000
53	80	0.0450	0.0270	0.0003	0.0350	0.0001	0.0400	0.0000	0.0450	0.0000
54	81	0.0936	0.0590	0.0012	0.0590	0.0012	0.0590	0.0012	0.0620	0.0010
55	82	0.0536	0.0400	0.0002	0.0510	0.0000	0.0560	0.0000	0.0480	0.0000
56	83	0.0411	0.0270	0.0002	0.0280	0.0002	0.0360	0.0000	0.0490	0.0001
57	84	0.0385	0.0290	0.0001	0.0310	0.0001	0.0320	0.0000	0.0340	0.0000
58	85	0.0413	0.0290	0.0002	0.0370	0.0000	0.0390	0.0000	0.0420	0.0000
59	86	0.0639	0.0300	0.0011	0.0330	0.0010	0.0340	0.0009	0.0370	0.0007
60	87	0.0371	0.0360	0.0000	0.0400	0.0000	0.0420	0.0000	0.0440	0.0000
61	93	0.0527	0.0290	0.0006	0.0390	0.0002	0.0420	0.0001	0.0430	0.0001
62	94	0.0440	0.0330	0.0001	0.0430	0.0000	0.0470	0.0000	0.0480	0.0000
63	95	0.0384	0.0290	0.0001	0.0360	0.0000	0.0430	0.0000	0.0480	0.0001
64	96	0.0428	0.0320	0.0001	0.0340	0.0001	0.0350	0.0001	0.0370	0.0000
65	97	0.0424	0.0330	0.0001	0.0370	0.0000	0.0370	0.0000	0.0330	0.0001
66	98	0.0404	0.0190	0.0005	0.0150	0.0006	0.0140	0.0007	0.0190	0.0005
67	99	0.0405	0.0360	0.0000	0.0400	0.0000	0.0410	0.0000	0.0370	0.0000
68	100	0.0396	0.0270	0.0002	0.0410	0.0000	0.0340	0.0000	0.0420	0.0000
69	108	0.0327	0.0290	0.0000	0.0260	0.0000	0.0250	0.0001	0.0310	0.0000
70	110	0.0483	0.0320	0.0003	0.0210	0.0007	0.0300	0.0003	0.0390	0.0001
71	111	0.0411	0.0200	0.0004	0.0240	0.0003	0.0240	0.0003	0.0200	0.0004
72	112	0.0437	0.0230	0.0004	0.0210	0.0005	0.0200	0.0006	0.0130	0.0009

73	118	0.0413	0.0710	0.0009	0.0680	0.0007	0.0650	0.0006	0.0630	0.0005
74	122	0.0413	0.0310	0.0001	0.0370	0.0000	0.0360	0.0000	0.0320	0.0001
75	123	0.0436	0.0220	0.0005	0.0330	0.0001	0.0400	0.0000	0.0490	0.0000
76	124	0.0413	0.0260	0.0002	0.0320	0.0001	0.0350	0.0000	0.0370	0.0000
77	125	0.0433	0.0220	0.0005	0.0310	0.0002	0.0330	0.0001	0.0370	0.0000
78	126	0.0436	0.0270	0.0003	0.0360	0.0001	0.0370	0.0000	0.0410	0.0000
79	127	0.0413	0.0410	0.0000	0.0390	0.0000	0.0370	0.0000	0.0340	0.0001
80	128	0.0462	0.0410	0.0000	0.0490	0.0000	0.0500	0.0000	0.0530	0.0000
81	130	0.0413	0.0460	0.0000	0.0450	0.0000	0.0440	0.0000	0.0430	0.0000
82	131	0.0411	0.0410	0.0000	0.0440	0.0000	0.0470	0.0000	0.0510	0.0001
83	134	0.0463	0.0390	0.0001	0.0280	0.0003	0.0280	0.0003	0.0310	0.0002
84	135	0.0388	0.0390	0.0000	0.0400	0.0000	0.0440	0.0000	0.0480	0.0001
85	136	0.0413	0.0380	0.0000	0.0410	0.0000	0.0410	0.0000	0.0390	0.0000
86	145	0.0443	0.0390	0.0000	0.0440	0.0000	0.0440	0.0000	0.0440	0.0000
87	146	0.0380	0.0340	0.0000	0.0410	0.0000	0.0420	0.0000	0.0420	0.0000
88	147	0.0494	0.0320	0.0003	0.0380	0.0001	0.0380	0.0001	0.0380	0.0001
89	149	0.0436	0.0300	0.0002	0.0360	0.0001	0.0380	0.0000	0.0390	0.0000
90	150	0.0456	0.0390	0.0000	0.0430	0.0000	0.0440	0.0000	0.0430	0.0000
91	151	0.0429	0.0480	0.0000	0.0550	0.0001	0.0570	0.0002	0.0590	0.0003
92	154	0.0400	0.0240	0.0003	0.0230	0.0003	0.0210	0.0004	0.0260	0.0002
93	155	0.0462	0.0280	0.0003	0.0260	0.0004	0.0260	0.0004	0.0320	0.0002
94	158	0.0663	0.0460	0.0004	0.0500	0.0003	0.0500	0.0003	0.0500	0.0003
95	159	0.0409	0.0400	0.0000	0.0460	0.0000	0.0490	0.0001	0.0530	0.0001
96	161	0.0937	0.0340	0.0036	0.0340	0.0036	0.0330	0.0037	0.0370	0.0032
97	162	0.0477	0.0390	0.0001	0.0410	0.0000	0.0410	0.0000	0.0410	0.0000
98	163	0.0383	0.0250	0.0002	0.0400	0.0000	0.0390	0.0000	0.0390	0.0000
99	164	0.0407	0.0300	0.0001	0.0270	0.0002	0.0260	0.0002	0.0300	0.0001
100	168	0.0468	0.0320	0.0002	0.0390	0.0001	0.0370	0.0001	0.0360	0.0001
101	169	0.0380	0.0250	0.0002	0.0370	0.0000	0.0480	0.0001	0.0540	0.0003
102	174	0.0397	0.0450	0.0000	0.0390	0.0000	0.0410	0.0000	0.0430	0.0000
103	175	0.0422	0.0260	0.0003	0.0490	0.0000	0.0600	0.0003	0.0660	0.0006
104	176	0.0436	0.0220	0.0005	0.0240	0.0004	0.0280	0.0002	0.0360	0.0001
105	177	0.0617	0.0290	0.0011	0.0340	0.0008	0.0360	0.0007	0.0440	0.0003
106	179	0.0455	0.0320	0.0002	0.0380	0.0001	0.0390	0.0000	0.0470	0.0000
107	180	0.0391	0.0360	0.0000	0.0420	0.0000	0.0400	0.0000	0.0400	0.0000
108	181	0.0398	0.0210	0.0004	0.0270	0.0002	0.0320	0.0001	0.0370	0.0000
109	182	0.0604	0.0250	0.0013	0.0330	0.0008	0.0330	0.0008	0.0330	0.0008
110	183	0.0383	0.0260	0.0002	0.0320	0.0000	0.0380	0.0000	0.0460	0.0001
111	184	0.0797	0.0300	0.0025	0.0410	0.0015	0.0360	0.0019	0.0390	0.0017
112	185	0.0457	0.0330	0.0002	0.0480	0.0000	0.0450	0.0000	0.0460	0.0000
113	186	0.0397	0.0300	0.0001	0.0500	0.0001	0.0520	0.0002	0.0560	0.0003
114	187	0.0420	0.0360	0.0000	0.0550	0.0002	0.0640	0.0005	0.0680	0.0007
115	188	0.0500	0.0320	0.0003	0.0400	0.0001	0.0440	0.0000	0.0500	0.0000
116	191	0.0707	0.0170	0.0029	0.0240	0.0022	0.0300	0.0017	0.0340	0.0013
117	192	0.0569	0.0220	0.0012	0.0390	0.0003	0.0340	0.0005	0.0430	0.0002
118	205	0.0413	0.0330	0.0001	0.0610	0.0004	0.0650	0.0006	0.0680	0.0007
119	208	0.0405	0.0270	0.0002	0.0460	0.0000	0.0510	0.0001	0.0510	0.0001
120	218	0.0778	0.0210	0.0032	0.0320	0.0021	0.0450	0.0011	0.0500	0.0008
121	219	0.0492	0.0270	0.0005	0.0350	0.0002	0.0370	0.0001	0.0410	0.0001
122	220	0.0420	0.0230	0.0004	0.0290	0.0002	0.0300	0.0001	0.0390	0.0000
123	221	0.0418	0.0260	0.0003	0.0330	0.0001	0.0370	0.0000	0.0450	0.0000
124	224	0.0721	0.0270	0.0020	0.0380	0.0012	0.0430	0.0008	0.0470	0.0006
125	225	0.0401	0.0230	0.0003	0.0300	0.0001	0.0350	0.0000	0.0380	0.0000

126	226	0.0428	0.0270	0.0002	0.0340	0.0001	0.0350	0.0001	0.0380	0.0000
127	228	0.0797	0.0300	0.0025	0.0370	0.0018	0.0390	0.0017	0.0410	0.0015
128	229	0.0420	0.0340	0.0001	0.0410	0.0000	0.0440	0.0000	0.0470	0.0000
129	230	0.0413	0.0240	0.0003	0.0270	0.0002	0.0280	0.0002	0.0300	0.0001
130	231	0.0429	0.0210	0.0005	0.0240	0.0004	0.0250	0.0003	0.0280	0.0002
131	234	0.0628	0.0150	0.0023	0.0230	0.0016	0.0250	0.0014	0.0290	0.0011
132	235	0.0403	0.0520	0.0001	0.0550	0.0002	0.0560	0.0002	0.0580	0.0003
133	236	0.0435	0.0460	0.0000	0.0460	0.0000	0.0460	0.0000	0.0460	0.0000
134	237	0.0875	0.0400	0.0023	0.0400	0.0023	0.0400	0.0023	0.0400	0.0023
135	238	0.0410	0.0220	0.0004	0.0350	0.0000	0.0370	0.0000	0.0410	0.0000
136	240	0.0391	0.0280	0.0001	0.0310	0.0001	0.0340	0.0000	0.0370	0.0000
137	241	0.0731	0.0300	0.0019	0.0330	0.0016	0.0360	0.0014	0.0390	0.0012
138	243	0.0379	0.0320	0.0000	0.0390	0.0000	0.0410	0.0000	0.0400	0.0000
139	244	0.0442	0.0190	0.0006	0.0270	0.0003	0.0290	0.0002	0.0310	0.0002
140	245	0.0473	0.0070	0.0016	0.0090	0.0015	0.0100	0.0014	0.0110	0.0013
141	246	0.0402	0.0240	0.0003	0.0310	0.0001	0.0330	0.0001	0.0340	0.0000
142	247	0.0438	0.0130	0.0010	0.0370	0.0000	0.0320	0.0001	0.0270	0.0003
143	250	0.0580	0.0290	0.0008	0.0440	0.0002	0.0460	0.0001	0.0470	0.0001
144	262	0.0988	0.1030	0.0000	0.1000	0.0000	0.1000	0.0000	0.1020	0.0000
145	264	0.0853	0.0130	0.0052	0.0260	0.0035	0.0310	0.0029	0.0460	0.0015
146	265	0.1194	0.0100	0.0120	0.0180	0.0103	0.0220	0.0095	0.0320	0.0076
147	271	0.0413	0.0090	0.0010	0.0120	0.0009	0.0160	0.0006	0.0240	0.0003
148	272	0.0433	0.0050	0.0015	0.0460	0.0000	0.0430	0.0000	0.0540	0.0001
149	274	0.0413	0.0310	0.0001	0.0380	0.0000	0.0340	0.0001	0.0440	0.0000
150	276	0.0413	0.0350	0.0000	0.0290	0.0002	0.0260	0.0002	0.0360	0.0000
151	277	0.0413	0.0370	0.0000	0.0240	0.0003	0.0200	0.0005	0.0280	0.0002
152	278	0.0413	0.0420	0.0000	0.0330	0.0001	0.0320	0.0001	0.0310	0.0001
153	284	0.1032	0.0560	0.0022	0.0630	0.0016	0.0710	0.0010	0.0740	0.0009
154	285	0.2854	0.1500	0.0183	0.1720	0.0129	0.1920	0.0087	0.2160	0.0048
155	290	0.1633	0.1390	0.0006	0.1790	0.0002	0.2150	0.0027	0.2670	0.0108
156	294	0.1296	0.0900	0.0016	0.1050	0.0006	0.1170	0.0002	0.1410	0.0001
157	297	0.0548	0.0470	0.0001	0.0560	0.0000	0.0590	0.0000	0.0660	0.0001
158	301	0.0464	0.0250	0.0005	0.0390	0.0001	0.0430	0.0000	0.0460	0.0000
159	303	0.0647	0.0620	0.0000	0.0670	0.0000	0.0690	0.0000	0.0750	0.0001
160	304	0.0496	0.0370	0.0002	0.0450	0.0000	0.0460	0.0000	0.0490	0.0000
161	310	0.0981	0.0620	0.0013	0.0460	0.0027	0.0460	0.0027	0.0650	0.0011
162	313	0.0452	0.0230	0.0005	0.0320	0.0002	0.0320	0.0002	0.0290	0.0003
163	314	0.0279	0.0250	0.0000	0.0280	0.0000	0.0310	0.0000	0.0330	0.0000
164	317	0.0963	0.0250	0.0051	0.0540	0.0018	0.0620	0.0012	0.0760	0.0004
165	319	0.0437	0.0190	0.0006	0.0390	0.0000	0.0430	0.0000	0.0480	0.0000
166	320	0.0632	0.0170	0.0021	0.0180	0.0020	0.0210	0.0018	0.0200	0.0019
167	321	0.0428	0.0160	0.0007	0.0190	0.0006	0.0220	0.0004	0.0230	0.0004
168	322	0.0397	0.0120	0.0008	0.0160	0.0006	0.0160	0.0006	0.0210	0.0003
169	323	0.0409	0.0080	0.0011	0.0100	0.0010	0.0120	0.0008	0.0170	0.0006
170	325	0.0426	0.0240	0.0003	0.0320	0.0001	0.0370	0.0000	0.0350	0.0001
171	326	0.0417	0.0140	0.0008	0.0220	0.0004	0.0290	0.0002	0.0490	0.0001
172	327	0.0413	0.0270	0.0002	0.0270	0.0002	0.0280	0.0002	0.0290	0.0002
173	329	0.0468	0.0300	0.0003	0.0380	0.0001	0.0400	0.0000	0.0440	0.0000
174	330	0.0417	0.0250	0.0003	0.0310	0.0001	0.0330	0.0001	0.0300	0.0001
175	331	0.0420	0.0190	0.0005	0.0300	0.0001	0.0330	0.0001	0.0370	0.0000
176	333	0.0406	0.0300	0.0001	0.0400	0.0000	0.0420	0.0000	0.0440	0.0000
177	335	0.0428	0.0170	0.0007	0.0200	0.0005	0.0210	0.0005	0.0210	0.0005
178	129b	0.0976	0.0320	0.0043	0.0670	0.0009	0.0780	0.0004	0.0790	0.0003

179	129c	0.0365	0.0230	0.0002	0.0290	0.0001	0.0320	0.0000	0.0370	0.0000
180	132a	0.1177	0.0510	0.0045	0.0670	0.0026	0.0710	0.0022	0.0890	0.0008
181	136a	0.0574	0.0280	0.0009	0.0280	0.0009	0.0350	0.0005	0.0500	0.0001
182	136b	0.0397	0.0280	0.0001	0.0310	0.0001	0.0340	0.0000	0.0330	0.0000
183	136c	0.0634	0.0140	0.0024	0.0270	0.0013	0.0150	0.0023	0.0180	0.0021
184	14a	0.0395	0.0430	0.0000	0.0380	0.0000	0.0390	0.0000	0.0390	0.0000
185	212a	0.0814	0.0290	0.0027	0.0360	0.0021	0.0440	0.0014	0.0520	0.0009
186	212b	0.0415	0.0210	0.0004	0.0260	0.0002	0.0300	0.0001	0.0330	0.0001
187	212c	0.0418	0.0260	0.0002	0.0350	0.0000	0.0350	0.0000	0.0380	0.0000
188	219A	0.0538	0.0230	0.0009	0.0220	0.0010	0.0130	0.0017	0.0180	0.0013
189	21a	0.0311	0.0200	0.0001	0.0340	0.0000	0.0370	0.0000	0.0410	0.0001
190	23b	0.0518	0.0260	0.0007	0.0330	0.0004	0.0360	0.0002	0.0400	0.0001
191	23c	0.0613	0.0440	0.0003	0.0500	0.0001	0.0510	0.0001	0.0530	0.0001
192	23d	0.1197	0.0400	0.0063	0.0440	0.0057	0.0520	0.0046	0.0570	0.0039
193	2b	0.0510	0.0040	0.0022	0.0150	0.0013	0.0260	0.0006	0.0280	0.0005
194	36d	0.0844	0.0390	0.0021	0.0440	0.0016	0.0450	0.0015	0.0460	0.0015
195	3a	0.0487	0.0260	0.0005	0.0450	0.0000	0.0480	0.0000	0.0520	0.0000
196	5a	0.0511	0.0050	0.0021	0.0150	0.0013	0.0220	0.0008	0.0230	0.0008
197	66b	0.0296	0.0190	0.0001	0.0310	0.0000	0.0300	0.0000	0.0180	0.0001
198	7a	0.0435	0.0090	0.0012	0.0270	0.0003	0.0360	0.0001	0.0360	0.0001
199	Link-03	0.2892	0.2200	0.0048	0.2890	0.0000	0.3050	0.0002	0.3000	0.0001
200	Link-09	0.1139	0.1070	0.0000	0.1250	0.0001	0.1250	0.0001	0.1250	0.0001
201	Link-10	0.1116	0.1070	0.0000	0.1260	0.0002	0.1210	0.0001	0.1210	0.0001
202	Link-11	0.1139	0.0820	0.0010	0.1270	0.0002	0.1310	0.0003	0.1230	0.0001
203	Link-14	0.1752	0.0910	0.0071	0.0910	0.0071	0.1230	0.0027	0.1220	0.0028
204	Link-17	0.2932	0.2200	0.0054	0.2850	0.0001	0.2930	0.0000	0.2890	0.0000
205	Link-19	0.1075	0.0540	0.0029	0.0730	0.0012	0.0730	0.0012	0.0760	0.0010
206	Link-23	0.1108	0.0330	0.0061	0.0550	0.0031	0.0690	0.0017	0.0790	0.0010
207	Link-24	0.0422	0.0080	0.0012	0.0390	0.0000	0.0400	0.0000	0.0350	0.0001
208	Link-28	0.0517	0.0350	0.0003	0.0460	0.0000	0.0480	0.0000	0.0480	0.0000
209	Link-29	0.0358	0.0420	0.0000	0.0480	0.0001	0.0490	0.0002	0.0520	0.0003
210	Link-30	0.0374	0.0270	0.0001	0.0280	0.0001	0.0290	0.0001	0.0300	0.0001
211	Link-31	0.0480	0.0380	0.0001	0.0490	0.0000	0.0510	0.0000	0.0540	0.0000
212	Link-32	0.0771	0.0010	0.0058	0.0340	0.0019	0.0540	0.0005	0.0600	0.0003
213	Link-35	0.0616	0.0170	0.0020	0.0300	0.0010	0.0350	0.0007	0.0410	0.0004
214	Link-37	0.0744	0.0330	0.0017	0.0370	0.0014	0.0390	0.0013	0.0400	0.0012
215	Link-39	0.0676	0.0210	0.0022	0.0340	0.0011	0.0370	0.0009	0.0370	0.0009
RMSE				**0.0363**		**0.0281**		**0.0255**		**0.0241**

Table 6: RMSE between Max flow rate of event on 28-11-2020 and Max flow rate of the rainfall intensities for 2, 5, 10, and 25 years return periods.

Pipe No.	Max flow in pipes with rainfall event in 28-11-2020 (Co)	Max flow in pipes with 2 years return period (Cp)	(Co-Cp)^2	Max flow in pipes with 5 years return period (Cp)	(Co-Cp)^2	Max flow in pipes with 10 years return period (Cp)	(Co-Cp)^2	Max flow in pipes with 25 years return period (Cp)	(Co-Cp)^2
1	0.084	0.051	0.0011	0.065	0.0004	0.065	0.0004	0.069	0.0002
2	0.123	0.044	0.0062	0.062	0.0037	0.067	0.0031	0.081	0.0018
3	0.052	0.001	0.0026	0.020	0.0010	0.024	0.0008	0.023	0.0008
4	0.075	0.002	0.0053	0.021	0.0029	0.028	0.0022	0.033	0.0018
5	0.108	0.008	0.0100	0.035	0.0053	0.048	0.0036	0.074	0.0012
6	0.064	0.001	0.0040	0.036	0.0008	0.039	0.0006	0.039	0.0006
7	0.090	0.003	0.0076	0.025	0.0042	0.034	0.0031	0.041	0.0024

8	0.089	0.002	0.0076	0.023	0.0044	0.034	0.0030	0.037	0.0027
9	0.054	0.006	0.0023	0.031	0.0005	0.04	0.0002	0.037	0.0003
10	0.046	0.002	0.0019	0.032	0.0002	0.032	0.0002	0.041	0.0000
11	0.050	0.001	0.0024	0.038	0.0001	0.043	0.0000	0.051	0.0000
12	0.087	0.020	0.0045	0.020	0.0045	0.018	0.0048	0.027	0.0036
13	0.068	0.019	0.0024	0.024	0.0019	0.022	0.0021	0.024	0.0019
14	0.068	0.063	0.0000	0.070	0.0000	0.069	0.0000	0.062	0.0000
15	0.044	0.067	0.0005	0.076	0.0010	0.076	0.0010	0.07	0.0007
16	0.054	0.035	0.0004	0.040	0.0002	0.041	0.0002	0.042	0.0001
17	0.068	0.037	0.0010	0.046	0.0005	0.048	0.0004	0.05	0.0003
18	0.054	0.025	0.0008	0.027	0.0007	0.028	0.0007	0.029	0.0006
19	0.057	0.025	0.0010	0.033	0.0006	0.034	0.0005	0.037	0.0004
20	0.086	0.032	0.0029	0.046	0.0016	0.047	0.0015	0.051	0.0012
22	0.056	0.003	0.0028	0.015	0.0017	0.023	0.0011	0.028	0.0008
23	0.078	0.014	0.0041	0.030	0.0023	0.033	0.0020	0.035	0.0018
24	0.056	0.005	0.0026	0.024	0.0010	0.031	0.0006	0.022	0.0012
25	0.050	0.002	0.0023	0.047	0.0000	0.057	0.0000	0.046	0.0000
26	0.043	0.030	0.0002	0.033	0.0001	0.034	0.0001	0.041	0.0000
27	0.059	0.044	0.0002	0.049	0.0001	0.052	0.0000	0.055	0.0000
28	0.037	0.023	0.0002	0.023	0.0002	0.022	0.0002	0.021	0.0003
29	0.063	0.038	0.0006	0.044	0.0004	0.048	0.0002	0.049	0.0002
31	0.089	0.002	0.0076	0.031	0.0034	0.043	0.0021	0.048	0.0017
32	0.066	0.001	0.0042	0.044	0.0005	0.045	0.0004	0.056	0.0001
33	0.061	0.033	0.0008	0.040	0.0004	0.072	0.0001	0.065	0.0000
34	0.076	0.030	0.0021	0.058	0.0003	0.058	0.0003	0.061	0.0002
35	0.042	0.002	0.0016	0.014	0.0008	0.021	0.0004	0.031	0.0001
36	0.042	0.021	0.0004	0.038	0.0000	0.039	0.0000	0.039	0.0000
37	0.062	0.002	0.0036	0.013	0.0024	0.017	0.0020	0.028	0.0012
38	0.042	0.017	0.0006	0.030	0.0001	0.031	0.0001	0.031	0.0001
39	0.038	0.001	0.0014	0.018	0.0004	0.024	0.0002	0.038	0.0000
40	0.064	0.011	0.0028	0.024	0.0016	0.034	0.0009	0.04	0.0006
41	0.050	0.006	0.0019	0.030	0.0004	0.035	0.0002	0.047	0.0000
42	0.033	0.001	0.0010	0.039	0.0000	0.046	0.0002	0.035	0.0000
44	0.035	0.034	0.0000	0.041	0.0000	0.043	0.0001	0.044	0.0001
45	0.067	0.040	0.0007	0.046	0.0004	0.047	0.0004	0.048	0.0004
46	0.063	0.034	0.0008	0.038	0.0006	0.038	0.0006	0.039	0.0006
47	0.068	0.017	0.0026	0.024	0.0019	0.026	0.0018	0.038	0.0009
48	0.066	0.026	0.0016	0.037	0.0008	0.037	0.0008	0.039	0.0007
49	0.050	0.021	0.0008	0.043	0.0000	0.047	0.0000	0.05	0.0000
50	0.354	0.050	0.0924	0.163	0.0365	0.185	0.0286	0.24	0.0130
51	0.039	0.022	0.0003	0.040	0.0000	0.044	0.0000	0.047	0.0001
52	0.059	0.011	0.0023	0.013	0.0021	0.012	0.0022	0.011	0.0023
53	0.082	0.020	0.0038	0.014	0.0046	0.013	0.0048	0.017	0.0042
54	0.061	0.015	0.0021	0.026	0.0012	0.034	0.0007	0.042	0.0004
55	0.068	0.018	0.0025	0.025	0.0018	0.027	0.0017	0.029	0.0015
57	0.144	0.023	0.0146	0.052	0.0085	0.064	0.0064	0.069	0.0056
58	0.090	0.020	0.0049	0.053	0.0014	0.055	0.0012	0.058	0.0010
59	0.038	0.008	0.0009	0.019	0.0004	0.021	0.0003	0.028	0.0001
60	0.037	0.005	0.0010	0.013	0.0006	0.015	0.0005	0.024	0.0002
61	0.049	0.007	0.0018	0.022	0.0007	0.023	0.0007	0.034	0.0002
62	0.123	0.004	0.0142	0.022	0.0102	0.029	0.0088	0.038	0.0072
63	0.069	0.002	0.0045	0.032	0.0014	0.051	0.0003	0.032	0.0014
64	0.011	0.011	0.0000	0.013	0.0000	0.013	0.0000	0.02	0.0001
65	0.043	0.030	0.0002	0.031	0.0001	0.031	0.0001	0.032	0.0001

66	0.042	0.042	0.0000	0.042	0.0000	0.042	0.0000	0.041	0.0000
67	0.047	0.049	0.0000	0.051	0.0000	0.052	0.0000	0.075	0.0008
68	0.050	0.056	0.0000	0.060	0.0001	0.069	0.0004	0.075	0.0006
69	0.042	0.048	0.0000	0.045	0.0000	0.047	0.0000	0.055	0.0002
70	0.068	0.068	0.0000	0.068	0.0000	0.068	0.0000	0.073	0.0000
71	0.046	0.023	0.0005	0.031	0.0002	0.039	0.0000	0.046	0.0000
72	0.036	0.027	0.0001	0.034	0.0000	0.036	0.0000	0.041	0.0000
73	0.035	0.030	0.0000	0.038	0.0000	0.042	0.0000	0.047	0.0001
74	0.052	0.035	0.0003	0.044	0.0001	0.047	0.0000	0.05	0.0000
75	0.017	0.037	0.0004	0.045	0.0008	0.046	0.0008	0.052	0.0012
76	0.090	0.077	0.0002	0.085	0.0000	0.086	0.0000	0.087	0.0000
77	0.035	0.019	0.0003	0.025	0.0001	0.028	0.0000	0.034	0.0000
78	0.047	0.022	0.0006	0.028	0.0004	0.028	0.0004	0.033	0.0002
79	0.025	0.025	0.0000	0.032	0.0000	0.033	0.0001	0.036	0.0001
80	0.038	0.027	0.0001	0.035	0.0000	0.04	0.0000	0.045	0.0000
81	0.064	0.059	0.0000	0.059	0.0000	0.059	0.0000	0.062	0.0000
82	0.055	0.040	0.0002	0.051	0.0000	0.056	0.0000	0.048	0.0000
83	0.053	0.027	0.0007	0.028	0.0006	0.036	0.0003	0.049	0.0000
84	0.033	0.029	0.0000	0.031	0.0000	0.032	0.0000	0.034	0.0000
85	0.067	0.029	0.0014	0.037	0.0009	0.039	0.0008	0.042	0.0006
86	0.065	0.030	0.0012	0.033	0.0010	0.034	0.0010	0.037	0.0008
87	0.064	0.036	0.0008	0.040	0.0006	0.042	0.0005	0.044	0.0004
88	0.043	0.035	0.0001	0.048	0.0000	0.051	0.0001	0.054	0.0001
91	0.068	0.051	0.0003	0.060	0.0001	0.063	0.0000	0.066	0.0000
92	0.065	0.046	0.0004	0.049	0.0003	0.05	0.0002	0.05	0.0002
93	0.051	0.029	0.0005	0.039	0.0001	0.042	0.0001	0.043	0.0001
94	0.056	0.033	0.0005	0.043	0.0002	0.047	0.0001	0.048	0.0001
95	0.060	0.029	0.0010	0.036	0.0006	0.043	0.0003	0.048	0.0001
96	0.042	0.032	0.0001	0.034	0.0001	0.035	0.0000	0.037	0.0000
97	0.055	0.033	0.0005	0.037	0.0003	0.037	0.0003	0.033	0.0005
98	0.032	0.019	0.0002	0.015	0.0003	0.014	0.0003	0.019	0.0002
99	0.059	0.036	0.0005	0.040	0.0004	0.041	0.0003	0.037	0.0005
100	0.058	0.027	0.0010	0.041	0.0003	0.034	0.0006	0.042	0.0003
101	0.078	0.046	0.0010	0.056	0.0005	0.057	0.0004	0.053	0.0006
102	0.076	0.049	0.0007	0.060	0.0003	0.063	0.0002	0.074	0.0000
103	0.070	0.048	0.0005	0.139	0.0048	0.143	0.0053	0.198	0.0164
105	0.082	0.061	0.0004	0.081	0.0000	0.083	0.0000	0.086	0.0000
106	0.077	0.035	0.0018	0.057	0.0004	0.06	0.0003	0.062	0.0002
107	0.068	0.033	0.0012	0.045	0.0005	0.049	0.0004	0.057	0.0001
108	0.048	0.029	0.0004	0.026	0.0005	0.025	0.0005	0.031	0.0003
109	0.046	0.039	0.0000	0.033	0.0002	0.039	0.0000	0.042	0.0000
110	0.052	0.032	0.0004	0.021	0.0010	0.03	0.0005	0.039	0.0002
111	0.042	0.020	0.0005	0.024	0.0003	0.024	0.0003	0.02	0.0005
112	0.034	0.023	0.0001	0.021	0.0002	0.02	0.0002	0.013	0.0004
114	0.069	0.027	0.0018	0.026	0.0018	0.024	0.0020	0.024	0.0020
115	0.049	0.054	0.0000	0.057	0.0001	0.056	0.0000	0.057	0.0001
117	0.050	0.071	0.0004	0.068	0.0003	0.066	0.0003	0.063	0.0002
118	0.041	0.071	0.0009	0.068	0.0007	0.065	0.0006	0.063	0.0005
119	0.105	0.030	0.0056	0.050	0.0030	0.062	0.0018	0.086	0.0004
121	0.055	0.026	0.0008	0.030	0.0006	0.027	0.0008	0.025	0.0009
122	0.026	0.031	0.0000	0.037	0.0001	0.036	0.0001	0.032	0.0000
123	0.055	0.022	0.0011	0.033	0.0005	0.04	0.0002	0.049	0.0000
124	0.062	0.026	0.0013	0.032	0.0009	0.035	0.0007	0.037	0.0006
125	0.024	0.022	0.0000	0.031	0.0000	0.033	0.0001	0.037	0.0002

126	0.041	0.027	0.0002	0.036	0.0000	0.037	0.0000	0.041	0.0000
127	0.030	0.041	0.0001	0.039	0.0001	0.037	0.0000	0.034	0.0000
128	0.030	0.041	0.0001	0.049	0.0004	0.05	0.0004	0.053	0.0005
129	0.054	0.071	0.0003	0.071	0.0003	0.071	0.0003	0.072	0.0003
130	0.038	0.046	0.0001	0.045	0.0000	0.044	0.0000	0.043	0.0000
131	0.029	0.041	0.0001	0.044	0.0002	0.047	0.0003	0.051	0.0005
132	0.066	0.039	0.0007	0.047	0.0004	0.05	0.0003	0.054	0.0001
133	0.036	0.042	0.0000	0.049	0.0002	0.051	0.0002	0.051	0.0002
134	0.051	0.039	0.0001	0.028	0.0005	0.028	0.0005	0.031	0.0004
135	0.023	0.039	0.0003	0.040	0.0003	0.044	0.0004	0.048	0.0006
136	0.044	0.038	0.0000	0.041	0.0000	0.041	0.0000	0.039	0.0000
137	0.021	0.043	0.0005	0.051	0.0009	0.053	0.0010	0.05	0.0008
138	0.021	0.047	0.0007	0.059	0.0014	0.063	0.0018	0.064	0.0018
139	0.050	0.072	0.0005	0.067	0.0003	0.065	0.0002	0.064	0.0002
140	0.065	0.037	0.0008	0.040	0.0006	0.045	0.0004	0.047	0.0003
141	0.076	0.044	0.0010	0.048	0.0008	0.054	0.0005	0.057	0.0004
142	0.076	0.051	0.0006	0.057	0.0004	0.058	0.0003	0.06	0.0003
143	0.043	0.065	0.0005	0.065	0.0005	0.065	0.0005	0.068	0.0006
144	0.053	0.035	0.0003	0.035	0.0003	0.035	0.0003	0.035	0.0003
145	0.063	0.039	0.0006	0.044	0.0004	0.044	0.0004	0.044	0.0004
146	0.069	0.034	0.0012	0.041	0.0008	0.042	0.0007	0.042	0.0007
147	0.063	0.032	0.0010	0.038	0.0006	0.038	0.0006	0.038	0.0006
148	0.048	0.033	0.0002	0.047	0.0000	0.048	0.0000	0.048	0.0000
149	0.071	0.030	0.0017	0.036	0.0012	0.038	0.0011	0.039	0.0010
150	0.038	0.039	0.0000	0.043	0.0000	0.044	0.0000	0.043	0.0000
151	0.059	0.048	0.0001	0.055	0.0000	0.057	0.0000	0.059	0.0000
152	0.056	0.040	0.0003	0.048	0.0001	0.05	0.0000	0.053	0.0000
153	0.076	0.048	0.0008	0.070	0.0000	0.085	0.0001	0.078	0.0000
154	0.045	0.020	0.0006	0.027	0.0003	0.254	0.0437	0.346	0.0906
155	0.048	0.019	0.0008	0.028	0.0004	0.917	0.7552	1.033	0.9702
156	0.038	0.047	0.0001	0.048	0.0001	0.049	0.0001	0.058	0.0004
157	0.090	0.019	0.0050	0.024	0.0044	0.024	0.0044	0.033	0.0032
158	0.066	0.024	0.0018	0.023	0.0018	0.021	0.0020	0.026	0.0016
159	0.067	0.028	0.0015	0.026	0.0017	0.026	0.0017	0.032	0.0012
160	0.058	0.050	0.0001	0.057	0.0000	0.058	0.0000	0.058	0.0000
161	0.046	0.046	0.0000	0.050	0.0000	0.05	0.0000	0.05	0.0000
162	0.081	0.040	0.0017	0.046	0.0012	0.049	0.0010	0.053	0.0008
163	0.060	0.034	0.0007	0.034	0.0007	0.033	0.0007	0.037	0.0005
164	0.070	0.039	0.0010	0.041	0.0008	0.041	0.0008	0.041	0.0008
165	0.058	0.038	0.0004	0.041	0.0003	0.041	0.0003	0.043	0.0002
166	0.075	0.043	0.0010	0.049	0.0007	0.05	0.0006	0.053	0.0005
167	0.080	0.046	0.0012	0.055	0.0006	0.057	0.0005	0.062	0.0003
168	0.051	0.025	0.0007	0.040	0.0001	0.039	0.0001	0.039	0.0001
169	0.055	0.030	0.0006	0.027	0.0008	0.026	0.0008	0.03	0.0006
170	0.079	0.040	0.0015	0.045	0.0012	0.046	0.0011	0.047	0.0010
171	0.070	0.046	0.0006	0.053	0.0003	0.055	0.0002	0.056	0.0002
173	0.067	0.036	0.0010	0.047	0.0004	0.047	0.0004	0.039	0.0008
174	0.048	0.032	0.0003	0.039	0.0001	0.037	0.0001	0.036	0.0001
175	0.084	0.025	0.0035	0.037	0.0022	0.048	0.0013	0.054	0.0009
176	0.065	0.045	0.0004	0.039	0.0007	0.041	0.0006	0.043	0.0005
177	0.071	0.026	0.0020	0.049	0.0005	0.06	0.0001	0.066	0.0000
178	0.072	0.019	0.0028	0.035	0.0014	0.042	0.0009	0.042	0.0009
179	0.082	0.022	0.0036	0.024	0.0034	0.028	0.0029	0.036	0.0021
180	0.096	0.029	0.0045	0.034	0.0038	0.036	0.0036	0.044	0.0027

181	0.075	0.032	0.0018	0.038	0.0014	0.039	0.0013	0.047	0.0008
182	0.090	0.036	0.0029	0.042	0.0023	0.04	0.0025	0.04	0.0025
183	0.065	0.021	0.0019	0.027	0.0014	0.032	0.0011	0.037	0.0008
184	0.058	0.025	0.0011	0.033	0.0006	0.033	0.0006	0.033	0.0006
185	0.051	0.026	0.0006	0.032	0.0004	0.038	0.0002	0.046	0.0000
186	0.054	0.030	0.0006	0.041	0.0002	0.036	0.0003	0.039	0.0002
187	0.081	0.033	0.0023	0.048	0.0011	0.045	0.0013	0.046	0.0012
188	0.089	0.030	0.0035	0.050	0.0015	0.052	0.0014	0.056	0.0011
189	0.041	0.016	0.0006	0.025	0.0003	0.028	0.0002	0.033	0.0001
190	0.028	0.038	0.0001	0.051	0.0005	0.057	0.0008	0.063	0.0012
191	0.034	0.036	0.0000	0.055	0.0004	0.064	0.0009	0.068	0.0012
192	0.042	0.032	0.0001	0.040	0.0000	0.044	0.0000	0.05	0.0001
193	0.038	0.033	0.0000	0.047	0.0001	0.047	0.0001	0.044	0.0000
194	0.056	0.045	0.0001	0.044	0.0001	0.049	0.0000	0.053	0.0000
195	0.040	0.052	0.0001	0.053	0.0002	0.054	0.0002	0.055	0.0002
196	0.020	0.050	0.0009	0.058	0.0014	0.059	0.0015	0.062	0.0018
197	0.058	0.055	0.0000	0.065	0.0000	0.07	0.0001	0.074	0.0003
198	0.061	0.035	0.0007	0.047	0.0002	0.05	0.0001	0.055	0.0000
199	0.084	0.036	0.0023	0.051	0.0011	0.055	0.0008	0.062	0.0005
200	0.063	0.024	0.0015	0.034	0.0008	0.039	0.0006	0.042	0.0004
201	0.055	0.030	0.0006	0.042	0.0002	0.048	0.0000	0.055	0.0000
202	0.119	0.039	0.0064	0.050	0.0048	0.054	0.0042	0.061	0.0034
203	0.071	0.031	0.0016	0.044	0.0007	0.046	0.0006	0.06	0.0001
204	0.086	0.028	0.0034	0.043	0.0018	0.047	0.0015	0.056	0.0009
205	0.054	0.017	0.0014	0.024	0.0009	0.03	0.0006	0.034	0.0004
206	0.072	0.019	0.0028	0.030	0.0018	0.034	0.0014	0.043	0.0008
207	0.059	0.018	0.0017	0.036	0.0005	0.039	0.0004	0.043	0.0003
208	0.071	0.022	0.0024	0.039	0.0010	0.041	0.0009	0.045	0.0007
209	0.125	0.086	0.0015	0.109	0.0003	0.113	0.0001	0.098	0.0007
210	0.065	0.057	0.0001	0.072	0.0000	0.074	0.0001	0.095	0.0009
211	0.035	0.033	0.0000	0.040	0.0000	0.045	0.0001	0.039	0.0000
212	0.061	0.052	0.0001	0.073	0.0001	0.08	0.0004	0.084	0.0005
213	0.054	0.020	0.0012	0.036	0.0003	0.043	0.0001	0.05	0.0000
214	0.065	0.022	0.0018	0.036	0.0008	0.04	0.0006	0.047	0.0003
215	0.094	0.022	0.0052	0.040	0.0029	0.047	0.0022	0.053	0.0017
216	0.103	0.101	0.0000	0.099	0.0000	0.098	0.0000	0.099	0.0000
217	0.089	0.091	0.0000	0.090	0.0000	0.09	0.0000	0.09	0.0000
218	0.068	0.033	0.0012	0.061	0.0000	0.065	0.0000	0.068	0.0000
219	0.051	0.027	0.0006	0.046	0.0000	0.051	0.0000	0.051	0.0000
220	0.078	0.021	0.0032	0.032	0.0021	0.045	0.0011	0.05	0.0008
221	0.073	0.027	0.0021	0.035	0.0014	0.037	0.0013	0.041	0.0010
222	0.075	0.075	0.0000	0.069	0.0000	0.067	0.0001	0.064	0.0001
223	0.067	0.070	0.0000	0.064	0.0000	0.064	0.0000	0.063	0.0000
224	0.052	0.023	0.0008	0.029	0.0005	0.03	0.0005	0.039	0.0002
225	0.042	0.026	0.0003	0.033	0.0001	0.037	0.0000	0.045	0.0000
226	0.033	0.027	0.0000	0.038	0.0000	0.043	0.0001	0.047	0.0002
227	0.055	0.068	0.0002	0.069	0.0002	0.068	0.0002	0.064	0.0001
228	0.047	0.023	0.0006	0.030	0.0003	0.035	0.0001	0.038	0.0001
229	0.023	0.027	0.0000	0.034	0.0001	0.035	0.0001	0.038	0.0002
230	0.025	0.030	0.0000	0.037	0.0001	0.039	0.0002	0.041	0.0003
231	0.038	0.034	0.0000	0.041	0.0000	0.044	0.0000	0.047	0.0001
232	0.075	0.073	0.0000	0.075	0.0000	0.073	0.0000	0.07	0.0000
233	0.057	0.048	0.0001	0.054	0.0000	0.053	0.0000	0.052	0.0000
234	0.048	0.024	0.0006	0.027	0.0004	0.028	0.0004	0.03	0.0003

235	0.036	0.021	0.0002	0.024	0.0001	0.025	0.0001	0.028	0.0001
236	0.030	0.015	0.0002	0.023	0.0000	0.025	0.0000	0.029	0.0000
237	0.060	0.052	0.0001	0.055	0.0000	0.056	0.0000	0.058	0.0000
238	0.033	0.046	0.0002	0.046	0.0002	0.046	0.0002	0.046	0.0002
239	0.085	0.029	0.0031	0.027	0.0034	0.028	0.0032	0.027	0.0034
240	0.043	0.040	0.0000	0.040	0.0000	0.04	0.0000	0.04	0.0000
241	0.078	0.022	0.0031	0.035	0.0018	0.037	0.0017	0.041	0.0014
242	0.058	0.025	0.0011	0.030	0.0008	0.032	0.0007	0.032	0.0007
243	0.035	0.028	0.0000	0.031	0.0000	0.034	0.0000	0.037	0.0000
244	0.038	0.030	0.0001	0.033	0.0000	0.036	0.0000	0.039	0.0000
245	0.041	0.032	0.0001	0.039	0.0000	0.041	0.0000	0.04	0.0000
246	0.064	0.019	0.0020	0.027	0.0014	0.029	0.0012	0.031	0.0011
247	0.078	0.007	0.0050	0.009	0.0048	0.01	0.0046	0.011	0.0045
248	0.083	0.020	0.0040	0.031	0.0027	0.038	0.0020	0.053	0.0009
249	0.044	0.018	0.0007	0.022	0.0005	0.027	0.0003	0.032	0.0001
250	0.062	0.024	0.0014	0.031	0.0010	0.033	0.0008	0.034	0.0008
251	0.064	0.031	0.0011	0.034	0.0009	0.032	0.0010	0.053	0.0001
260	0.112	0.103	0.0001	0.109	0.0000	0.101	0.0001	0.094	0.0003
261	0.050	0.013	0.0014	0.030	0.0004	0.03	0.0004	0.042	0.0001
262	0.037	0.013	0.0006	0.037	0.0000	0.032	0.0000	0.027	0.0001
264	0.067	0.029	0.0014	0.044	0.0005	0.046	0.0004	0.047	0.0004
265	0.110	0.103	0.0000	0.100	0.0001	0.1	0.0001	0.102	0.0001
266	0.210	0.197	0.0002	0.196	0.0002	0.195	0.0002	0.194	0.0003
267	0.210	0.197	0.0002	0.196	0.0002	0.195	0.0002	0.194	0.0003
268	0.146	0.032	0.0130	0.057	0.0079	0.074	0.0052	0.096	0.0025
269	0.335	0.220	0.0132	0.236	0.0098	0.239	0.0092	0.241	0.0088
270	0.123	0.018	0.0110	0.028	0.0090	0.039	0.0071	0.06	0.0040
271	0.083	0.013	0.0049	0.026	0.0032	0.031	0.0027	0.046	0.0014
272	0.077	0.010	0.0045	0.018	0.0035	0.022	0.0030	0.032	0.0020
273	0.103	0.009	0.0088	0.023	0.0064	0.033	0.0049	0.046	0.0032
274	0.061	0.005	0.0031	0.012	0.0024	0.016	0.0020	0.024	0.0014
275	0.052	0.029	0.0005	0.047	0.0000	0.048	0.0000	0.054	0.0000
276	0.055	0.031	0.0006	0.046	0.0001	0.043	0.0001	0.054	0.0000
277	0.107	0.035	0.0052	0.038	0.0048	0.034	0.0053	0.044	0.0040
278	0.086	0.037	0.0024	0.029	0.0032	0.026	0.0036	0.036	0.0025
279	0.115	0.042	0.0053	0.024	0.0083	0.02	0.0090	0.028	0.0076
280	0.104	0.033	0.0050	0.033	0.0050	0.032	0.0052	0.031	0.0053
281	0.124	0.040	0.0071	0.054	0.0049	0.061	0.0040	0.067	0.0032
282	0.107	0.037	0.0049	0.058	0.0024	0.067	0.0016	0.074	0.0011
283	0.107	0.052	0.0030	0.066	0.0017	0.074	0.0011	0.082	0.0006
284	0.115	0.056	0.0035	0.063	0.0027	0.071	0.0019	0.074	0.0017
285	0.355	0.150	0.0420	0.172	0.0335	0.192	0.0266	0.216	0.0193
286	0.227	0.156	0.0050	0.187	0.0016	0.186	0.0017	0.208	0.0004
287	0.408	0.161	0.0610	0.219	0.0357	0.229	0.0320	0.262	0.0213
288	0.084	0.159	0.0056	0.220	0.0185	0.229	0.0210	0.262	0.0317
289	0.138	0.169	0.0010	0.223	0.0072	0.233	0.0090	0.262	0.0154
290	0.138	0.139	0.0000	0.179	0.0017	0.215	0.0059	0.267	0.0166
291	0.190	0.100	0.0081	0.086	0.0108	0.107	0.0069	0.131	0.0035
292	0.133	0.093	0.0016	0.139	0.0000	0.156	0.0005	0.173	0.0016
293	0.107	0.086	0.0004	0.127	0.0004	0.146	0.0015	0.18	0.0053
294	0.180	0.090	0.0081	0.105	0.0056	0.117	0.0040	0.141	0.0015
295	0.078	0.050	0.0008	0.073	0.0000	0.081	0.0000	0.092	0.0002
296	0.085	0.066	0.0004	0.084	0.0000	0.088	0.0000	0.086	0.0000
297	0.098	0.047	0.0026	0.056	0.0018	0.059	0.0015	0.066	0.0010

298	0.084	0.046	0.0014	0.054	0.0009	0.054	0.0009	0.057	0.0007
299	0.101	0.042	0.0035	0.053	0.0023	0.053	0.0023	0.056	0.0020
300	0.094	0.047	0.0022	0.062	0.0010	0.069	0.0006	0.072	0.0005
301	0.060	0.025	0.0012	0.039	0.0004	0.043	0.0003	0.046	0.0002
302	0.088	0.057	0.0010	0.071	0.0003	0.076	0.0001	0.076	0.0001
303	0.059	0.062	0.0000	0.067	0.0001	0.069	0.0001	0.075	0.0003
304	0.058	0.037	0.0004	0.045	0.0002	0.046	0.0001	0.049	0.0001
306	0.348	0.136	0.0449	0.165	0.0335	0.173	0.0306	0.183	0.0272
307	0.151	0.112	0.0015	0.145	0.0000	0.151	0.0000	0.164	0.0002
308	0.126	0.111	0.0002	0.128	0.0000	0.138	0.0001	0.152	0.0007
309	0.076	0.086	0.0001	0.083	0.0000	0.082	0.0000	0.083	0.0000
310	0.068	0.062	0.0000	0.046	0.0005	0.046	0.0005	0.065	0.0000
311	0.065	0.048	0.0003	0.049	0.0003	0.052	0.0002	0.059	0.0000
313	0.052	0.023	0.0008	0.032	0.0004	0.032	0.0004	0.029	0.0005
314	0.083	0.025	0.0034	0.028	0.0030	0.031	0.0027	0.033	0.0025
315	0.087	0.025	0.0038	0.054	0.0011	0.066	0.0004	0.075	0.0001
316	0.079	0.032	0.0022	0.067	0.0001	0.078	0.0000	0.079	0.0000
317	0.093	0.025	0.0046	0.054	0.0015	0.062	0.0010	0.076	0.0003
318	0.069	0.020	0.0024	0.043	0.0007	0.049	0.0004	0.056	0.0002
319	0.062	0.019	0.0018	0.039	0.0005	0.043	0.0004	0.048	0.0002
320	0.079	0.017	0.0038	0.018	0.0037	0.021	0.0034	0.02	0.0035
321	0.029	0.016	0.0002	0.019	0.0001	0.022	0.0000	0.023	0.0000
322	0.077	0.012	0.0042	0.016	0.0037	0.016	0.0037	0.021	0.0031
323	0.058	0.008	0.0025	0.010	0.0023	0.012	0.0021	0.017	0.0017
325	0.062	0.024	0.0014	0.032	0.0009	0.037	0.0006	0.035	0.0007
326	0.063	0.014	0.0024	0.022	0.0017	0.029	0.0012	0.049	0.0002
327	0.032	0.022	0.0001	0.027	0.0000	0.028	0.0000	0.029	0.0000
328	0.051	0.017	0.0012	0.022	0.0008	0.026	0.0006	0.034	0.0003
329	0.029	0.030	0.0000	0.038	0.0001	0.04	0.0001	0.044	0.0002
330	0.039	0.025	0.0002	0.031	0.0001	0.033	0.0000	0.03	0.0001
331	0.044	0.019	0.0006	0.030	0.0002	0.033	0.0001	0.037	0.0000
332	0.033	0.020	0.0002	0.031	0.0000	0.033	0.0000	0.025	0.0001
333	0.076	0.030	0.0021	0.040	0.0013	0.042	0.0012	0.044	0.0010
334	0.050	0.018	0.0010	0.024	0.0007	0.022	0.0008	0.032	0.0003
335	0.067	0.017	0.0025	0.020	0.0022	0.021	0.0021	0.021	0.0021
336	0.023	0.017	0.0000	0.021	0.0000	0.021	0.0000	0.023	0.0000
337	0.088	0.042	0.0021	0.064	0.0006	0.072	0.0003	0.088	0.0000
338	0.062	0.044	0.0003	0.062	0.0000	0.062	0.0000	0.062	0.0000
339	0.069	0.045	0.0006	0.063	0.0000	0.063	0.0000	0.063	0.0000
115a	0.060	0.032	0.0008	0.036	0.0006	0.041	0.0004	0.042	0.0003
115b	0.031	0.019	0.0001	0.018	0.0002	0.022	0.0001	0.03	0.0000
115c	0.039	0.022	0.0003	0.027	0.0001	0.029	0.0001	0.03	0.0001
115e	0.011	0.046	0.0012	0.058	0.0022	0.062	0.0026	0.06	0.0024
115f	0.027	0.043	0.0003	0.053	0.0007	0.056	0.0008	0.052	0.0006
115g	0.032	0.035	0.0000	0.044	0.0001	0.049	0.0003	0.057	0.0006
115h	0.051	0.027	0.0006	0.033	0.0003	0.036	0.0002	0.041	0.0001
123b	0.031	0.036	0.0000	0.048	0.0003	0.053	0.0005	0.057	0.0007
127a	0.044	0.064	0.0004	0.061	0.0003	0.061	0.0003	0.06	0.0003
127b	0.039	0.070	0.0010	0.082	0.0018	0.085	0.0021	0.089	0.0025
127c	0.030	0.053	0.0005	0.058	0.0008	0.06	0.0009	0.067	0.0014
127d	0.017	0.032	0.0002	0.039	0.0005	0.039	0.0005	0.041	0.0006
127e	0.015	0.045	0.0009	0.062	0.0022	0.064	0.0024	0.069	0.0029
129a	0.033	0.039	0.0000	0.038	0.0000	0.042	0.0001	0.049	0.0003
129b	0.079	0.032	0.0022	0.067	0.0001	0.078	0.0000	0.079	0.0000

129c	0.013	0.023	0.0001	0.029	0.0003	0.032	0.0004	0.037	0.0006
129d	0.065	0.045	0.0004	0.063	0.0000	0.063	0.0000	0.063	0.0000
12a	0.074	0.027	0.0022	0.025	0.0024	0.027	0.0022	0.031	0.0018
12b	0.060	0.026	0.0012	0.029	0.0010	0.031	0.0008	0.037	0.0005
132a	0.043	0.051	0.0001	0.067	0.0006	0.071	0.0008	0.089	0.0021
132c	0.029	0.042	0.0002	0.058	0.0008	0.063	0.0012	0.071	0.0018
136a	0.075	0.028	0.0022	0.028	0.0022	0.035	0.0016	0.05	0.0006
136b	0.022	0.028	0.0000	0.031	0.0001	0.034	0.0001	0.033	0.0001
136c	0.034	0.014	0.0004	0.027	0.0000	0.015	0.0004	0.018	0.0003
14a	0.050	0.043	0.0000	0.038	0.0001	0.039	0.0001	0.039	0.0001
16a	0.054	0.043	0.0001	0.056	0.0000	0.055	0.0000	0.055	0.0000
18a	0.085	0.020	0.0042	0.046	0.0015	0.054	0.0010	0.064	0.0004
212a	0.077	0.029	0.0023	0.036	0.0017	0.044	0.0011	0.052	0.0006
212b	0.068	0.021	0.0022	0.026	0.0018	0.03	0.0014	0.033	0.0012
212c	0.059	0.026	0.0011	0.035	0.0006	0.035	0.0006	0.038	0.0004
212d	0.063	0.029	0.0012	0.038	0.0006	0.039	0.0006	0.042	0.0004
212e	0.085	0.031	0.0029	0.045	0.0016	0.046	0.0015	0.052	0.0011
219A	0.030	0.023	0.0000	0.022	0.0001	0.013	0.0003	0.018	0.0001
21a	0.075	0.020	0.0030	0.034	0.0017	0.037	0.0014	0.041	0.0012
233a	0.077	0.040	0.0014	0.052	0.0006	0.052	0.0006	0.05	0.0007
23b	0.059	0.026	0.0011	0.033	0.0007	0.036	0.0005	0.04	0.0004
23c	0.064	0.044	0.0004	0.050	0.0002	0.051	0.0002	0.053	0.0001
23d	0.066	0.040	0.0007	0.044	0.0005	0.052	0.0002	0.057	0.0001
251A	0.118	0.097	0.0004	0.094	0.0006	0.092	0.0007	0.107	0.0001
264A	0.100	0.096	0.0000	0.098	0.0000	0.097	0.0000	0.097	0.0000
26a	0.081	0.031	0.0025	0.049	0.0010	0.052	0.0008	0.058	0.0005
26b	0.131	0.034	0.0094	0.055	0.0058	0.059	0.0052	0.069	0.0038
296a	0.056	0.015	0.0017	0.046	0.0001	0.044	0.0001	0.037	0.0004
2a	0.041	0.008	0.0011	0.019	0.0005	0.025	0.0003	0.028	0.0002
2b	0.069	0.004	0.0042	0.015	0.0029	0.026	0.0018	0.028	0.0017
31a	0.045	0.010	0.0012	0.035	0.0001	0.044	0.0000	0.051	0.0000
32a	0.081	0.017	0.0041	0.042	0.0015	0.046	0.0012	0.052	0.0008
32b	0.064	0.035	0.0008	0.048	0.0003	0.052	0.0001	0.054	0.0001
32c	0.071	0.041	0.0009	0.048	0.0005	0.05	0.0004	0.049	0.0005
36d	0.080	0.039	0.0017	0.044	0.0013	0.045	0.0012	0.046	0.0012
3a	0.086	0.026	0.0036	0.045	0.0017	0.048	0.0014	0.052	0.0012
4a	0.068	0.008	0.0036	0.017	0.0026	0.027	0.0017	0.027	0.0017
5a	0.052	0.005	0.0022	0.015	0.0014	0.022	0.0009	0.023	0.0008
66a	0.080	0.039	0.0017	0.045	0.0012	0.048	0.0010	0.038	0.0018
66b	0.042	0.019	0.0005	0.031	0.0001	0.03	0.0001	0.018	0.0006
7a	0.060	0.009	0.0026	0.027	0.0011	0.036	0.0006	0.036	0.0006
Link-01	0.300	0.078	0.0493	0.159	0.0199	0.179	0.0146	0.216	0.0071
Link-02	0.258	0.212	0.0021	0.272	0.0002	0.281	0.0005	0.275	0.0003
Link-03	0.322	0.220	0.0104	0.289	0.0011	0.305	0.0003	0.3	0.0005
Link-04	0.070	0.070	0.0000	0.070	0.0000	0.07	0.0000	0.07	0.0000
Link-05	0.198	0.176	0.0005	0.202	0.0000	0.204	0.0000	0.201	0.0000
Link-06	0.105	0.057	0.0023	0.057	0.0023	0.057	0.0023	0.057	0.0023
Link-07	0.152	0.150	0.0000	0.171	0.0004	0.171	0.0004	0.171	0.0004
Link-08	0.152	0.145	0.0000	0.165	0.0002	0.166	0.0002	0.166	0.0002
Link-09	0.193	0.107	0.0074	0.125	0.0046	0.125	0.0046	0.125	0.0046
Link-10	0.220	0.107	0.0128	0.126	0.0088	0.121	0.0098	0.121	0.0098
Link-11	0.118	0.082	0.0013	0.127	0.0001	0.131	0.0002	0.123	0.0000
Link-12	0.145	0.061	0.0071	0.103	0.0018	0.116	0.0008	0.126	0.0004
Link-13	0.257	0.070	0.0350	0.148	0.0119	0.167	0.0081	0.203	0.0029

Link-14	0.091	0.091	0.0000	0.091	0.0000	0.123	0.0010	0.122	0.0010
Link-15	0.095	0.047	0.0023	0.063	0.0010	0.064	0.0010	0.047	0.0023
Link-16	0.127	0.061	0.0044	0.061	0.0044	0.061	0.0044	0.061	0.0044
Link-17	0.322	0.220	0.0104	0.285	0.0014	0.293	0.0008	0.289	0.0011
Link-18	0.530	0.427	0.0106	0.492	0.0014	0.51	0.0004	0.518	0.0001
Link-19	0.098	0.054	0.0019	0.073	0.0006	0.073	0.0006	0.076	0.0005
Link-20	0.057	0.037	0.0004	0.051	0.0000	0.055	0.0000	0.057	0.0000
Link-21	0.094	0.001	0.0086	0.041	0.0028	0.058	0.0013	0.063	0.0010
Link-23	0.079	0.033	0.0021	0.055	0.0006	0.069	0.0001	0.079	0.0000
Link-24	0.068	0.008	0.0036	0.039	0.0008	0.04	0.0008	0.035	0.0011
Link-27	0.064	0.035	0.0008	0.055	0.0001	0.022	0.0018	0.025	0.0015
Link-28	0.055	0.035	0.0004	0.046	0.0001	0.048	0.0000	0.048	0.0000
Link-29	0.073	0.042	0.0010	0.048	0.0006	0.049	0.0006	0.052	0.0004
Link-30	0.081	0.027	0.0029	0.028	0.0028	0.029	0.0027	0.03	0.0026
Link-31	0.073	0.038	0.0012	0.049	0.0006	0.051	0.0005	0.054	0.0004
Link-32	0.069	0.001	0.0046	0.034	0.0012	0.054	0.0002	0.06	0.0001
Link-35	0.079	0.017	0.0038	0.030	0.0024	0.035	0.0019	0.041	0.0014
Link-36	0.059	0.039	0.0004	0.046	0.0002	0.047	0.0001	0.048	0.0001
Link-37	0.050	0.033	0.0003	0.037	0.0002	0.039	0.0001	0.04	0.0001
Link-38	0.032	0.031	0.0000	0.031	0.0000	0.029	0.0000	0.03	0.0000
Link-39	0.009	0.021	0.0001	0.034	0.0006	0.037	0.0008	0.037	0.0008
Pipe-45	0.530	0.427	0.0106	0.492	0.0014	0.51	0.0004	0.518	0.0001
RMSE			**0.0505**		**0.0392**		**0.0575**		**0.0615**

Table 7: Infiltration rate data from SWMM modelling using the rainfall intensities for 2, 5, 10, and 25 years return periods.

The Combined Sewer System of Al-Rashadiya Quarter				
Infiltration System Results (mm/hr.) using different rainfall intensities with different return periods				
Time of simulation	2 years return period	5 years return period	10 years return period	25 years return period
00:05:00	0.89	0.9	0.9	0.9
00:10:00	0.59	0.69	0.76	0.82
00:15:00	0.54	0.6	0.61	0.61
00:20:00	0.48	0.5	0.5	0.5
00:25:00	0.44	0.43	0.43	0.44
00:30:00	0.4	0.39	0.39	0.39
00:35:00	0.37	0.36	0.36	0.37
00:40:00	0.35	0.34	0.35	0.35
00:45:00	0.34	0.33	0.33	0.33
00:50:00	0.32	0.32	0.32	0.32
00:55:00	0.31	0.3	0.3	0.3
01:00:00	0.29	0.29	0.29	0.29
01:05:00	0.28	0.28	0.28	0.28
01:10:00	0.28	0.27	0.27	0.28
01:15:00	0.27	0.27	0.27	0.27
01:20:00	0.26	0.26	0.26	0.26
01:25:00	0.26	0.26	0.26	0.26
01:30:00	0.25	0.25	0.25	0.25
01:35:00	0.25	0.25	0.25	0.25
01:40:00	0.24	0.24	0.24	0.24
01:45:00	0.24	0.24	0.24	0.24
01:50:00	0.23	0.23	0.23	0.24
01:55:00	0.23	0.23	0.23	0.23
02:00:00	0.23	0.23	0.23	0.23
02:05:00	0.22	0.22	0.22	0.23
02:10:00	0.22	0.22	0.22	0.22
02:15:00	0.22	0.22	0.22	0.21
02:20:00	0.21	0.21	0.21	0.21
02:25:00	0.21	0.21	0.21	0.21
02:30:00	0.21	0.21	0.21	0.21
02:35:00	0.21	0.2	0.2	0.2

02:40:00	0.2	0.2	0.2	0.2
02:45:00	0.2	0.2	0.2	0.2
02:50:00	0.2	0.2	0.2	0.2
02:55:00	0.2	0.2	0.2	0.2
03:00:00	0.2	0.2	0.2	0.2

Table 8: Flooded nodes in the combined sewage system and their flow rate data from SWMM modelling using the rainfall intensities for 2 years return period.

The Combined Sewer System Results using rainfall intensity for 2 years return period.					
Node Flooding					
Node	Hours Flooded	Maximum Rate CMS	Hours of maximum Flooded	Node Flood Volume 10^6 litters	Node Flood Volume CM
S266	2.08	0.252	00:21	0.974	974
A993A	2.76	0.061	00:19	0.354	354
S471	1.96	0.075	00:17	0.29	290
S989B	2.77	0.052	00:08	0.277	277
S311	1.96	0.054	00:18	0.261	261
S543	1.99	0.05	00:17	0.241	241
S989A	2.76	0.033	00:20	0.23	230
S175	1.93	0.076	00:16	0.23	230
S996B	2.05	0.036	00:11	0.158	158
S263	1.82	0.06	00:19	0.156	156
S231	1.74	0.062	00:19	0.131	131
S993B	2.62	0.048	00:16	0.126	126
S298	0.83	0.048	00:18	0.057	57
S541	0.78	0.03	00:18	0.046	46
S254	0.77	0.033	00:20	0.043	43
S191	1.49	0.013	00:10	0.034	34
S188	0.71	0.037	00:16	0.032	32
S281	1.00	0.027	00:17	0.03	30
S1002.2	0.98	0.044	00:13	0.026	26
S474	0.84	0.021	00:17	0.026	26
S1002	0.71	0.023	00:13	0.02	20
S520	0.41	0.029	00:19	0.019	19
S989D	0.80	0.043	00:14	0.016	16
S311A	0.40	0.033	00:13	0.011	11
S989C	2.77	0.05	00:09	0.008	8
S179	0.48	0.04	00:10	0.007	7
S252	0.13	0.042	00:14	0.003	3
S267N10	0.13	0.047	00:15	0.002	2
S274	0.12	0.012	00:17	0.002	2
S358	0.01	0.061	00:16	0.001	1
S269A	0.01	0.057	00:16	0.001	1
S549	0.23	0.004	00:15	0.001	1
S206	0.01	0.027	00:16	0.001	1
S269	0.01	0.051	00:15	0.001	1
S267A5	0.01	0.178	00:13	0.001	1
S258	0.01	0.051	00:15	0.001	1
Sum of Total of Nodes Flooding Volume m^3					**3817**

Table 9: Flooded nodes in the combined sewage system and their flow rate data from SWMM modelling using the rainfall intensities for 5 years return period.

The Combined Sewer System Results using rainfall intensity for 5 years return period.					
Node Flooding					
Node	Hours Flooded	Maximum Rate CMS	Hours of maximum Flooded	Node Flood Volume 10^6 litters	Node Flood Volume CM
S266	2.18	0.321	00:15	1.52	1520
A993A	2.81	0.099	00:14	0.446	446
S471	2.03	0.129	00:15	0.443	443
S175	2.02	0.128	00:15	0.39	390
S311	2.04	0.073	00:15	0.343	343
S231	1.94	0.116	00:15	0.325	325
S543	2.07	0.052	00:13	0.323	323
S263	1.96	0.089	00:16	0.313	313
S989B	2.82	0.066	00:08	0.284	284
S989A	2.81	0.037	00:16	0.262	262
S993B	2.68	0.073	00:14	0.218	218
S298	1.81	0.107	00:15	0.211	211
S996B	2.12	0.051	00:10	0.201	201
S541	1.79	0.061	00:15	0.137	137
S254	1.77	0.047	00:12	0.133	133
S188	1.51	0.057	00:15	0.106	106
S281	1.89	0.048	00:15	0.097	97
S474	1.81	0.043	00:15	0.09	90
S520	0.98	0.073	00:15	0.088	88
S1002	1.58	0.045	00:16	0.076	76
S252	0.65	0.066	00:15	0.076	76
S267A4	0.49	0.075	00:18	0.074	74
S311A	0.97	0.06	00:15	0.071	71
S191	1.93	0.021	00:09	0.071	71
S1002.2	1.9	0.061	00:11	0.068	68
S989D	1.62	0.056	00:12	0.062	62
S267N10	0.7	0.048	00:12	0.05	50
S179	1.09	0.044	00:09	0.041	41
S477A	0.27	0.068	00:18	0.038	38
S549	0.73	0.016	00:22	0.022	22
S274	0.63	0.018	00:15	0.022	22
S200	0.42	0.031	00:15	0.021	21
S300A	0.4	0.031	00:12	0.019	19
S239	0.22	0.054	00:14	0.019	19
S261	0.38	0.025	00:15	0.017	17
S989C	2.82	0.056	00:08	0.016	16
S503A	0.03	0.444	00:44	0.015	15
S503	0.06	0.398	00:32	0.015	15
S310	0.37	0.052	00:09	0.015	15
S342	0.23	0.036	00:17	0.014	14
S267N8	0.39	0.022	00:15	0.014	14
S507	0.24	0.068	00:44	0.013	13

S193	0.46	0.02	00:09	0.01	10
S271	0.24	0.035	00:11	0.009	9
S511A	0.24	0.021	00:13	0.008	8
S496	0.14	0.068	00:12	0.008	8
S219	0.19	0.022	00:13	0.008	8
S548	0.22	0.018	00:15	0.008	8
S451	0.2	0.033	00:15	0.007	7
S248F	0.17	0.038	00:13	0.006	6
S177	0.27	0.039	00:11	0.006	6
S476	0.19	0.027	00:10	0.006	6
S515	0.17	0.037	00:11	0.005	5
S354	0.18	0.017	00:12	0.005	5
S273	0.27	0.041	00:10	0.004	4
S291	0.12	0.026	00:12	0.003	3
S255	0.16	0.029	00:08	0.003	3
S206	0.13	0.04	00:13	0.003	3
S996A	0.18	0.063	00:09	0.003	3
S289	0.16	0.019	00:10	0.003	3
S267A5	0.01	0.166	00:11	0.002	2
S262	0.15	0.011	00:15	0.002	2
S460	0.11	0.048	00:11	0.002	2
S361	0.13	0.044	00:12	0.002	2
S445	0.07	0.013	00:18	0.002	2
S305B	0.01	0.05	00:12	0.001	1
S268AA	0.01	0.051	00:12	0.001	1
S358	0.02	0.072	00:13	0.001	1
S269A	0.01	0.066	00:13	0.001	1
S199	0.06	0.031	00:12	0.001	1
S999	0.1	0.044	00:10	0.001	1
S548D	0.01	0.055	00:11	0.001	1
S545	0.03	0.022	00:11	0.001	1
S451AA	0.01	0.049	00:12	0.001	1
S194	0.01	0.059	00:13	0.001	1
S267A6	0.01	0.251	00:11	0.001	1
S284	0.04	0.028	00:13	0.001	1
S228	0.11	0.026	00:09	0.001	1
S254A	0.01	0.063	00:11	0.001	1
S269	0.01	0.058	00:12	0.001	1
S1002.1	0.8	0.033	00:11	0.001	1
S305A	0.01	0.04	00:12	0.001	1
S258	0.01	0.053	00:12	0.001	1
Sum of Total of Nodes Flooding Volume m^3					**6912**

Table 10: Flooded nodes in the combined sewage system and their flow rate data from SWMM modelling using the rainfall intensities for 10 years return period.

The Combined Sewer System Results using rainfall intensity for 10 years return period.					
Node Flooding					
Node	Hours Flooded	Maximum Rate CMS	Hours of maximum Flooded	Node Flood Volume 10^6 litters	Node Flood Volume CM
S266	2.21	0.339	00:15	1.754	1754
S471	2.05	0.15	00:15	0.518	518
A993A	2.82	0.118	00:16	0.497	497
S175	2.04	0.145	00:15	0.477	477
S231	1.98	0.13	00:18	0.425	425
S263	2.00	0.096	00:15	0.385	385
S311	2.06	0.082	00:15	0.379	379
S543	2.09	0.053	00:12	0.344	344
S298	1.93	0.128	00:15	0.31	310
S989B	2.83	0.07	00:08	0.286	286
S989A	2.82	0.048	00:08	0.271	271
S993B	2.71	0.075	00:13	0.264	264
S996B	2.15	0.058	00:09	0.216	216
S541	1.92	0.073	00:15	0.194	194
S254	1.92	0.057	00:15	0.191	191
S188	1.86	0.069	00:15	0.16	160
S267A4	0.72	0.119	00:17	0.15	150
S520	1.43	0.08	00:15	0.142	142
S281	1.94	0.056	00:15	0.136	136
S474	1.93	0.047	00:15	0.13	130
S252	0.92	0.09	00:15	0.129	129
S1002	1.91	0.052	00:15	0.119	119
S311A	1.41	0.072	00:15	0.114	114
S989D	1.91	0.063	00:11	0.098	98
S1002.2	1.95	0.068	00:10	0.085	85
S191	1.98	0.025	00:09	0.084	84
S267N10	1.02	0.054	00:15	0.083	83
S477A	0.48	0.123	00:12	0.081	81
S179	1.55	0.051	00:08	0.067	67
S239	0.37	0.075	00:16	0.055	55
S267N8	0.61	0.046	00:15	0.043	43
S200	0.63	0.042	00:15	0.038	38
S274	0.89	0.02	00:15	0.035	35
S342	0.42	0.04	00:17	0.034	34
S549	1.07	0.016	00:28	0.033	33
S496	0.30	0.116	00:11	0.032	32
S300A	0.61	0.046	00:11	0.031	31
S261	0.57	0.033	00:15	0.031	31
S310	0.56	0.051	00:09	0.031	31
S503A	0.09	0.317	00:18	0.026	26
S445	0.21	0.071	00:15	0.026	26
S503	0.08	0.747	00:32	0.025	25

S255	0.31	0.041	00:08	0.022	22
S989C	2.83	0.059	00:08	0.02	20
S219	0.32	0.033	00:15	0.018	18
S476	0.30	0.03	00:10	0.018	18
S507	0.36	0.079	00:23	0.018	18
S451	0.37	0.044	00:14	0.018	18
S193	0.69	0.024	00:09	0.018	18
S548	0.36	0.024	00:15	0.017	17
S515	0.29	0.043	00:10	0.016	16
S511A	0.40	0.029	00:15	0.015	15
S271	0.37	0.044	00:10	0.015	15
S177	0.42	0.043	00:10	0.014	14
S248F	0.30	0.044	00:12	0.014	14
S354	0.30	0.027	00:15	0.013	13
S262	0.27	0.034	00:08	0.011	11
S291	0.23	0.024	00:11	0.009	9
S289	0.28	0.023	00:09	0.009	9
S361	0.25	0.047	00:12	0.009	9
S460	0.22	0.051	00:11	0.008	8
S273	0.46	0.043	00:10	0.008	8
S206	0.24	0.043	00:12	0.008	8
S996A	0.30	0.071	00:09	0.007	7
S999	0.20	0.049	00:09	0.007	7
S199	0.16	0.029	00:11	0.007	7
S228	0.21	0.032	00:09	0.006	6
S305C	0.18	0.025	00:11	0.006	6
S341	0.11	0.035	00:15	0.005	5
S197A2	0.03	0.644	00:23	0.004	4
S309	0.19	0.024	00:09	0.004	4
S482	0.13	0.026	00:15	0.004	4
S248C	0.13	0.088	00:11	0.004	4
S284	0.13	0.03	00:13	0.004	4
S248E	0.16	0.038	00:12	0.003	3
S535	0.17	0.035	00:09	0.003	3
S267A6	0.01	0.319	00:10	0.003	3
S197A1	0.01	0.453	00:23	0.002	2
S358	0.02	0.078	00:12	0.002	2
S282	0.12	0.009	00:15	0.002	2
S1002.1	0.95	0.039	00:10	0.002	2
S548E	0.15	0.043	00:09	0.002	2
S545	0.09	0.043	00:07	0.002	2
S267N6	0.10	0.007	00:10	0.001	1
S338	0.01	0.029	00:14	0.001	1
S268AA	0.01	0.055	00:11	0.001	1
S996C	0.01	0.064	00:10	0.001	1
S269A	0.01	0.069	00:12	0.001	1
S248B	0.01	0.062	00:12	0.001	1
S547	0.13	0.045	00:07	0.001	1

S305A	0.04	0.042	00:11	0.001	1
S267A3	0.01	0.037	00:10	0.001	1
S305B	0.01	0.052	00:11	0.001	1
S235	0.08	0.043	00:10	0.001	1
S269	0.01	0.06	00:11	0.001	1
S194	0.01	0.062	00:12	0.001	1
S258	0.01	0.056	00:11	0.001	1
S528	0.01	0.042	00:12	0.001	1
S183	0.01	0.043	00:11	0.001	1
S492	0.09	0.018	00:10	0.001	1
S250	0.01	0.044	00:12	0.001	1
S526	0.08	0.023	00:12	0.001	1
S451AA	0.01	0.052	00:12	0.001	1
S548D	0.01	0.057	00:10	0.001	1
S450	0.04	0.022	00:15	0.001	1
S542	0.01	0.172	00:12	0.001	1
Sum of Total of Nodes Flooding Volume m^3					**8929**

Table 11: Flooded nodes in the combined sewage system and their flow rate data from SWMM modelling using the rainfall intensities for 25 years return period.

The Combined Sewer System Results using rainfall intensity for 25 years return period.					
Node Flooding					
Node	Hours Flooded	Maximum Rate CMS	Hours of maximum Flooded	Node Flood Volume 10^6 litters	Node Flood Volume CM
S266	2.26	0.356	00:15	2.130	2130
S471	2.08	0.185	00:15	0.672	672
S175	2.07	0.182	00:15	0.665	665
S231	2.04	0.141	00:20	0.615	615
A993A	2.84	0.123	00:15	0.595	595
S263	2.04	0.108	00:15	0.516	516
S298	2.00	0.148	00:15	0.503	503
S311	2.08	0.099	00:15	0.447	447
S543	2.13	0.056	00:11	0.370	370
S993B	2.72	0.078	00:12	0.357	357
S267A4	1.37	0.181	00:15	0.351	351
S254	2.00	0.071	00:15	0.291	291
S989B	2.84	0.082	00:07	0.291	291
S989A	2.84	0.052	00:07	0.286	286
S541	2.00	0.088	00:15	0.283	283
S188	1.99	0.099	00:15	0.276	276
S520	1.92	0.092	00:15	0.274	274
S252	1.82	0.119	00:15	0.273	273
S996B	2.18	0.065	00:09	0.244	244
S311A	1.97	0.088	00:15	0.224	224
S281	2.01	0.07	00:15	0.217	217
S474	2.01	0.05	00:20	0.205	205
S1002	1.99	0.061	00:15	0.200	200
S989D	1.99	0.077	00:15	0.181	181
S477A	0.95	0.127	00:11	0.181	181

S267N10	1.93	0.072	00:15	0.173	173
S239	0.73	0.116	00:15	0.136	136
S179	1.97	0.067	00:08	0.133	133
S1002.2	2.01	0.069	00:09	0.108	108
S267N8	1.21	0.067	00:13	0.105	105
S191	2.04	0.032	00:15	0.104	104
S496	0.63	0.139	00:10	0.097	97
S200	1.19	0.063	00:15	0.084	84
S445	0.47	0.102	00:15	0.084	84
S342	0.85	0.041	00:14	0.075	75
S255	0.60	0.073	00:15	0.071	71
S310	1.07	0.057	00:08	0.070	70
S274	1.79	0.024	00:15	0.070	70
S261	1.09	0.051	00:15	0.069	69
S549	1.92	0.016	00:19	0.066	66
S300A	1.18	0.052	00:10	0.063	63
S503	0.21	0.604	01:21	0.053	53
S507	0.72	0.093	01:11	0.049	49
S515	0.57	0.063	00:15	0.048	48
S219	0.63	0.054	00:15	0.047	47
S511A	0.81	0.039	00:16	0.045	45
S476	0.60	0.045	00:15	0.045	45
S451	0.77	0.042	00:12	0.043	43
S193	1.30	0.03	00:08	0.041	41
S503A	0.12	0.373	01:43	0.039	39
S548	0.72	0.026	00:14	0.037	37
S354	0.58	01:01	00:15	0.037	37
S177	0.79	01:14	00:09	0.036	36
S262	0.54	01:09	00:15	0.033	33
S271	0.75	01:06	00:09	0.033	33
S989C	2.85	01:39	00:08	0.031	31
S248F	0.60	0.05	00:11	0.031	31
S341	0.28	0.057	00:15	0.030	30
S248C	0.29	0.095	00:10	0.028	28
S460	0.43	0.055	00:09	0.027	27
S361	0.50	0.05	00:10	0.027	27
S291	0.48	0.037	00:10	0.026	26
S999	0.40	0.037	00:08	0.024	24
S289	0.58	0.039	00:08	0.024	24
S305C	0.33	0.035	00:15	0.023	23
S199	0.31	0.041	00:10	0.022	22
S228	0.44	0.036	00:15	0.021	21
S206	0.47	0.045	00:11	0.021	21
S482	0.32	0.042	00:15	0.020	20
S273	0.84	0.042	00:09	0.019	19
S996A	0.59	0.094	00:09	0.019	19
S267N6	0.32	0.031	00:15	0.016	16
S309	0.36	0.036	00:08	0.016	16

S535	0.35	0.031	00:08	0.015	15
S492	0.26	0.026	00:15	0.014	14
S338A	0.17	0.039	00:15	0.014	14
S282	0.27	0.032	00:15	0.014	14
S548E	0.32	0.055	00:09	0.013	13
S235	0.24	0.057	00:09	0.012	12
S284	0.27	0.035	00:09	0.012	12
S197A2	0.02	0.519	00:49	0.010	10
S248E	0.35	0.05	00:11	0.010	10
S197A1	0.01	0.485	00:22	0.009	9
S526	0.22	0.023	00:15	0.009	9
S305A	0.23	0.053	00:10	0.008	8
S444	0.13	0.024	00:15	0.008	8
S545	0.22	0.046	00:07	0.008	8
S450	0.18	0.025	00:13	0.008	8
S210	0.18	0.026	00:08	0.007	7
S1002.1	1.05	0.042	00:09	0.005	5
S196	0.18	0.026	00:10	0.005	5
S267A6	0.01	0.382	00:09	0.005	5
S265	0.21	0.092	00:09	0.005	5
S256	0.15	0.078	00:10	0.005	5
S358	0.14	0.075	00:10	0.005	5
S182	0.21	0.046	00:09	0.005	5
S497	0.13	0.048	00:11	0.004	4
S248B	0.15	0.059	00:11	0.003	3
S257	0.20	0.045	00:10	0.003	3
S250	0.14	0.051	00:11	0.003	3
S473	0.14	0.056	00:08	0.003	3
S345	0.08	0.017	00:15	0.003	3
S990A	0.10	0.078	00:08	0.003	3
S276	0.16	0.034	00:10	0.002	2
S214	0.10	0.013	00:15	0.002	2
S267A5	0.12	0.077	00:09	0.002	2
S467	0.10	0.03	00:12	0.002	2
S547	0.28	0.015	00:07	0.002	2
S267A3	0.01	0.061	00:09	0.001	1
S305B	0.01	0.055	00:10	0.001	1
S314	0.01	0.066	00:09	0.001	1
S996C	0.01	0.073	00:09	0.001	1
S323A	0.07	0.056	00:09	0.001	1
S300	0.12	0.052	00:09	0.001	1
S267N13	0.01	0.063	00:09	0.001	1
S316	0.06	0.032	00:09	0.001	1
S321	0.01	0.052	00:10	0.001	1
S548D	0.01	0.059	00:09	0.001	1
S490	0.08	0.042	00:09	0.001	1
S468	0.01	0.051	00:12	0.001	1
S463	0.07	0.08	00:09	0.001	1

S221	0.04	0.044	00:11	0.001	1
S183	0.02	0.046	00:10	0.001	1
S270	0.08	0.068	00:10	0.001	1
S178	0.01	0.047	00:10	0.001	1
S238.2	0.01	0.049	00:11	0.001	1
S268AA	0.01	0.059	00:10	0.001	1
S528	0.01	0.047	00:11	0.001	1
S269	0.01	0.064	00:10	0.001	1
S258	0.01	0.064	00:10	0.001	1
S308	0.10	0.038	00:09	0.001	1
S338	0.06	0.028	00:13	0.001	1
S542	0.01	0.215	00:11	0.001	1
S451AA	0.01	0.056	00:10	0.001	1
S269A	0.02	0.075	00:11	0.001	1
S194	0.01	0.066	00:11	0.001	1
S538	0.01	0.056	00:09	0.001	1
S540	0.08	0.044	00:08	0.001	1
Sum of Total of Nodes Flooding Volume m^3					**13434**

Table 12: The flooded nodes results from SWMM modelling of the stormwater system using the different rainfall intensities.

The Stormwater Sewer System Nodes Flooding results using rainfall intensity for 2-year return period.					
Node	Hours Flooded	Maximum Rate CMS	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr.	Total Flood Volume m^3
R59	2.75	0.031	00:15	0.267	267
R47	2.76	0.028	00:00	0.117	117
R357A4	1.65	0.02	01:21	0.071	71
R205	2.76	0.008	00:26	0.07	70
R64	0.01	0.021	00:15	0.001	1
Total Nodes Flooding Volume m^3					**526**
The Stormwater Sewer System Nodes Flooding results using rainfall intensity for 5-year return period.					
Node	Hours Flooded	Maximum Rate CMS	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr.	Total Flood Volume m^3
R47	2.94	0.158	00:00	1.01	1010
R357A4	2.82	0.112	00:11	0.759	759
R59	2.92	0.044	00:11	0.457	457
R60	2.9	0.035	00:17	0.361	361
R205	2.88	0.009	00:10	0.073	73
R64	2.9	0.036	00:06	0.007	7
R210	0.05	0.023	00:07	0.002	2
Total Nodes Flooding Volume m^3					**2669**
The Stormwater Sewer System Nodes Flooding results using rainfall intensity for 10-year return period.					
Node	Hours Flooded	Maximum Rate CMS	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr.	Total Flood Volume m^3
R47	2.98	0.205	00:00	1.463	1463
R357A4	2.79	0.123	00:00	0.652	652
R60	2.94	0.054	00:55	0.564	564
R59	2.94	0.047	01:20	0.491	491
R205	2.89	0.04	00:03	0.074	74
R64	2.92	0.034	00:05	0.069	69
Total Nodes Flooding Volume m^3					**3316**
The Stormwater Sewer System Nodes Flooding results using rainfall intensity for 25-year return period.					
Node	Hours Flooded	Maximum Rate CMS	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr.	Total Flood Volume m^3
R47	3	0.290	00:00	2.349	2349
R357A4	2.93	0.156	00:07	1.364	1364

R60	2.98	0.094	00:36	0.997	997
R59	2.96	0.054	00:13	0.567	567
R64	2.94	0.051	00:01	0.104	104
R61	2.95	0.065	00:00	0.091	91
R205	2.89	0.039	00:02	0.074	74
R440	2.6	0.017	00:01	0.017	17
R210	0.06	0.023	00:06	0.002	2
R48	0.01	0.171	00:00	0.001	1
R49	0.01	0.142	00:00	0.001	1
Total Nodes Flooding Volume m^3					**5568**

Table 13: The changes of pollutants concentrations in SWMM modelling at disposal point during simulation time.

Table - Node Out-1						
Date	Time	TSS (MG/L)	BOD (MG/L)	Cu (MG/L)	Pb (MG/L)	Cr (MG/L)
11/28/2020	5	0.000	0.000	0.000	0.000	0.000
11/28/2020	10	451.927	48.177	0.053	0.019	0.004
11/28/2020	15	1343.137	157.386	0.146	0.055	0.013
11/28/2020	20	1748.770	239.545	0.292	0.109	0.026
11/28/2020	25	1564.972	244.689	0.351	0.118	0.035
11/28/2020	30	1044.213	187.687	0.311	0.104	0.039
11/28/2020	35	516.551	107.542	0.234	0.083	0.037
11/28/2020	40	221.237	53.354	0.162	0.059	0.034
11/28/2020	45	88.997	24.688	0.105	0.041	0.033
11/28/2020	50	34.835	10.999	0.068	0.031	0.032
11/28/2020	55	13.393	4.748	0.047	0.027	0.031
11/28/2020	60	5.160	1.992	0.037	0.025	0.031
11/28/2020	65	2.357	0.863	0.033	0.025	0.031
11/28/2020	70	1.621	0.431	0.031	0.024	0.031
11/28/2020	75	1.498	0.271	0.030	0.024	0.031
11/28/2020	80	1.545	0.221	0.030	0.024	0.031
11/28/2020	85	1.777	0.239	0.030	0.024	0.031
11/28/2020	90	2.212	0.310	0.030	0.024	0.031
11/28/2020	95	2.776	0.412	0.030	0.024	0.032
11/28/2020	100	3.254	0.506	0.031	0.024	0.032
11/28/2020	105	3.491	0.559	0.031	0.024	0.032
11/28/2020	110	3.370	0.550	0.031	0.024	0.033
11/28/2020	115	2.915	0.482	0.031	0.024	0.033
11/28/2020	120	2.280	0.380	0.031	0.025	0.034

الخلاصة

قد تكون الفيضانات في أنظمة الصرف الصحي ناتجة عن التحضر عند زيادة المناطق غير المنفذة وتقليل معدل التسلل أو تغيرات استخدام الأراضي أو تغير المناخ الذي يتسبب في زيادة كثافة هطول الأمطار أو سوء استخدام السكان، كل ذلك يؤثر على أداء هذه الأنظمة.
تهدف الدراسة الحالية إلى البحث في تأثير منطقة مكتظة بالسكان على تشغيل نظام الصرف الصحي المشترك في ظل كثافة هطول الأمطار العالية باستخدام نموذج إدارة مياه العواصف (SWMM) من خلال محاكاة الزيادة المستقبلية في شدة هطول الأمطار للحد من فائض نظام الصرف الصحي المشترك في الدراسة منطقة. اختارت الدراسة الحالية حي الرشادية الواقع في مدينة النجف كدراسة حالة.
كانت الخطوة الأولى في هذه الدراسة هي إنشاء منحنيات الكثافة - المدة - التردد (IDF) من خلال إيجاد المعادلات التجريبية لهذه المنحنيات بناءً على بيانات هطول الأمطار التاريخية للفترة من 1989 إلى 2018، تم استخدام ثلاث توزيعات إحصائية للتنبؤ بأعلى هطول للأمطار شدة فترات العودة 2 و5 و10 و25 سنة. تشمل هذه التوزيعات توزيع Gumbel و Log Pearson وLognormal، حيث تم الحصول على شدة هطول الأمطار العالية باستخدام توزيعGumbel ، حيث تم استخدام كثافة هطول الأمطار هذه في نمذجة SWMM لتقدير أحجام الفيضانات القصوى في أنظمة الصرف الصحي في منطقة الدراسة.
البيانات المتوفرة تمثل حدثا واحدا فقط لهطول الأمطار بتاريخ 2020/11/28 والذي تم استخدامه لأغراض معايرة النموذج الكمي حيث بلغ عمق هطول الامطار 55 ملم في مدينة النجف الاشرف.
كما أجريت مقارنات بين معدلات تدفق التصميم ومعدلات تدفق نموذج الحدث ومعدلات تدفق النماذج باستخدام شدة هطول الأمطار المختلفة، باستخدام مؤشرات متوسط الخطأ التربيعي الطبيعي، ومعامل التحديد، ومتوسط الخطأ التربيعي الجذر. تساعد هذه المؤشرات في تقدير أداء النمذجة والحصول على أقرب شدة لهطول الأمطار لحدث هطول الأمطار، وهو كثافة هطول الأمطار لفترة العودة البالغة 5 سنوات. تم استخدام كثافة هطول الأمطار هذه في نمذجة SWMM لجودة مياه الأمطار في منطقة الدراسة لتقدير أحجام الملوثات.
تبلغ أحجام الفيضانات المقدرة في نمذجة نظام الصرف الصحي المشترك 3817 م^3 و6912 م^3 و8929 م^3 و13434 م^3 باستخدام شدة هطول الأمطار لفترات العودة 2 و5 و10 و25 سنة على التوالي. تم استخدام كميات الغمر التي تم الحصول عليها كمعدل تدفق خارجي من عقد نظام الصرف الصحي المجمعة إلى أقرب العقد في نظام تصريف مياه الأمطار.
كانت نتيجة الغمر باستخدام نمذجة نظام تصريف مياه الأمطار 526 م^3، و2669 م^3، و3316 م^3، و5568 م^3 وذلك باستخدام شدة هطول الأمطار لفترات العودة 2 و5 و10 و25 سنة على التوالي، حيث كانت أحجام الفيضانات هي الفيضان النهائي. مجلدات في منطقة الدراسة.
كما أجريت اختبارات معملية على مياه الأمطار عند نقطة التخلص في نهاية نظام تصريف مياه الأمطار في الطقس الجاف والرطب. تم استخدام نتائج الاختبارات التي تم الحصول عليها أثناء هطول الأمطار في عملية معايرة نموذج جودة مياه الأمطار لتقدير عوامل تراكم الملوثات والغسيل في منطقة الدراسة.

كانت كميات الملوثات الناتجة عند نقطة تصريف مياه الأمطار 1589.34 كغم من المواد الصلبة الذائبة و250.302 كغم من BOD_5 و0.514 كغم من النحاس و0.227 كغم من الرصاص و0.165 كغم من الكروم و0.309 كغم من المنجنيز باستخدام محاكاة نموذج جودة SWMM لمدة ساعتين.

تشمل السيناريوهات المقترحة زيادة أقطار بعض الأنابيب في نظام الصرف الصحي المشترك، حيث أظهرت النتائج المتحصل عليها انخفاض نسبة الفيضان في نظام الصرف الصحي المجمع بنسبة 53.52٪، 39.65٪، 33.3٪، 24.41٪ من إجمالي الفيضانات، حيث جاء هذا السيناريو. القدرة على تقليل كمية الملوثات التي تأتي من فيضان نظام الصرف الصحي المشترك أثناء أحداث هطول الأمطار عندما يدخل هذا الفائض في مداخل نظام مياه الأمطار.

يتضمن السيناريو الآخر استخدام وحدة مدمجة في نهاية نظام مياه العواصف لمعالجة مياه العواصف الملوثة، والتي تعتبر مشكلة لا يمكن السيطرة عليها، بسعة معالجة تبلغ 500 متر مكعب / ساعة.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة كربلاء
كلية الهندسة
قسم الهندسة المدنية

تأثير المنطقة ذات الكثافة السكانية العالية على عمل نظام الصرف الصحي المشترك: دراسة حالة، مدينة النجف

أطروحة مقدمة لقسم الهندسة المدنية في جامعة كربلاء بتحقيق جزئي لدرجة ماجستير العلوم في الهندسة المدنية.

من قبل:
عمار رشيد مجيد
بكالوريوس في الهندسة المدنية 1999 / جامعة الكوفة

بإشراف

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أيلول 2021