Analysis and evaluation of a sewage network during heavy rains using the SSOAP toolbox

Basim K Nile, Hussein Ali Mohammed, and Khawlah A Htif
University of Kerbela, College of Engineering, Iraq
Email: engkhawla114@gmail.com.

Abstract. One of the major problems facing urban areas is the recent increase in precipitation intensity over design standards due to global warming. This significantly increased precipitation depth directly influences sewage systems by causing increased flow and infiltration (RDII), which eventually leads to flooding of the systems. The aim of this study was to analyse and evaluate a sewage network during such severe rainfall, to determine the excess amount of rain entering the system. To achieve this, the Hay Al-Hurr region of Karbala was selected as a case study, and the Sanitary Sewer Overflow Analysis and Planning (SSOAP) toolbox was used to estimate the volumes of inflow and infiltration (RDII) entering the sewer network, while the stormwater management software (SWMM5) within the toolbox was used for hydraulic assessment of the sewage system. The sewage network of the main pipeline of the study area was analysed with regard to two rain events in 2016, one of which was a standard event of 25 mm, and the other a torrential event of 105 mm. The RDII was 2.29 mm for the first event and 2.58 mm for the second event; on calibrating these results with SWMM5, a display of flood areas for each event was created showing the percentage overflows for two events were 30% and 65%, respectively. These results were realistic and according to predictions, allowing the study to help improve engineering knowledge and decision-making capabilities with regard to designing sewage networks, as well as facilitating the development of appropriate solutions to rehabilitate those areas most vulnerable to standardised entry by developing specific strategies to reduce or eliminate the surplus runoff.

Keyword: Karbala, SSO, RDII, SSOAP toolbox, SWMM

1. Introduction
The sewage network is one of the most critical parts of city infrastructure, though it is often referred to as the "hidden infrastructure". In modern society, sewage networks are an essential element despite being out of sight and often tough to reach. Flooding of the sewage networks due to rain that exceeds design capacity is a significant problem in most countries of the world [1, 2], as about 80% of overflows from sewage network are caused by rain [3]. The Intergovernmental Panel on Climate Change (IPCC) has noted that there has been a rise in global temperatures in the last 100 years [4], warning that this is likely to increase the frequency of torrential rains during the 21st century [5]. These increases in the intensity and depth of rainfall lead to other environmental risks [6, 7]; in particular, growing urbanisation alongside higher intensity rain increases flood risks in developing countries, as many of these do not have the necessary measures to address such issues [8, 9, 10]. Sewage flow (SSO) occurs when the amount of rain entering a sewer system exceeds the design capacity; when the sewage network is filled with rainwater, the runoff basins may be unable to accommodate the volume of pumping, which can then lead to SSO in the proximity of pumping stations [12]. Increases in urbanisation have increased the
volume of surface flow tenfold, causing levels of flooding that would otherwise be predicted to occur only every 100 years to increase by 30% [13, 14, 15].

In the planning of sewage systems, it is necessary to diagnose flood areas in terms of cases, flow volume, and infiltration (RDII) in order to develop appropriate plans to address these. Flow can be defined as the direct drift that occurs early during precipitation, passing through sewage pipes via direct connections. The mainstream sources of this are drainage pipes from the roofs of buildings that are illegally connected to the sewers, which constitutes a high percentage of such flow as a result of the exploitation of home gardens during the construction of residential homes. The condition of the sewage network, manhole covers, storm sewer connections, and so on, in addition to the quantity of mud and debris that enters the storm network [16], may predispose it to blockage, and water entering the network illegally is rarely properly filtered. Another type of problematic influx is categorized as infiltration or flow; this reaches sewage pipes through fractures, sections of leaky pipes, loose connections, or defective manhole walls, usually bringing with it a load of soil [17]. This paper thus offers a potentially useful estimation of flow and infiltration (RDII) using the Sanitary Sewer Overflow Analysis and Planning Toolbox (SSSOAP) to create a starting point to address this issue.

A residential neighbourhood in the centre of Karbala, Iraq, was selected to be the subject of investigation, based on the low topography of the area and the proliferation of home gardens in construction, with most pipe surfaces connected to the sewage network, making it more vulnerable to flow. In order to estimate the RDII flow, precipitation data and the flow control data were used. SSSOAP applies the popular RTK Synthetic Unit Hydrograph (U.H.) technique, calibrated through synthetic U.H. curve structure analysis. There is more than one method for analysing RTK parameters, though in this case, the trial and error method was used. While this can be a long and imprecise procedure, manual modification with a genetic algorithm allows the measurement RDII [18]. The SSSOAP software simplifies various longstanding methods of calibrating the necessary parameters, R, T, and K, as well as allowing data visualization [19], and the RDII valuation method for SSSOAP appears to be consistent with the appropriate selection of evaluation methods as suggested by previous researchers.

Recently, a great deal of research has focused on preserving water resources [20], especially rainwater, which is the main source of clean water in many places. Several studies have been conducted with the aim of finding ways to reduce sewage flooding by separating flow and infiltration from sewage, and these have applied multiple scenarios such as using rain gardens, green roofs, and rain tanks [21, 22] or increasing the efficiency of the rain network by using a filter to get rid of mud and debris [16]. A proposal for new rain lines to increase the capacity of the rain network to absorb a greater volume of rain [23] has also been developed.

Too much rainwater entering the sewage system, causes it to overflow. When comparing the amount of rain entering the sewer network in the first rain event in this study, the volume was 11.37 ml, while in the second rain event, it was 27.85 ml, causing overflow in the manholes; the rate of overflow was then 30% and 60% for periods of 24 and 28 hours respectively. A number of researchers have analysed sewage networks using different programs with estimated data, so that the cause of sewage flood infiltration or direct flow at the local level was not identified. By using a new program that depends on real data, accurate determination of the cause of the flow exceeding specifications, whether that is direct flow or infiltration through pipes and broken manhole walls can be made, thus facilitating the diagnosis of the problem and allowing development of an appropriate solution to reduce overflow. The underlying aim of this study was thus to analyse the sewerage network and to determine the amount of rain entering during specific rainfall events by means of the RTK parameter finding method. The network was then hydraulically evaluated based on identifying the most extreme areas during storm conditions.
2. METHODOLOGY

The research methodology is outlined below:

2.1 The case study area.
In this study, the specific case study area (Hay Al-Hurr) was chosen due to its experience of flooding of the sewage network during heavy rains, which occurs both because of its topography and the nature of land use, as shown in Fig (4). The area served by the sewage network under examination is 1,034,699 square meters, and the length of the sewage network is 22,810 meters (Directorate of Karbala Sewers, 2020). The area’s population exceeds about 10,000 people (Karbala Planning Directorate), as it is one of the oldest residential neighbourhoods nearby. The location of the main flow monitoring device was on the mainline, with daily flow recorded by the sanitation department of the Directorate Karbala from 2016 to 2019. From this data, 2016 was selected as an example rainy year, as the amount of rain was recorded at 105 mm, with 25.5mm/h intensity in that period.

![Figure 1. Hay Al-Hurr, Karbala, Iraq](image)

2.2 Data collection and analysis

2.2.1 Hydrological data: This includes rain data obtained from the General Directorate of Climate and seismology for the years 2016 to 2019 at intervals of one hour, and the IDF curve for Kerbela city.

2.2.2 Hydraulic data: This includes wastewater flow monitoring device data obtained from the General Directorate of Sewerage for the years 2016 to 2019 at one-hour intervals.

2.2.3 Sewershed data: This includes the area served by the sewage network, with parks and other public facilities subtracted, as drawn from the Geographic Information Systems (G.I.S).

2.2.4 Data on the physical properties of the sewage network: This data was provided by the Karbala Sewerage Directorate

2.3 SSOAP toolbox
SSOAP is an integrated toolkit that analyses the capacity of a sewage system by determining the relevant value of RDII. This Toolbox also includes the EPA's Storm Water Management (SWMM5)
[20], used for performing dynamic routing of flows through the sanitary sewer system for capacity evaluation.

The SSOAP toolkit includes valuable equipment designed to support SSO Mitigation Manual technical review and sanitation evaluation efforts by

1. Analysing and managing rain data and flow data.
2. Identifying RDII properties.
3. Identifying those areas most vulnerable to flooding to allow prioritisation of rehabilitation.
4. Allowing a complete evaluation of the sewage system by evaluating the RDII volume associated with the flood amount and facilitating hydraulic system evaluation using SWMM [20].

![SSOAP toolbox interface](image)

**Figure 2.** SSOAP toolbox interface

The main tools in the program are the
- Database Management tool (DMT);
- RDII Analysis Tool;
- RDII Hydrograph Generation tool;
- SWMM5 Interfacing tool; and
- Condition assessment support tool

2.3.1 *Database Management tool (DMT):*
This is the SSOAP tool command centre, which organises and manages file recovery, as well as allowing and managing numerous electronic software interfaces and data inputs from electronic repositories. Relevant external sources include the sewage system GIS data, flow management system data, weather data, and the results of hydraulic analysis.

The functionality of DMT has three main aspects:

1. Data monitoring of rainfall and flow.
2. Data management and analysis.
3. Scenario management for planning and reducing SSO.
2.3.2 RDII Analysis Tool planning
This analyses the hydrographs of wastewater to calculate RDII using R, T, and K parameters. Hydrograph analysis is used to calculate the variables relevant to wastewater flow in the wastewater system, while the wastewater cycle is used for evaluating the flows and RDII features in the sewage system as described in figure 3, based on the three specific wastewater components identified.

![Figure 3. Three primary wastewater components.](image)

2.3.2.1 Base Wastewater Flow (BWF).
This refers to all wastewater that enters the network from residential, commercial, and industrial areas that crosses the main source of wastewater.

2.3.2.2 Infiltration of groundwater (GWI).
This refers to water from ground level seeping into the sewage network through defective pipes, the walls of manholes, or from contact connections; this thus offers a measure of the quality of the hydraulic system as it approaches the lowest level [19].

2.3.2.3 Rainfall Derived Inflow and Infiltration (RDII).
Rain enters the sewage network during a rain event, either directly or by infiltration. In humid weather, RDII is a significant component of peak sewage, and thus may cause flooding of sewage networks during major events.
The technique uses a set of three triangular hydrographs that depend on rainfall entry simultaneously to estimate RDII. Each of the three hydrographs has three parameters [21], described in the SWMM user manual as follows:
R: The fraction of rainfall volume entering the sewer system.
T: The time from the onset of rainfall to the unit hydrograph (U.H.) peak, in hours.
K: The ratio of time to recession of U.H. to the time to peak.
The first triangle represents early flow and is generally 1 to 3 hours. The second triangle represents the average event represented by flow and infiltration, lasting for 3 to 5 hours. The last triangle represents the offside, which occurs after rain events and lasts the longest.

2.3.3 RDII Hydrograph Generation Tool
This tool's function is to generate hydrographic data using rain data and details of the area served by the sewers (sewershed data). The RDII volume generated by the RDII Analysis Tool requires manual entry of the relevant parameters (R T K) as inputs in the SWMM hydraulic model in order to analyse drainage system capacity and evaluate network performance. It can, however, export RDII hydrographs to other
hydraulic steering motors as well as SWMM. Figure 4 shows a study of rainy weather utilising the RDII analysis system.

![Figure 4. Hydrographic analysis in a program SSOAP toolbox (Vallabhaneni and Camp, 2007)](image)

2.3.4 SSOAP-SWMM5 interface tool.
This tool provides communication between SSOAP and SWMM5, facilitating hydraulic analysis. There are three functions that this tool performs: organising and preparing the hydrographs generated by the RDII Hydrograph Generation Tool as SWMM5 input files; SWMM simulation; and transferring the results to the ranking data management tool.

3. Result and discussion

3.1 RDII analysis
This stage has two main components, as illustrated below:

3.1.1 Establishing dry-weather flow (DWF): DWF refers to the amount of free flow without rain. The RDII Analysis Tool thus identifies dry days during the week and at weekends and represents these automatically based on rain data and wastewater flow for the observation period. In terms of the GWI, this can be extracted from the minimum daily flow rate, which is 80 to 90% for residential areas and 50% for commercial spaces, universities, and similar institutions, [24, 25] SSOAP can also identify the GWI based on specific ground use, as DWF is divided into BWF and GWI. Figure 5 shows an analysis of dry-weather flow for the Al-Hurr sector.
3.1.2 Hydrographic analysis: To determine the RDII component of each storm event, the DWF hydrograph must be subtracted from the hydrograph observed in wet weather. This is an important first step in measuring RDII. An example of a hydrographic analysis of a trough on the Hay Al-Hurr trunk line shows that the RDII flow eventually returns to zero after the precipitation event has retreated. Figure 6 offers a visualisation of the hydrograph unit (RTK) parameters for the February storm in the case study.

An analysis of the RDII standards for the November storm based on Figure 6 shows three curves: the rapid response, R1; the intermediate response, R2; and the slow response, R3. The sum of the curves is the total R. The value of R1 is the highest, indicating that direct flow prevails. Here, the ADWF wastewater was 0.046 cm (represented by a light blue line), while peak total flow rate during this event was 0.151 cm (represented by a green line). The disparity between dry and rain weather flow represents the RDII.

For any of the three triangular hydrographic units, a visual system helps to identify the most suitable R, T, and K values. A curve was rendered so that the RDII simulated flows closely matched the RDII flows generated by decomposing the measured data into flow data [18]. This data was validated in
parameters. Figures 7 and 8 illustrate this verification for two extreme events of rain. The results of mutual verification show that on 22/2/2016 and 23/3/2016, using the mean square root and Nash-Sutcliffe Efficiency coefficient ($E_{NS}$) tests, the results indicate reasonable data accuracy.

\[
E_{NS} = 1 - \frac{\sum_{i=1}^{N} |Q_{obs}^i - Q_{simu}^i|^2}{\sum_{i=1}^{N} |Q_{obs}^i|^2}
\]  

Figure 8. Model calibration for the second event.

where $Q_{obs}$ refers to Observed flow; $Q_{simu}$ refers to simulated flow; and $N =$ Number of monitoring station.
\( E_{NS} \) is useful for assessing hydraulic flow accuracy [27]: the closer the \( E_{NS} \) value is to 1, the more accurate the results, indicating the extent to which measured flow corresponds to observed flow.

Table 1. RDII Event Summary Spreadsheet with Computed Total R-Value for Events in Hay Al-Hurr, Karbala.

| Start date | End date | Duration (hour) | Rain volume (mm) | Total R | Intensity (mm/h) | Peak total flow (cms) | peak I/I | \( R^2 \) | \( E_{NS} \) |
|------------|----------|-----------------|------------------|---------|-----------------|------------------------|---------|-------|---------|
| 22/2/2016  | 22/2/2016| 9               | 2.29             | 0.0916  | 17.5            | 0.12                   | 0.08    | 0.9508| 0.85    |
| 26/3/2016  | 28/3/2016| 59              | 2.583            | 0.0246  | 25.5            | 0.151                  | 0.105   | 0.9605| 0.88    |

Table 1 shows the RDII values for the two rain events. The total R represents the amount of rain entering the sewage network overall. If the value of \( R_2 + R_3 \) is greater than the total R, then the infiltration is greater than the flow. The parameters of T and K are changed to suit the event and have no effect on other events. The table also indicates that the calibration results are satisfactory for both events, with the correlation coefficients being 0.95 and 0.96, respectively, while the values of \( E_{NS} \) were 0.85 and 0.88, which are sufficiently close to 1.

3.2 Evaluation of hydraulic performance.

The stormwater management model used, SWMM5, includes a runoff portion for hydrography created by the RDII Analysis Tool using RTK Parameter. SWMM5 thus provides an interactive platform for editing data from field experiments, simulating hydrological and hydraulic quality, and displaying the results in various forms. These include drainage colour-coded areas as well as transport system maps, graphs, and time series tables, profile plots, and analyses of statistical frequency.

Hydraulic analysis was performed on the manholes containing SSOs and surcharges for 2016. Figure 9 shows the precipitation on February 22, when the cumulative daily rainfall was one inch, with a rain density of 17.5 mm/h with a 10-year return. As a result of heavy rain, the number of manholes to which additional charges accrued increased to 8 (of 25 holes in the network), and one manhole was affected by flooding.

![Figure 9](image_url)

Figure 9. Schematic diagram with a hydraulic profile showing SSO sites and surcharges on 22/2.

Figure 10 illustrates a hydraulic analysis of the main sewage network pipeline for the most significant rain event in 2016, when a total precipitation of 4.08 inches occurred from 26 to 28 March,
with a rain density of 25.5 mm/h and a return time of 10 years. The hydraulic analysis shows that three manholes were flooded, and 16 other manholes suffered from additional charges.

Figure 10. Hydraulic plot showing SSO sites, and surcharges for the event 26 to 28/3/2016

Table 2 displays the analysis results of the SWMM program, with flood period and size at manholes for both events.

Table 2. Simulation results: SWMM5 summary of events.

| Events | Intercept or | Design Capacity cms | Diameter | Total overflow volume (ML) | Manhole Depth (m) | Capacity Used | Capacity Remain | Duration Surcharged (h) | Notes |
|--------|--------------|----------------------|----------|----------------------------|-------------------|---------------|-------------------|------------------------|-------|
| Event 1 Section1 | 0.16 | 0.4 | 9.52 | 1.37 | 100% | 0 | 24 | Flooding |
| Event1 Section2 | 0.15 | 0.4 | N/A | 1.41 | 80% | 20% | N/A | N/A |
| Event1 Section3 | 0.16 | 0.4 | 1.517 | 1.5 | 100% | 0 | 24 | Surcharged |
| Event1 Section4 | 0.63 | 0.4 | N/A | 1.66 | 42% | 48% | N/A | N/A |
| Event1 Section5 | 0.63 | 0.4 | N/A | 2.5 | 85% | 15% | N/A | N/A |
| Event1 Section6 | 0.15 | 0.4 | N/A | 0.7 | 64% | 36% | N/A | N/A |
| Event1 Section7 | 0.15 | 0.4 | N/A | 1.24 | 10% | 90% | N/A | N/A |
| Event2 Section1 | 0.16 | 0.4 | 11.58 | 1.37 | 100% | 0% | 48 | Flooding |
| Event2 Section2 | 0.15 | 0.4 | N/A | 1.41 | 85% | 15% | 0 | N/A |
| Event2 Section3 | 0.16 | 0.4 | 1.517 | 1.5 | 100% | 0 | 23 | Surcharged |
| Event2 Section4 | 0.63 | 0.4 | N/A | 1.66 | 53% | 47% | 0 | N/A |
| Event2 Section5 | 0.63 | 0.4 | 10.504 | 2.51 | 100% | 0 | 33 | Flooding |
The findings given in Table 2 show that, for the first of the two events in 2016, one manhole had sewer overflows, whereas eight had sewer surcharges for 24 hours at 11.37 ML. In the second event, three manholes had sewer overflows, whereas 16 had sewer surcharges at 27.855 ML.

Overall, the two models offer an excellent fit to the simulation data and may thus be used as planning stage tools to evaluate available options without the necessity to build a full simulation model. For the earliest part of the decision-making process, this thus allows rapid progress toward which simulation models to develop. The simulated flow of events for RDII events and the observed flow in the manholes were calibrated using the correlation coefficient R and the ENS coefficient, with good results, indicating that the simulated flow was close to the observed flux. This also explains the hydraulic classification and allows a comparison of the impact of medium and heavy rain on the existing sewage network.

As the present study provides a proper evaluation of the state of the sewage network by determining the amount of rain entering the system and the ability of the network to absorb rain events that exceed its design, the selected indicators can be used to indicate risk of network failure and inability to absorb in the case of light or medium and severe events. The results showed that, in the case of regular activity, the surpluses and surcharges amounted to 30% of the network volume, at 11.37 ML for 24 hours. In the case of the most severe event, the surplus and additional fees represented 65% of the entire network, however, with a surplus volume of 30.37 ML for 28 hours. Table 2 shows the sections in which the flooding occurred, the additional fees, and the size and duration of the event. This clarifies the necessity to develop strategies and plans to reduce flood risks and their health and environmental impacts.

**4 Conclusions**

The aim of this study was to analyse and determine the amount of rain water entering the sewage network and to identify the worst affected sites in the case study area. One of the most challenging tasks was thus the quantitative estimation of rainwater entering the sewage network. Many researchers have found the hydrograph method to be one of the most successful methods of quantitative analysis; this passes through multiple stages, yet the SSOAP program makes it easy to implement, allowing rapid determination of the amount of rain entering the sewage network. Network performance can then be evaluated by using SWMM to identify flood areas to be repaired or to mitigate flood risks. The results thus developed were realistic in this case study; however, what distinguishes this program is that rapid direct flow is defined as the prevailing RI for RDII analysis. Where a great deal of rainwater enters the sewage system, this may cause it to overflow. Comparing the amount of rain that entered the drainage network in the first rain event, 11.37 ML, to that of the second event, 27.8 ML, these led to varying numbers of manholes exceeding capacity, at 1 and 3 manholes, respectively. The highest discharge recorded in the first event was 0.12 cm, while in the second event it was 0.151 cm. One of the most important causes of sewage flow is roofs of homes being connected directly to the network in the absence of gardens that can help absorb rainwater, an issue compounded by the low topography of the area.
5 References.

[1] Hassan W H, Nile B K and Al-Masody B A 2017 Climate change effect on storm drainage networks by storm water management model

[2] Nile B K, Hassan W H and Alshama G A 2019 Analysis of the effect of climate change on rainfall intensity and expected flooding by using ANN and SWMM programs ARPN J. Eng. Appl. Sci. 14 974–84

[3] Nayel M O, Nile B K and Al-Hamami H A M 2018 Estimation of the floods that occur in the drainage network during the rainy season J. Eng. Appl. Sci. 13 8178–87

[4] Meehl G A 2007 Global Climate Projections: Supplementary Materials BT - Climate change 2007-the physical science basis: Working group 1 contribution to the fourth assessment report of the IPCC vol 4 (Cambridge university press)

[5] Willems P, Arnbjerg-Nielsen K, Olsson J and Nguyen V T V 2012 Climate change impact assessment on urban rainfall extremes and urban drainage: Methods and shortcomings Atmos. Res. 103 106–18

[6] Howe C and Jones R N 2005 Implications of potential climate change for Melbourne’s water resources (CSIRO Atmospheric Research, CSIRO Urban Water, and Melbourne Water)

[7] Hunter T and Beck M 2011 Sewage reaches the bay again Age (Omaha). 58 7250–7

[8] Shinde K 2007 Pilgrimage and the environment: Challenges in a pilgrimage centre Curr. Issues Tour. 10 343–65

[9] Obaid H A, Shahid S, Nile B K and Shreesivadasan C 2014 Modeling sewrage overflow in an urban residential area using sorn water management model Malaysian J. Civ. Eng. 26 163–71

[10] Hussein A O, Shahid S, Basim K N and Chelliapan S 2016 Modeling Sewer Flow in a Pilgrimage City J. Environ. Eng. 142 05016005

[11] Sajudeen P A, Jayachandran K and Ashiq M 2012 Pilgrimage and depleting water quality: A preliminary study from river pamba Ecol. Environ. Conserv. 18 869–72

[12] Mohammed S R, Nile B K and Hassan W H 2020 Modelling Stilling Basins for Sewage Networks IOP Conf. Ser. Mater. Sci. Eng. 671 12111

[13] Obaid H A, Shahid S, Basim K N and Chelliapan S 2015 Modeling of wastewater quality in an urban area during festival and rainy days Water Sci. Technol. 72 1029–42

[14] Ogden F L, Sharif H O, Senarath S U S, Smith J A, Baecck M L and Richardson J R 2000 Hydrologic analysis of the Fort Collins, Colorado, flash flood of 1997 J. Hydrol. 228 82–100

[15] Nile B K 2018 Effectiveness of Hydraulic and Hydrologic Parameters in Assessing Storm System Flooding Adv. Civ. Eng. 2018

[16] Mohsen K A, Nile B K and Hassan W H 2020 Experimental work on improving the efficiency of storm networks using a new galley design filter bucket IOP Conf. Ser. Mater. Sci. Eng. 671 12094

[17] Muleta M K and Boulos P F 2008 Analysis and calibration of RDII and design of sewer collection systems World Environmental and Water Resources Congress 2008: Ahupua’a - Proceedings of the World Environmental and Water Resources Congress 2008 vol 316 pp 1–10

[18] Karuppasamy E and Inoue T J 2012 Application of USEPA SSOAP software to sewer system modeling World Environmental and Water Resources Congress 2012: Crossing Boundaries, Proceedings of the 2012 Congress pp 3494–504

[19] Mikalson D T 2011 Development of Analytical Probabilistic Models for the Estimation of Rainfall Derived Inflow / Infiltration by Copyright c 2011 by Daley Travis Mikalson

[20] US Environmental Protection Agency (EPA) 2016 Sanitary Sewer Overflow Analysis and Planning (SSOAP) Toolbox

[21] Nile B K, Hassan W H and Esmaeel B A 2018 An evaluation of flood mitigation using a storm water management model [SWMM] in a residential area in Kerbala, Iraq IOP Conf. Ser. Mater. Sci. Eng. 433 12001
[22] Rossman L A and Huber W C 2016 Storm Water Management Model User’s Manual (National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency Cincinnati)

[23] Hussein A O, Shahid S, Basim K N and Chelliapan S 2015 Modelling Stormwater Quality of an Arid Urban Catchment Appl. Mech. Mater. 735 215–9

[24] Shamsi U M 2012 Modeling Rain Garden LID Impacts on Sewer Overflows J. Water Manag. Model. 113–126

[25] Vallabhaneni S and Burgess E H 2007 Computer Tools for Sanitary Sewer System Capacity Analysis and Computer Tools for Sanitary Sewer System (Planning: U.S. Environmental Protection Agency, Office of Research and Development)

[26] Zhang M, Liu Y, Cheng X, Zhu D Z, Shi H and Yuan Z 2018 Quantifying rainfall-derived inflow and infiltration in sanitary sewer systems based on conductivity monitoring J. Hydrol. 558 174–83

[27] Coutu S, Del Giudice D, Rossi L and Barry D A 2012 Parsimonious hydrological modeling of urban sewer and river catchments J. Hydrol. 464–465 477–84