MODELING SEWERAGE OVERFLOW IN AN URBAN RESIDENTIAL AREA USING STORM WATER MANAGEMENT MODEL

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Abstract: Storm Water Management Model (SWMM) is used in this study for simulating rainfall driven flow in a sewer system that can cause overflow in sewer networks. The simulation is carried out in a residential area located in the Karbala city of Iraq where storm water network is not fully developed. The study reveals that severe rainfall events cause sewer overflow and surface inundation in the area. A number of measures have been proposed including capacity improvement of sewer system, reduction of discharge peak and reduction of exfiltration as a countermeasure to solve the inundation problem. It is expected that the study will help in operational management of the sewerage system and mitigate the flooding problem.

Keywords*: Sewerage system; urban drainage; storm water management model, sewer overflow, urban flooding*

1.0 Introduction

Sewerage systems are being used for carrying off liquid and solid sewage from early civilization (Metcalf & Eddy, 1981). However, sewerage systems are still not properly developed in many cities (Hassan, 2003; Burian & Edwards, 2002). This often causes urban pollution due to sewerage overflow during peak hours or high rainfall events. For proper management of urban sewerage, it is necessary to understand the causes of sewerage overflow. However, understanding sewer flow in urban area is not simple. It is often very difficult to simulate runoff in urban catchment due to man-med changes in topography. Variations in water use in household and business activities also cause large variability in sanitary sewer flow. This made the simulation of urban drainage system a challenging task. This especially true for the cities where rainfall is very sparse and erratic. Sudden extreme rainfall often causes urban flash flood in such cities. Surface inundation often occurs when rainfall exceeds the urban drainage capacity. Therefore, simulation of flow in a sewerage system is very crucial for designing and management of sewerage system and mitigation of urban flooding.

The present study simulates rainfall driven flow in a sewer system that can cause overflow through manhole and flooding. Many models have been proposed by different researchers to simulate urban sewerage system (Kokkonen and Jakeman, 2001) such as the Corp of Engineers' HEC-1 and HEC-HMS (US Army Topographic Engineering Center, 2002), the Soil Conservation Service's TR-20 and TR-55 (US Dept. of Agriculture, Natural Resources Conservation Service, National Water & Climate Center, 2002), the Watershed Modeling System's Rational Method, the Hydrologic Simulation Program - Fortran (HSPF) (Crawford and Linsley, 1966), and the USGS-NHA-FEMA National Flood Frequency (NFF) Model. However, Storm Water Management Model (SWMM) is used in this study as it has been reported to perform better to anticipate both the total volume runoff and discharge peak rate (Huber, 2003). SWMM is a semi-distributed hydrological model based on the conceptual/experimental representation of operations that generate runoff and the physical formulation of the transfer of runoff in open/closed channels. Bulter (1993) studied the patterns of wastewater generation in London, and reported that SWMM has the ability to simulate the control options of sewerage system. Yoo (2005) reported that the potential information produced by SWMM can be used in decision-making support for redevelopment in any city with better wastewater drainage system. Urbonas (2007) stated that SWMM can be used for developing guidance of discretize watershed properly and to simulate rainfall,-runoff. Performance of SWMM is compared with fuzzy logic based model by Wang and Altunkaynak (2011). They suggested that SWMM can be used in decision making for best administrative practices to achieve environmental objectives. Kazezyilmaz-Alhan (2007) mentioned that the SWMM can simulate the water control structure using the principles of mentoring relationships between spillway storage and unloading stage known. Therefore, SWMM is used in the paper for the simulation of rainfall driven flow in a sewer system that can cause overflow through manhole and flooding.

The simulation is carried out in a 34.8 hectares residential area called Shohada al Maudfeen located in the Karbala city of Iraq, where storm water network is still not fully developed. Shohada al Maudfeen has an old sewer network, and a partial storm water network. The presence of gaps, holes, broken covers manholes allow rain water to enter into sewers and consequently, increases the discharge in sewage pipes, which in turn causes flooding in networks as well as increased operational problems in the sewage systems.

The objective of the present study is to identify the places where the sewerage overflow or flooding occurs during peak time and heavy rainfall events. This is done by comparing the total flow in the sewers before and after the events of rain. It is expected that the identification of manholes that are more prone to flood during rain will help in mitigation of urban flooding due to sewer overflow.

2.0 Introduction to SWMM

The Storm Water Management Model (SWMM), developed by the United States Environmental Protection Agency (US-EPA) is a dynamic rainfall-runoff simulation model which can be used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps. SWMM was first developed in 1971 and has undergone several major upgrades since then. It continues to be widely used throughout the world for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. The current edition, Version 5, is a complete re-write of the previous release. Running under Windows, SWMM 5 provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats.

3.0 Study Area and Data Collection

The Shohada al Maudfeen residential district is located in the center of the city of Karbala (Lat: 32° 36′ 51″ N, Long: 44° 01′ 29″ E) as shown in Figure 1. Karbala is one of the wealthiest cities in Iraq. It comprises of two districts namely, Old Karbala is the most important religious center of Iraq, and New Karbala, the residential district containing Islamic schools and government buildings. The total population of the city is 1,066,600 according to the census in 2011 (City population, 2011).

Karbala experiences a hot desert climate with extremely hot, dry summers and cool winters. Almost all of the yearly precipitation occurred between November and April, though no month is truly wet (World Weather Information Service, 2014).The rainfall highest occurs in January (17.6 mm) while the lowest average can be observed in July and August (0 mm) (World Weather Information Service , 2014).

Thirty three years (1976-2008) rainfall, temperature and sewer flow data are used in Storm Water Management Model (SWMM) for this purpose. Geographical information system is used for the preparation of topographic and soil maps (World Weather

Information Service, 2014). The annual average temperature for the period 1980-2010 recorded the maximum temperature exceeds 47.4° in August 2010 and the minimum temperature is 1.6° in January 1983. The monthly evaporation rates recorded at Karbala station varies between 483.9mm in July and 64.7mm in January through the period 1980-2010 (Iraqi meteorological organization, 2011).

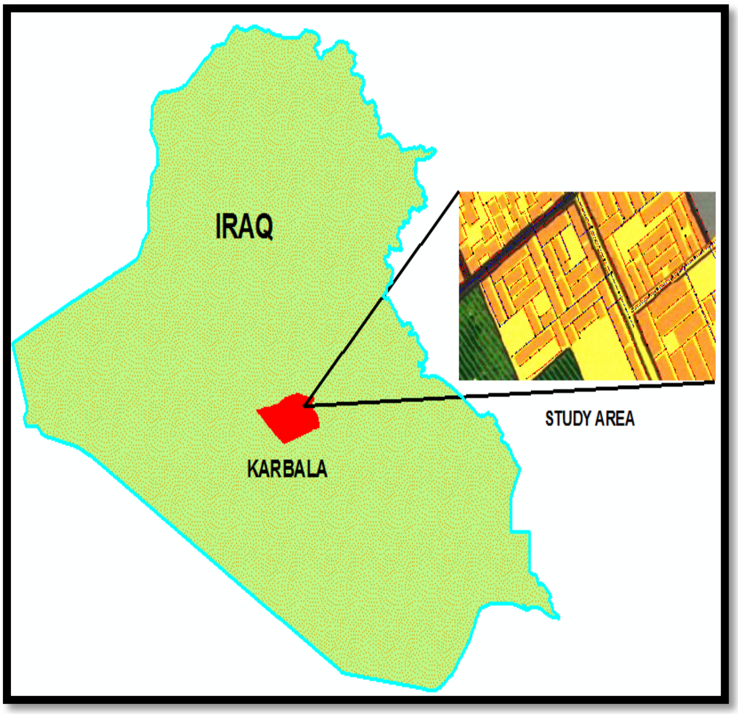

Figure 1: Location of study area in Shohada al Maudfeen residential district

4.0 Results

4.1 Flooding in Nodes

The sewer overflow and flooding in drainage systems occur due to water surge in a completely filled sewage network. Figure 2 illustrates sewer network with manhole locations in the study area. The figure shows no flood during dry period in the study area.

When rainfall starts, the amount of water starts to rise in sewer system. Consequently, overflows happen in some of the manholes. Figure 3 shows the overflow in few manholes of the sewer network simulated by SWMM. It is observed that the manholes located at the west part start to overflow first and therefore, this part can be considered as the most prone to flood due to sewer overflow. The flood continues to increase with the increase in rainfall.

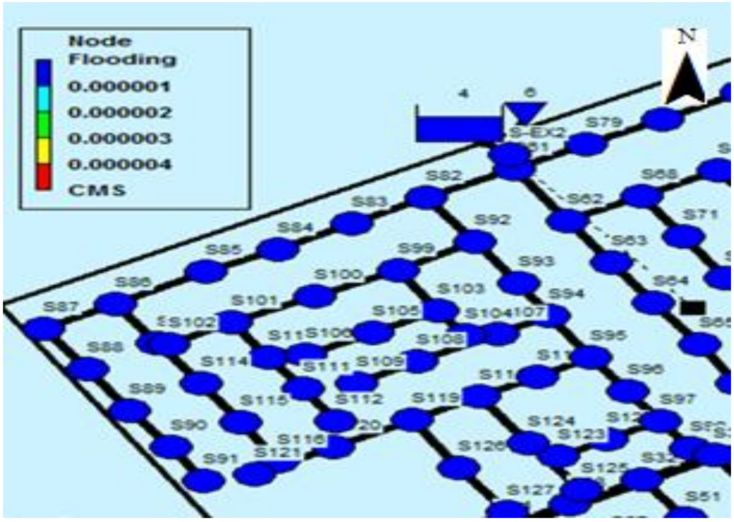

Figure 2: Sewer network with manhole location shows no flood during dry period

The presence of gaps, holes and broken covers manholes allow rain water to enter into sewers in the western part of the study area. These increase the discharge through sewage pipes, which in turn causes overflow through manholes and flooding. This is major cause of high vulnerability of the west part to sewer flooding.

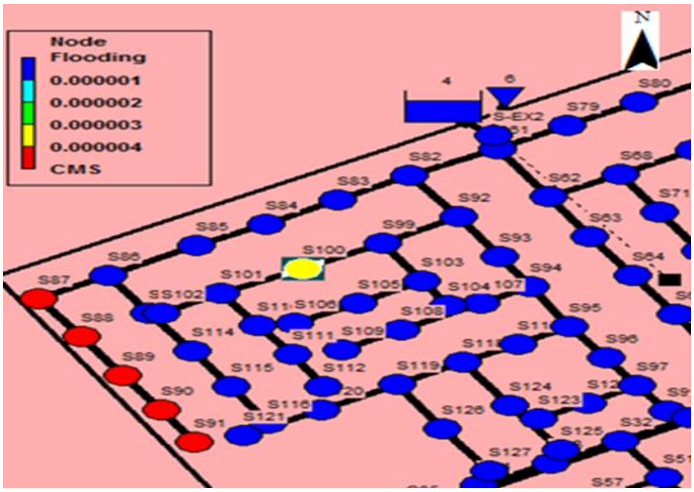

Figure 3: Flooding of manholes in the west part of the area during rainfall

4.2 Total Flow in Sewer Networks

Another simulation of sewer overflows during rainfall due to fault in sewer operation system in presented in this section. Figure 4 represents a case of the sewerage condition without rainfall. The overflow in the mid of the study area as shown in Figure 4 is due to fault in system operation. This faulty sewer network is used to simulate during rainfall. Figure 5 represents water surge and flooding in the network during rainfall. It can be seen from Figure 5 that overflows occur mostly in the manholes located in the west and north of the residential area.

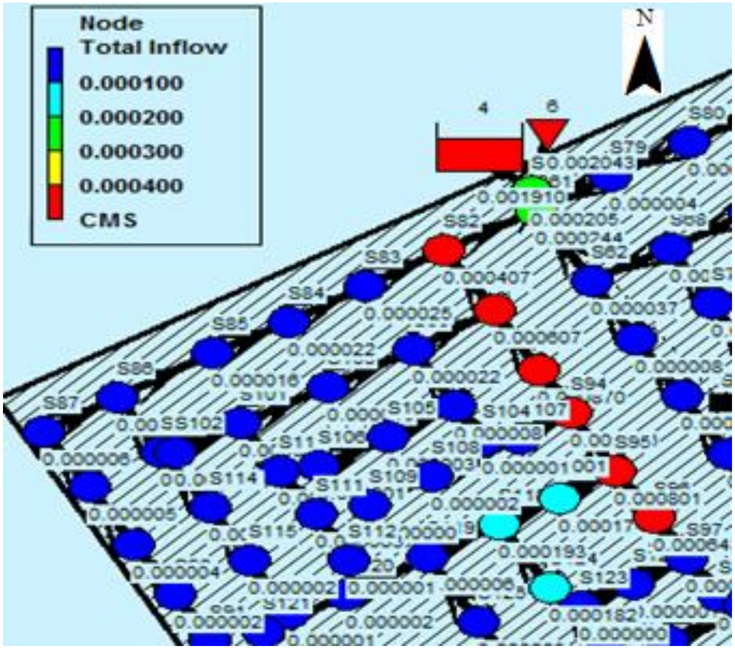

Figure 4: Total flow in sewer networks before rainfall

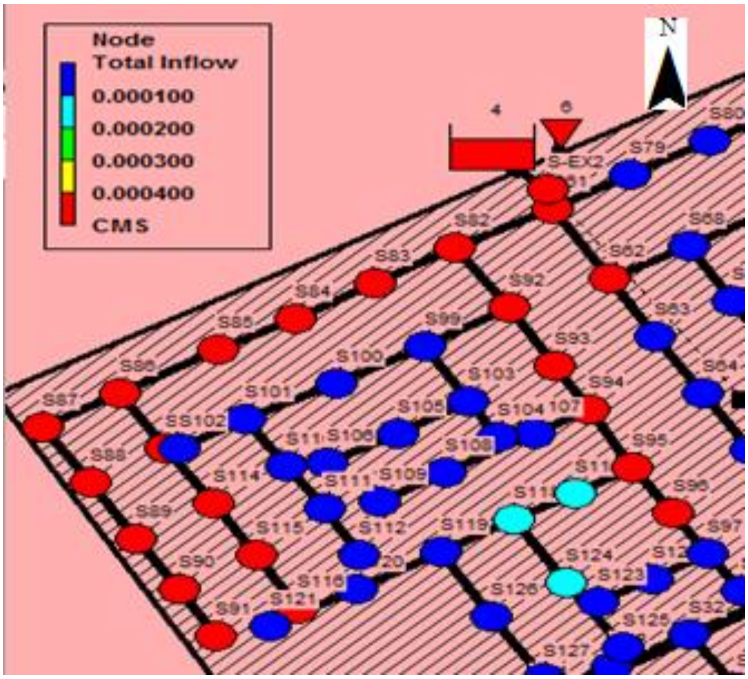

Figure 5: Overflow in faulty sewer networks during rainfall

5.0 Discussion and Conclusion

A study has been carried out to identify the sewerage overflow or flooding during peak time and heavy rainfall events in Shohada al Maudfeen residential area of Karbala city. Storm Water Management Model (SWMM) was used for this purpose. Storm Water Management Model (SWMM) used for this purpose. The results indicate that the west part of the residential area is most prone to flood due to sewer overflow.

Despite the existence of storm water network, water enters into the sewage system during rains and consequently, fills the drainage network. Due to the fact that manholes in the west part of the study area are located in the downstream of the sub-catchment, sewer discharge from the whole sub-catchment accumulate in the area. The system cannot drainage this high volume of water quickly. Furthermore, the presence of gaps, holes and broken cover manholes allow rain water to enter into sewers in the western part of the study area which cause further rise of water volume in sewer network. These all together cause sewer overflows through manholes and flooding in the west part of the study area.

It is recommended that the rehabilitation of drainage systems and regular maintenance is required to reduce the events of sewer overflow. Monitoring gaps and holes in sewer network for sealing, and replacement broken cover manhole on regular basis can reduce leakage of rainfall water to sewer system. Similarly, mitigation measures should be taken to prevent groundwater from entering into sewer pipelines. Lift pump can be used for quick discharge sewer water during rains. Proper monitoring and management of sewer flow can also reduce sudden accumulation of sewer in the downstream and consequent overflow.

The study reveals that SWMM can be used effectively simulate sewer flooding area which can be useful to adopt proper mitigation measures. Therefore, SWMM can be used effectively for operational management of sewer system. The major outcome of the study is identification of vulnerable zones or manholes in the sewer network in Shohada al Maudfeen residential area of Karbala city. It is expected that outcome of the study will be helpful for the municipal authority, sanitary and sewer management authority, and other local organizations of Karbala city of Iraq in planning sewer overflow mitigation measures.

References

Butler, David, (1993).The Influence of Dwelling Occupancy and Day of the week on Domestic *appliance wastewater discharges. Building and environment.Vol.23, No.1, pp.73-79.*

Butler D, Davies JW (2010) Urban Drainage, 3rd Edition. Spon Press: New York.

Burian, S. and Edwards, F. (2002) Historical Perspectives of Urban Drainage. Global Solutions for *Urban Drainage: pp. 1-16.doi: 10.1061/40644(2002)284.*

City population (2011). Karbala. Iraq Governorates, Regions & Major Cities - Statistics & Maps *on City Population.* http://www.citypopulation.de/Iraq.html.

Crawford, N. H. and Linsley, R. K. (1966), Digital simulation in hydrology: Stanford watershed *model IV, Technical Report 39, Dept. of Civil Engineering, Stanford University.*

Iraqi meteorological organization (2011). http://www.iode.org/index.php?option=com_oe&task=viewInstitutionRecord&institutionID=14043

Joint Task Force of the Water Environment Federation and the American Society of Civil *Engineers (ASCE) (2007). Gravity sanitary sewer design and construction. ASCE manuals* and reports on engineering practice no. 60. 2nd ed. Reston, VA: ASCE press.

Kite, G. (1989). "Use of time series analysis to detect climatic change." Journal of Hydrology *111(1): 259-279.*

Kazezyilmaz-Alhan, C. M., M. A. Medina Jr and C. J. Richardson (2007). "A wetland hydrology *and water quality model incorporating surface water/groundwater interactions." Water* Resources Research 43(4).

Kokkonen, T. S. and A. J. Jakeman (2001). "A comparison of metric and conceptual approaches in *rainfall-runoff.*

Huber, W. (2003). Wet-Weather Treatment Process Simulation Using SWMM. Watershed *Management, American Society of Civil Engineers: 253-264.*

Metcalf & Eddy, Inc. (1981). Wastewater engineering: collection and pumping of wastewater. *Tchobanoglous, G., Ed. New York: McGraw-Hill Book Company.*

McAllister, M. and Snoeyink, J. (1999), Extracting consistent watersheds from digital river and *elevation data, in 'ASPRS conference'.*

Rohrer, C. A. and L. A. Roesner (2007). A North Carolina piedmont application of protocols for *studying wet weather impacts and urbanization patterns.*

Toma, L., Arge, L., Chase, J., Halpin, P., Urban, D., Vitter, J. and Wickremesinghe, R. (2002), *'Computations on massive grids: The terraflow project', http:// www.cs.duke.edu/geo*/* terraflow/.

US Geological Survey (2002), '1-degree USGS digital elevation models', http://edc.usgs.gov */glis/hyper/guide/1_dgr_dem.*

US Dept. of Agriculture, Natural Resources Conservation Service, National Water & Climate *Center (2002), 'TR-55, urban hydrology for small watersheds', http://www.wcc. nrcs.usda.* gov/water/quality/common/tr55/tr55.html.

US Army Topographic Engineering Center (2002), 'Hydrologic modeling system (HEC-HMS)', *www.hec.usace.army.mil/software/software_distrib/hec-hms/hechmsprogram.html*, http://www.waterengr.com/HECHMS.html.

World Weather Information Service (2014). Iraq-Karbala. *http://worldweather.wmo.int/en/city.html?cityId=1465*.

Wan, B. and W. James (2002). SWMM Calibration Using Genetic Algorithms. Global Solutions *for Urban Drainage, American Society of Civil Engineers: 1-14.*

Wang, K. and A. Altunkaynak (2011). "Comparative Case Study of Rainfall-Runoff Modeling *between SWMM and Fuzzy Logic Approach." Journal of Hydrologic Engineering 17(2): 283*-291.

Yoo, J. (2005). "GIS-based simulation of urban sewerage flow volume." Urban Water Journal 2(1): *1-12.*