Transaction A: Civil Engineering
Vol. 17, No. 3, pp. 236–243

Research Note

Water Harvesting of Urban Runoff in Kuwait

N.A. Zaghloul[1,*] and B.L. Al-Mutairi[2]

Abstract. *This paper presents the application of the SWMM model to estimate the runoff due to rainfall over urban areas in Kuwait. The SWMM provides a powerful tool, in terms of its graphical capabilities and fast convergence to optimal design parameters for large urban areas. More importantly, simulation of the dynamic wave resulting from the urban runoff-transport phenomenon leads to a more accurate design for the storm drainage system, which, in Kuwait, has traditionally been based on the Rational Method. The results of this study confirm the quantitative viability of harvesting the otherwise lost runoff towards providing an additional water resource in Kuwait. A preliminary analysis of storm water quality also confirms its qualitative viability. A carefully designed, comparative questionnaire was used to solicit public opinion from various layers of society. The findings clearly indicate a strong public support in favor of using harvested storm water versus recycled waste water. Given the semi-arid nature of Kuwait, multiplicity of fresh water resources is vital. This study presents harvested storm water as a strong vital option. The strategic decision, vis-à-vis the optimal combination of fresh water resources, should be based on thorough technical and financial analyses. Resorting to the SWMM in designing storm drainage systems instead of the Rational Method will certainly minimize the ill effects of flooding, as recently experienced in Kuwait.*

Keywords: *Unsteady gradually varied flow; The explicit method; Urban drainage and sewerage systems; Storm Water Management Model (SWMM); PCSWMM 2004; Runoff and EXTRAN blocks; Runoff harvesting; Quantity and quality assessment of harvested runoff; Harvested runoff and its use as alternative water resource in arid and semi arid areas.*

INTRODUCTION

Kuwait is located in a desert zone, with no rivers or lakes, and it has a scarcity of fresh water resources. Scant natural fresh water resources have led Kuwait, since it was founded to look for other sources to secure potable water requirements.

In the past, Kuwait relied mainly on rain water existing near the surface in shallow wells. Due to the rapid growth of population, these scant resources became insufficient to cater for the growing demand.

Kuwait depends on two water resource supplies:

1. **Ground water wells**: Ground water aquifers are recharged from storm water that infiltrates from the ground surface and percolates through to the underlying strata [1]. In Kuwait, two types of ground water well exist:

a) Fresh ground water wells: Limited quantities were discovered at both Al-Rawdatain and Um Al-Aish fields (which have a productive capacity of 1-2 Million Imperial Gallons per day MIG/day). Various problems face this natural ground water resource in Kuwait:
   i) Excessive pumping of ground water;
   ii) Sea water intrusion;
   iii) Oil and pollutant intrusion;
   iv) Quantity produced from wells is not enough for drinking purposes;

b) Brackish water wells: The main locations of the brackish water wells are: The Sulaibiya field, the Shagaya field and the Um-Qudair field which were commissioned in October 1986 and the Al-Wafra and Al-Abdaliya fields currently utilized by the Kuwait Oil Company [KOC],

1. *Department of Civil Engineering, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait.*
2. *Engineer at Authority of Housing Welfare, State of Kuwait.*
*. *Corresponding author. E-mail: zaghlouln1@yahoo.com*

Received 1 April 2007; received in revised form 16 September 2007; accepted 17 December 2007

and the agricultural areas of Al-Wafra and Al-Abdali.

The total production of brackish water during 2004 was 33,187.668 MIG [2]. The amount of brackish water used for irrigation, landscaping, household purpose and construction work was 25,801.9 MIG [2]. The rest of the brackish water was used for blending with distilled water to produce fresh water.

2. **Water Desalination**: Due to rapid development, Kuwait relies on the desalination of sea-water to satisfy its need for distillated water, which is blended with brackish water to produce fresh water. Production of distilled water during 2004 was 97,469.0 MIG [2].

The increase of water consumption necessitates the construction of more desalination stations, which would be very costly in capital and operation phases.

An additional valuable water resource supply, which should be assessed for its viability, is the Harvesting of Rainwater. Rainwater harvesting is defined as a method of inducing, storing and conserving surface runoff for agriculture and other purposes in arid and semi-arid regions [3]. The problem of rain water in arid zones is one of low annual rainfall and the unfavorable distribution of rainfall throughout the year.

Kuwait, as in other arid countries, can experience sudden heavy rainfall that causes severe flooding, when the rainfall is of at least 30 mm and lasts for a few hours duration.

Since 1934 till today, Kuwait has experienced heavy rainfall, which has caused severe flooding and damage to life and property (see Table 1).

The storm drainage system in Kuwait is of a separate type, which can lead to the harvesting of almost clean rain water, free of waste water. By using the Storm Water Management Model (SWMM), it is easy to estimate the quantity of harvested rain water.

STUDY OBJECTIVES

1. The use of the SWMM model to estimate the quantity of harvested water and its use as an alternative water resource.
2. To study the possibility of using harvested runoff water, the quality of this water and its acceptability for use by the public.

QUANTITY OF STORM WATER IN KUWAIT

The rainfall season in Kuwait starts in October and ends in May. Analysis of the rain data, as recorded at the Airport Meteorological Station, shows the following:

- The average annual rainfall until 2002 was 110.5 mm.
- The total annual rainfall from 1958 to the year 2002 was 4970.9 mm.
- The minimum rainfall recorded was 30 mm in 1960, and the maximum recorded was 300 mm in 1934.

The rainy season's distribution in Kuwait, as given in Figure 1, indicates:

- Six seasons of rain less than 50 mm (13% of the available rain record).
- Sixteen seasons of rain between 50-100 mm (36% of the available rain record).
- Twelve seasons of rain between 100-150 mm (27% of the available rain record).
- Six seasons of rain between 150-200 mm (13% of the available rain record).

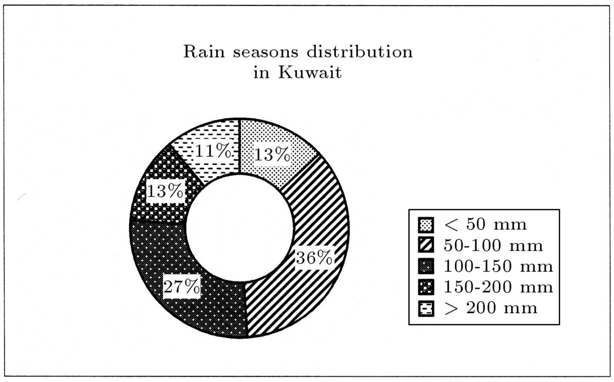

Figure 1. Distribution of the last 45 winter seasons in Kuwait.

Table 1. Storm events in Kuwait*.

Date of Storm	Quantity of Rainfall (mm)	Duration (hr)	Remarks
1934	300	1.50	Destroyed houses
07/03/1954	52	1.00	Destruction around 500 houses & 18000 person left homeless
04/04/1976	48.4	1.00	Closed main roads and left people homeless
11/11/1997	60	0.75	6 persons were dead, 57 wounded and 200 traffic accidents

*: Based on Meteorological Department at Kuwait International Airport and local newspaper

- Five seasons of rain more than 200 mm (11% of the available rain record).

The storm water runoff is collected in gullies and open inlets from streets and open areas. Then, the surface runoff is routed through pipes and box culverts to various outfall locations on the Gulf (see Figure 2).

Given the average yearly precipitation of 110.5 mm and the country's developed urban area of 1720 km^2, the volume of storm water drained and/or collected by the drainage system can be calculated. Assume that 50% of the total falling rain will be lost by evaporation, infiltration and depression storage. The remaining rain will be collected by the drainage system and the estimated collected storm water volume would be:

Estimated collected storm water volume

$$= \{\text{Net rainfall} = 50\% \text{ of total falling rain}\}$$

$$*\{\text{Developed urban area}\}$$

$$*\{\text{Conversion to Imperial Gallon (Imp Gal.)}\} \text{ [4]},$$

$$\left\{ \left(110.5 \frac{\text{mm}}{\text{yr.}} * \frac{\text{m}}{1000 \quad \text{mm}} \right) * (0.5) \right\}$$

$$* \left\{ 1720 * \text{km}^2 * 10^6 * \frac{\text{m}^2}{\text{km}^2} \right\}$$

$$* \left\{ \frac{1000}{\text{m}^3} * \frac{\text{Imp Gal.}}{4.5461} \right\} = 2.09 * 10^{10} \text{ Imp Gal./yr.}$$

From the above calculation, the harvested volume of storm water (2.09*10^{10} Imp Gal./yr) is compared to the country's fresh water and brackish water consumption (see Table 2).

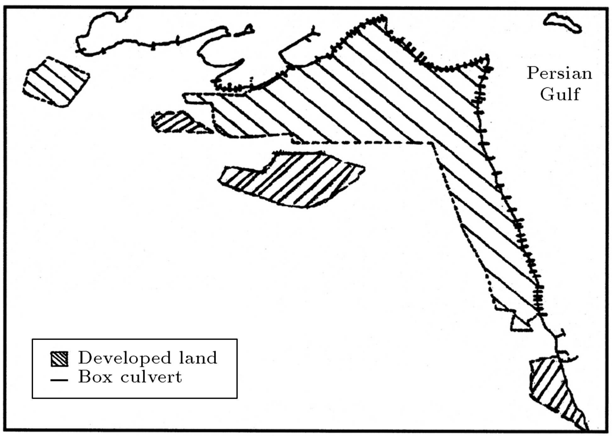

Figure 2. Kuwait developed land and box culvert location [4].

This indicates the potential use of the harvested storm water as brackish water to be blended with distilled water to produce fresh water all over the year or to be used in the summer months as brackish water (without blending). This confirms the quantitative viability of harvesting and its use as an additional water resource in Kuwait.

THE STORM WATER MANAGEMENT MODEL (SWMM)

The Environmental Protection Agency Storm Water Management Model (USEPA-SWMM) is one of several advanced computer-assisted models designed to simulate urban storm water runoff [5]. The SWMM is capable of predicting and routing the quantity and quality constituents of urban storm water runoff. The model consists of four functional program blocks, namely: Runoff, Transport, Extended Transport EXTRAN and Storage/Treatment, plus, a coordinating executive block. The blocks can be overlaid and run sequentially or can be run separately with interfacing data being supplied via tape or disk. The choice of mode depends on user needs.

The latest version of the Personal Storm Water Management Model (PCSWMM) is PCSWMM 2004 [6,7]. PCSWMM provides a large array of: file management, time series management and editing, model development, model calibration, dynamic output visualization and reference tools for the storm water modeler. Written for Windows 32-bit operating systems (Windows 95 and NT, up to and including Windows XP), PCSWMM has taken a new approach to providing an unprecedented level of simplicity and power at a remarkable price point.

For a fraction of the price of competing software, PCSWMM supports unlimited model sizes (1000's of elements), provides a complete array of graphical and dynamic model management, including development and analysis tools, and goes further to provide some unique tools such as; automatic Sensitivity, Calibration and Error Analysis (SCEA), as well as storm water modeling, bibliographic databases, rainfall analysis tools, data processing, a Best Management Practices (BMP) wizard, and integration with the Internet.

PCSWMM is flexible enough to be used with any version of the SWMM engine, and is distributed with the latest version of SWMM4.4h, as well as the official US EPA SWMM4.3 and later SWMM4.31, 4.40 and 4.4gu releases. PCSWMM provides full support for all modules of SWMM, including the Rain, Temperature, Runoff, Transport, EXTRAN, Storage/Treatment, Combine and Statistics Modules.

Only the blocks used in this study are described

Table 2. Water consumption (Imp Gal.) in year of 2004 [8].

Type of Water	Consumption in Year 2004 [Imp Gal.]	Consumption in Summer May-Oct. 2004 (Imp Gal.)
Fresh water (distilled + brackish water)	$9.788*10^{10}$	$5.365*10^{10}$
Brackish water	$2.5801*10^{10}$	$1.534*10^{10}$
Brackish water used for blending	$0.665*10^{10}$	—
Fresh underground water wells	$0.06*10^{10}$	—

briefly herein.

Runoff Block

The runoff block simulates the quantity runoff phenomena of a drainage area and the routing of the surface flows to the major conduits. It represents the drainage area by an aggregate of idealized subcatchments and gutters. The runoff program accepts the rainfall hyetograph, makes a step by step accounting of abstractions (evaporation, infiltration and depression storage) and computes the overland flow from each subcatchment, leading to the calculation of a number of inlet hydrographs. The infiltration capacity is computed by Horton's or Green-Ampt equations, based on soil type [6]. The continuity and Manning's equation are solved to determine the overland flow in subcatchments and flows in the gutters. Pollutographs are generated, based on the volume of storm runoff and antecedent conditions, including rainfall history, street sweeping data, land use and related data.

EXTRAN Block

EXTRAN is a hydraulic routing model for open channel and/or closed conduit systems. The EXTRAN block receives the hydrograph input at specific nodal locations and performs the dynamic routing of storm water flows through the storm water drainage system. The conceptual representation of the drainage system is based on the 'link-node' concept. This concept will facilitate the discrete representation of the prototype and the mathematical solution of the gradually varied unsteady flow equations, which form the mathematical basis of the model. Links transmit the flow from node to node. Nodes are the storage elements of the system and correspond to manholes or pipe junctions in a physical system. The program can simulate branched or looped networks, backwater, due to tidal or nontidal conditions, free surface flow, pressure flow or surcharge condition, flow reversals, flow transfer by weirs, orifices and pumping facilities, and storage at on or off line facilities.

DESCRIPTION OF THE CATCHMENT AREA AND DRAINAGE SYSTEM

The location of the South Al-Doha area is shown in (Figure 3). South Al-Doha is situated 26 km west of Kuwait city, 22 km west of Kuwait international Airport and 13 km east of the Al-Jahra area. The south Al-Doha area has an area of 212 ha., 45.28% of which is occupied by houses and 9.5% of which is open space and green land. The streets and parking occupy 42.5% and other paved areas constitute 2.4% of the area. The house roofs are not connected to the drainage system.

All streets are surfaced with asphalt and bordered with concreted curbs, and gutter inlets are distributed along the sides of the street. The drainage system is of a separate type and is comprised of circular concrete pipes, in which the water flows entirely by gravity to the outlet.

Subcatchment Data

The land use map of the catchment was used to define the boundary of the urban area and the percentage of various land use activities.

The total area was divided into 336 subcatchments, each leading to one manhole. Since the RUNOFF block cannot handle more than 250 subcatchments, the total area was divided into two parts; both leading to the same outfall. The first part has 181 subcatchments and the second part has 155.

The Horton's infiltration parameters used were 80 mm/hr and 15 mm/hr, for the initial infiltration capacity and the ultimate infiltration capacity, respectively. The decay rate was 0.0022 sec^{-1}. These values were based on a local field study in Kuwait and were conducted by A. Kamel [9]. The parameters were fed to the RUNOFF block and were kept constant for various rain storm simulations.

Since, in most cases, rainfall intensities are less than the infiltration capacity of the soil [10], the pervious areas are not contributing to runoff. Most buildings are not connected directly to the drainage system but are surrounded by pervious areas, so that they are not contributing to runoff. The streets and off

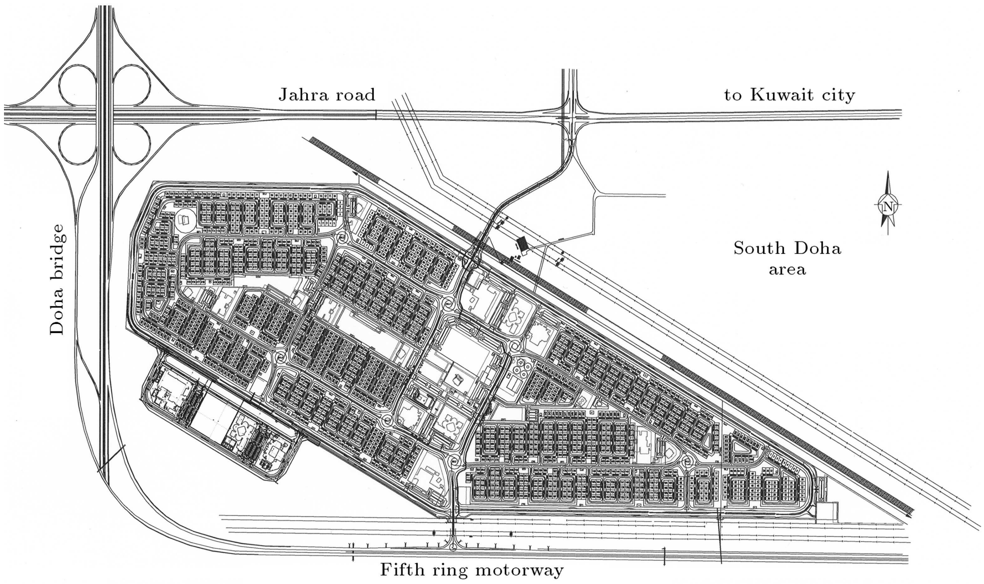

Figure 3. South Al-Doha area.

street paved areas that are directly connected to the drainage system, were treated as impervious parts. The total area of the subcatchment and impervious portions (paved areas connected to the drainage system) were measured using AutoCAD. The percentage imperviousness was calculated for each subcatchment. The length of the subcatchment was taken as the distance between the drain inlet and the most remote point in the subcatchment. The width of the subcatchment equals the area of the subcatchment divided by its length. The slope of each subcatchment was determined, based on the elevation difference.

The Manning Roughness (n) was based on Chow's tables [11] and was taken as 0.014 for the impervious (paved asphalt) area and 0.02 for the pervious (sand) area. The values of the depression storage for Kuwait were taken as 5.00 mm for pervious areas, based on Shurbaji [10], and for impervious areas as 1.40 mm, based on Zaghloul [12].

Drainage System Data

The network sewer parameters, such as pipe diameters, lengths, invert elevation of the pipes connected to the junction and the ground elevation of junctions were taken from the storm drainage map. The pipe Manning Roughness (n) was taken from Chow's tables [11] as 0.013. The storm drainage system was composed of 840 sewers and was used in the EXTRAN block.

SWMM MODEL SIMULATION AND ANALYSIS OF RESULTS

The existing drainage system was designed under the sponsorship of the Public Authority for Housing Welfare, using the Rational Method for computing peak flow rates [8]. The runoff coefficient was taken as 0.65 for paved areas. The design storm, based on a return period of 5 years and 15 min duration, gave intensity equal to 132.0 l/s/ha. The size of the storm sewers was calculated using the Manning equation, based on full flow conditions. The SWMM Model was used to test the performance of the existing drainage system and the accuracy of the design method used. Two storm events namely were selected as follows for the simulation:

1. **Real Storm Event of Nov. 11, 1997**
   The real storm had 60 mm of rainfall in a 45 min duration (see Table 1) and, hence, rain intensity is 80.0 mm/hr. The calculated peak flow was 24.0 m^3/s in the first part and 20.5 m^3/s in the second part, totaling 44.5 m^3/s (see hydrograph given in Figure 4). The storm drainage system of the catchment area could not handle this storm. Flooding occurred in 268 pipes, which represents 77.9% of all network pipes. This indicates that the designed sewers are undersized and a better design criteria should be adopted.
2. **Design Storm Used by the Rational Method**
   The rational method was used to design the storm sewers in Kuwait, with 5 years frequency of storms. The calculated peak flow was 12.0 m^3/s in the first part and 9.0 m^3/s in the second part, totaling 21.0 m^3/s (see hydrograph given in Figure 5). The performance of the storm drainage system was not adequate, resulting in the flooding of 149 pipes, which represents 43.3% of all network pipes. It is obvious that the use of 5 years frequency of storm with an intensity of 132.0 l/s/ha. is not adequate.

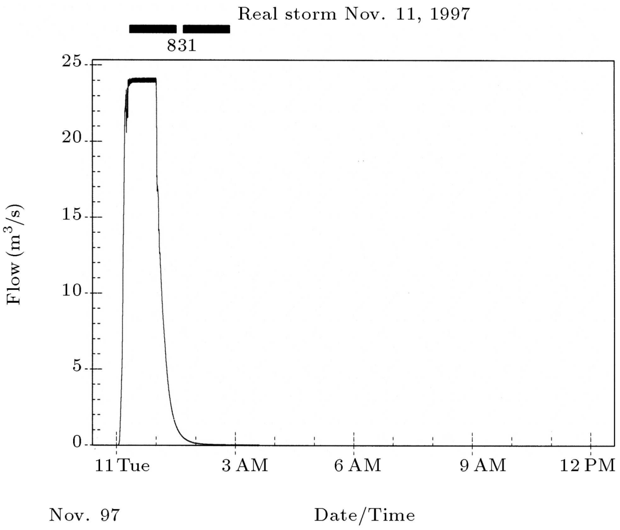

Figure 4a. Hydrograph from 1st part area.

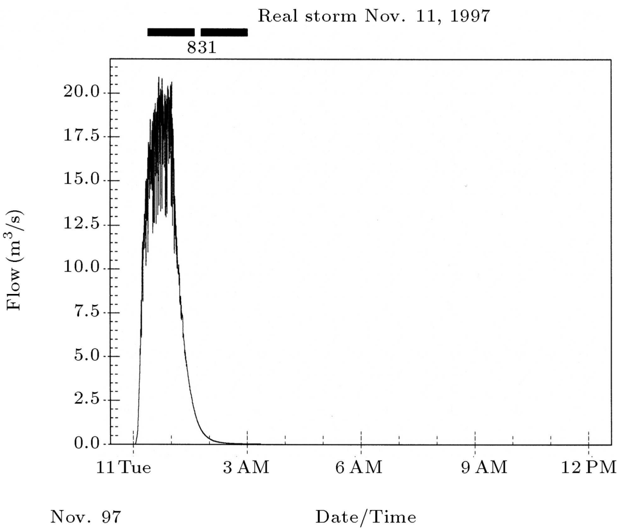

Figure 4b. Hydrograph from 2nd part area.

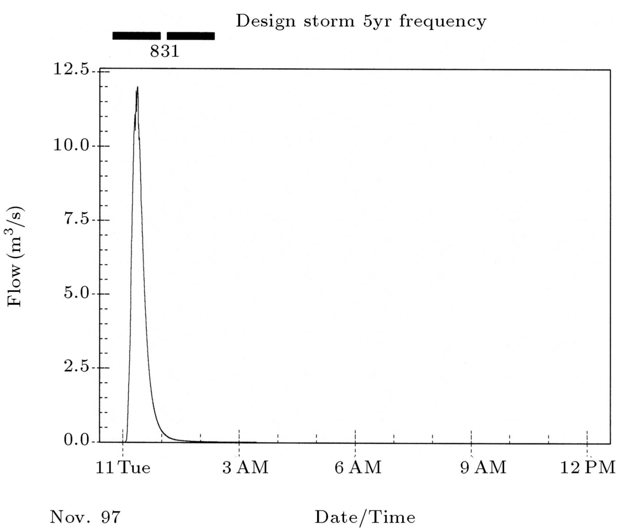

Figure 5a. Hydrograph from 1st part area.

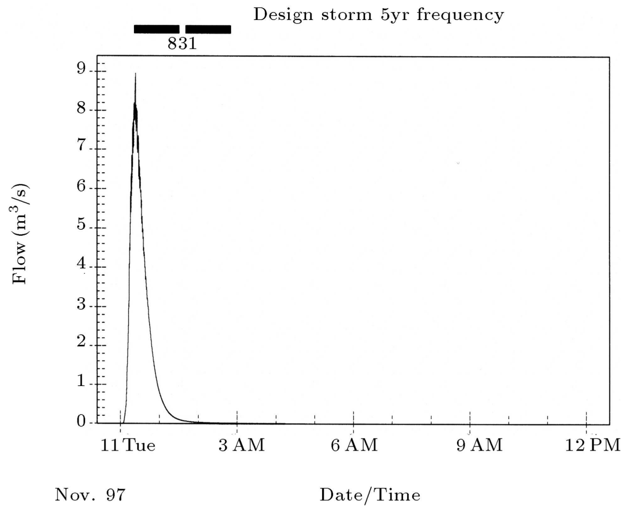

Figure 5b. Hydrograph from 2nd part area.

Table 1 indicates that severe flooding, which causes damage to life and property, is repeated every 20 years. Therefore, it is recommended to base future urban drainage design on 20-25 yr frequencies.

QUALITY OF STORM WATER RUNOFF

Precipitation in the form of rain may contain trace amounts of mineral matter, gases and other substances as it forms and falls through the earth's atmosphere. Precipitation, however, has virtually no bacterial content [13]. Dust fall is a continuous process of the atmospheric deposition of pollutants. These pollutants are then later picked up by the storm water runoff and contribute to the total pollutant concentration of the storm water runoff. Many pollutants have been reported in rainfall, including nutrients (nitrogen and phosphorus), metals, organics and suspended solids [4].

In order to test the quality of the storm water runoff, lab tests were conducted on 4 samples, taken in a season of 2002, at different locations in Kuwait. Sample no. 1 was taken from a gully, sample no. 2 was from the exit of a roof pipe, sample no. 3 was collected as rainfall before reaching the earth and sample no. 4 was taken from the outlet of a box culvert outfall.

The samples' results are compared with the standard requirements for bottled and unbottled drinking water and irrigation. Figure 6 shows that the pH for each sample does not exceed the range of the standard pH for drinking or irrigation. For the TDS level, it is under the maximum level for drinking water (both bottled and unbottled), except in one sample, which was taken from the exit of the box culvert.

The cost of the distillation of sea water and the treatment of waste water is far more than the cost of the treatment of storm water runoff. In addition, the use of treated waste water for irrigation is restricted. The Public Authority for Agriculture Affairs and Fish

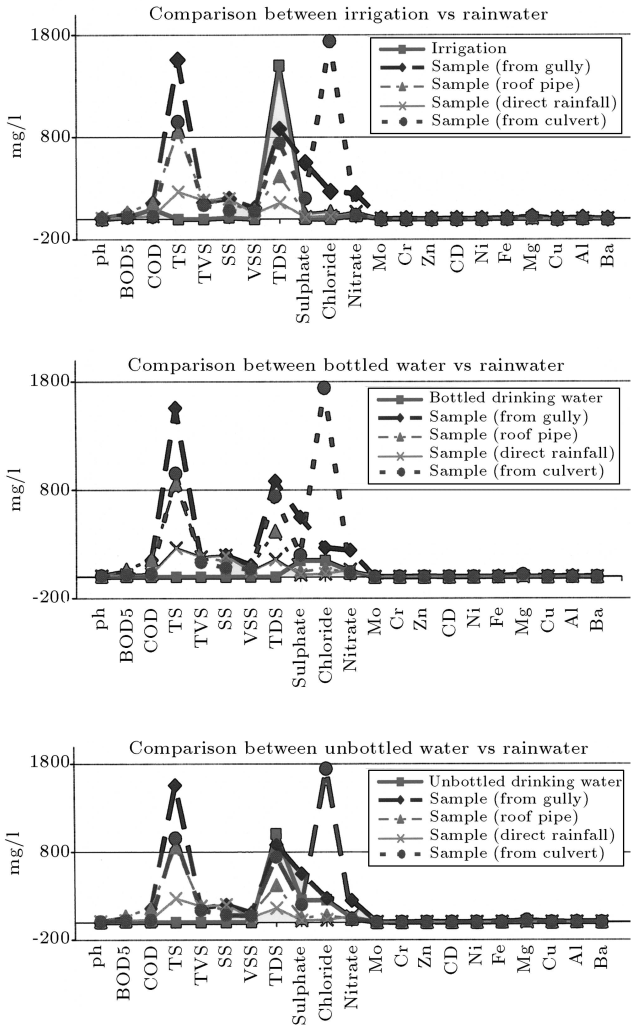

Figure 6. Rainwater quality comparison.

Resources restricts the irrigation of vegetable produce (which is eaten raw without cooking) by treated waste water [14].

Public perception of using treated waste water for drinking and domestic use was very negative in comparison to using the treated storm water runoff.

A carefully designed, comparative questionnaire was used to solicit public opinion from various layers of society. A sample of two hundred people was polled; 70.5% of whom were diploma holders or above. The results clearly indicate strong public support in favor of using harvested storm water versus recycled waste water (see Figure 7).

- For drinking treated storm water runoff, 61% approved and 26.5% disapproved.
- For drinking treated waste water, 85.5% disapproved and 6.5% approved.
- For irrigation using treated storm water runoff, 88% approved, while, for treated waste water, 71% approved. The difference is not significant.

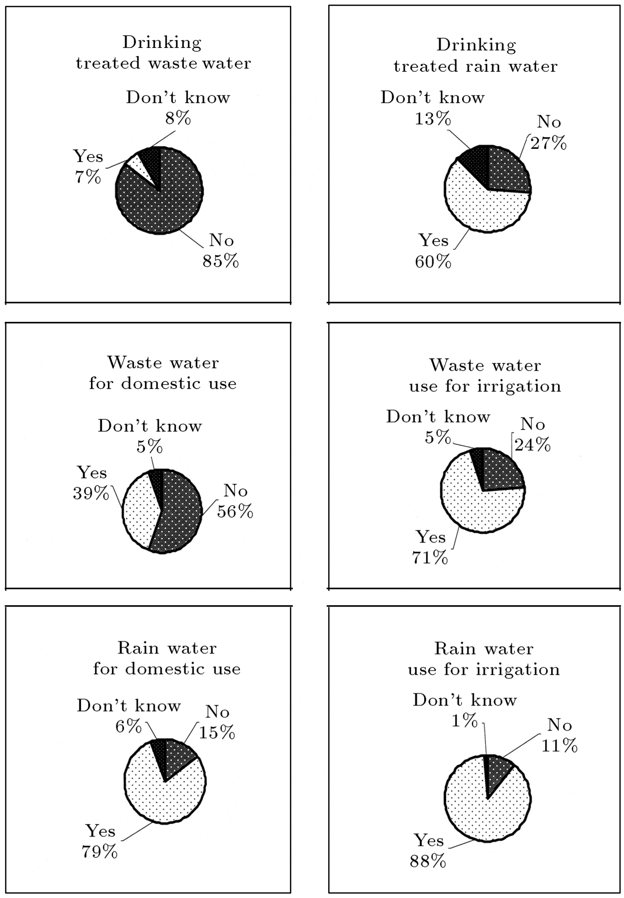

Figure 7. Results of questionnaire.

CONCLUSION

1. The SWMM routing technique is superior to other routing models. The SWMM model can be incorporated with no difficulty to simulate urban drainage systems in Kuwait. The model gives accurate results and is a good replacement for the Rational Method currently used.
2. In Kuwait, using the values of a 5 yr frequency design storm is not adequate and results in an excessive flooding of urban areas. Noticing storm event records in Kuwait since 1934, a value of 20-25 yrs for a rainfall frequency design storm is more adequate.
3. The cost of building a storm water drainage system, using a design based on a 10 yr frequency, would be about 6 to 11 percent more than a system design based on 5 yrs [8].

   In the South Al-Doha area, the cost of constructing a drainage system based on a 5 yr frequency is 11,756,019.07 K.D, which is equivalent to 40.50 million US dollars. Considering a cost increase of 11% for selecting a higher design frequency, the cost estimation for a 10 yr frequency is 44.96 million US dollars, for a 20 yr frequency is

49.90 million US dollars and for a 25 yr frequency is 55.39 million US dollars.

A difference of 15 million US Dollars in capital cost is observed between 5 yr and 25 yr design frequencies. This is a small price to pay to avoid loss of life and property damage due to flooding.

4. The quantity of harvested storm water runoff is a viable additional water resource. It is enough to meet the demand for brackish water in the summer months or for blending with distilled water all year round.
5. The quality of storm water runoff indicates its viable use for irrigation purposes without treatment and, with some treatment, for use as drinking water.
6. A carefully designed questionnaire indicates strong public support in favor of using harvested storm water versus recycled waste water.

ACKNOWLEDGMENTS

The authors are grateful to the Public Authority for Housing Welfare and the Meteorological Department at Kuwait International Airport for providing the necessary data. The use of civil engineering laboratories and computer facilities at Kuwait University is greatly appreciated.

REFERENCES

1. Wanielista, M., Kersten, R. and Eaglin, R., *Hydrology and Water Control*, Wily, Second Edition (1997).
2. *Statistical Year Book*, Ministry of Electricity and Water, Kuwait (2001).
3. Boers, Th.M. "Rainwater harvesting in arid and semi arid zones", *Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement*, Publication No. 55 (1994).
4. Al-Hoti, B.A. and Abdullah, R. "Reuse of collected storm water turnoff for irrigation in Kuwait", *Desalination*, **75**, pp. 329-340 (1989).
5. Huber, W.C. and Dickinson, R.E. "Storm water management model", *User's Manual Version 4*, US Envi. Protection Agency, Athens, Ga. (1992).
6. "Water systems models (hydrology)", *User Guide to SWMM4 Runoff and Supporting Modules (Rain, Temperature, Combine and Statistics)*, James, W., James, R.C., Huber, C. and Dickinson, R., Eds., p. 313 (1998).
7. "Water systems models (hydraulics)", *User Guide to SWMM4 Transport, EXTRAN, and Storage Modules*, James, W., James, R.C., Huber, C. and Dickinson, R., Eds., p. 306 (1998).
8. A joint committee of the American society of civil engineers and the water pollution control federation, *Design and Construction of Sanitary and Storm Sewers* (1969).
9. Kamel, A. "Modified infiltration model for steady rainfall", Master Thesis, Civil Engineering, Kuwait University (1989).
10. Shurbaji, A. "Storm water management model for urban area in Kuwait", Master Thesis, Civil Engineering, Kuwait University (1989).
11. Chow, V.T., *Open Channel Hydraulics*, McGraw Hill, New York (1959).
12. Zaghloul, N. and Shurbaji, A. "A storm water management model for urban areas in Kuwait", Water Resources Bulletin, American Water Resources Association, AWRA, **26**(4), pp. 563-575 (1990).
13. Davis, M.L. and Cornwell, D.A., *Introduction to Environmental Engineering*, WCB/McGraw Hill, New York (1998).
14. Al-Gady, A. "Use of treated wastewater in irrigated agriculture and producing agriculture without any effect in health and environment", *Public Authority for Agriculture Affairs and Fish Resources* (in Arabic) (1992).

BIOGRAPHIES

Nabil A. Zaghloul was born in Cairo, Egypt, in 1945. He received his BS degree in Civil Engineering from Ain Shams University (Egypt) in 1966, and MS degree in Water Resources from University of Windsor (Canada) in 1970, and PhD degree in Water Resources from University of Windsor (Canada) in 1974. He is faculty member of Civil Engineering Kuwait University. His research field involves Water Harvesting, Urban drainage, Computer Applications in Water Resources, Finite difference and Finite Element Applications, Sediment Transport and Sand Dune Movements.

Badryia Lafi Al-Mutairi was born in Kuwait in 1977. She received her BS degree in Civil Engineering from Kuwait University in 1999 and MS degree in Civil Engineering from Kuwait University in 2003. She is Senior Engineer at the Authority of Housing Welfare, State of Kuwait. Her research involves the Use of PCSWWM Model and Microsoft Excel Spreadsheet.