تقييم أداء النموذجين الهيدروجيولوجيين في تقدير الجريان السطحي

Evaluation the Performance of Two Hydrological Models for the Estimation of Surface Run-off

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المُلَخَّص

نُفذت الدراسة بهدف تقييم أداء النموذجين الرياضيين HEC-1 وHYDROMED لتقدير منحني التصريف للأحواض الساكبة باستعمال المعطيات الهيدرولوجية لإحدى الأحواض الساكبة الصغيرة في سورية. استُعملت عاصفة مطرية واحدة لمعايرة النموذجين الرياضيين، وثلاث عواصف مطرية من أجل تقييمهما. تم استعمال دليل المنحني (CN) وزمن التأخير (T_{lag}) كمتحولات في معايرة النموذج HEC-1، أما بالنسبة للنموذج الرياضي HYDROMED، فقد تمّ استعمال معدل التسرب الأعظمي (Z_{max})، ومعدل التسرب الأصغري (Z_{min}) وزمن التأخير(T_{lag}) كمتحولات معايرة.

كانت نتائج النموذج الرياضي HEC-1 مقبولة بالنسبة لتقدير حجم الجريان السطحي، وزمن الذروة، وشكل منحني التصريف، حيث كان الخطأ في تقدير حجم الجريان أقل من 32 %. أما الخطأ في تقدير ذروة الجريان فقد كان مرتفعاً، حيث وصل إلى 55 %. وقد لوحظ أن الفارق بين ذروة الجريان المقدرة والمقاسة قد ازداد بزيادة كمية الهطل المطري. تراوح الخطأ المتوسط التربيعي بين القيمة المقاسة والمقدرة لحجم الجريان بين 56 و 102.

أما بالنسبة لنتائج النموذج الرياضي HYDROMED فقد كانت مقبولة بالنسبة لتقدير حجم الجريان السطحي، حيث كان الخطأ في تقدير حجم الجريان الناتج عن العواصف المطرية الثلاث المستعملة في التقييم أقل من 28 %، ولكن لم تكن نتائج النموذج جيدة بالنسبة لتقدير ذروة الجريان وشكل منحني التصريف، حيث وصل خطأ تقدير ذروة الجريان الى 74 %. وتراوح الخطأ المتوسط التربيعي بين القيمة المقاسة والمقدرة لحجم الجريان بين 61 و119.

الكلمات المفتاحية: الحد الفاصل، حجم الجريان، ذروة الجريان ، نموذج هيدروجيولوجي، هيدروميد، نموذج رياضي.

Abstract

The main objective of this study was to evaluate the performance of the HEC-1 and HYDROMED models to predict run-off hydrograph using hydrological data collected from a small watershed in Syria. One storm was used for calibrated of the two models and three storms for evaluating them. The calibration parameters for the HEC-1 model were curve number (CN) and lag time (T_{lag}). The calibrated parameters for the HYDROMED model were maximum infiltration rate (Z_{max}), minimum infiltration rate (Z_{min}), and lag time. The HEC-1 model produced satisfactory results for of estimation run-off volume, time to peak, and shape of the hydrograph. The error in the estimation of run-off volume was less than 32%. The discrepancy between estimated and predicted peak discharge increased as storm depth increased. Error in estimating peak discharge was as high as 55 %. The root mean square error between measured and predicted values of the hydrograph ranged from 56 to 102. The HYDROMED model reasonably estimated the run-off volume. The error in estimating the run-off volume from the three storms used for the model evaluation was less than 28 %. However, the model did not produce satisfactory result using the calibrated parameter for estimation of the peak discharge and the shape of the hydrograph. The error in estimation of the peak discharge was as high as 74 %. The root mean square error between measured and predicted values of the hydrograph ranged from 61 to 119.

Keywords: Watershed, Run-off, Peak discharge, Hydrograph, Hydrological model

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Introduction

In arid and semi-arid regions, interests are growing in using water harvesting technology to provide additional water sources. However, watersheds in such regions typically are ungaged and no measured data of surface run-off are available. Therefore, a good estimation of run-off is needed for site selection and engineering design of water harvesting systems and other hydraulic structures.

There are several model which are capable of predicting storm water run-off (CREAMS, EPIC, HEC-1, HYDROMED). The main objective of this study is to evaluate the performance of the two hydrological models: HEC-1 and HYDROMED in assessing run-off volume and peak discharge for a small watershed in Syria.

HYDROMED is a conceptual model developed for semi-arid regions. The model is described in detail in Ragab et al.2001)و) and only a brief description will be given here. In this model the infiltration access was estimated using Pitman’s approach (Pitman , 1973). In this approach the predicted run-off from a given input of rainfall (r) is given by the following equation:

For $Z_{min} \leq r \leq Z_{mean}$: $Q = \dfrac{2(r - Z_{\min})^3}{3(Z_{\max} - Z_{\min})^2}$

For $Z_{mean} \leq r \leq Z_{min}$: $Q = r - Z_{mean} + \dfrac{2(r - Z_{\min})^3}{3(Z_{\max} - Z_{\min})^2}$

For $r \geq Z_{max}$: $Q = r - Z_{mean}$ (1)

Where Z_{max}, Z_{min}, and Z_{mean} are maximum, minimum, and mean infiltration rate , *r* rainfall depth (mm), and *Q* run-off volume (mm)

Z_{max} and Z_{min} can be estimated from infiltration test or alternatively they can be determined by calibration.

The time delay of runoff was calculated using Muskingham equation given as:

$$O_{T+1} - O_T = \frac{\Delta t(I_t - O_T)}{T_{lag} + 0.5\Delta t} + \frac{\Delta t(I_{t+1} - I_t)}{2(T_{lag} + 0.5\Delta t)} \qquad (2)$$

where O_t and I_t are the flow and lagged flow, respectively at time *t* ($m^3.s^{-1}$),

Δt is time step in the model, and T_{lag} is the lag time.

HEC-1 model was developed by the US army corps of engineers as single event model to simulate the rainfall –run-off relationship (Hydrologic Engineering Center, 1990). The model is based on the unit hydrograph method to transform infiltration access to run-off hydrograph. HEC-1 has several options for unit hydrograph and for estimating infiltration access. In this study, rainfall access was calculated using the NRCS curve number method (USDA-SCS,1972). The standard NRCS unit hydrograph was used to produce the runoff hydrograph. The initial estimate of lag time was determined using the NRCS lag equation.

Methodology

The two models were evaluated using data obtained from the Syndiane reservoir which is located approximately 30 km west of Homs - Syria. Syndiane reservoir, was built in 1967, has maximum capacity of 400,000 m^3 and collects runoff water from a 330 ha catchment area. In 1997, meteorological station's equipments were installed next to the reservoir. These equipments included tipping bucket rain gage, air temperature sensor, and water level sensors. Data from these sensors were recorded in 5 minutes interval and stored using a data logger. Evaporation was measured manually using a class A evaporation pan. Rainfall depths, water level in the reservoir, and evaporation data are available for the period 1997-2003. A 1:25000 topographic map was digitized and converted to a digital elevation map using ArcGIS software.

Using the digital elevation map , the Syndiane watershed boundary and characteristics were determined using WMS software package (Figure 1). The watershed area is 3.3 km^2, the length of the main channel is 3.9 km, and the average slope of the watershed is 7.4%.

The pipe spillway in the body of the dam becomes operational when storage reaches its maximum. Since the release from this pipe was not recorded, the storms which were used for the models calibration and evaluation were chosen at times when the storage in the reservoir is minimum (at all events the storage at the beginning of the storms was less than 30% of the maximum capacity of the dam).

The 4 February, 1999 storm was used to calibrate the models. The calibrated parameters for the HEC-1 model were CN and lag time (T_{lag}). The calibrated parameters for the HYDROMED were Z_{max}, Z_{min}, and lag time. Table 1 shows the value of calibrated parameters for the HEC-1 and HYDROMED models.

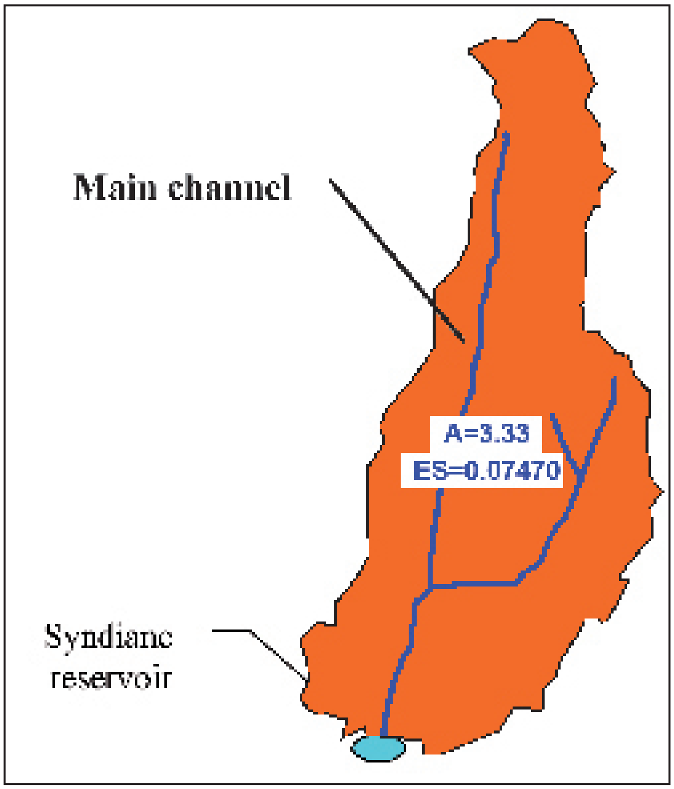

Figure 1. The Syndiane watershed boundary

Table 1. Values of calibrated parameters for HEC-1 and HYDROMED models.

HEC-1		HYDROMED		
CN	T_{lag} (hr)	Z_{max} (mm/hr)	Z_{min} (mm/hr)	T_{lag} (hr)
75.63	2.16	3.21	2.59	10.5

Three storms were used to evaluate the performance of two models: 7/1/1998, 27/1/1999, and 19/12/2001 storms. The two models were evaluated by comparing the simulated hydrographs with the measured hydrographs estimated from the changes in the reservoir volume.

The agreement between measured and predicted runoff hydrograph was quantified using the root mean square error (RMSE) as a statistical measures of goodness of fit (Loague and Green, 1991):

$$\text{RMSE} = \left[\frac{\sum (P_i - O_i)^2}{N} \right]^{0.5} \times \left(\frac{100}{\overline{O}} \right) \qquad (3)$$

where, P_i is the simulated value, O_i is the observed value, $\overline{O}$ is the observed mean, and N is number of observation. RMSE is a measure of the deviation of simulated values from measured values. Ideally it should be equal to zero.

Results and Discussion

HEC-1 model:

Comparison of predicted run-off volume using HEC-1 model with the measured one (Table 2) shows that HEC-1 model always underestimated the run-off volume . The difference between measured and observed run-off volume ranged from 1% to 32%. The deviation between measured and predicted run-off volume increased as the storm depth increased (Table 2). This could be due to the fact that the curve number value increases as the soil moisture increases. Hawkins et al., (1985) indicated change of CN value during rainfall event. However, in the HEC1 model CN was fixed during simulation.

It has been found a good match between the measured and predicted time to peak discharge (Figure 2) ; however, there was some discrepancy between the measured and predicted peak discharge values. In general, the deviation in peak flow increased as the storm depth increased. The error in peak discharge ranged from 24% underestimation to 55% overestimation (Table 2). In NRCS unit hydrograph method the peak discharge is calculated using the following equation :

$$Q_p = \frac{0.208A}{T_{lag} - 0.5tr} \qquad (4)$$

where Q_p is the peak discharge (m^3/sec), A is the watershed area (km^2), T_{lag} is lag time (hr), and tr unit hydrograph duration. Equation 4 indicates that for specific watershed Q_p decreased as lag time increased. Lag time is defined as the difference in time between the center of mass of rainfall excess and the center of mass of run-off (or peak rate of flow) (Gupta, 2001).

In term of physical meaning, lag time is related to the travel time of a water particle along the main channel and is a function of watershed characteristics and in some cases rainfall intensity and volume. Since the rainfall intensity and volume and some of the watershed characteristics were not the same for all storms used in the evaluation, it is expected to have variable values for lag time . Therefore, using

Table 2. Comparison of measured and simulated run-off volume and peak discharge using HEC-1 model.

Event	Rainfall (mm)	Run-off volume (m^3)			Peak flow (m^3/sec)						RMSE
		Measured	Predicted*	Error (%)	measured		predicted		Error (%)		
4-2-1999	48.5	32000	34524	3	1.19		1.22		2.5		56
27-1-1999	44.5	28064	28438	1	0.87		1.35		55		102
19-12-2001	89	159134	122099	24	2.5	2.8	2.3	2.1	6	24	51
7-1-1998	102	229128	145775	32	6.0	8.4	2.3	4.3	61	48	99

* Rainfall on reservoir was added

fixed value of lag time is expected to result in some discrepancy in estimating peak discharge values. Mccuen (1998) reported that as much as 75% of the total error in the estimation of the peak discharge can result from errors of lag time.

There was a reasonable match in the shape of measured and simulated hydrograph (Figure 2). The root mean square error between measured and predicted values of the hydrograph ranged from 56 to 102.

HYDROMED model:

In general, there was a high deviation between the shape of the measured and observed hydrograph for all events (Figure 2). However, the error in estimating run-off volume for the three storms used in the model evaluation was less than 28 % (Table 3).

HYDROMED consistently underestimated peak discharge (Figure 2 and Table 3). The difference between measured and simulated peak discharge ranged from 15 to 74 %. The deviation between measured and simulated peak discharge was more pronounced in double peak events such as the 7/1/1998, and 19/12/2001 events. As indicated by equation 2, the reduction in peak discharge could be due to large value of calibrated lag time (T_{lag}). Value of T_{lag}= 10.5 hr is much higher than the lag time calculated from different empirical equation based on watershed characteristics (Table 4). This indicates that the values of calibrated parameters do not have much physical meaning and they are viewed as being empirical constants. Using measured infiltration parameters and calculated lag time based on the watershed characteristics could improve the model performance.

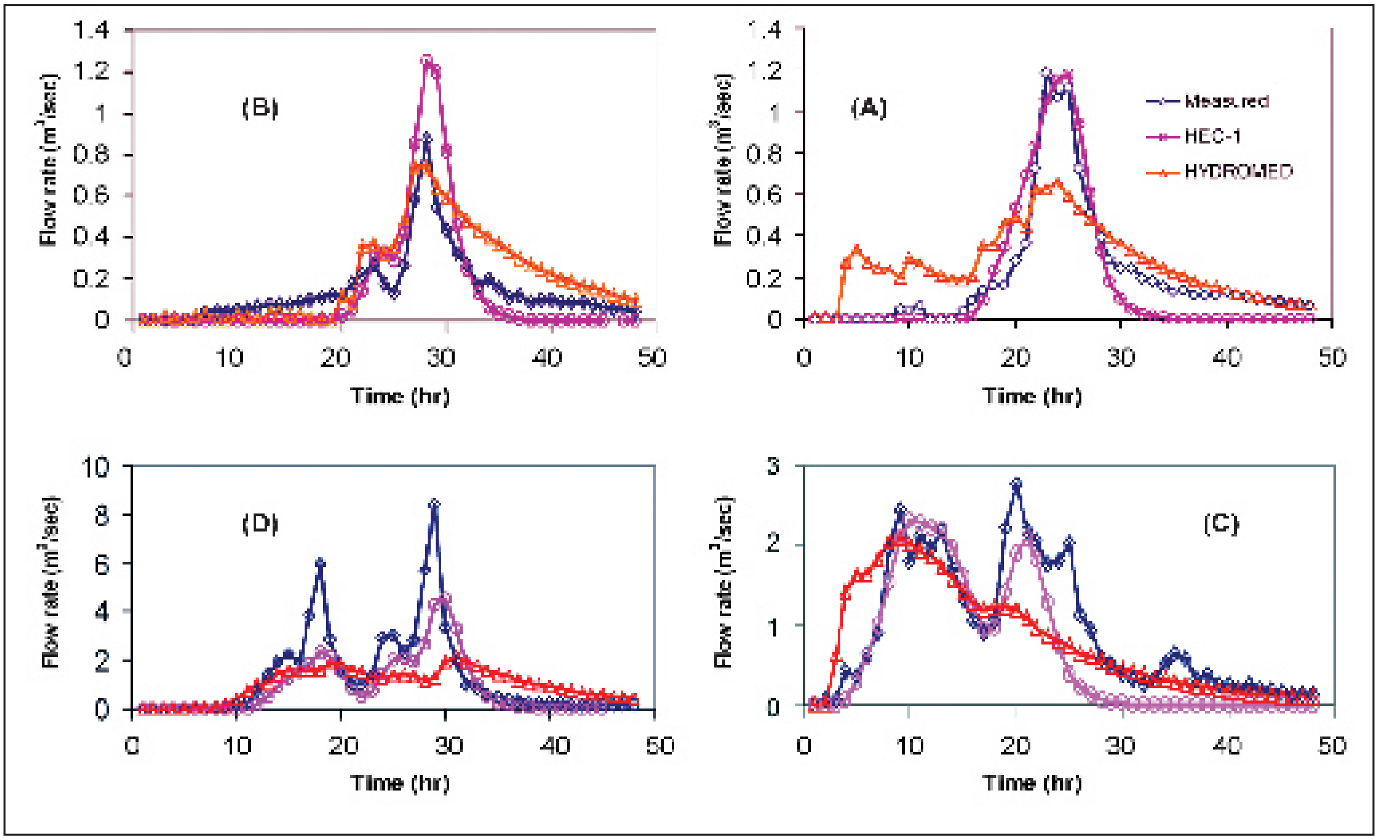

Figure 2. Comparison of measured hydrograph and simulated hydrograph using HEC-1 and HYDROMED models: (a) 4 /2 /1999 storm (used for calibration), (b) 27 /1 /1999 storm, (c) 19 /12 /2001 storm, and (d) 7 /1 /1998 storm.

Table 3. Comparison of measured and simulated run-off volume and peak discharge using HYDROMED model

Event	Rainfall (mm)	Runoff volume (m^3)			Peak flow (m^3/sec)						RMSE
		Measured	predicted	Error (%)	measured		predicted		Error (%)		
4-2-1999	48.5	32000	46531	45	1.19		0.66		44		94
27-1-1999	44.5	28064	35863	28	0.87		0.74		15		85
19-12-2001	89	159134	140548	12	2.5	2.8	2.0	1.2	18	57	61
7-1-1998	102	229128	175706	22	6.0	8.4	1.9	2.2	68	74	119

The root mean square error between measured and predicted values of the hydrograph ranged from 61 to 119.

Table 4. Lag time calculated from different equations.

Method	Equation	Lag time (hr)
Taylor method	$k = \frac{0.6}{\sqrt{s}}(LL_{ca})^{m}$ *	4.25
TNRC method	$k = \frac{L^{0.8}}{1900\sqrt{y}}\left(\frac{1000}{CN}-9\right)^{0.7}$ **	1.01

* s is watershed slope = 0.034, L is watershed length = 2.398 mi, Lca is length to centroid =1.035 mi, m is power coefficient = 0.3

** L is watershed length = 12662.8 ft, CN is curve number =75.65 , and Y is watershed slop in percent = 7.404%.

Conclusion

The main objective of this study was to evaluate the HEC-1 and HYDROMED models using hydrological data collected from a small watershed in Syria. HEC-1 produced satisfactory result for estimation run- off volume, time to peak, and shape of the hydrograph. Using a fixed value of curve number during the simulation could be the cause of the deviation between measured and simulated run-off volumes. In general, the discrepancy between estimated and predicted peak discharge increased as storm depth increased. The lag time should be varied as the storm depth and intensity change.

HYDROMED reasonably estimated the run-off volume; however, the model did not produce satisfactory result using the calibrated parameter for the estimation of peak discharge and the shape of the hydrograph. This could be mainly due to non realistic values of lag time resulting from calibration. More evaluating for the model is needed using measured infiltration parameters rather than calibrated values.

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