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Determination of the Ability of HEC-HMS Model Components in Rainfall-run-off Simulation

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ABSTRACT

The lack of measured hydrological data is a problem in most of the developing countries resulted from inadequate gauging stations, short length of record period and relatively low accuracy of measurement. Due to the above mentioned problem, it is important to develop models which can carry out acceptable simulation of run-off behavior especially for the ungauged catchents. This research was designed to evaluate HEC-HMS model for prediction of flood and modeling of rainfall-run off process. After calibration of the model, the hyetograph and related hydrographs of 6 rainfall events were used and the observed and estimated hydrographs were compared from different points of view. It was observed that Curve Number (CN) and initial loss are the main parameters affecting the results. Another evaluation was the comparison of the lag time produced by Snyder and SCS methods, showing more accuracy of the lag time predicted by SCS approach. In this study the common hypothesis "initial loss is about 0.2 of S" was also evaluated and observed that in Toroq watershed, the value of 0.22S is more reliable for the initial loss. About the comparison of the estimated run off produced by SCS and Snyder approaches, it was seen that the results of SCS approach is more close to the measured values.

Key words: HEC-HMS, hydrograph, initial loss, curve number, hydrological parameters

INTRODUCTION

Estimation of flood flow that involves the development of hydrologic models is one of the most important factors for all structural and non-structural measures that may help to reduce the amount of damages incurred. Due to the complexity of hydrological systems and lack of measured data in most of the catchments, it is very important and valuable to develop and use methods that are able to predict run off resulted from rainfall in ungauged catchments. Hydrologists are continuously improving the capability of hydrologic models to predict accurately the frequency of flood events in a changing climate (Naden, 1992; Billa *et al.*, 2004; Knebl *et al.*, 2005; Yener *et al.*, 2006; Bahat *et al.*, 2009). Knebl *et al.* (2005) integrated different model to forecast flood on a regional scale. The model consists of a rainfall-runoff model (HEC-HMS) that converts precipitation excess to overland flow and channel runoff, as well as a hydraulic model (HEC-RAS) that models unsteady state flow through the river channel network based on the HEC-HMS-derived hydrographs. The HEC-HMS program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed. Any mass or energy flux in the cycle can then be presented with a mathematical model. In most cases, several model choices are available for representing each flux. Zorkeflee *et al.* (2009) analyzed the impact of land use change to hydrologic behavior of Sungai Kurau Basin and by using the Geographical Information System (GIS) and HEC-HMS model for catchments management. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study and engineering judgment (USACE-HEC, 2006). For example, Yener *et al.* (2006) use HEC-HMS in event base hourly simulations and runoff scenarios using intensity duration frequency curves for modeling studies in Yuvacik Basin, Turkiye. In this study, Yuvacýk Basin is selected as the study area and basin parameters (infiltration and baseflow) are calibrated using the rainfall-runoff data of the basin that are collected by 8 rainfall and 3 runoff stations for 2001-2005 period. Cydzik and Hogue (2008) evaluated the HEC-HMS' ability to simulate discharge in prefire and postfire conditions in a semi arid watershed and the necessary parameterizations for modeling hydrologic response during the immediate and subsequent recovery, period after a wildfire. Verma *et al.* (2010) used HEC-HMS and WEPP models for simulation of run-off flow in Baitarani catchment of India and stated the sutability of HEC-HMS model for this application. Razi *et al.* (2010) employed HEC-HMS model for flood estimation in Johor river basin in Melaysia and compared the results to the observed values mentioning the satisfactory of the model results. Shieh *et al.* (2007) used HEC-HMS to evaluate the effects of check dams on river flow characteristics in Taiwan.

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of watershed systems. It is designed to be applicable in a wide range of geographic areas to solve the widest possible range of problems. This includes large river basin, water supply and flood hydrology and small urban or natural watershed runoff. In this model, interception, evaporation and infiltration processes in a catchment are determined from loss components while runoff processes are computed as the pure surface routing using transform component (Yusop *et al.*, 2007). In HEC-HMS model, some parameters are required as inputs to simulate the runoff hydrographs. Some of the parameters can be estimated through observation and measurements of stream and basin characteristics (Yener *et al.*, 2006). The method generally uses either an empirically-derived unit hydrograph or some standard shape defined by one or two parameters, such as the time to peak (Naden, 1992). In some of the application case, the capabilities of the HEC-HMS for rainfall simulation have been exploited to describe single events on which the rating curves to be estimated were tested. Thus continuous simulations are not performed and modeling is limited to single events (Pistocchi and Mazzoli, 2002). Anderson *et al.* (2002) used the mesoscale model, MM5, to transfer the Eta forecast data down to the appropriate space and time scales are required to link the Eta model precipitation forecast results to the watershed model, HEC-HMS, for runoff prediction. A number of flood related studies have shown that these models provide accurate and useful results.

As mentioned earlier, control and management of surface run off is one of the most important purposes in national policy of each country and a large amount of money is spent to reach this purpose every year. In the other hand, as hydrological analysis and estimation of flood discharges is an important factor to design and evaluate the efficiency of water related projects, small error in this regard can cause considerable risks for the related investments. Therefore, specification and employment of an accurate method to carry out hydrological analysis and estimation is important.

This research was carried out to evaluate the applicability of HEC-HMS model and geographic information system data in flood flow modeling in Torogh dam watershed of containing 131.34 km^2 in area located in Mashhad, Khorasan Razavi province.

MATERIALS AND METHODS

Study area: Study area of this research is Toroq dam watershed with area of 131.34 km^2, located about 25 km distance from Mashhad in Iran (Fig. 1). Average slope of the watershed area in 39.12% and its climatic condition is arid and semi-arid. Mean annual precipitation is 320.20 mm and the main soil groups (according to FAO classification) are Lithosols, Regosols, Leptosols and Flovisols. Figure 2 shows the land use map of the watershed. Three different land uses are orchards (15% of the catchment area), range lands and rainfed crops (19% of the catchment area) and poor range lands (66% of the catchment area). Different parts of the watershed is different is soil depth and therefore capacity of water holding. Figure 3 shows the soil depth in different parts of the watershed. Using the land use map as well as hydrologic soil groups, the CN (run off Curve Number) map of the watershed was prepared that is shown in Fig. 4. Table 1 indicates the area related to each hydrologic soil group.

Research method: After specification of the research area, rainfalls as well as run-off data were collected. Then using Arc GIS and field observation, the required information data maps such as land use, hydrologic soil groups and CN maps were prepared. For simulation of rainfall run-off process and prediction of peak flow HEC-HMS model was employed in this study. For evaluation

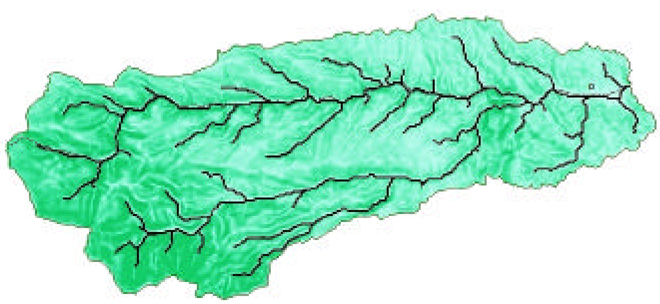

Fig. 1: Water way network map of the studied watershed

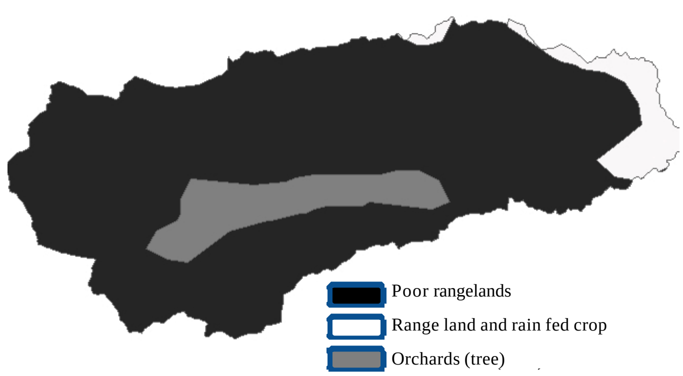

Fig. 2: Land use map of the studied watershed

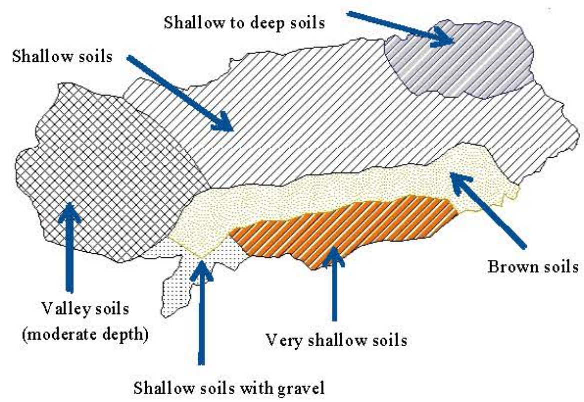

Fig. 3: Soil depth in different parts of the studied watershed

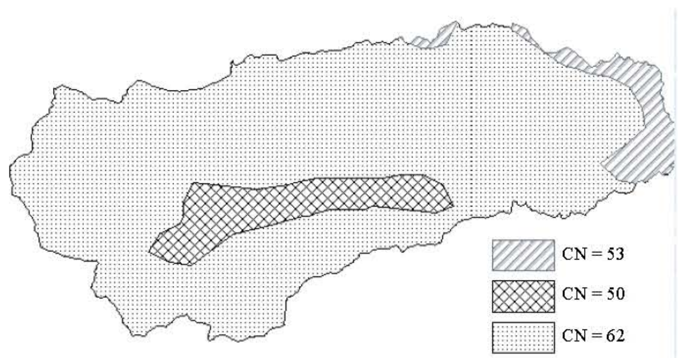

Fig. 4: The CN (run off Curve Number) map of the watershed

Table 1: Area of the different hydrologic soil groups in the studied watershed

Hydrological soil group	Area (km^2)
A	33.19
B	3.24
C	53.53
D	45.34

of the effects of the related hydrological parameters on flow discharge, sensitivity analysis of CN, initial loss and run-off lag time was carried out. Then six rainfall events were selected for calibration of the model. Some new rainfall run-off events were used for verification of the model and evaluation of its applicability was completed by comparing the model outputs and the observed values. Hydrologic Modeling System (HEC-HMS) is new generation software for precipitation runoff simulation that will supersede the HEC-1 Flood Hydrograph Package. HEC-HMS was developed by the U.S. Army Corps of Engineers and is a Windows version of HEC-1 with significant advances in computer science and hydrologic engineering. The HEC-HMS computer model has a large number of options, such as multiple basin watersheds, flood damage analysis, etc. The Soil Conservation Service (SCS) TR 55 approach to the determination of interception/infiltration and unit hydrographs will be used. This approach is commonly used for urban watersheds by the U.S. Army Corps of Engineers. After HEC-HMS is applied, the results must be checked to confirm that they are reasonable and consistent with what to be expected. The model parameters are calibrated until the results are favorable with close proximity of the observed and the simulated hydrographs. Calibration is a process to determine the properties or parameters of a system. Some parameters such as initial abstraction, curve number, impervious, lag time, initial discharge, recession constant and ratio are determined through the calibration process where the parameters are adjusted until the observed and simulated hydrographs are close fit. Some parameters such as slope, Manning, n, bottom width, shape and length of river are obtained from topographic map Zorkeflee *et al*. (2009). The model parameters obtained will be validated using different sets of events.

RESULTS AND DISCUSSION

Determination of optimized CN, initial loss and lag time: The amount of initial loss plays an important role in run off generation and water balance calculation of the watersheds. As calculation of this parameter is usually difficult, in most of the cases, the amount of initial loss is assumed to be about 0.2 of S (surface detention). However, in different areas as well as different rainfall events, the values of this parameter would be different. Table 2 shows the values of optimized CN, initial loss and the surface detention (S) and also the rate of initial loss to S. The average amount of initial loss for the rainfall events used in this study is about 0.22 of S. Optimized lag time for the selected events is shown in Table 3.

Sensitivity analysis of hydrologic parameters: Sensitivity analysis of run-off lag time calculated using two methods (SCS and Snyder) shows high sensitivity of this parameter in the range of 0 and -20%, means that the catchment discharge is more sensitive to smaller values of lag time. In the other word, underestimation of lag time would cause more error on prediction of discharge in comparison to overestimation of this parameter. In addition, outputs of the model are slightly more sensitive to lag time calculated by SCS method than that calculated by the Snyder method (Fig. 5). The same condition is obtained about the CN value, as the output of the model is

Table 2: Optimized CN, initial loss and S for the watershed

Event date	Optimized CN	Initial looses	Surface detention (S)	Initial loose/S
16/03/1992	61	35.42	162.394	0.2181
23/04/1992	61	35.12	162.394	0.2162
25/02/1993	59	37.00	50.176	0.2096
4/12/1994	62	35.33	155.6774	0.2269
27/03/1997	60	35.75	169.3333	0.2111
17/10/1996	64	33.33	142.875	0.2333

Table 3: Comparison of the lag time estimated by SCS and Snyder methods

	Events date					
Parameter	27/03/97	17/10/96	04/12/94	25/02/93	23/04/92	16/03/92
Lag time Snyder (initial)	8.80	8.80	8.80	8.80	8.80	8.80
Lag time Snyder (optimized)	5.90	6.54	6.60	5.40	6.58	6.12
Lag time SCS (initial)	6.61	6.61	6.61	6.61	6.61	6.61
Lag time SCS (optimized)	7.16	8.40	7.21	7.10	7.25	7.59

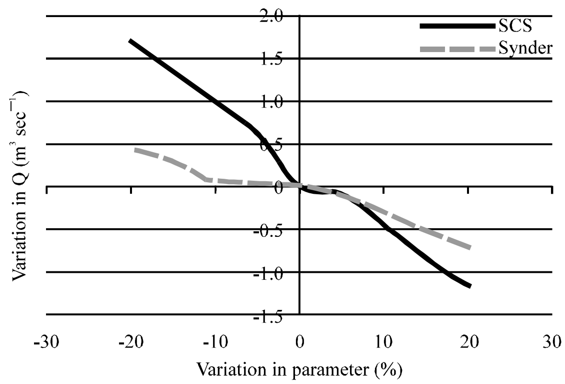

Fig. 5: Variations of in Q due to the changes in SCS and Snyder lag time for event 22 Feb.1995

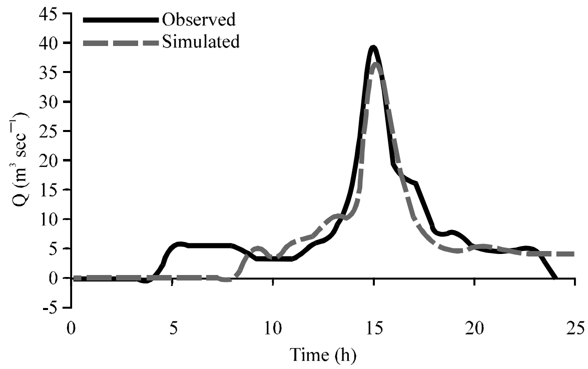

Fig. 6: Simulated hydrograph against the observed hydrograph (event: 17/10/1996)

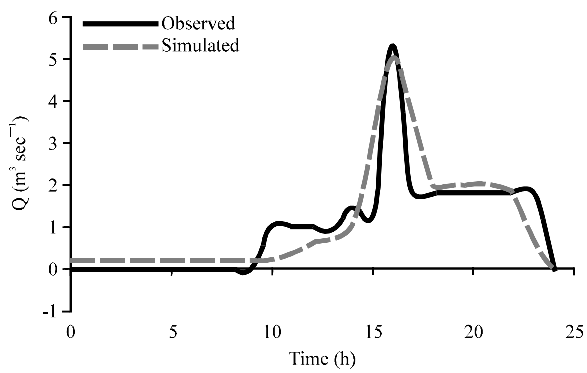

Fig. 7: Simulated hydrograph against the observed hydrograph (event: 27/03/1997)

more sensitive to underestimation of the CN values. Figure 6 and 7 shows the simulated and the observed hydrographs for two different rainfall run-off events.

Verification of the model: Table 4 and 5 show the predicted peak discharge and time to peak and the related observed values for a rainfall event used for verification of the model. The results show that calibration of parameters such as CN and initial loss could considerably improve the outputs

Table 4: Simulated peak discharge after verification (event: 13/02/1998)

Parameter	SCS	Snyder
Observed peak discharge	3.50	3.50
Calculated peak discharge	3.498	2.985
Error (%)	0.40	0.90

Table 5: Simulated time to peak after verification (event: 13/02/1998)

Parameter	SCS	Snyder
Observed peak discharge	17.08	19.50
Calculated peak discharge	17.25	19.00
Error (%)	1	2.60

of the model. This is similar to the results obtained by Knebl *et al.* (2005). The results also show suitability of the calibrated HEC-HMS model in prediction of peak discharge, flood flow volume, time of concentration and the shape of hydrograph. This findings are in favor of the findings reported by Knebl *et al.* (2005) and Verma *et al.* (2010).

The most important findings of the research can be concluded as follows:

- Results obtained in this research indicate good ability of HEC-HMS model in rainfall-run off simulation in ungauged catchments. However, parameters such as CN, Initial loss and lag time plays an important role in accuracy of the results produced by the model. Therefore, these parameters must be correctly estimated during the calibration process
- Comparing the outputs of the model in two different conditions (using SCS and Snyder methods) to the observed values indicates priority and robustness of SCS method for run off estimation (both in peak flow and lag time) in ungauged catchments
- Sensitivity analysis of the hydrological parameters indicated that although variation in CN, initial loss and lag time affects the outputs of the model but the outputs are more sensitive to CN in comparison to initial loss and lag time (specially in the range of 0 to -20). Therefore, underestimation of CN value would cause more error on prediction of discharge in comparison to overestimation of other two mentioned parameters
- Results of this research showed that the optimized average value for initial loss is 0.22S for the studied watershed and the used rainfall events
- Finally for ungauged catchments where no enough measured data is available, HEC-HMS is a reliable method for rainfall-run off simulation and flood flow estimation. This model has appropriate ability to estimate peak discharge with acceptable error (less than 1%) comparing to observed values

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