Practical Study of HEC-HMS to Access the Most Optimum Hydrograph Computed by this Software in Basin Area

Case study: Jo Kanak Basin Area

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ABSTRACT
Since the effect of various natural disasters (including flooding, earthquake and etc.) has always been one of the main causes of human and financial loss and its outcomes in human communities, the researchers and experts decided to control these factors to prevent or reduce the damages and losses by presenting appropriate practical solutions. One of these risk factors is due to sudden rainfalls that lead to huge and uncontrollable flooding. However, since rainfall is one of the most complex hydrologic phenomena, the researchers tried to study this issue with more precision through practical software and create various models. At the end, after many investigations, HEC-HMS was invented and designed that provides the possibility of stimulation of rainfall-runoffs in basin areas and can appropriately present various models by its capabilities. This paper tries to present the calculation method and modeling of rainfall-runoffs in the most practical way and then study the results of this software and its application and specify the most optimum hydrograph in basin area.

KEY WORDS: flooding, rainfall, hydrology, basin area, HEC-HMS.

INTRODUCTION
HEC-HMS is one of the computer models that is used for analysis of rainfall-runoff process. This software is in fact replaced for the upgraded version of HEC-1. This has been introduced into the market in 1998 by engineering department of American military and each year a new capability is added to it. Concerning easy use and its application in a wide range of geographical areas, it is widely considered and used by the experts of hydrology sciences.

This software is a combination with programing languages whose graphic section has been written by C-language and its overall hydrologic algorithm is written in FORTRAN language. This software determines the reaction of basin area on rainfall and the current flows in the basin. In other words, it provides the possibility of stimulation of rainfall-runoffs in basin areas. The other capability of this software is the calculation of basins’ runoffs, collection of surface waters in urban areas, routing of the flooding of rivers and reservoir, designing of reservoir overflowing, hydrographic analysis of the floods due to dam failure and the effect of urbanization trend in hydrology of basins.

However, the most important parameters that have attracted the attention of all experts and designers of hydrology about this software is easy use of software, high capability for the user, easy management of file by the user, simple revision of data, tabulation and graphic representation of inputs and outputs, the possibility of reporting, the possibility of optimization of results by change of parameters in the allocated range to the software.

The mathematical models in the software determine the reaction of basin area toward rainfall and the flow in the basin. As example, the routing model of water in the main path describes a differential equation that is unidirectional flow in open canal. However, to use this software for planning, designing and utilization, in addition to variation of flows, the flow rate in different times is also required. The basin that has been investigated in this paper by this software is a basin with the area of 2937 km2 and surrounding of 343 km. This basin is located in southwest of Iran and east and northeast of Ramhormoz (located in Khuzestan) that is presented in the following.
1. Various components in software:
   Concerning what was mentioned, it can be claimed that stimulation of basin area in this software is introduced by three general components to HEC-HMS software including:

2. The components of basin model:
   The physical specification of basin area, rivers and their associated facilities in the basin area is introduced to the software. Moreover, for stimulation of tree network of basin, various hydrologic elements will be used. Hydrologic elements in the model of basin include seven elements. The calculation process related to losses determination in the basin, transfer of extra rainfall to runoffs, the base flow rate and stimulation of flow in the canals and reservoirs and also their routing is done in the basin model. There are various methods for calculation of losses according to the selection of runoff production in basins and the user can just use one method for each secondary basin. The stimulation of flow in rivers and open canals and their routing is possible through various hydrologic methods. The base flow in each secondary basin can be introduced to software through abatement, monthly constant and linear reservoir model.

3. Aerologic data analysis:
   Aerologic data analysis is done through aerologic model consisted of raining and perspiration. For raining data analysis, there are seven methods and for calculation of evaporation and perspiration, there is one method in this software.

4. Model analysis and optimization of results:
   In case of lack of various modeling errors, model analysis has been simultaneously done with project implementation and the results and tables in each element are graphically observable. The implementation of all projects is possible with creation of at least one basin model, an aerologic model and a control element and the results of the first implementation of project through calibration method is utilizable. During this process, the values of introduced parameters to the model are corrected with the aim of having access to homogenous results with real and natural data. At the beginning of optimization operation, it is required to select initial values for all parameters used in the model; the optimization operation ends with achievement of the best fitness between observed hydrographs.

4-1. The capabilities of HEC-HMS:
   HEC-HMS package has various capabilities including:
   - The use of strong and easy graphical environment for stimulation of basins
   - The possibility of graphical and tabulated reporting of the results
   - The use of wide range and hydrologic relations in calculations
   - The capability of continuous hydrologic analysis
   - The capability of call for HEC-1 files and its convert to HEC-HMS files
   - The possibility of attachment to other software such as Arcview-GIS
   - The possibility of applying variation coefficient in inputs and the comparison of results
   - The possibility of calibration of parameters and optimization of results

4-2. The selection of rainfall-runoff model and raining losses for computational hydrographs:
   As we know, the researchers have presented various methods for determining the best raining-runoff model for drawing computational hydrographs by HEC-HMS, some of which has been used in this study that are as follow:
   Rainfall- runoff model through Clark model with scs losses
   Rainfall- runoff model through scs method with Green and Ampete losses
   Rainfall- runoff model through Schneider model with Green and Ampete losses
   Rainfall- runoff model through scs method with scs losses
   Rainfall- runoff model through Schneider method with scs losses

4-3. Clark moment unit hydrograph model:
   To obtain moment unit hydrograph, Clark model is used with two parameters of focused time in respect to hour and saving factor in respect to hour.
   Clark equation (1945) for obtaining IUH is in form of equation2.

\[
   u_i = \left( \frac{\Delta t}{k + 0.5\Delta t} \right) I_i + \left( \frac{k - 0.5\Delta t}{k + 0.5\Delta t} \right) u_{i-1}
\]

(2)
where, $u_i$ is the value of moment unit hydrograph and $\Delta t$ is the computational time interval. HEC-HMS uses conversion of time-area graph to flow to obtain the input components, i.e. $I_i$. This software is capable to optimize the focused time and saving coefficient values. To use HEC-HMS software, a secondary basin has been used in this study. The elements of basin, aerologic data, control and observational data were also entered to the calculations of the model. Moreover, falling was considered in form of initial losses and constant rate of penetration, where, constant penetration rate is $\phi$ index and initial losses of rainfall is the rainfalls that are absorbed before the effective rainfall. To enter the parameters of transfer model, approximate value has been used for initial calculations and the model was implemented using these initial values. At the end, observational values were entered to the output to perform optimization. In the optimization section, Nelder and Mead method was used for simultaneous calculation of optimum values of two parameters in each of rainfall and runoff events. The reason for this selection is the recommendation of technical reference of software on the application of Nedler and Mead method for simultaneous optimization of more than one parameter. For optimization, target function of sum of squares of remaining was used as target function. The argumentation for this selection is such that the aim of the study is to estimate appropriate form of hydrograph; thus, the comparison should be done between equivalent flows. Tolerance 0.1 and repetition of 50 times were selected for this optimization.

4-4. SCS model or Soil Conservation Service of America:

The hydrograph in this model is a curve where flow is drawn in form of the ratio of flow to maximum flow and time in form of the ratio of time to maximum time (figure 1, b). If maximum flow and delay time for extra rainfall of a certain basin, its unit hydrograph can be estimated from a dimensionless artificial hydrograph. Hydrograph is represented by a simple triangle (figure 1-a) with raining duration of $t_r$ (hour), time to achieve maximum flow ($T_R$) and abatement time of $B$ (hour) and peak flow ($Q_P$). The direct runoff volume equals to:

$$\text{Runoff volume (VOL)} = (Q_R T_R / 2) + (Q_P B / 2)$$  \hspace{1cm} (3)

Or

$$Q_P = (2 \times \text{VOL} / (T_R + B))$$

The study of many hydrographs yield the following result, $B = 1.67 T_R$

Thus, for one inch of extra rainfall, the calculations are as follow:

$$Q_P = (0.75 \text{VOL} / T_R)$$ \hspace{1cm} (4)

$$Q_P = (0.75 \times 640 \div A \div 1) / T_R$$ \hspace{1cm} (5)

After investigation of equation 5, Kapco et al (1984) concluded that value 10 to 15 has better results for flat basin and the basin with high level of underground water rather than 484.

Fig. 1: SCS dimensionless unit hydrograph a. Triangular hydrograph b. dimensionless hydrograph.

from figure 1, equation 6 is obtained:

$$T_R = t_r / 2 + t_L R$$  \hspace{1cm} (6)

$T_L R$ from proposed equation SCS is determined as follow:

$$T_L R = L^{0.8} (s+1)^{0.7} / 1900^{0.5}$$ \hspace{1cm} (7)

in this equation, $t_L R$ is in respect to hour and the length of main river (Km) from the exit point of the basin to the highest point of basin and $L_C$ is the length of main river from exit point to the point of river that has the closest distance to the gravity center of the basin (Km) and in metric unit, it equals to 0.75 and in English unit, it equals to 1 and $C_1$ is the coefficient that indicates the variation of slope and reservoir in basin. This coefficient

4-5. Schneider model:

In 1983, Schneider carried out studies on Apalachian Mountains in America and presented a standard unit hydrograph that includes three factors of delay time, peak flow in surface unit for a unit of extra rainfall and base time (figure 2). Schneider defined his standard unit hydrograph whose extra rainfall duration was $t_r$ and delay time of its peak flow was $t_I$ as follow: $t_I = 5.5 t_r$

Then delay time of peak flow that is from the extra rainfall center until artificial hydrograph peak time can be determined by the geometrical specification of the basin through the following equation:

$$t_L = C_1 C_2 (L \cdot L_B)^{0.3}$$ \hspace{1cm} (9)

in this equation, $t_L$ is in respect to hour and the length of main river (Km) from the exit point of the basin to the highest point of basin and $L$ is the length of main river from exit point to the point of river that has the closest distance to the gravity center of the basin (Km) and in metric unit, it equals to 0.75 and in English unit, it equals to 1 and $C_1$ is the coefficient that indicates the variation of slope and reservoir in basin. This coefficient
is 1.8 for plains and 2.2 for mountainous basins (in English unit). Moreover, in Schneider standard unit hydrograph, maximum flow in area is introduced in respect to \( \text{m}^3/\text{s.Km}^2 \) or \( \text{cfc/mi}^2 \).

\[
Q_{p} = C_{2} C_{p} / t_{r}
\]  \( (10) \)

**Fig. 2:** Schneider artificial unit hydrograph a. Standard unit hydrograph \( (t_{l} = 5.5 \text{ t}_{i}) \) b. Search unit hydrograph. \( (t_{L,R} = 5.5 \text{ t}_{q}) \).

In this equation, \( C_{2} = 2.75 \) is in metric unit (in English unit, it equals to 640) and \( C_{p} \) is the coefficient related to water saving in basin (Behbahani, 2001).

For calculation of \( C_{t} \) and \( C_{p} \) in the basin with hydrometric station, \( L \) and \( L_{c} \) values are measured from topography map and then \( C_{t} \) and \( C_{p} \) values are determined from the unit hydrograph of that basin. Since in such basins, \( t_{L,R} \), \( t_{R} \) and \( q_{R} \) parameters are clear using runoff data, thus, it is possible to obtain duration of extra rainfall and delay time \( t_{L,R} \) and maximum flow in area \( q_{R} \) from the studied hydrograph.

5. **Calibration of various models:**

After drawing all observational hydrographs and determining the best one, according to what was mentioned so far, it is required to process all data of determined hydrographs through HEC-HMS for calibration of the above hydrographs. To this end, it is required to determine various parameters including peak time, peak coefficient, delay time, focus time etc. each of these parameters has been calculated with equations and replacement of the required values using natural conditions in the above relation. However, it is required to explain that these parameters have been introduced in certain range of the software beforehand. Thus, the software provides this possibility to change the input parameters in trial and error form in the defined range to the extent that both hydrographs obtain the best condition after entering the required data and parameters in various user software models through comparison of observational and computational hydrograph (drawn by software). It is obvious that the best condition is full conformity of observational hydrographs and computational ones that is never fully achieved. The sum of above-mentioned explanations is called calibration.

6. **The studied area:**

Usually for construction of dams, bridges, cities or cultivating lands, it is required to perform initial studies for investigation of flooding in this area. To this end, it is required to study the hydrographs obtained from raining of past year of the intended area. Thus, since Jo Kanak area contains many agricultural lands and a dam called Jareh dam, concerning the statistical weakness of the area, it was tried to prepare hydrographs from the rainfalls of the studied area using existing hyetographs and select the most appropriate raining-runoff model for this area.

**Fig. 3:** The geographical situation of the studied area.

7. **The comparison of the observational hydrographs with calibrated computational hydrographs:**

In these studies, it is required to draw hydrographs manually to compare them with the computational hydrographs obtained from software and achieve the best result. However, since this study aims at investigation
of the performance of the software, the issue of hand drawing of hydrographs has not been proposed; however, for clarification of the issue, the conformity of two hydrographs obtained from software output has been used. Here, it is possible to select the best drawn hydrograph by schematic observation of all hydrographs in various models.

**Graph 1:** The comparison of observational hydrograph with calibrated computational hydrograph through Clark rainfall-runoff method and losses by SCS method.

**Graph 2:** The comparison of observational hydrograph with calibrated computational hydrograph through Clark rainfall-runoff method and losses by SCS method.

**Graph 3:** The comparison of observational hydrograph with calibrated computational hydrograph through Clark rainfall-runoff method and losses by SCS method.

**Graph 4:** The comparison of observational hydrograph with calibrated computational hydrograph through SCS rainfall-runoff method and losses by SCS method.

**Graph 5:** The comparison of observational hydrograph with calibrated computational hydrograph through SCS rainfall-runoff method and losses by SCS method.
Graph 6: The comparison of observational hydrograph with calibrated computational hydrograph through SCS rainfall-runoff method and losses by SCS method.

Graph 7: The comparison of observational hydrograph with calibrated computational hydrograph through SCS rainfall-runoff method and losses by G.A. method.

Graph 8: The comparison of observational hydrograph with calibrated computational hydrograph through SCS rainfall-runoff method and losses by G.A. method.

Graph 9: The comparison of observational hydrograph with calibrated computational hydrograph through SCS rainfall-runoff method and losses by G.A. method.

Graph 10: The comparison of observational hydrograph with calibrated computational hydrograph through Schneider rainfall-runoff method and losses by SCS method.
Graph 11: The comparison of observational hydrograph with calibrated computational hydrograph through Schneider rainfall-runoff method and losses by SCS method.

Graph 12: The comparison of observational hydrograph with calibrated computational hydrograph through Schneider rainfall-runoff method and losses by SCS method.

Graph 13: The comparison of observational hydrograph with calibrated computational hydrograph through Schneider rainfall-runoff method and losses by G.A. method.

Graph 14: The comparison of observational hydrograph with calibrated computational hydrograph through Schneider rainfall-runoff method and losses by G.A. method.

Graph 15: The comparison of observational hydrograph with calibrated computational hydrograph through Schneider rainfall-runoff method and losses by G.A. method.

As it was expained, in the process of determination of the optimum hydrograph, first we draw hydrographs through EXCELL using the hyteographs of the intended area (these drawings are called manual or observational hydrographs that are overally studied in this paper; however, its graphs have been used in above hydrographs in blue color). Then, we begin data entering to software that at the end draws various hydrographs (like red graphs). Now, it is possible to introduce the most optimum hydrograph as the one with the best conformity between observational and computational hydrographs.

8. **Conclusion:**

Concerning what was mentioned, to determine the best raining-runoff model, the statistics of raining of previous years is enough and the more is the statistics, the precision will be more. Thus, without the mentioned statistics, no method has yet been proposed for determination of the best raining-runoff model.

In this study, Clark, SCS and Schneider models have been used for raining-runoff models and SCS and G.A. have been used for raining losses; however, concerning the presented hydrographs in this section, with precise study of hydrographs, it is possible to determine the best model with the following parameters:
1) Which model has presented the best conformity between observational and computational hydrographs?
2) Which model has the lowest error?

After precise investigation of hydrographs, the best conformity state between observational and computational hydrographs in this study have been respectively presented in Clark model, then Schneider and SCS.

**REFERENCE**