Combine Catchments Flood Forecasting Using Shuffled Complex Evolution (SCE) Method

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Abstract

The successful application of a flood forecasting model depends in large measure on how well the model is calibrated. it is typically difficult to apply these models without obtaining unique optimal values for their parameters. Also the model construction and parameters must be defined with high precision to place reasonable degree of confidence on the estimated parameter values. In this research the combined catchments flood forecasting is being accomplished by incorporating hydrological and meteorological data. Flood forecasting used in this research is a combination of watershed model that consists of two parts: conceptual rainfall-runoff (CRR) model in the basin and Muskingum-Cung routing method in the river. Because the calibration process is difficult and complex, there is a need for robust, effective, efficient and reliable automatic calibration procedure. In addition, those procedures must have a high probability of finding the global optimum without being trapped in a local optimum. Therefore, in this research we use the shuffled complex evolution method that is a new global optimization strategy designed to be effective and efficient for a broad class of problems. The SCE method combines the strengths of the simplex procedure with the concept of controlled random search, competitive evolution and the newly developed concept of complex shuffling. As the search progresses, the entire population tends to converge toward the neighborhood of the global optimum. This method is used for flood forecasting in Seimareh River in southwest of Iran and its results indicate that it is a reasonably accurate and reliable method.

KEY WORDS: combine catchments, Flood Forecasting, SCE Method, Muskingum-Cung Routing

INTRODUCTION

The flood forecasting is one of the ways to postpone the destructive effects of floods. The forecasting needs a powerful model for simulating the nonlinear complicated processes of rainfall-runoff. Among different models that can be indicated for rainfall-runoff prediction is the zero dimension models (lumped). One of the advantages of these models in simulating the nonlinear rainfall-runoff relationships is its simple relationships and calculations.

Conceptual rainfall-runoff models are the most applied tools that represent the watershed outflow as a runoff and the excessive rainfall relationship in terms of parametric relationships. These models (CRR) are designed for simulating the physical process governed the hydrologic cycle. Therefore, these models are more popular among engineers and hydrologists. Generally, the CRR model results are based upon assigning the governing parameters by calibration. These models include lots of parameters that cannot be identified directly and have to be assigned by calibration. The main goal of calibration is assigning optimized values for the different parameters in the model.

In this investigation, the prediction of flood for combined catchments has been studied. A combined catchments consists of one main downstream sub-watershed and several upstream sub-watersheds. The runoff first flows from upstream sub-watersheds and then inters the main river of the main sub-watershed. Therefore, to predict the rainfall-runoff of these type of watersheds it is necessary to rout the flow of each sub-watershed to the main river and down to the outlet of the whole watershed.

In recent years, different researchers tried to develop optimization models to calibrating rainfall-runoff models. In the last three decades, lots of studies and efforts to calibrate CRR models have been conducted, Ibbitt (۱۹۷۲), Johnston and pilgreem (۱۹۷۶), Sorooshian and Dracup (۱۹۸۰), Gupta and Sorooshian(۱۹۸۳), Troaman (۱۹۸۵), Duan et al.(۱۹۸۸, ۱۹۹۸), Madson (۲۰۰۰), Kany et al. (۱۹۹۶), and Wang (۱۹۹۱) are some of them. Each of the researchers followed different approaches in his calibration. In this study, the global optimization SCE method has been used for the auto-calibration of NAM storage model that was applied for the combined catchments of Holilan-Gharabaghestan-Gamasiab located in Karkhe watershed.

THE STRUCTURE OF FLOOD FORECASTING MODEL

As referred above, in this study flood forecasting is based on rainfall-runoff and river flood routing procedure. First, the fundamentals that govern the rainfall-runoff and relationships among the different parameters and then river flood routing and its governing relationships and combining all those components are introduced.

Rainfall-runoff model structure

The basis and general concepts that govern this model is based on NAM model. In this model, the quantitative simulation of watershed is based on hydrologic cycle. This model works as a zero dimension model and its parameters represent an average value for the whole watershed. Figure ۱ shows the general structure of the model with its four different and mutually interrelated storages and their corresponding flows. The four storage layers are: ۱-Snow storage, ۲- Surface storage, ۳- Lower zone storage, and ٤- Underground storage and the three flows are ۱- Surface flow (Q_{OF}), ۲- Underflow (Q_{IF}), and ۳- Underground flow (Q_{BF}). Generally, the input data needed for this model are rainfall, potential evaporation and temperature and the output of the model is the watershed outflow with respect to time.

Fundamentals Governing River Flow Routing

In this study, the Muskingham method, which is one of the hydrologic flows routing in rivers, has been used. Cunge modified this method. Therefore, this approach matches the diffusion wave method. The Muskingham-Cunge method can be used for routing lateral flow or any collected flow as a hydrograph to Main River. The main assumption in this method is its combination of continuity equation and the diffusion form of the momentum equation. By combining the two equations the diffusion transfer formula would be obtained. In this study, the four points Muskingham-Cunge method has been employed. The main river flow routing starts downstream once the rainfall-runoff of the upstream sub-watersheds is computed and assigned at their outlets.

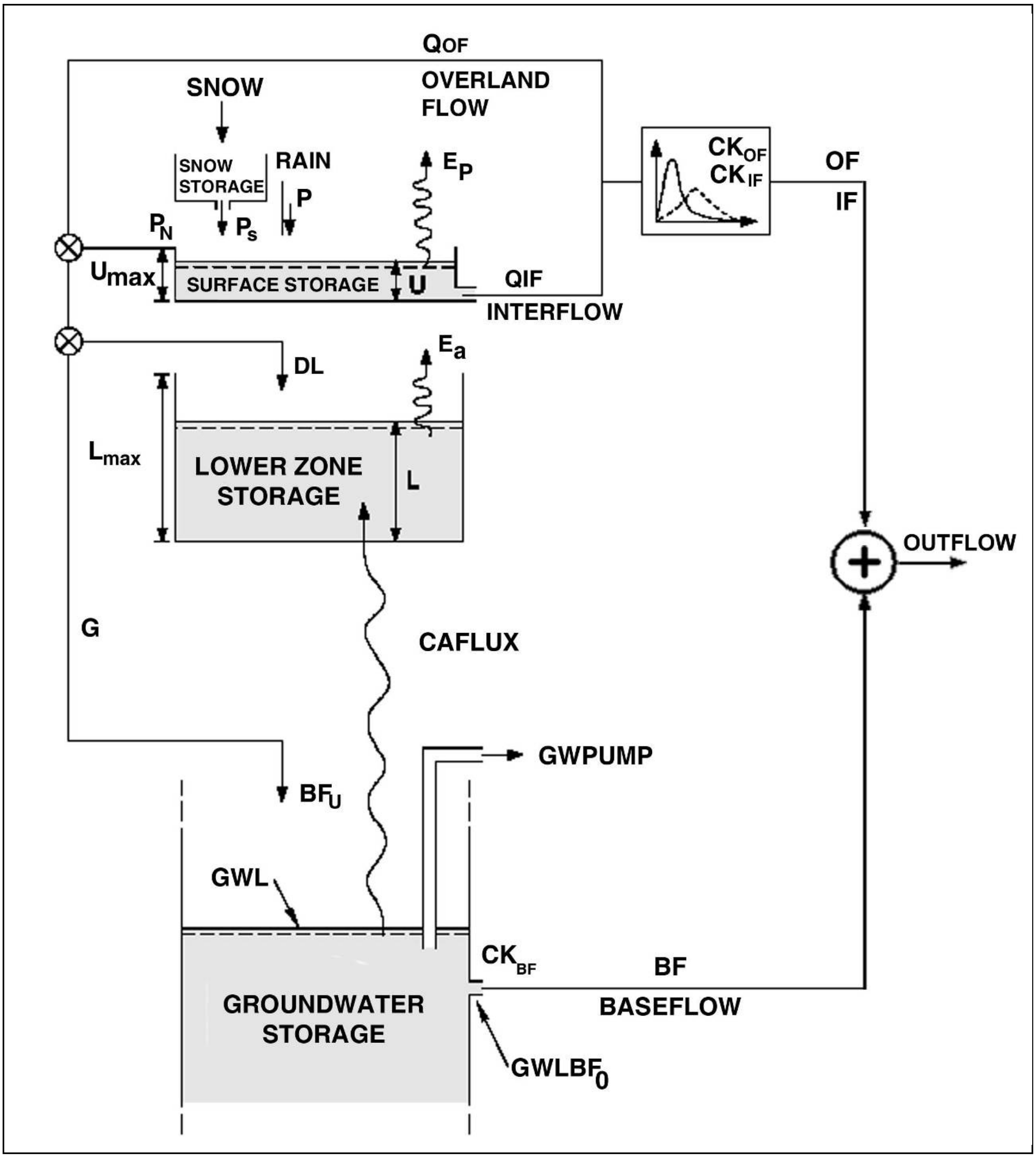

Figure ١ Flowchart of rainfall-runoff model structure

The System Simulation

A schematic of the flood forecasting of the combined catchments is shown in Figure ٢ As shown in the figure, the rainfall-runoff model, based upon the selected stations of Gharabaghestan and Gamasiab sub-watersheds, is applied and then the calculated outflows of the sub-watersheds flow downstream towards the main river of Holilan. The final outcomes will the routed flow at the end point of Holilan sun-watershed.

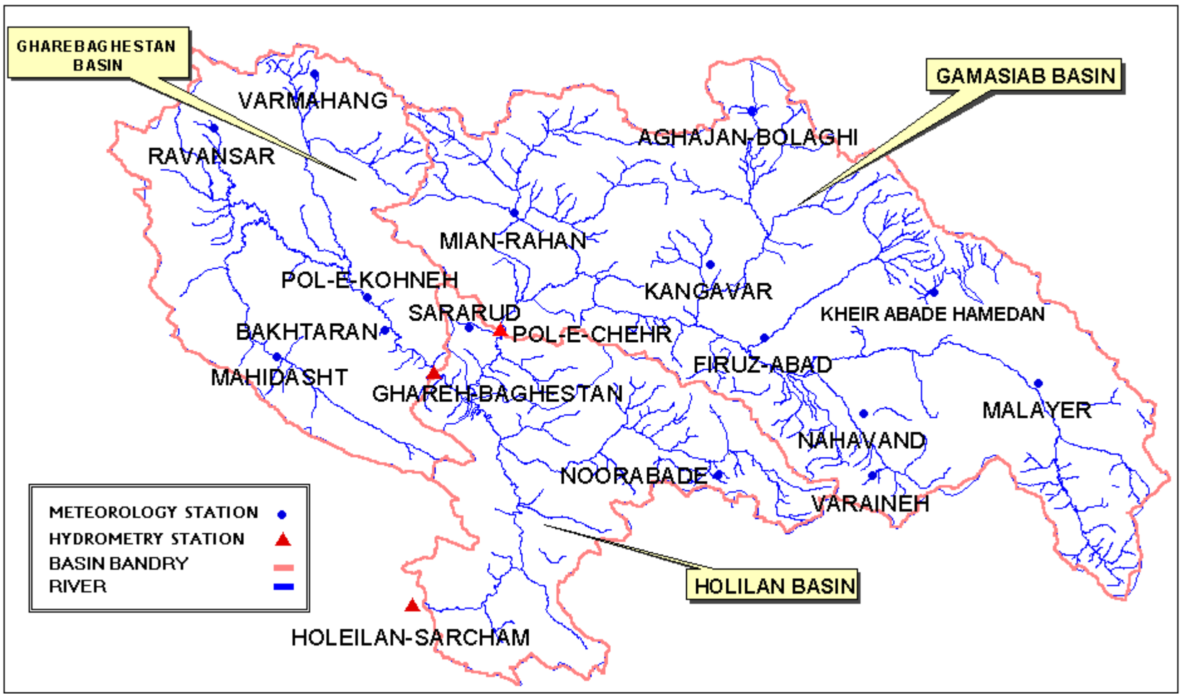

Figure ٢ Combined catchments of Holilan-Gharabaghestan-Gamasiab

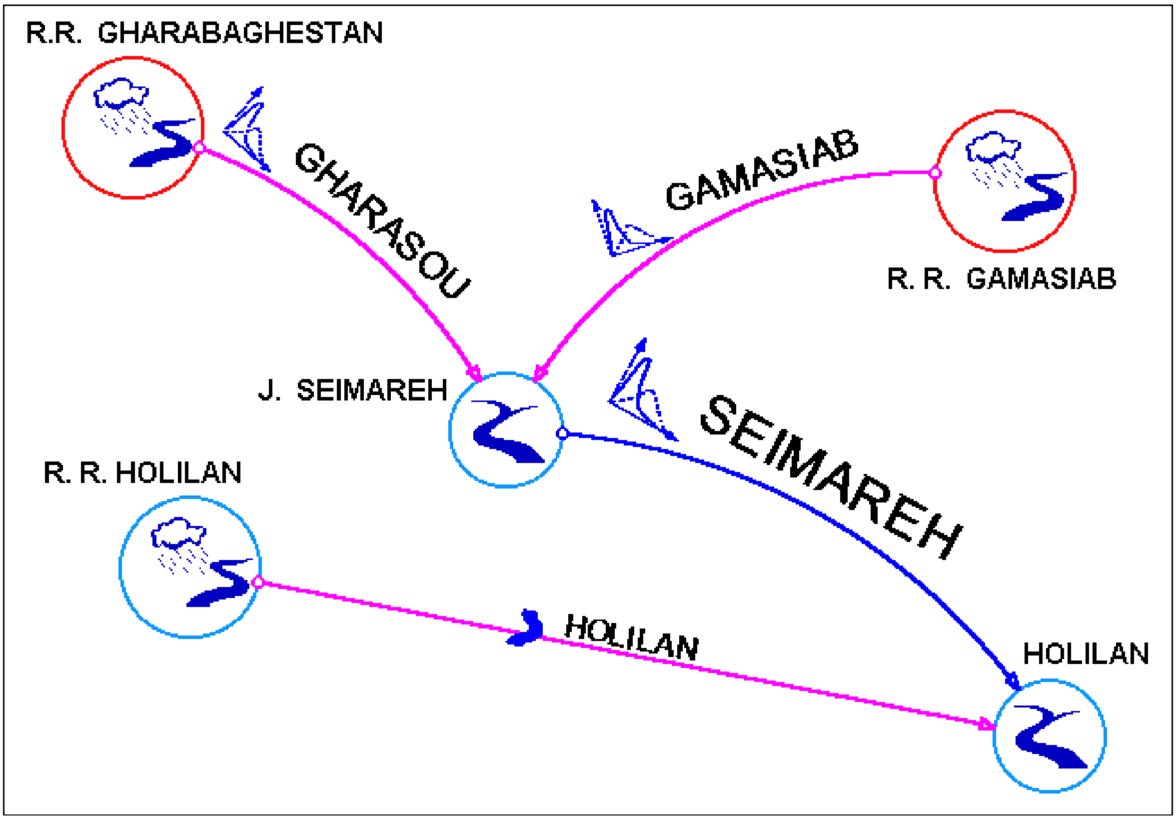

Figure ۳ The system structure for flood forecasting in combined catchments of Holilan

THE SCE METHODOLOGY

In this method, the global optimization approach of SCE, which is a strong and effective approach for auto-calibration for lots of problems, is employed. To obtain the global optimization point, this method uses four basic concepts. The four concepts are: ۱- combination of random and deterministic approaches (Dixon and Szego, ۱۹۷۸; Torn and Zilinskas, ۱۹۸۹); ۲-Clustering (Becker and lago, ۱۹۷۰; Torn ۱۹۷۸; Timmer, ۱۹۸۷);۳-The concept of a systematic evolution of a complex of point spanning the space (Price, ۱۹۸۳ , ۱۹۸۷); ٤- The concept of competitive evolution (Holland, ۱۹۷٥). The success of each of the above concepts in separate application has been proved (Sorooshian et al, ۱۹۹۳; Duan, ۱۹۹۲, ۱۹۹۳; Holland, ۱۹۷٥ Price, ۱۹۷۸; Manetsch, ۱۹۹۰; Wang, ۱۹۹۱). The combination of these concepts made the SCE known as a powerful, effective and flexible method. SCE method is a developed one that consists of two parts, SCE and competitive complex evolution (CCE). SCE algorithm is presented in Figure ٤.

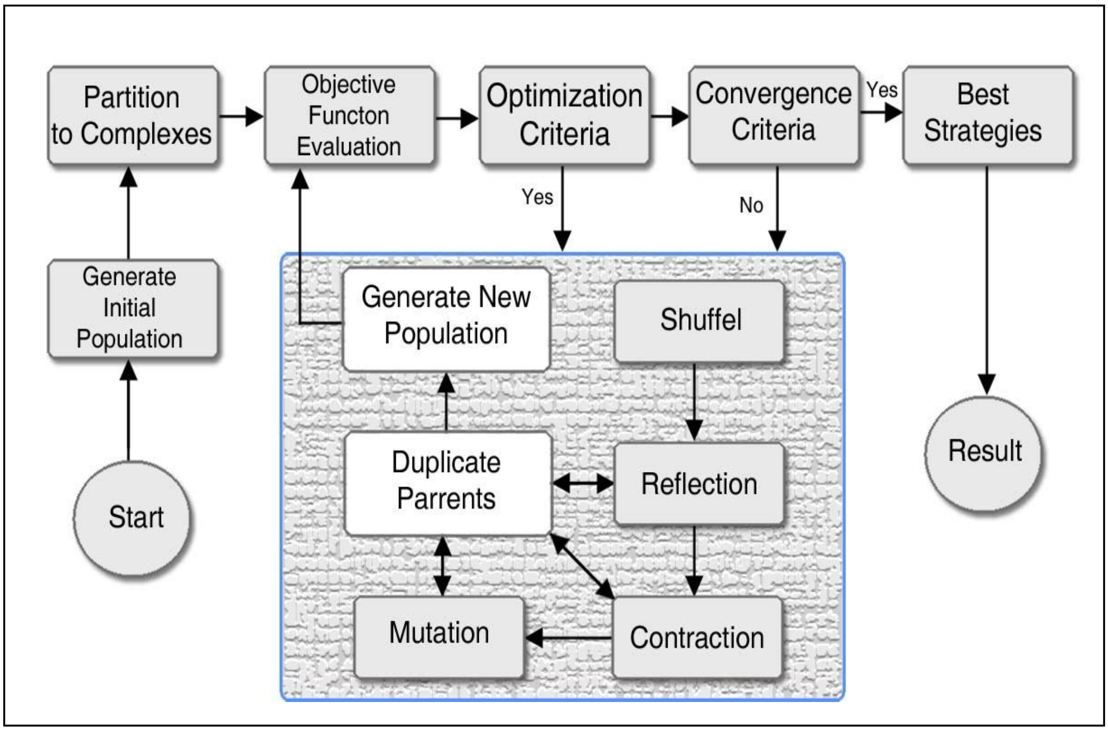

Fig ۴ SCE Algorithm

SCE Algorithm

۱- Selecting a point in a space that includes S points $x_1 \ldots x_s$ in the feasible space and compute the function value f_i at each one of the point.

۲- Rank points. Sort the points in order of increasing function value.

۳- Dividing the points in S into P complexes where each complex includes m member. Indeed S is going to be divided into complexes A١, A٢ ... A^P where each of these has m member meaning that:

$$A^k = \left\{ X_j^k, f_j^k \middle| X_j^k = X_{k+P(j-1)}, f_j^k = f_{k+P(j-1)}, j = 1,...,m \right\}. \quad [١]$$

٤- Evolve each complex A^K, K=١… P according to the developed CCE algorithm outlined separately.

۵- Shuffle complexes: A١... A^P complexes are again get shuffled in a way that $D = \left\{ A^k, k = 1,..., P \right\}$ and then sort D's in order of increasing function values.

۶- Satisfying any of the convergence criteria.

۷- If the convergence criteria (step ٦) aren't satisfied then return to step ٣ and continue the steps until step ٦ applies.

The random selection of initial points in the parametric domain enables the user not to be trapped into local optimum point. Classifying the initial points into complexes makes it easier to search the space in different directions and each of which complexes is permitted to evolve independently. After a certain number of generations, remixing the complexes enhance survivability by sharing information gained independently by each community.

Competitive Complex Evolution (CCE) for each complex is an important part in SCE algorithm. The procedure of CCE is based on the concept of reproducing new born and keeping parents with stronger features. Basically, CCE algorithm is part of the general algorithm of SCE. In this algorithm once step ۴ is reached the CCE get into the procedure and each of the complexes will be developed separately and again return to the main stream of the procedure. In CCE all points have the chance to behave as parents and behave in the way of reproduction. The duty of sub complexes is similar to parents except more than one couple (parents) can be utilized. Utilizing random method for the sub complexes enable users to conduct the search with complete converge of parameters domain.

In this investigation the SCE for auto-calibration of CRR model has bee employed. The SCE model combines the algorithm developed by Duan et al. (١٩٩٢ and ١٩٩٣) to the method introduced by Liong et al. (۲۰۰۴) for the determination of SCE parameters. Other modifications have been added to the SCE model to enhance its speed of convergence and reduce the obstacles to reach the global optimum point. In the algorithm, a complete random sample from the initial population is generated and along the time of the program run any similar parents will be eliminated from the evolution cycle.

MODEL VERIFICATION AND COMPARISION

A set of ٨ standard functions has been employed to evaluate the optimization model. Each of the functions has one globe optimum point and several local ones. For each run, random initial points S has been assigned. The criteria for terminating the run, is obtaining less than ۰.۰۰۰١ values for the function and of course that was within up to ٢۵۰۰۰ iterations.

Two criteria for each run are employed. One is NF criteria or the number of failures out of the ١۰۰ trials. The second statistical criterion is the average number of function evaluations (AEF) for the successes. These criteria give the effectiveness and efficiency of the algorithm. Almost all results of this model

(Eslami et al., ۲۰۰۴) show the strength of this approach compared to other ones like the models of Duan et al. (۱۹۹۳) and Liong et al (۲۰۰۴).

AUTO-CALIBRATION OF RAINFALL-RUNOFF MODEL

As the model has been verified, the model then can be auto-calibrated for real cases especially those involved rainfall-runoff parameters in a specific watershed. The input data involves rainfall (mm), evaporation (mm), and temperature (dc) and the output involves the outflow at the end of watershed (cms). The map of sub-watershed of Holilan and its upstream sub-watersheds with synoptic and hydrological stations located in are shown in Fig. ۲. In this study ۲۱ parameters including NAM model (۱۰ parameters), snow model (۳ parameters), at least ۵ parameters for rainfall monitoring stations, and ۳ weighted parameters for evaporation stations are calibrated at the same time. The calibration is conducted for a ۴ years period (۱۹۹۴-۱۹۹۸).

RESULTS VALIDATION AND MODEL EVALUATION

When the model is well calibrated for the ٤ years period, now it is the turn to validate the model results of rainfall-runoff. To conduct the validation and evaluate its results, the year ١٩٩٨-١٩٩٩, has been selected and the model has been executed for this period. Figure ٥ shows the calculated results of the model. The results show the high accuracy of the model prediction. The indices of this evaluation are the normal error square root, the model efficiency, and the normal average error where their results are ٠, ١, and ٠, respectively. The results for the applicability indices evaluation are ٢.٧٦, ٠.٩٢, and ٤.٠٧, respectively.

CONCLUSIONS

As it is shown in Figure ٥, the calculated and measured results show good agreement. Therefore, the model is effective in reaching the optimum points. It is concluded from this study that combining the conceptual rainfall-runoff model with river flow routing and employing a powerful optimization method will lead to powerful model for flood forecasting. Compared to previous methods the proposed method is less in terms of time consuming and more effective in reaching the global optimum point.

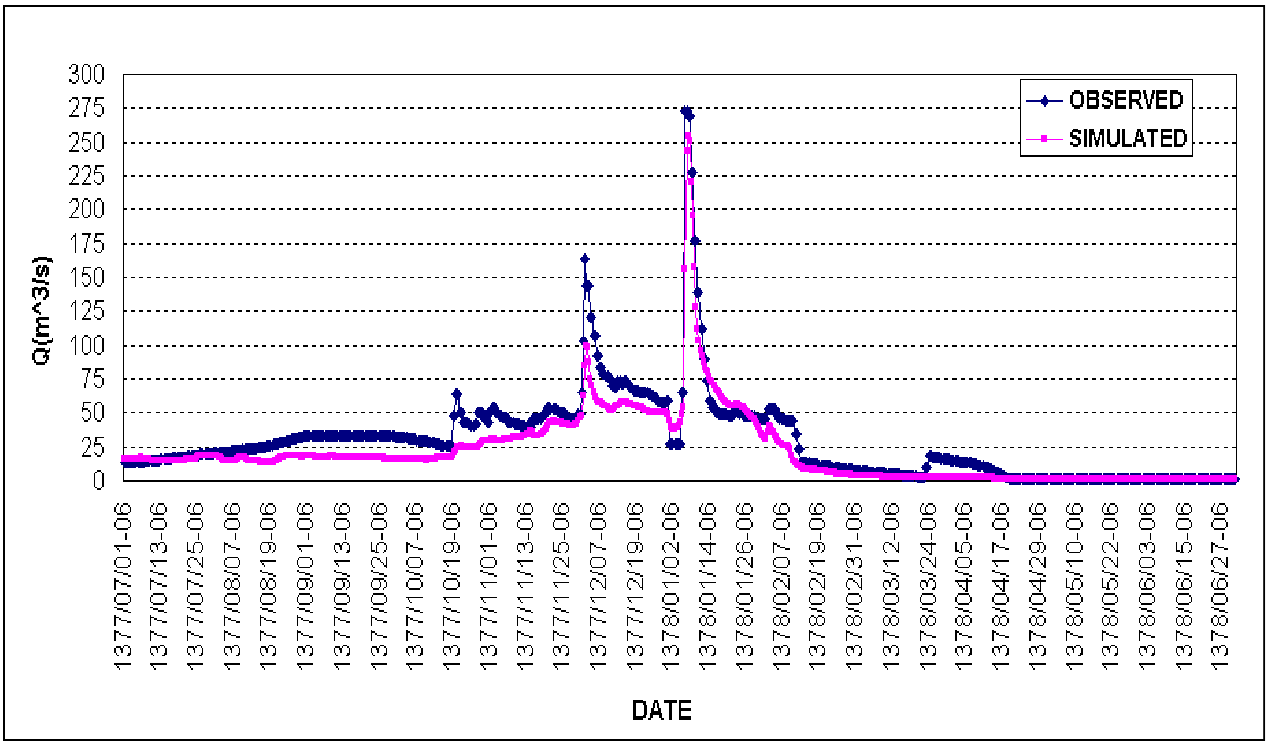

Figure ۵ Comparison of calculated and measured flow rates for the combined catchments of Holilan-Gharabaghestan-Gamasiab for the year ١٩٩٨-١٩٩٩.

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