Calculation of Flood Hydrograph for Karun Basin by Different Methods.

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ABSTRACT
In structural and un-structural methods of flood control, it is necessary to predict flood potential in the water closed basin. In this research, the purpose is simulating flood in the basin of SCS hydrologic model of HEC-HMS and comparing with mod-Clark method by using geographic information system (GIS) in Golestan watershed. Finding a model that can properly predict floods at large and sensitive basins like Karun the largest river in Iran is necessary. Because of being prone to flooding, identifying areas prone to flood and flood production levels according to physical characteristics of the catchment is essential. In this research, hydrologic modeling has been performed on the Karun basin, and flood hydrograph has been estimated through both lumped and distributed mathematical models in order to analyze how close they are in reality from Karun basin to Shalou bridge. In this method DEM basin was created in GIS software by topography maps. By application of created DEM, canals and sub-basin maps were mined. Then by mixing soil hydraulic group maps with the previous data, ground user was achieved. Data of previous moisture in GIS environment and number curve (CN) map of Karun under watershed are then measured and credited with raining data and observation running of watershed (which has been fixed in HEC-HMS model) and finally they have been compared by mod-clark method within GIS software. Formation of precipitation and surface flow after rainfall and formation of hydrograph has been studied using both SCS lumped model and Mod-Clark (modified Clark) distributed model. Field data has identified that the distributed model results are closer to the recorded hydrograph of the basin.

Keywords: Lumped methods, distributed methods, Mod-Clark, SCS, HEC-HMS.

Abbreviations:
GIS: geographic information system; CN: number curve.

INTRODUCTION
Flooding problem has been one of the numerous Khuzestan plain problems that has raised among governmental administrative concerns. Recorded and even non recorded floods before the establishment of the hydrometric stations and the damage caused by them indicates the region to be prone to flooding. Comparing peak discharge and floods damage before and after the construction of Dez and Karun dams in the Khuzestan plain represents the dams’ ability in flood mitigation and damage reduction of downstream floods.

Great national investment in the Khuzestan plain and the importance that this area has in agricultural and industrial development of the areas, the great Khuzestan plain protection from overflow and preventing the region from going under water has made it inevitable. In this context, flood forecasting using advanced methods and geographical data system to aggregate information for basins and their use in forecasting models is essential.

Following increase population increasing and consumption competition, conflict and contradiction in how the exploration of rivers would be is growing. True understanding of the country catchments and characteristic and the natural behavior of rivers in order to perform maintenance and good management for the health of rivers the life of society is essential and inevitable.

The overall object of this research is also finding a model to predict a correct and close idea of a flood. We assume that by using computer hydrologic models such as HEC-HMS and GIS, a proper method to obtain desired information about flood damage can be presented. Also special and applied objectives of this research are identifying more accurate methods for calculating the...
hydrograph of the flood basin and comparing lumped and distributed models of basin outflow calculation.

By application of HMS and Geographic Information System (GIS), Sunwan Werakamthorm (1994) studied effects of user changes in upstream lands of watershed on the flooding pattern in downstream areas of basin. He assessed that in his study, five variables as inputs to the system can be used. The five variables include rainfall, infiltration rate, surface runoff, watershed area and the flood routing factors. He has used ArcGIS software to determine and integrate related maps. Simulation of flood hydrographs in the past and future with loss scenarios and increasing basin forests showed that by decreasing forest area, main and sub-basin runoff basins will increase.

In another study, Johnson et al. (2001) examined the use of HEC-HMS model and its GIS related extension called HEC-Geo HMS to generate a precipitation-runoff distributed model. Their study area was the eastern tributary of the San Jacinto River with 235 square miles area, and performance of the mentioned extension in distributed simulation was studied. While the results obtained from the simulation were satisfactory with maximum discharge difference of 4%, a similarity between observed and calculated values seems reasonable. However Hec-GeoHMS deficiency has been its rely on radar rainfall data. Thus, the use of this program in simulating runoff by hydrologists is limited to certain areas where radar rainfall data is available.

Savant et al (2004) examine the mentioned program ability and compared the extracted physiographic parameters in the Upper Pearl basin located in Mississippi river with USGS data. In this research the basin boundary and the extracted sub-basins were introduced as most important physiographic parameters and have been used as a benchmark for evaluating the method performance. The results of this study indicate that the application of HEC-Geo HMS is corresponding with data from the USGS.

Saghafian and Khosrowshahi (2005) used the Damavand basin vegetation map from satellite imagery GIS and then in the GIS environment by using ArcView software, they combined user map of farms and soil hydrologic groups and calculated the curve number (CN) for the entire basin and sub-basins. They then used HMS hydrologic model and SCS method design to obtain the hydrograph design caused by rainfalls (12-hour rainfall with are turn period of 50years). They combined HMS model with three rainfall runoff observed events, and were calibrated to determine the flood-producing rainfall, average rainfall of each sub-basin at the time of flood in Arc View environment was introduced to the model. In their study the flood routing Muskingum method was used and finally, the intensity of sub-basins flood rise prioritized with regard to their participation in the total output discharge of the basin.

Khakbaz et al. (2006) developed a model to predict excessive shear in basin that used HEC-GeoHMS program to extract basin physiographic characteristics. After calibration and validation, the model results indicate the high accuracy of the model. Wang et al. (2006) emphasized on modifying DEM and filled the empty spaces of data and also provided a model based on the programming language C++. The model accuracy was based on comparing it with HEC-GeoHMS program. The conducted comparisons suggested that the model has an acceptable accuracy.

Abu-Hasan et al. (2009) developed a hydrologic model for the Sangay Kiovara basin in Prague by using HEC-HMS model and evaluated this basin’s hydrologic response to land use changes. They converted DEM to HEC-HMS import files using HEC-HMS. Then, they calibrated the hydrologic model for storms during 2004 and evaluated storms during 1999. In their study consistency of the simulated model with observed data shows that HEC-HMS is a suitable model for predicting hydrological changes of the Kiovara basin.

A joint investigation was conducted by the Department of Civil Engineering, Environmental Engineering, and Center for Remote sensing and Hydrometeorology of American University of California on Illinois River basin of Arkansas State. In their study, rainfall - runoff system of basin was stimulated by semi-distributed and lumped models. Then using the recorded output hydrograph of the basin, calibration was done and outflow discharges of the models were calculated (Khakbaz, 2009).

Generally two categories of climatic and basin factors are involved in creating floods. Source of many floods, especially in arid and semi-arid regions is rainstorms with high intensity and relatively short persistence of events. Thus in
 MATERIALS AND METHODS

Rainfall-Runoff Simulation:

Rainfall-runoff simulation is significant in basin management. Simulation of the basin hydrology indicates resource capacity. To water resource assessment, it is necessary to have an understanding of flow conditions unaffected by human-induced land cover and water use changes, ‘naturalized flow’. Flow naturalization adjustments consist primarily of removing the effects of historical reservoir storage and evaporation, water supply diversions, and return flows from surface and groundwater supplies and in some cases other considerations (Wurbs, 2006).

HMS Model:

HMS model is the Windows version of HEC-1 model. HMS model was presented by the hydrologic center of US Corp of Engineers to supply the flood’s hydrograph in 1981 and after that, so many changes were made on that and finally in 1998 presented as HMS and under the license of Windows.

HMS is one of the computer mathematical models which consists of some subcategories as runoff sections, the surface flow, the base flow and the total flow and they are used to simulate the hydrologic behavior of the basins. His model includes three main sections by the names of Basin Model, Meteorological Model and Control Specification. In addition, this model is able to optimize and calibrate the parameters. This model can be used for simulation and predicting the effects of the parameters’ variation after validation.

The basin simulator is responsible to clarify the whole structure of the basin and simulation will be possible by clarifying the overall structure of the basin.

In fact, the hydrologic elements of the basin and the way these elements are interrelated are going to be determined. By considering some suppositions, each basin can be named as three separate processes of losses, the transformation of rainfall to runoff and the base flow. All the ground of one basin is divided into two parts: permeable surfaces and impermeable surfaces. The impermeable part is a part of the basin which in the whole rainfall without any infiltration, interception, evaporation or some other losses will be transformed into runoff. Permeable surfaces have losses.

The impermeable surface area of a basin is determined by its permeable percentage. There are some methods to measure the rainfall losses in HMS model and in the present research four methods namely, the Green and Ampt, initial/constant, SCS Curve Number and deficit/constant have been used.

Initial/Constant Method:

A layered system along with recycling is used to simulate infiltration in this method. The recycling of the drainage process of the soil pillars, evapotranspiration will be done. The maximum deficiency is indicative of the whole depth of storage. The primary deficiency is indicative of the empty depth of storage at the starting point of simulation. There will be no excess rainfall until the first storage of the primary deficiency is not filled.

Green and Ampt Method:

This is a significant infiltration model of rainfall in a basin. Based on this model, Richards’s equation through the infiltration process will be influential in the soil profile and they are also effective in the soil capacity to be infiltrated. Propulsion system of this combined transmission is taken from the unsaturated flow form in Darsy and the Conservation of Mass law. Green and Ampt model measures the rainfall losses in the permeable regions as follows:

\[
f_i = c \frac{1+(\phi-\theta_i)S}{F} 
\]

Where, \(f_i\) stands for the losses rate in time, \(K\) indicates the saturated hydraulic conductivity, \(\phi-\theta_i\) stands for the deficiency of the humidity volume, \(S\) shows suction of the humidity front, and \(F\) shows the cumulative losses in t (time).

Deficit/Constant Method:

This method is on a basis that the maximum potential rate of the rainfall losses (\(f_i\)) will be...
stable throughout one rainfall event. Therefore, if $P_r$ is taken to be the depth of MAP (The Average Regional Rainfall) in a time period, from $(t)$ to $(t + \Delta t)$; the excess rainfall, $(P_{e_o})$ in the time period will be as follows:

\[ P_{e_o}(t) = \frac{(P_r - f_e) - P_r}{P_r} \]

If the primary losses $I_a$ are added to the model to present the water puddles and the plant absorption, there will be no runoff until the cumulative rainfall on the permeable surfaces does not exceed the primary losses capacity, so the excess rainfall is measured by the following equations:

\[ P_e = \begin{cases} 
0 & \text{if } \sum P_r < I_a \\
(P_r - f_e) - \sum P_r > I_a, P_r > f_e & \sum P_r > I_a, P_r < f_e
\end{cases} \]

This model includes, a parameter (fixed rate) and a primary condition (primary losses). These two indicate successively the physical properties of the basin soils, the land use and the initial humidity conditions. By having the soil’s primary humidity conditions, the primary losses can be measured, and the fixed rate of the losses can be estimated by the chart presented by Skaggs and Khaleel (1982).

**SCS Curve Number Method:**

The curve number model (CN) of the U.S. Conservation Service (SCS) estimates the excess rainfall as an integral taken from the cumulative rainfall, soil covering, land use, initial humidity by the following equation:

\[ P_e = \left(\frac{P - I_a}{P_r + S}\right)^2 
\]

Where, $P_e$ stands for the cumulative excess rainfall in the time period $(t)$, $P$ stands for the depth of the cumulative rainfall in the time period $(t)$, $I_a$ indicates the initial losses and, $S$ shows maximum potential maintenance (A criterion for the absorption ability and the rainfall maintenance).

The excess rainfall will be equal to zero if the cumulative rainfall does not exceed the primary losses. With respect to the many experiment gained through performing some experiments in laboratory on small basins, SCS of an experimental equation between $I_a$ and $S$ can be extended as follows:

\[ I_a = 0.2S \]

Therefore, the cumulative excess rainfall can be measured as follows:

\[ P_e = \left(\frac{P - 0.2S}{P - 0.8S}\right)^2 
\]

This method is a contiguous method which can simulate the system's behavior in both wet and dry conditions, despite the single event methods. Besides that, this model also simulates the flow and the storage of the water on the vegetation, surface of the soil, profile of the soil and layers of the groundwater. With having rainfall and potentials evapotranspiration, this model can measure the surface runoff of the basin, groundwater, losses caused by evapotranspiration and deep percolation throughout the whole basin.

**Model Calibration:**

Every model which exists in HEC-HM has some parameters. The amount for every parameter must be determined in order to estimate the runoff and the flood hydrograph. How can suitable adjustable values be chosen for every parameter? In case of having observable rainfall and runoff, calibration will be the answer of this question. Calibration makes use of the observable hydro-climate data in order for the parameters to be determined to make the best fit between the observable and simulated results in a systematic study.

This study is often called optimization. Calibration starts with the collection of the data. The time periods of rainfall-runoff are the required data for the rainfall-runoff models. The model by means of the primary amounts can measure the considered output (the runoff hydrograph).

In this research, the data of 10 floods which had more complete hydrographs compared to the other floods that happened from 2001 to 2009 were selected. 5 floods among the 10 floods were chosen for calibration and the other 5 floods were used for validation assessment.

**HEC-GeoHMS Extension:**

HEC-GeoHMS is an extension used with ArcGIS. This program is a software on GIS which was developed with ESRI to analyze all the spatial data for using on HEC-HMS. The version no. 4.2.93 of this program is procured by ESRI and HEC cooperatively.

This software has got some geographical data to be used in HEC-HMS. In addition, in this software, one can observe HEC-HMS output results graphically. This program makes the input file by means of the acquired data taken from ArcGIS shape files and DEM of the region under study. Thus, it is necessary to have a DEM described in a disordered triangular network mould. The layers made from these data are called HMS layers. The geographical data are deducted from the measurements carried out on these layers. The background drawings, the basin model files, the meteorological model files which can be used in HEC-HMS for hydrologic modeling are among the other capabilities of this model. The basin model file consists of hydrologic elements, their relation and also includes the surface of sub-basins and some other hydrologic parameters.

**HEC-SSP Software:**

HEC-SSP software is a version under the license of Windows software HEC-FFA, which is very...
strong software to perform statistical analyses of hydrologic data. It is also used to control the outliers. A proper return period is taken into consideration for these floods with respect to the floods happened earlier. HEC-SSP will make you able to have a statistical analysis of the hydrologic data to the users. The first official version of HEC-SSP was published in August 2008 and also the version 2.0 was published in April 2010 which made it easy to revise the data, show the results, reports and it also made it easy to analyze the volume-time frequency.

**Study Area Location:**
The Great basin of Karun in the Zagros highlands has surgical borders with Karkheh, salt lake, Zayandeh roud river, Bakhtegan-Maharlu and Zohreh-Jarahi basins. The basin in the division’s office of water resources was marked as the third basin among Persian Gulf catchment. The Great Karun catchment consists of the Dez and Karun rivers in the Zagros highlands are limited to geographical coordinates 00-48 to 30-52 degrees east longitude and 30-00 to34.05 degrees north longitude. The catchment area is 67,257 square kilometers, 67 percent of it is in mountainous areas and high plains are form its 33 percent of area.

Karun Basin to Shahid Abbas pour Dam is called Karun upstream catchment and our study zone is to Shalou bridge with the area of 23,400 square kilometers and the geographical location of 31-45 to 20-32 north longitude and 8-50 to 40-51 east longitude. This range consists of three main sub-basins (Khorasan, Bazaft and upper Karun) and four minor sub-basins Vanak, Koohrang, Bazaft and Behesht Abad (Fig. 1 and 2).

![Fig. 1. The location of the study area in Iran.](image1)

The Highest Point in this region is the Dena with the height of 4409 meters and its lowest point is located in Shalou Bridge with the height of 700 meters. The study area is approximately 76% mountainous. 95% has over 1500 m elevation and 25% is above 2500 meters elevation. Over 14% of the area makes up the great alluvial fan. Hill areas are 4.7% and sedimentary plains 3.9% and river terraces 1.1% of all the area.

![Fig. 2. Study area location in the great Karun catchment.](image2)
where, $t_{cell}$ = travel time for each cell, $t_c$ = basin time of concentration, $d_{cell}$ = distance to move from each cell to the outlet of the basin, $d_{max}$ = movement distance for the cell that has the most distance to the outlet.

Each cell area is marked and based on this area, the inflow volume to the linear reservoir for each period of time, which is due to excess rainfall, is calculated. Excess rainfall equals the difference between the Mean Areal Precipitation in each cell and the amount of cell loss. Inflow into the linear reservoir has been routed and creates output hydrograph for each cell. HEC-HMS combines the cells output hydrograph and determines the direct runoff hydrograph of the whole basin.

Among 226 stations with data available, 97 stations that have better data and shared with the hydrometric stations were statistically analyzed are located. Accordingly, 87 stations are within the Great Karun basin. Since the statistical periods are different in stations and since 1956 until recent years, some stations were opened after analyzing and adequacy test of the data, statistical indicators of the years 1963 to 2007 were selected. Among the stations mentioned some of them were newly established and some had too many missing statistics on their test results, as a result their statistics were not sufficient in the goodness fit test and were removed. Remaining stations were completed and verified.

Firstly, the discharges were measured in the available stations were revised and complemented. Then by sending them to the statistical software, HEC-SSP2.0, different discharges were measured with different returning periods.

Within the study area range, 60 of the stations were equipped with rain gauges and to determine rainfall pattern the statistics of these stations were used, and rather important recorded rainfalls were extracted from these stations.

The Basin physiographic parameters in the first stage using the HEC-GeoHMS software as an extension installed on ArcMap were calculated. With HEC-GeoHMS extension installation in ArcMap, the extension ArcHydro will also be installed.

The HEC-GeoHMS provides the basin model using Mod-Clark method for HEC-HMS software and can save all the necessary characteristics for flood calculation and routing within certain cells with desired dimensions. As mentioned above, the program input is the digital elevation model (DEM) of the basin after various stages, makes the basin model for the HEC-HMS program.

To simulate flooding by Mod-Clark distributed method CN raster maps should be obtained. At this stage, combining two layers of soil and land use by the Arc CN-Runoff application, land-use-oil type layer was created and then by providing Curve Number Lookup table, the data necessary to calculate and create CN raster map is formed (Fig. 3).

After the output file HMS was produced using HEC-GeoHMS software and refreshing it that consists of basin model and meteorological model, are lumped and distributed by different methods. Its basin and sub-basin map and hydrology elements were prepared as seen in Fig. 4.

For the Distribution method the basin is divided into smaller levels and effective rainfall in each level is calculated and develop direct runoff. The rainfall networking method is used and the related networking data will be chosen. In this software to describe each cell in the database, each cell location, navigation to the output gap, cell size and cell CN and precipitation of time are included. In the lumped approach, rainfall and loss are determined to the total average of the sub-basin.

In this study to calibrate and validate the model, the hydrograph of all available floods have been investigated and finally, five events for calibration and five events for validation of the model were selected.
After calibration and considering the information that was mentioned and the maximum 24-hour rainfall per each return period of 2 to 100 years, we tried to estimate the peak and flood hydrograph in Mod-Clark distributed approach and SCS lumped approach. Table 1 and Fig. 5-7 show flood hydrograph under the basins. These hydrographs were obtained by means of basin modeling and using HEC-HMS.

### Table 1. Floods discharge per different return periods by Clark’s model (CM)

<table>
<thead>
<tr>
<th>River</th>
<th>Station</th>
<th>Return Period(year)</th>
<th>SCS</th>
<th>CM</th>
<th>SCS</th>
<th>CM</th>
<th>SCS</th>
<th>CM</th>
<th>SCS</th>
<th>CM</th>
<th>SCS</th>
<th>CM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bazeft</td>
<td>Morigak</td>
<td>2</td>
<td>88.4</td>
<td>75.2</td>
<td>138.2</td>
<td>125.5</td>
<td>189.2</td>
<td>175.6</td>
<td>285.5</td>
<td>272.7</td>
<td>377.6</td>
<td>364.6</td>
</tr>
<tr>
<td>Lordega</td>
<td>Morghak</td>
<td>5</td>
<td>22.1</td>
<td>18.3</td>
<td>28.9</td>
<td>25.8</td>
<td>47.9</td>
<td>44.2</td>
<td>94</td>
<td>90.9</td>
<td>144.1</td>
<td>139.9</td>
</tr>
<tr>
<td>Khesran</td>
<td>Barez</td>
<td>10</td>
<td>54</td>
<td>64.1</td>
<td>97.5</td>
<td>112.1</td>
<td>159.7</td>
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<td>272.1</td>
<td>301.2</td>
<td>394.6</td>
<td>403.6</td>
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<tr>
<td>Abvanak</td>
<td>Pol karbas</td>
<td>25</td>
<td>48.3</td>
<td>40.9</td>
<td>130.1</td>
<td>124.2</td>
<td>218.9</td>
<td>207.3</td>
<td>395.3</td>
<td>386.6</td>
<td>560.9</td>
<td>553.8</td>
</tr>
<tr>
<td>Kohrang</td>
<td>Kaj</td>
<td>50</td>
<td>13.4</td>
<td>11.3</td>
<td>36.8</td>
<td>31.7</td>
<td>65.3</td>
<td>63.1</td>
<td>126</td>
<td>121.9</td>
<td>185.8</td>
<td>182.2</td>
</tr>
<tr>
<td>Beheshtahbad</td>
<td>Beheshtabad</td>
<td>100</td>
<td>25.4</td>
<td>20.4</td>
<td>42.3</td>
<td>39.4</td>
<td>76.6</td>
<td>69.9</td>
<td>166.9</td>
<td>163.3</td>
<td>267.8</td>
<td>261.6</td>
</tr>
<tr>
<td>Karun</td>
<td>Pol shalo</td>
<td>3</td>
<td>193</td>
<td>168.1</td>
<td>385.6</td>
<td>371.5</td>
<td>597.7</td>
<td>572.7</td>
<td>1036.8</td>
<td>1000.6</td>
<td>1610.6</td>
<td>1585.6</td>
</tr>
<tr>
<td>Karun</td>
<td>Armand</td>
<td>5</td>
<td>61.8</td>
<td>52.7</td>
<td>149.4</td>
<td>161.1</td>
<td>254.3</td>
<td>264.5</td>
<td>539.6</td>
<td>547.7</td>
<td>865.6</td>
<td>882.6</td>
</tr>
</tbody>
</table>

**Fig. 5.** Sub-basins hydrograph outline.

**Fig. 6.** Hydrographs in Shalou bridge per different return periods.

**Fig. 7.** Comparison of flood hydrographs in Shalou bridge using SCS and Mod-Clark.
By having the ability to change spatial characteristics of the basin and distributed rainfall data, hydrological models have high potential for improving flood hydrographs simulation. According to the following reasons, distribution models and their results are closer to the recorded hydrograph in the basin:

- Considering the range of changes in soil properties, hydrologic groups and finally the curve number in the basin, providing these characteristics for the model on spatial average in the entire basin as it is used in lumped method, would reduce the accuracy of forecasts. Particularly in the Karun basin precipitation across the basin according to elevation change is too severe. This is true for the curve number SCS determination.

- Due to powerful GIS tools like ArcGIS that different extensions applications about basin can be installed on, the usages of distributed models has a great impact and have made operations easier.

- The drastic changes in recent years that created in basins such as land use changes, climate change and also the construction of dams and facilities has challenged predictions on lumped models. Impact of these changes easily forecasted considering the possibility of quick applying in GIS maps and the communication these maps have with distributed models.

- Studies on various factors affecting the production of flood, like CN, permeability, indicators related to land and vegetation according to the GIS tools through modeling in distributed methods have been possible and will have high accuracy and its results will be beneficial.

CONCLUSION

Determining hydrologic parameters such as peak discharge in water management systems is very important. Due to various limitations in calculating these parameters, we require using precipitation-runoff models that currently their structure has changed to distribution models structure. Hydrologic distribution models with spatial change compatible, basin characteristics and rainfall data have high potential for simulating flood hydrograph. According to the following reasons, distribution models and results of them are suitable for hydrograph simulation:

a. Given the extent of changes in soil properties, hydrologic groups and curve number in basin, providing these characteristics as average spatial in the whole of basin (like unified methods) will reduce prediction accuracy, especially in Karun Basin that rainfall changes at various points of the basin are high because of elevation changes.

b. According to powerful GIS programs such as ArcGIS that have various extensions, the efficiency of distribution models is very important and smoothen the performance.

c. Big changes in recent years in basins such as land use change, climate change and also construction of dams and different facilities made some difficulties in prediction with unified methods. Due to the possibility of rapid importing of these changes in GIS maps their effects can be easily predicted.

d. According to GIS tools, study of factors effective on flood generation such as CN, infiltration, vegetation is possible through modeling using distribution models and has a high accuracy and will be very useful.

e. The study results shown that the flood peak decreases by increasing cell size. Peak flow reduction level depends on the spatial distribution of rainfall depth and land characteristics of the watershed so that by increment of precipitation or infiltration of the basin, changes of flood peak discharge at different cell sizes will decrease. By decreasing each of these two factors, the duration of the program run increases. Increase in cell size and time step will cause decreasing the calculated flood peak.

REFERENCES


