# CONTINUOUS HYDROLOGIC MODELING OF MAJOR FLOOD HYDROGRAPHS USING SEMI-DISTRIBUTED MODEL

**[*]Tanveer Abbas, Ghulam Nabi, Muhammad Waseem Boota, Muhammad Faisal, Muhammad Imran Azam, Muhammad Yaseen, Fiaz Hussain**
[1] Centre of Excellence in Water Resources Engineering, University of Engineering and Technology Lahore
[*]Corresponding Author's email: tanveer.abbas14@yahoo.com

***ABSTRACT:*** *Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation. Continuous hydrologic modeling synthesizes hydrologic processes and phenomena i.e., synthetic responses of the basin to a number of rain events and their cumulative effects over a longer time period that includes both wet and dry conditions. Continuous hydrologic modeling with the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is discussed in this study and an application to the Simly watershed is presented. Specifically, four flood periods were selected for calibrating and validation the continuous hydrologic model on daily time scale. The simulations provided hydrologic details about quantity and variability of runoff in the watershed. The model shows statistical value of $R^2$ >0.75 and NSE >0.71 with a reasonably good value of PBIAS for the whole calibration and validation period. These obtained square functions indicate satisfactory performance of HEC-HMS model in simulation runoff hydrograph. Sensitivity analysis indicated that most sensitive parameter in the Simly watershed was the CN and impervious area. The model produced reasonable results, but illustrated the need for more refined application of specific parameters.*

**Keywords**: HEC-HMS, Continuous Modelling, Flood events, Semi-distributed

## INTRODUCTION

Accurate understanding of rainfall-runoff modeling is an important precondition for flood management, and serves various purposes such as overall assessment of the catchment response as a part of strategic and master planning to detailed network and ancillary elements design. The biggest challenge facing modelers is choosing a rainfall-runoff model which can correctly simulate a wide range of floods. The availability and quality of data are often an issue one needs to cope with. Sometimes, one has to compromise the overall modeling quality because of insufficient high-resolution data for developing, calibrating, and validating the model. Under these circumstances, it is critical to develop an effective modeling strategy that not only takes full advantage of the available data but also maximizes the accuracy of modeling. Advances in remote surveillance techniques and the availability of geo-spatial databases have enabled estimation of a range of hydro-climatic variables and a better description of hydrological regimes, reducing uncertainty in predictions at a range of scales (e.g., [1, 2, 3].

Continuous hydrologic modeling synthesizes hydrologic processes and phenomena i.e., synthetic responses of the basin to a number of rain events and their cumulative effects over a longer time period that includes both wet and dry conditions. Continuous hydrologic models account for the soil moisture balance in the catchment over a long-term period. Different hydrologic physical processes such as: interception, surface depression storage, infiltration, soil storage, percolation, and groundwater storage should be considered in continuous hydrologic modeling. In this paper, the Hydrologic Modeling System (HMS) model was used for continuous hydrologic simulation of the Simly watershed. HEC-HMS, the successor to HEC-1, is a Precipitation-runoff routing model that represents a drainage basin as an interconnected system of hydrologic and hydraulic components. It is designed to simulate the rainfall-runoff processes of dendritic watershed systems [16]. Previous studies on HEC-HMS proved its ability to simulate and forecast stream flow based on different datasets and catchment types [4, 5, 6, 7, 8, 9]. The goal of the current study is to study the rainfall runoff relations using continuous hydrologic modeling with the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) [10]. This approach has been applied to Simly watershed, located near capital of Pakistan, Islamabad. Four different rainfall periods were selected for the calibration and verification of the model.

## DESCRIPTION OF STUDY AREA

Simly Dam watershed is situated above 19 miles East of Islamabad and Rawalpindi, Pakistan. Simply watershed is situated between 33.870-33.654 N latitude and 73.411-73.513 E longitude, encompassing a drainage area of 160km$^2$. The elevation ranges from 693 to 2261 meters above mean sea level (a.m.s.l) with a mean elevation of 1500 meters and steady rises from south to north. Mean annual precipitation in the catchment area is 1774 mm. The coldest month is January with the mean maximum temperature is 17.7 $^{o}$C and minimum up to -5 $^{o}$C From February to May, temperature rises 5 $^{o}$C per month. The highest temperature recorded in the month of June when it may rise to 40$^{o}$C in lower part of basin in the district of Islamabad. Five main tributaries contribute to Simly dam which are Soan, Khad, Mangal, Basant and Bissa. Soan River at Simly has a catchment area of 59 km$^2$ which rises from within a few kilometers of Murree Hills. Its watershed comprises three parallel hill divisions of Murree Hills. Eastern side of Murree divisions, western side of Chrihan divisions give rise

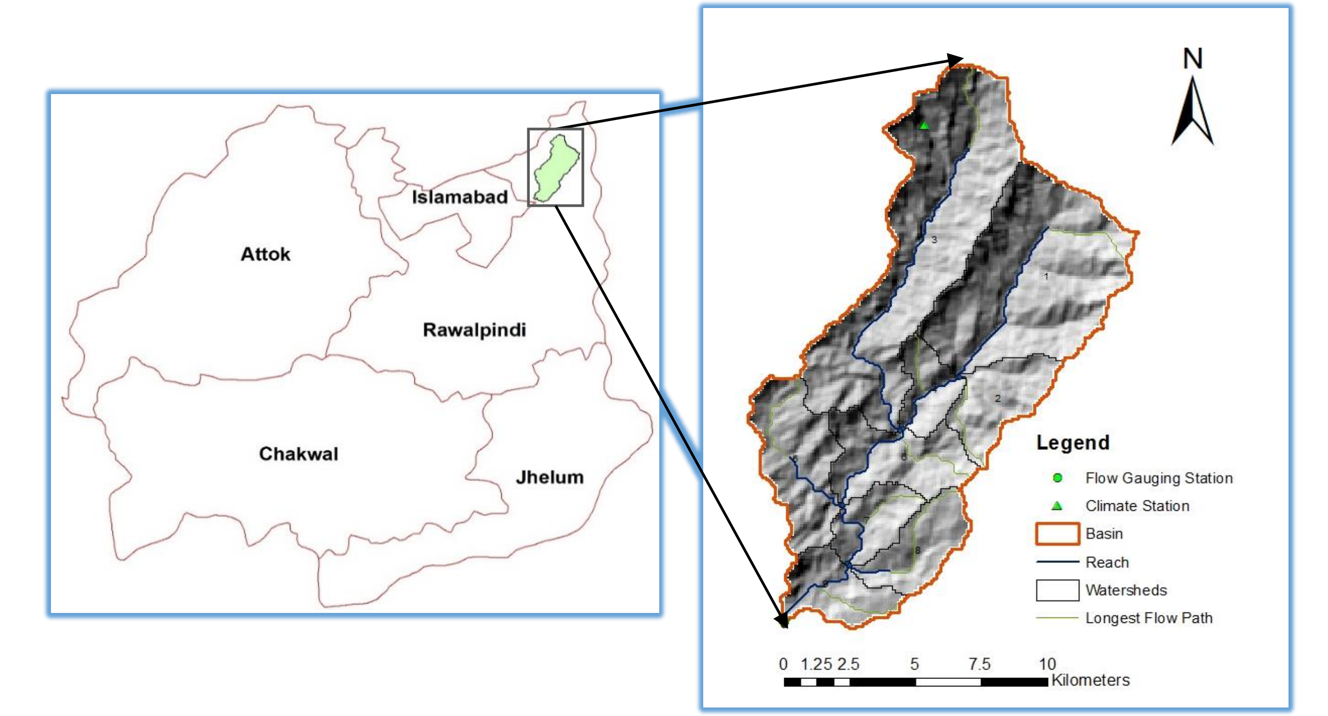


**Fig. 1 Location of Study Area**

to Soan tributary and western side of Puphundi division and eastern side of Charihan division give rise to Khad tributary, which join each other at village Chhaka a few kilometers above Simly dam [11].

## MATERIALS AND METHODS

### Model Data Base

For hydrological modelling long term datasets of daily rainfall, minimum and maximum temperature, wind speed, humidity are required. Simly watershed has only one weather station in the Murree district installed by Pakistan Meteorological Department (PMD) shown in Fig.1. Climatic data i.e. Daily rainfall, minimum and maximum temperature, wind speed, humidity data for the years 1990-2010 was collected from Pakistan Meteorological Department (PMD). The climate datasets were processed according to the model input format. A code is prepared for precipitation and also temperatures file in Microsoft Excel to convert them into .txt files which are required for SWAT model. Hydrological data is required for the calibration and validation of the model for the Soan River. There is only one water level station in the study area. The observed flows data covering the years 1983-2012 was collected from Capital Development Authority (CDA) Islamabad. The mean monthly flows at the outlet varies between 0.61 $m_3$/s (minimum) to 11.98 $m_3$/s (maximum) for 30 years of record . The average annual flows varies between 1.6 $m_3$/s (minimum) to 7.9 m3/s (maximum) for 30 years of record. The topographic data digital elevation model (DEM) was downloaded from the NASA USA website (USGS NASA) with a spatial resolution of 30 m. The Digital Elevation model (DEM) was utilized (Fig.2) to delineate sub- basins, stream network and longest flow path and other parameters like slope and reach length were also extracted from DEM. The landuse map was prepared by the supervised classification of Landsat images TM with spatial

**Table 1 Data input for HEC-GeoHMS and HEC-HMS**

| Data Type | Source | Resolution | Description |
|---|---|---|---|
| Topography | U.S. Geological Survey (USGS) | 30m | Topographic data, DEM |
| Landuse | Developed from Landsat TM data | 30m | Classified land use such as forest, water etc. |
| Soil | United Nation Food and Agriculture Organization | 250 Km | Classified soil and physical. |
| Climate | Pakistan Metrological Department (PMD) | Daily | Precipitation, Temperature, Solar radiation, Wind Speed |
| Hydrology | Water and Power Development Authority (WAPDA) | Daily | River discharge |

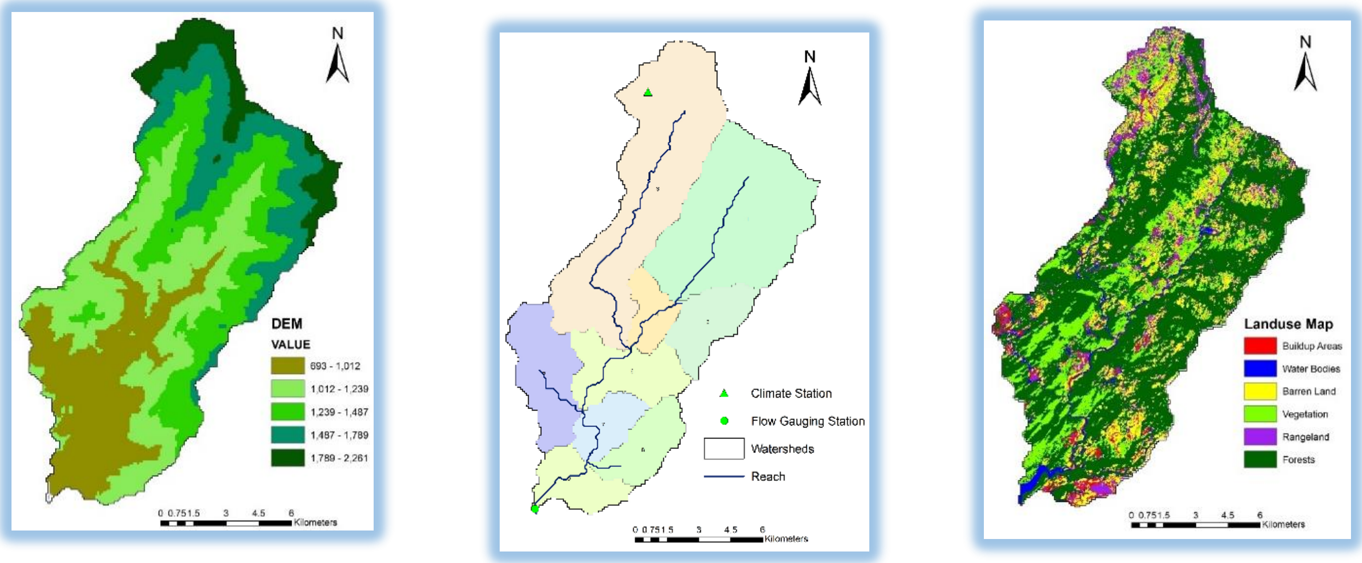


**Fig. 2 Spatial data required for HEC-GeoHMS**

resolution of 30 m downloaded from NASA USGS website (USGS NASA). Erdas Imagine model to identify the major landuse classes in the watershed. Six major classes were identified (Fig.2).

The dominant landuse classes are forests; 49.74%, Vegetation/agriculture land; 16.87%, build up areas; 4.32%, Water bodies; 3.27%, Rangeland; 8.84% and Barren land; 16.95%. The soil map was assimilated from IPCC Global soil classes developed by the UNO agency Food and Agriculture Organization (FAO) (FAO, USA) database. The necessary input information required by the SWAT model was extracted from the same database for the soil type, namely soil texture, Hydrological Soil Group (HSG), soil depth, rock fragments, and organic carbon content were obtained for the soil type.

**Models Evaluation Criteria**

Three methods Nash and Sutcliffe (NSE) [9], coefficient of determination (R2) [11] and [12], percent bias (PBIAS) [13] were used to quantify the goodness of fit between the simulated and observed flows.

$$\mathrm{R2} = \frac{[\sum(\mathrm{Q_{m,i}} - \bar{\mathrm{Q}}_\mathrm{m})(\mathrm{Q_{s,j}} - \bar{\mathrm{Q}}_\mathrm{s})]^2}{\sum(\mathrm{Q_{m,j}} - \bar{\mathrm{Q}}_\mathrm{m})^2 \sum(\mathrm{Q_{s,i}} - \bar{\mathrm{Q}}_\mathrm{s})^2} \quad (1)$$

$$NSE = 1 - \frac{\sum_i (Q_m - Q_s)^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \quad (2)$$

$$PBIAS = \frac{\sum_{i=1}^{n} (O_i - S_i) \times 100}{\sum_{i=1}^{n} O_i} \quad (3)$$

Where Qm, Qs, $\bar{Q}m$ ,$\bar{Q}s$ are the measured, simulated, average measured discharge and average simulated discharge respectively. Note that if all observed discharges are the same as the simulated ones, the NSE, R2, and PBIAS values equal 1, 1, and 0, respectively.

**HEC-HMS MODEL DESCRIPTION**

The Hydrologic Engineering Center hydrologic modeling system (HEC-HMS) is designed for both continuous and event-based hydrologic modeling, and provides the user with several different options for modeling various components of the hydrologic cycle. Event-based modeling uses a smaller simulation time window that begins just before a storm and ends a short time after the storm stops. This may be several hours to several days, depending on watershed size. Continuous modeling has a much larger time window, including dry and wet periods, typically ranging from months to several years. The primary difference is that evapotranspiration (ET) and groundwater seepage can typically be ignored for event based modeling, but not in continuous modeling, because these are critical processes of soil drying [14]. Different loss methods in HMS that include a representation of evapotranspiration are used. In this study, SCS curve number method is as the loss rate method associated with each sub basin.

HEC-HMS includes three main components: basin model, meteorological model, and control specifications. The basin model stores the datasets describing the catchment properties and the meteorological model includes precipitation, evapotranspiration, and snowmelt data. Control specifications controls the time span of a simulation by including a starting and ending date and time, and computation time step.

The loss rate model utilized in this study is the Soil Conservation Service (SCS) Curve Number (CN) method to compute the runoff volume. The SCS-CN method accounts for the watershed characteristics, such as soil type, land use, hydrologic condition, and antecedent moisture condition [15], using the following relationships:

The SCS-CN model can be expressed as [15],

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \quad (4)$$

$$I_a = \alpha S \quad (5)$$

$$S = \frac{2540}{CN} - 25.4 \quad (SI\ Unit\ System, cm) \tag{6}$$

Where P= cumulative rainfall; $P_e$= cumulative effective rainfall (Pe>0; otherwise, R=0; S=potential maximum retention; $I_a$=initial abstraction (all initial losses: surface depression storage, vegetation interception); α=initial abstraction coefficient; and CN=curve number.

For the direct flow the SCS unit hydrograph model was accomplished. A relationship between the time of concentration ($T_c$) and the lag time ($T_{lag}$) was developed by the SCS. The time of concentration can be estimated based on sub-basin characteristics including topography and the length of the reach.

$$T_{lag} = 0.6T_c \tag{7}$$

$$T_c = 0.0078 * \left(\frac{L^{0.77}}{S_{0.385}}\right) \tag{8}$$

## HEC-HMS MODEL SETUP

A Digital Elevation Model (DEM) with a spatial resolution of 30m of Simly Watershed has been input for basin preprocessing under ArcGIS platform with HEC-GeoHMS extension. The purpose of basin preprocessing is to perform terrain analysis and prepare the dataset for later use in HEC-HMS processing. Terrain preprocessing was done step by step or by filling the sinks, flow direction, flow accumulation, stream definition, stream segmentation, watershed polygon processing, stream segment processing, and watershed aggregation. A new project was started and outlet for the study area was selected and generated a new project called Simly Watershed. Basin characteristic has been done to extract river length, slope calculations, centroid determination, longest flow path and centroidal flow path calculations. Some steps under HMS menu can be completed before importing files to HEC-HMS, such as reach auto name, basin auto name, map to HMS units, HMS check data, HMS schematic, HMS legend, background map file, .etc. After that import mapfile and hmsfile to HEC-HMS, then a basin model, meteorological model, and control specifications was generated. We can add precipitation gauges and discharge gauges. HMS project should have three components before it can be run: basin model, meteorological model, and control specifications. The basin model and basin features were created through HEC-GeoHMS extension for model simulation. This observed precipitation and discharge data were being utilized to generate the actual meteorological model using the user gauge weighting approach and, consequently, the control specification model was created. The control specifications ascertain time structure for the simulation; it is characteristics are: a starting date and time, an ending date and time, and a computation time step. To run the system, the basin model, the meteorological model, and the control specifications were being put together. The observed data of one precipitation

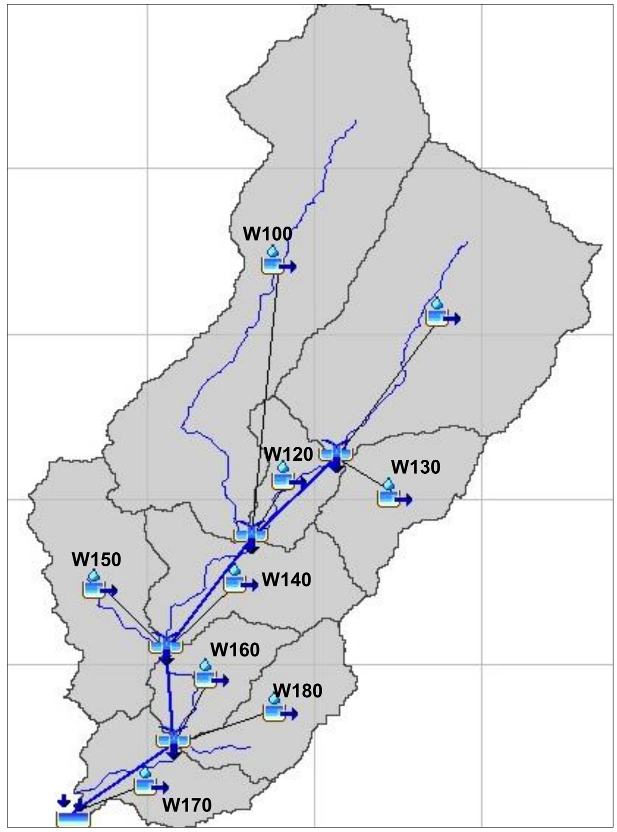


**Fig. 3 HEC-HMS Setup and sub basins**

gauge addressing each and every sub-catchment and one flow gauge station within the Simly dam watershed were utilized for calibration and validation of the model.

**Continuous Hydrologic Modeling**

In the continuous hydrologic model, the four simulation time period ranged from March 23, 2009 to April 21, 2009, July 15, 2009 to Sep 9, 2009, July 19, 2010 to Aug 20, 2010 and June 23, 2011 to Sep 23, 2011 and a daily time step was used. The SCS curve number method was employed for the loss method. The SCS unit hydrograph method was used to model the transformation of precipitation excess into direct surface runoff. None was used to model base flow.

The lag model was used to model the reaches. Initial values of some parameters e.g. slope, longest flow path, lag time, initial abstraction etc. were estimated using the data acquired from DEM. Later on, the trial and error technique, in which a subjective modification of parameter values between simulations is made in order to attain the minimum values of parameters that give the best fit between the observed and simulated hydrograph, was employed to calibrate the model.

**Table 2 Spatial data required for HEC-GeoHMS**

| Sub-basins | W100 | W110 | W120 | W130 | W140 | W150 | W160 | W170 | W180 |
|---|---|---|---|---|---|---|---|---|---|
| **Parameters** | | | | | | | | | |
| **Area (Km$^2$)** | 48.76 | 40.06 | 6.02 | 10.02 | 12.94 | 15.58 | 7.23 | 8.71 | 9.13 |
| **Initial Abstraction (mm)** | 14.41 | 14.60 | 14.42 | 15.01 | 13.72 | 13.55 | 14.08 | 13.28 | 14.65 |
| **Curve Number** | 77.89 | 77.66 | 77.89 | 77.18 | 78.72 | 78.94 | 78.28 | 79.26 | 77.61 |
| **Impervious Area (%)** | 4.4 | 6.0 | 1.0 | 0.1 | 2.2 | 2.0 | 2.6 | 10 | 2.3 |
| **Lag Time (hour)** | 11 | 6 | 3 | 3 | 5 | 6 | 4 | 5 | 5 |
| **Slope (%)** | 7 | 11 | 12 | 14 | 11 | 6 | 12 | 8 | 11 |
| **Longest Flow Path (m)** | 19054 | 11563 | 5001 | 4977 | 8298 | 8439 | 5608 | 6510 | 7630 |

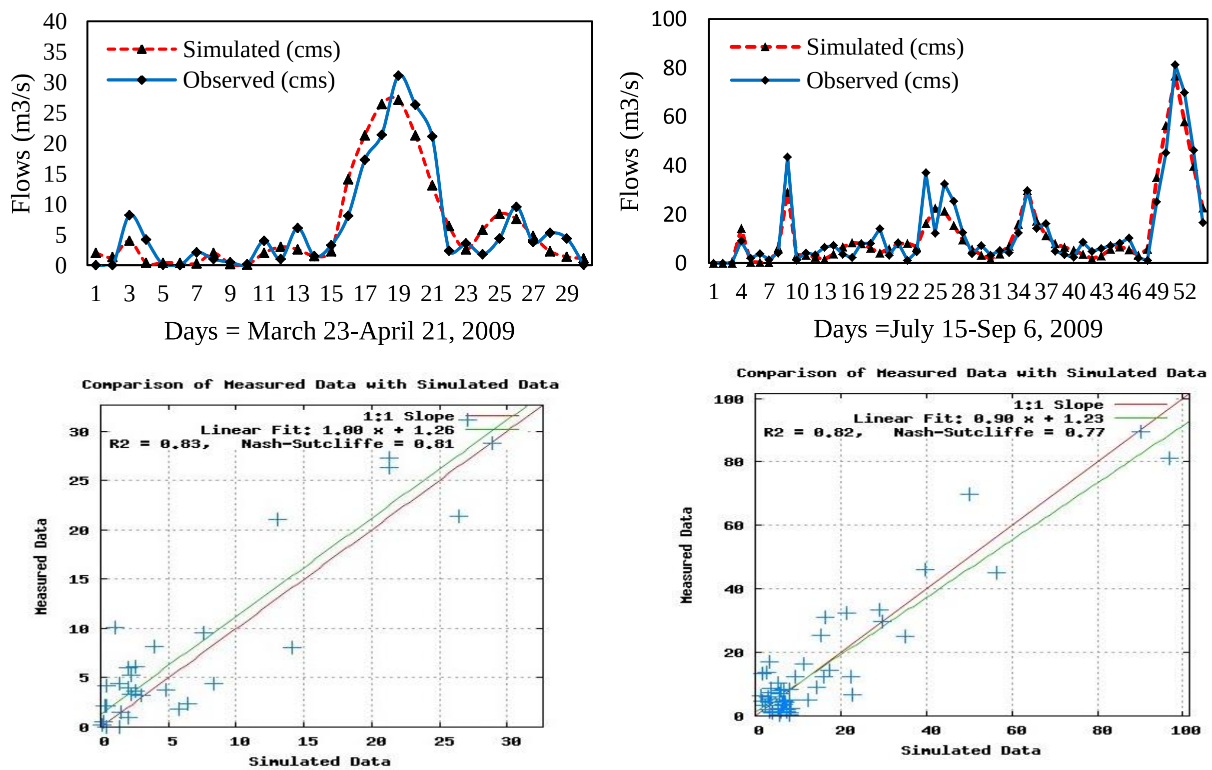


**Fig. 4 Model Calibration for two flood events 1) March 23-April 21, 2009 2) July 15-Sept 6, 2009**

Although the model was calibrated manually, the HEC-HMS built-in automatic optimization trial manager was used to authenticate the acceptability and suitability of the parameter values and their ranges as applicable to their uses in HEC-HMS. The R2, NSE and NOF methods also were applied to quantify the fit of the simulated hydrographs to the observed ones.

**Sensitivity Analysis**

The final parameters used in the calibrated model were considered a baseline parameter set. The model was then run repeatedly with the baseline value for one parameter multiplied by 0.8 and 1.2, while keeping all other parameters at their baseline values. The hydrograph of the changed parameter model was then compared to the baseline model hydrograph.

## RESULTS AND DISCUSSION

The subbasin stream flow are calibrated for the four periods, 1) March 23-April 21, 2009, 2) July 15-Sep 9, 2009, and validated for the period, 3) July 19-Aug 19, 2010 and 4) June 23-Sep 23, 2011. A recalibration approach was implemented during the 2$_{nd}$ calibration period (July 15-Sep 9, 2009), and some parameters were adjusted to better estimate flows during this period. The parameters (Table.3) adjusted during the 2nd calibration were used during two validation periods.
Validation approach taken for this study was simply to extend the time window of the calibration period, without

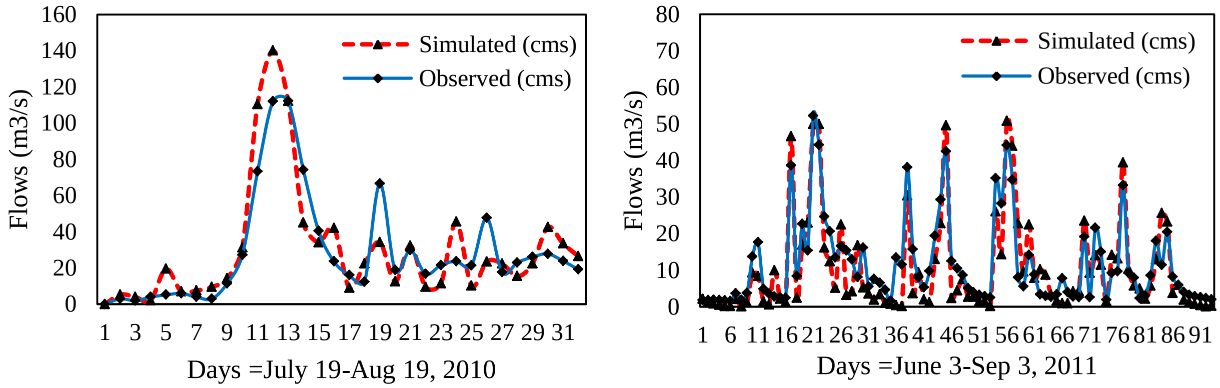


**Fig. 5 Validation results of HEC-HMS Model**

**Table 3 Calibration and Validation results of HEC-HMS Model**

| Periods | Flood Period | Simulated (cms) | Observed (cms) | $R^2$ | NSE | PBIAS (%) |
|---|---|---|---|---|---|---|
| Calibration | March 23-April 21,2009 | 186 | 192 | 0.83 | 0.81 | 3.47 |
| | July 15-Sep 9,2009 | 650 | 678 | 0.82 | 0.77 | 7.06 |
| Validation | July 19-Aug 20,2010 | 958 | 913 | 0.74 | 0.71 | -4.86 |
| | June 23-Sep 23,2011 | 944 | 1077 | 0.77 | 0.71 | 12.32 |

adjusting model parameters, to see how closely the model matches the observed data. Because of the potential for over-fitting a model to observed data, validation results provide a better estimate of model predictive ability. A manual calibration approach was deemed to yield better fitting hydrographs than the automatic optimization methods provided in HEC-HMS. Sets of calibrated and validated hydrographs of the Soan River in Simly watershed are shown in Fig.4&5. The hydrograph comparisons show that the low flows are not relatively well captured by HEC-HMS.

Performance of the continuous modeling was quantitatively evaluated by using R2, NSE and PBIAS. The highest value of NSE and R2 obtained is 0.83 and 0.77 respectively. The lowest value of NSE=0.72 was obtained during the validation period 2 as given in Table.3. The model underestimated runoff during the calibration period suggesting a good agreement between the simulated and observed hydrographs. Most of the peak values were perfectly matched as shown in Fig.4&5. The average tendency of the data was good for the calibration period. However this value increased a little bit during the validation period. For calibration, the volume difference between observed and simulated flows was lowest during the $1_{st}$ calibration period with a value of Dv=6.7%. However this difference was observed larger during $2^{nd}$ calibration and $1^{st}$ and $2^{nd}$ validation period (Table.3).

As the first calibration period was chosen during (March-April). This indicate that model performed well during the period in which the watershed flows were not affected by snowmelt, while the other periods were chose during the months of June-September in which the watershed flows are mostly contributed by snowmelt. This poor performance during the snowmelt days can be the limitation of HEC-HMS for snowmelt runoff modeling. Apart from limitations in the calibration procedure, input data uncertainties in the stream flow model, and limited representation of the energy budget, some differences between the observed and simulated peaks may be caused by undocumented increases in river stage, although further investigation would be needed to attribute discrepancies to this phenomenon. A sensitivity analysis was carried out by adjusting different parameter values in HEC-HMS for all sub-basins. After running the models repeatedly, the simulated stream flow results were compared with monitored values at each change of parameters. The most sensitive parameter in the HEC-HMS model was the CN and impervious area. The results in Table.3 elaborate the results for the calibration and validation periods. The highest volume difference was observed in the 2nd validation period from June 23-Sep 23, 2009 following a highest value of PBIAS = 12.32%. The flows were underestimated in this period. Model prediction for other periods was relatively good. The result of the validation procedure is shown in Fig.5 The modeled hydrograph show a reasonably good fit to the measured data.

## CONCLUSION

HEC-HMS model is used for simulation of runoff hydrograph for four flood periods in Simly watershed, Pakistan. The initial calibration parameter was derived with the help of geomorphologic characteristics. By obtaining optimization technique, final validation parameter were derived and considered as global values for the model. The HEC-HMS model used for rainfall-runoff simulation in the selected watershed shows a R2 >0.75 and NSE >0.71 with a reasonably good value of PBIAS for the whole calibration and validation period. These obtained square functions indicate satisfactory performance of HEC-HMS model in simulation runoff hydrograph. A sensitivity analysis indicated that most sensitive parameter in the HEC-HMS model was the CN and impervious area. Despite difficulties, limitations and uncertainties associated with obtaining observations and measured parameters, this study ended-up with optimistic results for the simulation of rainfall-runoff process and hence the HEC-HMS model may be used to simulate rainfall-runoff process in the Simly watershed.

## REFERENCES


[1] Ogden, F. L., Garbrecht, J., Debarry, P. A., and Maidment, A. R. (2001). "GIS and distributed watershed models II: Modules, interfaces, and models." J. Hydrol. Eng., 6(6), 515–523

[2] Hoblit, B. C., Liu, L., and Curtis, D. C. (2002). "Extreme rainfall estimation using radar for Tropical Storm Allison." Proc. 2002 Water Resources Planning and Management Conf., Environmental and Water Resources Institute, Washington, DC, 1–8

[3] Emerson, H. C., Welty, C., and Traver, R. G. (2005). "Scale evaluation of a system of storm water detention basins." J. Hydrol. Eng., 10(3), 237–242

[4] Anderson ML, Chen ZQ, Kavvas ML, Feldman A (2002) Coupling HEC-HMS with atmospheric models for prediction of watershed runoff. J Hydrol Eng 7:312–318

[5] Bournaski E, Iliev R, Kirilov L (2009) HEC-HMS modelling of rainstorm in a catchment. The mesta case study. Comptes Rendus de L'Academie Bulgare des Sciences 62:1141–1146

[6] Chu XF, Steinman A (2009) Event and continuous hydrologic modeling with HEC-HMS. J Irrig Drain Eng ASCE 135:119–124

[7] Cydzik K, Hogue TS (2009) Modeling postfire response and recovery using the hydrologic engineering center hydrologic modeling system (HEC-HMS). J Am Water Res Assoc 45:702–714

[8] Knebl MR, Yang ZL, Hutchison K, Maidment DR (2005) Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin Summer 2002 storm event. J Environ Manage 75:325–336

[9] Yusop Z, Chan CH, Katimon A (2007) Runoff characteristics and application of HEC-HMS for modelling stormflow hydrograph in an oil palm catchment. Water Sci Technol 56:41–48

[10] United States Army Corps of Engineers, Hydrologic Engineering Center USACE-HEC. 2006. Hydrologic modeling system HEC-HMS user's manual, Davis, Calif.

[11] F.Hussain, A.Khaliq, M. Irfan, and A. Khan "Morphological and Hydrological Responses of Soan and Khad Rivers to Impervious Land Use in District Murree, Pakistan" J. Agric. Res, 52(2), 2014.

[12] 14. J.E. Nash, J.V. Sutcliffe River flow forecasting through conceptual models, discussion of principles J. Hydrol., 10 (3) (1970), pp. 282–290

[13] 30. D. Moriasi, J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, T.L. Veith Model evaluation guidelines for systematic quantification of accuracy in watershed simulations;Trans ASABE, 50 (3) (2007), pp. 885–900

[14] A. Fadil, Hassan Rhinane, K. Abdelhadi, K. Youness, Omar A. Bachir; Hydrologic modeling of the bouregreg watershed (morocco) using GIS and SWAT model; J. Geogr. Inform. Syst., 3 (2011), pp. 279–289

[15] Ibbitt, R. P., and O'Donnell, T. 1971. "Fitting methods for conceptual catchment models." J. Hydr. Div., 979, 1331–1342

[16] Scharffenberg W, Fleming M (2010) Hydrologic modeling system HEC-HMS v32 user's manual. USACEHEC, Davis

[17] Mishra SK, Singh VP (2004) Long-term hydrological simulation based on the soil conservation service curve number. Hydrol Processes 18:1291–1313

[18] 20.USDA. 1986. "Urban Hydrology for Small Watersheds." Technical Release 55 TR-55, Natural Resources Conservation Services, Washington, D.C.