GIS-BASED HYDROLOGICAL MODELING: A COMPARATIVE STUDY OF HEC-HMS AND THE XINANJIANG MODEL

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ABSTRACT

The last few years have witnessed an enormous study in the area of integrated hydrological modeling with GIS application. In this research, attempt was made to critically look at the application of HEC-GeoHMS which is an extension of ArcView in HEC-HMS; an HEC package which is a new generation of software being developed for rainfall-runoff simulation. The main role of HEC-GeoHMS is to formulate a watershed data structure under the platform of GIS that can be imported directly to HEC-HMS. With the topographic information supplied by HEC-GeoHMS, HEC-HMS works more readily and exactly. The performance of HEC-HMS was compared with that of the Xinanjiang conceptual model using historical flood data from the Wanjiabu catchment in China. The results obtained in the course of this study indicate that HEC-HMS is more convenient for flood stimulation especially in optimizing parameters but not quite accurate as compared with Xinanjiang model. The plausible reason for this could be due to the fact that the Xinanjiang model has more parameters thereby making it flexible to fit a flood event. Based on the results obtained as stated, it is thus suggested that with improvement in data conditions, runoff yield could be calculated on grid format and results for both models appropriately enhanced.

Keywords: GIS; HEC-HMS; HEC-GeoHMS; Xinanjiang model; optimizing parameters

INTRODUCTION

The last few years have witnessed an enormous interest in the application of hydrological modeling coupled with GIS. The GIS technology has the ability to capture, store, manipulate, analyze, and visualize the georeferenced data. On the other hand, hydrological features are inherently temporally and spatially distributed, thus producing large data requirements for hydrologic modeling. Therefore, the integration of hydrological model and GIS is quite natural.

Hydrological modeling is a powerful technique in the planning and development of integrated approach for management of water resources. GIS can assist in design,

calibration, modification and comparison of models. It has influenced the development and implementation of hydrologic models at several different levels, and it provides representations of these spatial features of the Earth, while hydrologic modeling is concerned with the flow of water and its constituents over the land surface and in the subsurface environment. GIS could benefit from the temporal modeling capabilities of hydrological models and hydrologic models can benefit from the spatial modeling capabilities of GIS, Singh and Fiorentino (1996). GIS with its upcoming advanced technology has been a great asset to Hydrologic Modeling, and it has made an enormous contribution in the field of water resources engineering. More specifically, it has become a powerful tool for supporting a number of hydrological modeling applications. In order to successfully manage natural systems, one must have a thorough understanding of numerous physical, biological, and chemical variables in regards to their characteristic temporal and spatial scales. The spatial nature of these variables associated with water resources and hydrological modeling is the single most significant factor that contributes to the complexity of data management, William (1994). However, with GIS's ability to combine a variety of data into an easily understood format, GIS software can drastically change the way engineers handle water resources modeling.

DELINEATING WATERSHEDS AND STREAM NETWORKS WITH HEC-GeoHMS:

The Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) is a public-domain software package for use with the ArcView Geographic Information System. GeoHMS uses ArcView and Spatial Analyst to develop a number of hydrologic modeling inputs. Analyzing the digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities include the development of grid-based data for linear quasi-distributed runoff transformation (ModClark), HEC-HMS basin model, physical watershed and stream characteristics, and background map file, Maidment and Djokic (2000). The current version of HEC-GeoHMS creates a background map file, lumped basin model, a grid cell parameter file, and a distributed basin model, Figure 1. The background map file contains the stream alignments and sub basins boundaries. The lumped basin model contains hydrologic elements and their connectivity to represent the movement of water through the drainage system. The lumped basin file includes watershed area, and reserves empty fields for hydrologic parameters. To assist with estimating hydrologic parameters, tables containing physical characteristics of streams and watersheds can be generated. Additional interactive capabilities allow user to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures, and other control points. Physical characteristics of the watershed and river are computed and used to estimate hydrologic parameters. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed.

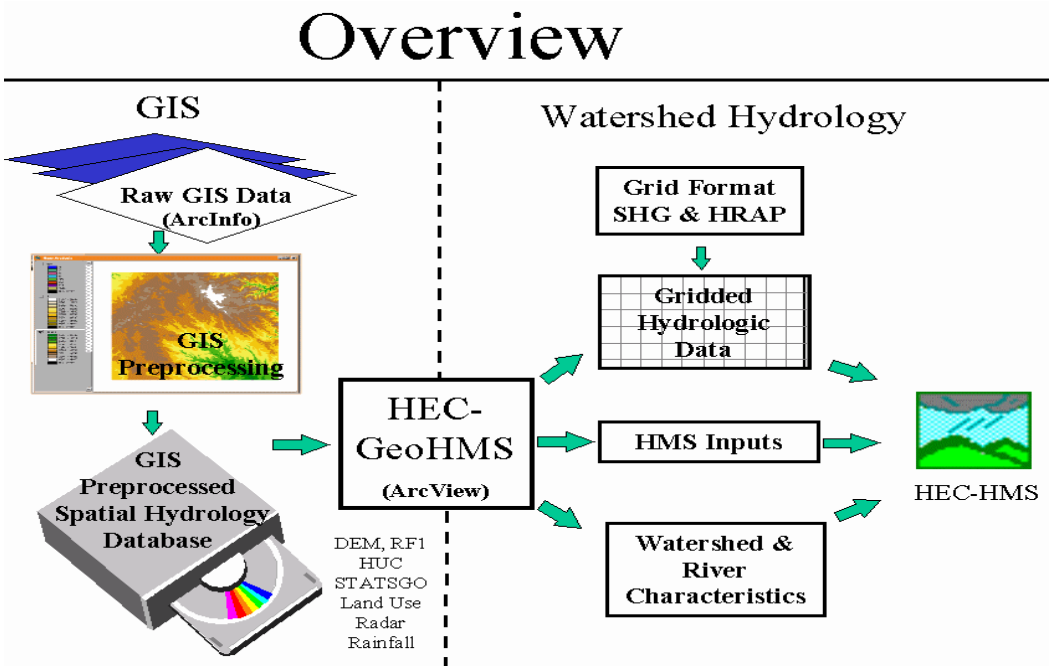

Fig. 1 The relationship between GIS, HEC-GeoHMS and HEC-HMS

OVERVIEW OF HEC-HMS AND XINANJIANG MODEL:

HEC-HMS (Hydrological Modeling System):

The Hydrologic Modeling System (HEC-HMS) is a new generation software being developed for precipitation-runoff simulation that will supersede the Hydrologic Engineering Center's HEC-l program. HEC-HMS provides a variety of options for simulating precipitation-runoff processes. In addition to unit hydrograph and hydrologic routing options, capabilities currently available include a quasi-distributed runoff transformation that can be applied with gridded (e.g., radar) rainfall data, and a simple "moisture depletion" option that can be used for continuous simulation. Editors can be accessed for individual elements, or "global" editors can be accessed which enable entering or editing values for parameters of a given type for all associated elements. Upon completion of a simulation, summary tables and graphical displays of results can be accessed from pop-up menus associated with the icons. Several options are available for defining the precipitation input for a watershed. The options include capability to process "point" data from gauges, gridded data such as is obtained from radar, and generalized data associated with frequency-based or Standard Project design storms. HEC-HMS can utilize gridded precipitation data in two ways:

a) The data can be used directly with the ModClark method.
b) The data can be spatially averaged for use as a lumped input.

HEC-HMS is designed to be applicable in a wide range of geographic area for solving the widest possible range of problems. This range includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for

studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, flood-loss reduction studies, environmental studies, reservoir design studies and systems operation, Charley et al. (1995).

HEC-HMS Features: Data entry can be performed for individual basin elements such as subbasins and stream reaches or simultaneously for entire classes of similar elements. Tables and forms for entering necessary data are accessed from a visual schematic of the basin. Each HEC-HMS project requires three data components: a Basin Model, a Meteorological Model, and Control Specifications, Figure 2.

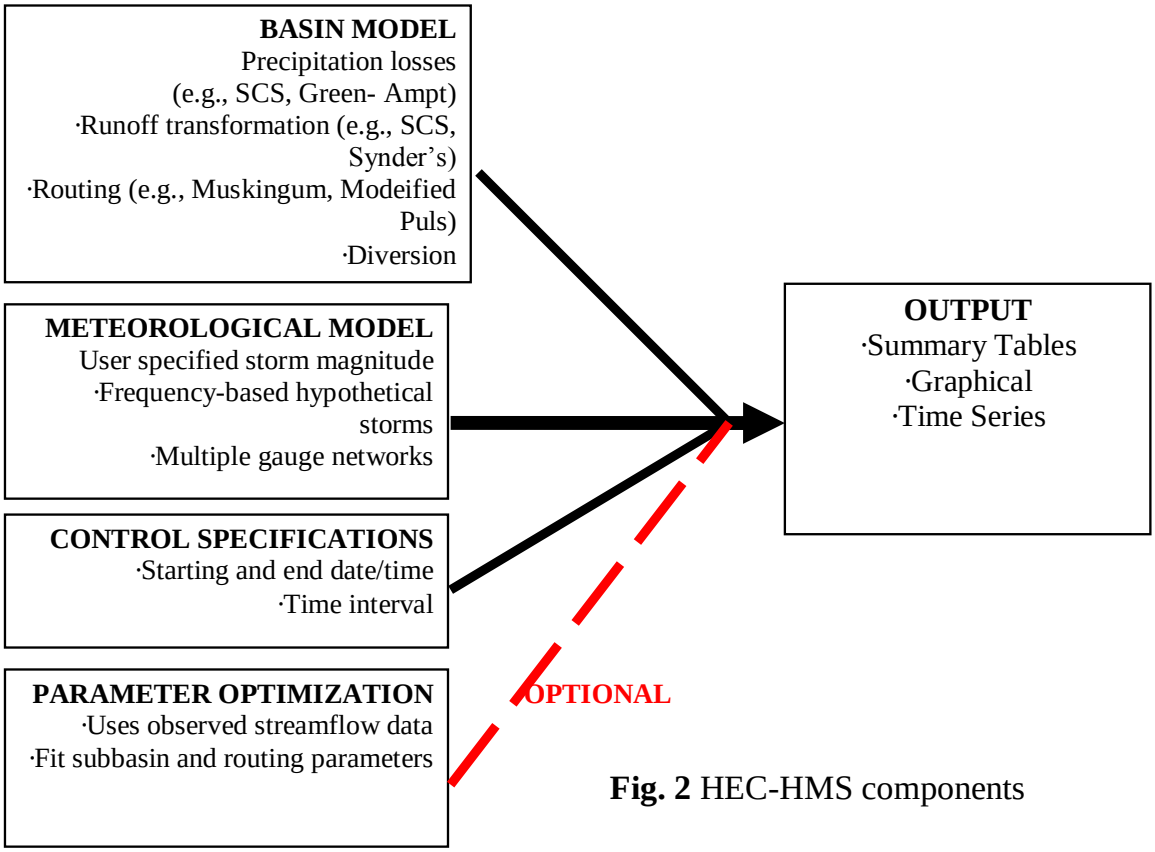

Fig. 2 HEC-HMS components

Basin Model Data: The basin model contains data, which represents the physical system. The descriptive data is entered by the user or imported from GIS and can be edited. Such data includes specification of the hydrologic elements of which the basin model is comprised, information on how the hydrologic elements are connected, and values of parameters for the hydrologic elements. A basin model consists of hydrologic elements, of which there are seven types: sub basin, routing reach, junction, reservoir, diversion, source, and sink. The development of a basin model requires the specification of such elements and data that controls their 'behavior'.

Meteorological Model: The Precipitation Model is a set of information required to define historical or hypothetical precipitation to be used in conjunction

with a basin model. Types of hypothetical storm include frequency-based and the Corps of Engineers' Standard Project Storm. Frequency-based storms require that the user provide rainfall depths for various durations.

Control Specifications: Lastly, the Control Specifications define time-related information for a simulation, including the starting and ending dates and the time interval for computations. The function of control specifications is to set the starting and ending dates and times and time (computation) interval.

The Xinanjiang Model:

The Xinanjiang model was developed in 1973 and published in 1980. Initially the model was applied to the catchment of Xinanjiang reservoir therefore the name "Xinanjiang" was given. Its main feature is the concept of runoff formation on repletion of storage, which means that runoff is not produced until the soil moisture content of the aeration zone reaches field capacity, and thereafter runoff equals the rainfall excess without further loss, Fig. 3. This hypothesis was first proposed in China in the 1960s, and much subsequent experience supports its validity for humid and semi-humid regions. According to the original formulation, runoff so generated was separated into two components using Horton's concept of final, constant, infiltration rate .Infiltrated water was assumed to go to the groundwater storage and the reminder to surface, or storm runoff. However, evidence of variability in the final infiltration rate, and in the unite hydrograph assumed to connect the storm runoff to the discharge from each sub-basin, suggested to the necessity of a third component. Guided by the work of Kirkby (1978) and additional component, interflow, was proved in the model in 1980. The modified model is now successfully and widely used in China.

The Concept of Runoff Formation on Repletion of Storage: Soil, or indeed any porous medium, possesses the ability of holding indefinitely against gravity a certain amount of water constituting storage. This is sometimes called "field moisture capacity". By definition, water held in this storage cannot become runoff and the storage can be depleted only by evaporation or the transpiration of the vegetation. Hence, evaporation becomes the controlling factor producing soil moisture deficiency. In humid regions, soil moisture measurements show that the soil moisture can often reach field capacity within the entire soil cover. This implies that the replenishment in the next period of rainfall will be equal to the evaporation in the intervening period. This suggests a very simple relationship between rainfall and runoff viz. Zhao (1992).

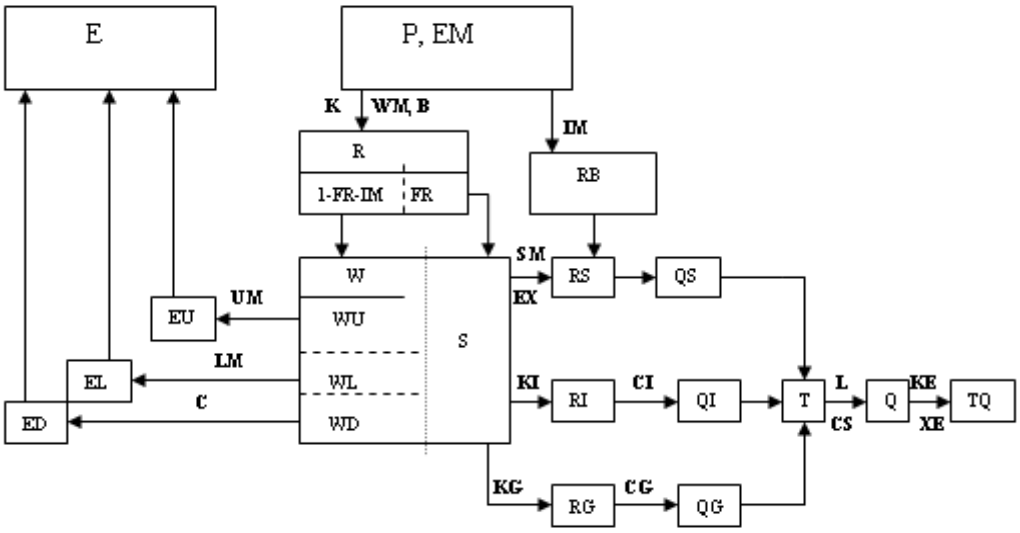

Fig. 3 Flowchart of the Xinanjing model

METHODOLOGY

Catchment's Description (Wanjiabu Catchment):

The catchment is located in Jiangxi Province, China (within Xiu-River Basin) and the total area is about 3548 km^2, Fig. 4. The annual average rainfall ranges from 1400 mm to 2000 mm in the basin, and the annual average runoff is about 125*10^8 m^3. The monsoon season is usually from April to July. There are eight precipitation-gauging stations inside the catchment and thereby the catchment was divided into eight sub-catchments based on the Thiessen polygon method, but in this study other two nearby stations were also used. The monsoon season is usually from April to July.

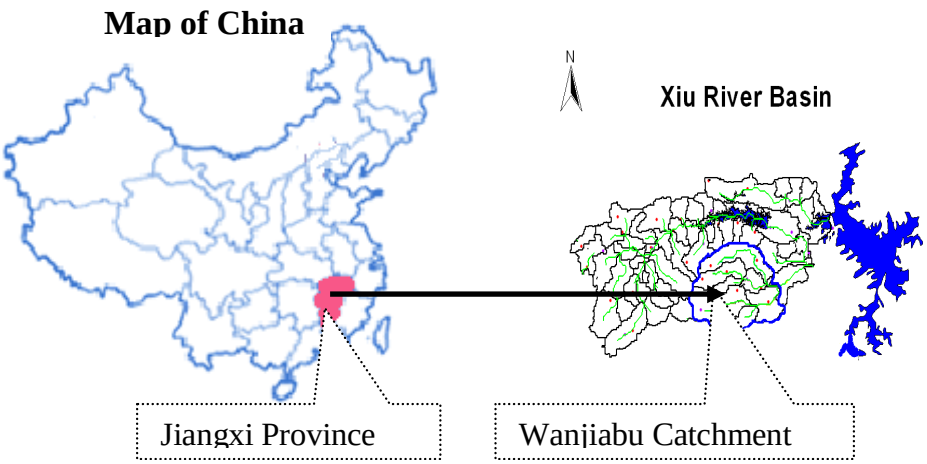

Fig. 4 Wanjiabu Catchment location

Required Data, Programs and Extensions:

Data include the DEM of Xiushui catchment in Jiangxi province, the basic hydrologic data such as rainfall data, observed discharge data, and some related data about streams like roughness, cross-section information and so on. DEM which were available is regularly spaced at 30-arc seconds (approximately 1 kilometer), including elevation, boundary, roads, gauges etc. Hydrological Data include Rainfall (daily) and in 6 hours, discharge (daily) and 2 hours, evaporation (daily). Verifications of the reliability, consistency and typicality of the offered hydrologic data are available, for 1983 year and from 1988 to 2000 year. Arcview software, HEC-GeoHMS, Spatial Analyst Extensions, HEC-HMS, and Xinanjiang Code for Wanjiabu Catchment all were used to accomplish this study.

Data Preprocessing with HEC-GeoHMS and HEC-HMS:

A Digital Elevation Model (DEM) of Xiu River Basin is required as input for basin preprocessing under platform of Arcview with HEC-GeoHMS extension and Spatial Analyst. The purpose of basin preprocessing is to perform initial analysis of the terrain and prepare the dataset for later processing. Terrain preprocessing can be done step by step or by full preprocessing setup including filling the sinks ,flow direction, flow accumulation, stream definition, stream segmentation, watershed delineation, watershed polygon processing, stream segment processing, and watershed aggregation and after that one can start new project and select an outlet for the study area and generate a new project called Wanjabu Catchment. This type of work was performed within the ProjView, Figure 5, and there are various methods of basin processing like basin merge, river merge, etc. Basin characteristic can be done to extract river length, slope calculations, centroid determination, longest flow path and centroidal flow path calculations. Some steps under menu HMS can be done before imported 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 generate basin model, meteorological model, and control specifications, and we can add precipitation gauges and discharge gauges.

Model simulation: HEC-HMS takes a watershed as a system, and simulates the process of a rainfall-runoff event within the whole basin. The input of the system is rainfall data and the output is discharge process in watershed outlet and sub-outlets. A hydrological model is, in form, expressed as two dimensions that are structure and parameter. Usually a rainfall-runoff event is characterized as two stages namely runoff yield process and routing process. The model structure contains the runoff yield principle and routing measure respectively. In HEC-HMS, there are several candidate methods can be combined in building the model. Therefore, there remains the question how to make the combination, which is likely leading to group comparisons before the best model structure is determined. It can also be called model structure calibration.

Checkup of the forecasting results: Forecasting results will be checked up in the way of making comparison to the observed flood process. In actual simulations, the selected catchment is studied. Each of those hydrological stations has a long set of observed discharge data, which offers the possibility to do the verification. Comparisons with outcomes of Xinanjiang model will be done to show the results.

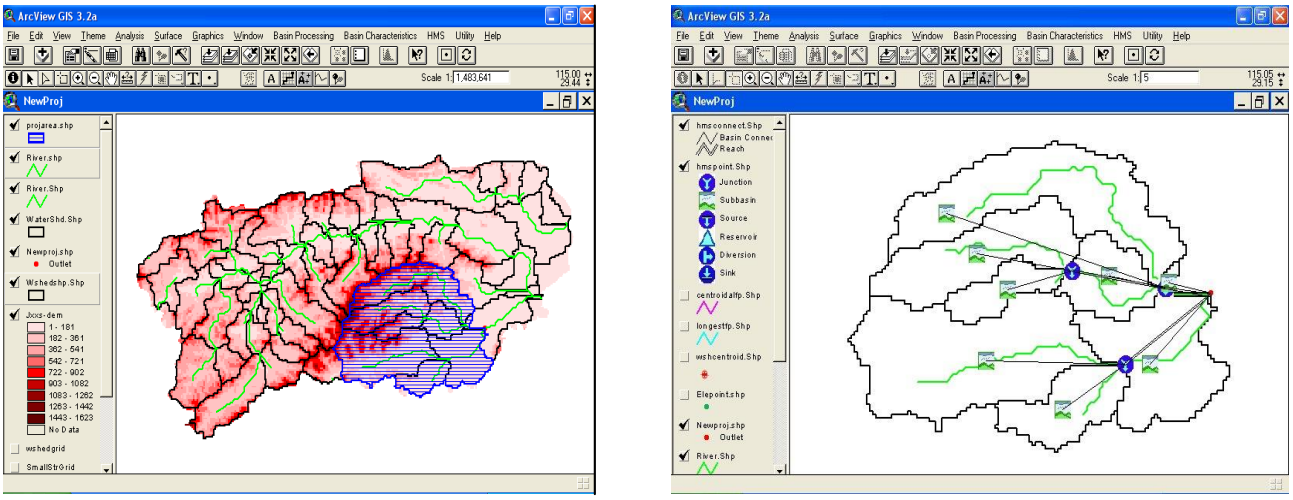

Fig. 5 Wanjiabu in ProjView

Applying Xinanjiang Hydrological Model for Wanjiabu Catchment:

To complete this study, the Xinanjiang Model was applied to Wanjaibu Catchment, with the same data (Precipitations, Evapotranspiration) which was been used in HEC-HMS, and for the same flood events. The model was then calibrated to be also have optimized parameter values. Then results obtained were comparing it with that of HMS results.

RESULTS DISCUSSIONS AND CONCLUSIONS:

HEC-HMS and Xinanjiang model were applied for Wanjiabu catchment. Runoff hydrograph at the Wanjiabu outlet was simulated using both models for comparison. Forecasting results were checked up in the way of making comparison to the observed flood process. In actual simulations, the selected catchment was studied. Combination of different runoff yield and routing procedures were tried to search the best model components (i.e. the model structure). The parameter calibration of HEC-HMS model was done with the option of optimization in HEC-HMS. Given initial estimates of the parameters, the models of HEC-HMS can be used with the observed boundary conditions (rainfall or upstream flow) to compute the output, either the watershed runoff hydrograph. The goodness of fit indices include: Sum of absolute errors, Sum of squared residuals, Percent error in peak, and average root mean square error, Bakir (2004).

HEC-GeoHMS extracts topographic, topologic and hydrologic information from digital spatial data, and prepares an input file for the basin component of HEC-HMS, which when opened automatically creates a topologically correct schematic network of sub-basins and reaches, and attributes each element with selected hydrologic parameters. HEC-GeoHMS also generates an input file for the precipitation component of HEC-HMS. By using HEC-GeoHMS, the determination of physical parameters for HEC-HMS is a simple and automatic process that accelerates the setting up of a hydrologic model and leads to reproducible results. Twelve flood events were chosen, and then HEC-HMS and Xinanjiang model were applied. Precipitation and discharge data can be easy and clearly shown with graph or time series shape, so that we can check the data easily. Considering the fact that the residual time series between a model and the physical data it represents is a direct indication of the deficiencies of the model and the data used along with it, it is worthwhile to have an understanding of the forecast errors of the model. For it is basically true that the pattern in this residual could therefore be expected to be highly non-linear and also contaminated by noise coming from the data. From Fig. 6 we can notice the residual (errors) in HMS for the flood events are more than Xinanjiang model, Bakir (2004).

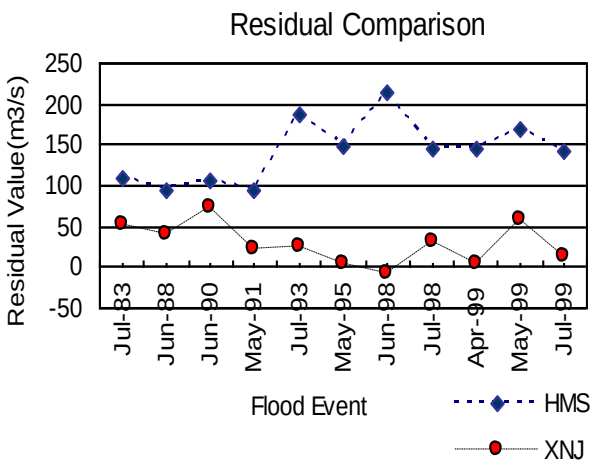

Fig. 6 Comparative Performance in term of absolute residual

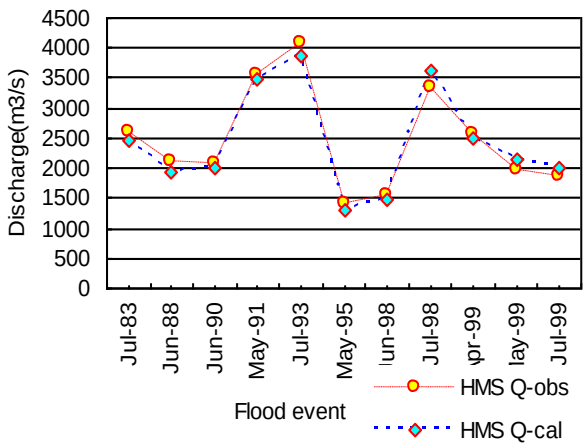

Fig. 7 Q-obs and Q-Cal, HMS

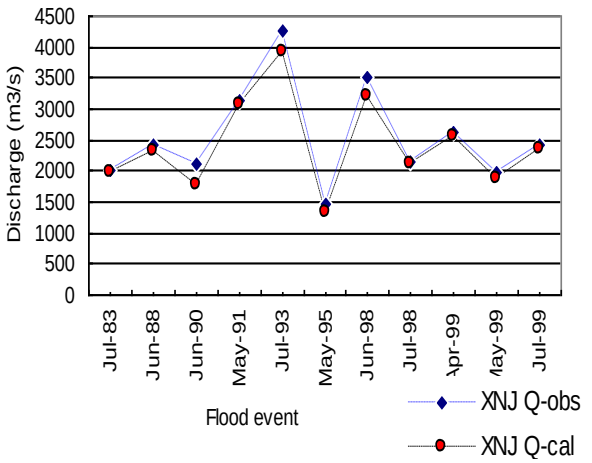

Fig. 8 Q-obs and Q-Cal, XNJ

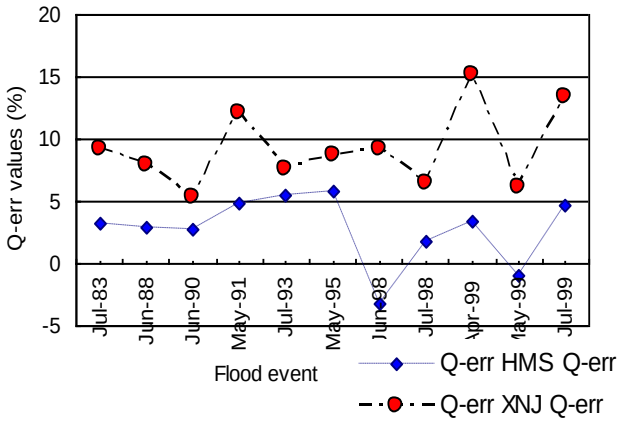

Fig. 9 Q-err for HMS and XNJ

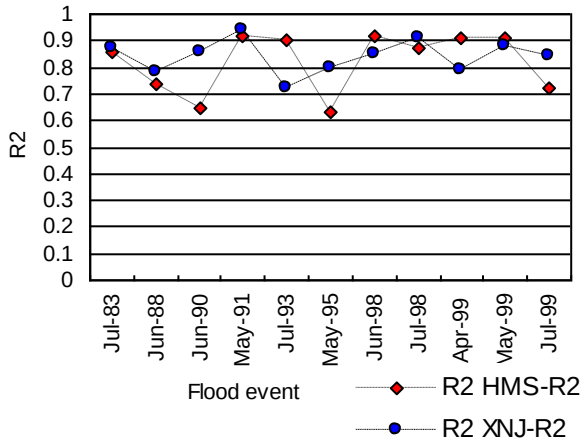

Fig. 10. R^2 Values for HMS and XNJ

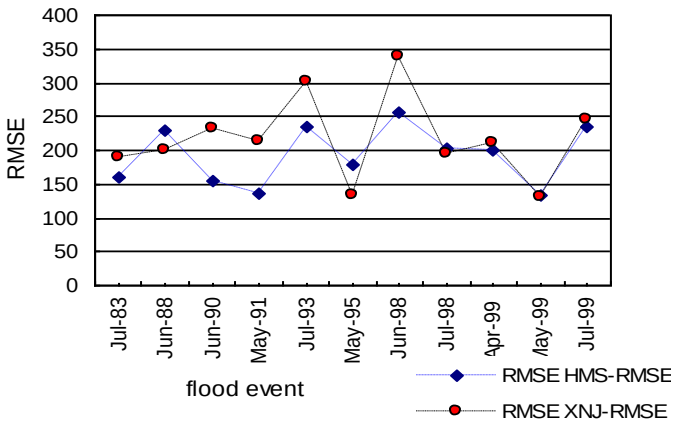

Fig. 11 RMSE Value for HMS and XNJ

CONCLUSIONS AND RECOMMENDATIONS

The performance of HEC-HMS was compared with that of the Xinanjiang conceptual model using historical flood data from the Wanjiabu catchment in China. The results obtained in the course of this study indicate that HEC-HMS is more convenient for flood stimulation especially in optimizing parameters but not quite accurate as compared with Xinanjiang model. The plausible reason for this could be due to the fact that the Xinanjiang model has more parameters thereby making it flexible to fit a flood event. Based on the results obtained as stated, it is thus suggested that with improvement in data conditions, runoff yield could be calculated on grid format and results for both models appropriately enhanced. Based on the analyses carried out in the course of this work, we found that HEC-HMS is a very powerful and flexible software provided existing enough and accurate hydrological data which is needed to run multiple models inside it. HMS provides precipitation- specification options, loss models which can estimate the volume of runoff, and direct runoff and hydrologic routing models, and also includes a calibration optimization package. On the other hand, Xinanjiang model results were good for flood forecasting runoff and stream flow provided it is properly calibrated, Bakir (2004).

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