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## **FLASH FLOOD SIMULATION USING GEOMORPHIC UNIT HYDROGRAPH METHOD: CASE STUDY OF HEADWATER CATCHMENT OF XIAPU RIVER BASIN, CHINA**

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**Abstract:** The flash flood refers to flood produced by heavy local rainfalls and often occurs in mountainous areas. It is characterized by a quick rise of water level causing a great threat to the lives of those exposed. Many countries and regions face the threat of flash floods. However, some traditional hydrological models can hardly simulate the flash flood process well due to the lack of hydrological data and the insufficient understanding of complicated runoff mechanism in mountainous and hilly areas. According to this condition, a new hydrological model based on the framework of Xinanjiang model, widely used in humid and semi-humid regions in China, is presented to simulate flash flood. The highlight of new model is using the geomorphic unit hydrograph method to simulate the overland flow process. This method has clear physical concept and can easily provide unit hydrographs of various time intervals only based on DEM data. This feature makes the method extremely valuable in ungauged catchment. The new presented hydrological model is used in the headwater catchment of Xiapu River basin and the results demonstrate that the computed data generally agrees well with the measured data and it can be treated as a useful tool for flash flood hazard assessment in mountainous catchment.

**Keywords:** flash flood, hydrological model, geomorphic unit hydrograph, Xiapu River

### **1. INTRODUCTION**

The flash floods induced by heavy rainstorms, which are characterized by a quick rise of water levels and often occurred in small-sized catchments, have destructive power, and can cause disasters easily. The process of flash flood formation is complex, and especially they often occurred in the ungauged catchment, therefore the research work of flash flood is very difficult. At present, the flash flood defence is becoming a worldwide problem posing a great challenge to many countries and regions because of their abrupt nature. Many scholars have conducted the study on flash flood and it has been shown that the morphometric variables of a catchment control its hydrologic response (Angellieri, 2008 [1]; Moussa, 2003 [6]). Based on the understanding, geomorphic unit hydrographs have been one of the most useful tools for estimating hydrological process when instrumental data are inadequate (Du et al., 2009 [4]; Diakakis, 2011 [3]). With the development of GIS technology in recent years, the calculation of geometric basin parameters becomes easier.

In this paper, a new distributed conceptual hydrological model is presented based on the framework of Xinanjiang model and the geomorphic unit hydrographs based on the grid cell

approach are obtained using the digital elevation model (DEM )data with the help of GIS software. To verify its capability, the new hydrological model are used in the headwater catchment of Xiapu River basin and it perfoms very well when dealing with the complex flash flood process.

## 2. STUDY AREA

The headwater catchment of Xiapu river basin, with its major information shown in Figure 1, covers an area of 112.5 km<sup>2</sup> in Xianning city, a southeastern department in the Province of Hubei, China. This catchment lies between longitudes 114°17'-114°31'E and latitudes 29°18'-29°27'N. The catchment belongs to a typical hilly area and its average slope reached 0.58, elevation values between the 157m-1304m. Because of its geographical location, the specific study area has a general arid and semiarid climate. In the summer period of April-October, intense downpours of short duration cause flash flood easily and the region's steep gradient help drain these precipitated volumes quickly. The flood characterized by large flow rates and high transport ratios of alluvial matter can cause severe damage to the area.

There are several land use types, mainly including arable land, forest, mining and residential land, among which the forest land accounts for the major part. There are four small hydropower stations in the catchment and they are Zhanghekou, Lengshuiping, Dachayuan and Egongjing. Among of them, the first three hydropower stations are all diversion-type and the height of weir is low, only about 1m above the river bottom. Therefore, in this study the impacts of the first three hydropower stations to the flash flood process aren't considered. However, the Ergongjing hydropower power station has a small reservoir, whose drainage area is 45 km<sup>2</sup> and total capacity is 984,000 m<sup>3</sup>, so the regulation function of the reservoir need to be considered. Within the study area, there are three rainfall stations, which are named Sanbao, Linshang and Huangjin respectively. Dawuchang hydrologic station locates in the catchment outlet and the discharge data will serve as the main basis for model verification.

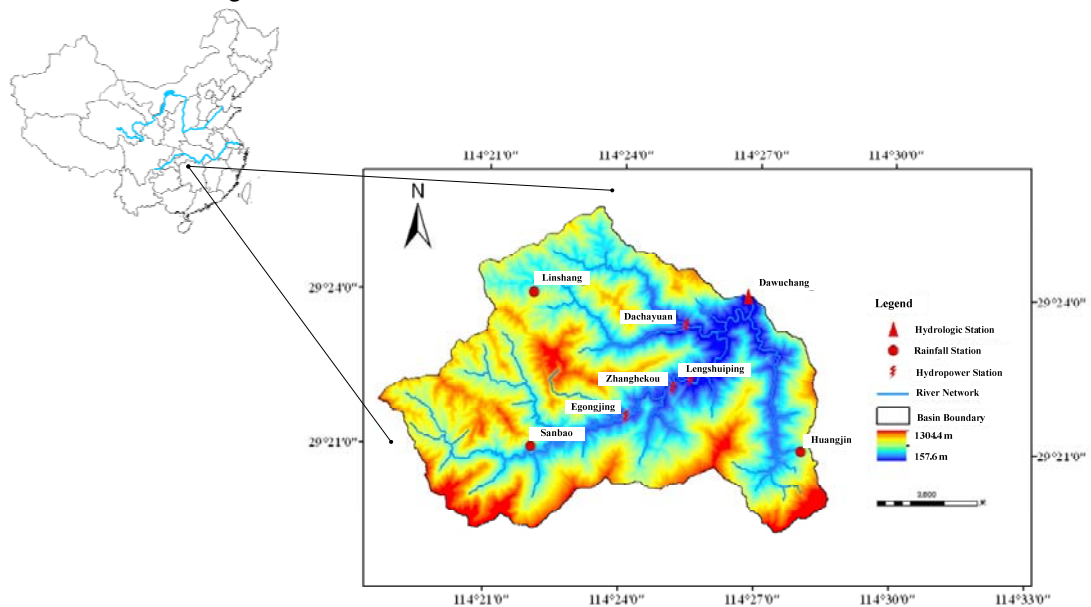


Figure 1. Study area

### 3. MODEL FORMULATION

Xinjiang hydrological model developed by Zhao et al (1984) [7] is very popular used in arid and semi-arid areas in China. The new distributed conceptual hydrological model is based on the framework of Xinjiang model. The study catchment is divided into some sub-catchment and the Muskingum flood propagation method is used to link flood of each sub-catchment to the outlet. For the flash flood, the surface flow is the main component of the runoff, so the accuracy of the surface flow dominates the whole calculation accuracy of the runoff process. In order to calculate the surface flow efficiently, the method of geomorphic unit hydrograph is used. To maintain the integrity of the model, the subsurface flow and underground flow are also calculated using the simple linear reservoir method. For the new hydrological model, the novelty is the geomorphic unit hydrograph method based on DEM data, so the following content is mainly focused on introduction of this method.

To get the concentration time of raindrops in each grid, the velocity of raindrops should be determined first. In theory, the movement of surface flow is mainly driven by gravity, and there is a close relationship between flow velocity and average slope of the catchment. Generally, the velocity of overland flow is estimated by the following equation (Li, 2005 [5]):

$$V = KS^{1/2} \quad (1)$$

Where,  $V$  is velocity of overland flow;  $K$  is velocity coefficient;  $S$  is the average slope of catchment. The value of  $K$  should be determined by calibration according to actual hydrological data. And it could also be estimated according to geomorphologic features of mountainous areas if there is no enough or even no hydrologic data. Any point in the catchment has its own flow path to the outlet. Based on DEM data, water flows into the adjacent grid with the maximum gradient according to the D8 algorithm; then the flow path to the outlet can be determined. The following Figure 2 shows how it works.

The concentration time of water in each grid can be determined by the following equations according to the size of grid and the velocity of water in the grid.

$$\Delta\tau = L/V \text{ OR } \Delta\tau = \sqrt{2}L/V$$

$$\tau = \sum_{i=1}^m \Delta\tau_i \quad (2)$$

Where,  $L$  is the distance of grid center;  $m$  is the number of grids along the flow path;  $\Delta\tau$  is the moving time of raindrop from one grid to another;  $\tau$  is the whole time along the path.

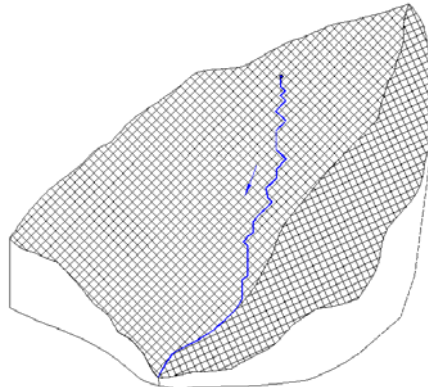


Figure 2. Moving path of raindrop in the catchment

Assuming that the time period of unit hydrographs is  $\Delta t$ , by counting the number of raindrops reaching the outlet in each period, and according to the time-area method, the dimensionless unit hydrograph can be determined by dividing raindrop numbers of each period with the total gird numbers.

If the precipitation of a period is given as  $i$ , the period unit hydrograph can be calculated according to dimensionless unit hydrograph:

$$q(\Delta t, t) = \frac{F}{\Delta t} u(\Delta t, t) i \quad (3)$$

Where,  $q(\Delta t, t)$  is period unit hydrograph;  $F$  is basin area;  $u(\Delta t, t)$  is dimensionless unit hydrograph;  $\Delta t$  is the actual time period of unit hydrograph.

To the watersheds with large areas, the storage function of watershed should also be considered (Clark, 1945 [2]; Li, 2005 [5]). And the linear reservoir method is as follows:

$$Q_i = c \left( \frac{q_i + q_{i-1}}{2} \right) + (1-c) Q_{i-1} \quad (4)$$

Where,  $Q$  is the final value of period unit hydrograph;  $c = 2\Delta t / (2k_1 + \Delta t)$ , where  $k_1$  is the coefficient of linear reservoir.

#### 4. RESULT

According to the standard scales of  $10\text{km}^2$ , simultaneously considering the special control point (such as hydropower stations), the catchment is divided into 10 sub-catchments, seen in Figure 3, whose areas range from  $0.58\text{ km}^2$  to  $29.7\text{ km}^2$ .

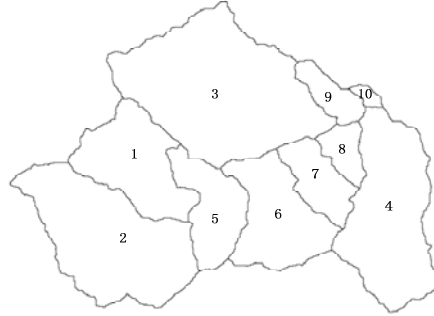


Figure 3. Sub-catchments of the study area

Ten flash flood events are selected from the historic hydrologic data from 1992 to 2010, which will be used to verify the presented hydrological model. The selected flash flood events are as shown in Table 1.

Table 1. Selected flash flood events

Flood NO.	Start time	End time
940626	1994-06-26 00:00	1994-06-29 14:00
950701	1995-07-01 04:00	1995-07-04 18:00
960714	1996-07-14 00:00	1996-07-20 15:00
970902	1997-09-02 00:00	1997-09-04 08:00
990521	1999-05-21 20:00	1999-05-25 20:00
020513	2002-05-13 00:00	2002-05-16 08:00
030624	2003-06-24 08:00	2003-06-30 20:00
040429	2004-04-29 08:00	2004-05-02 23:00
050626	2005-06-26 15:00	2005-06-30 08:00
100714	2010-07-14 05:00	2010-07-17 08:00

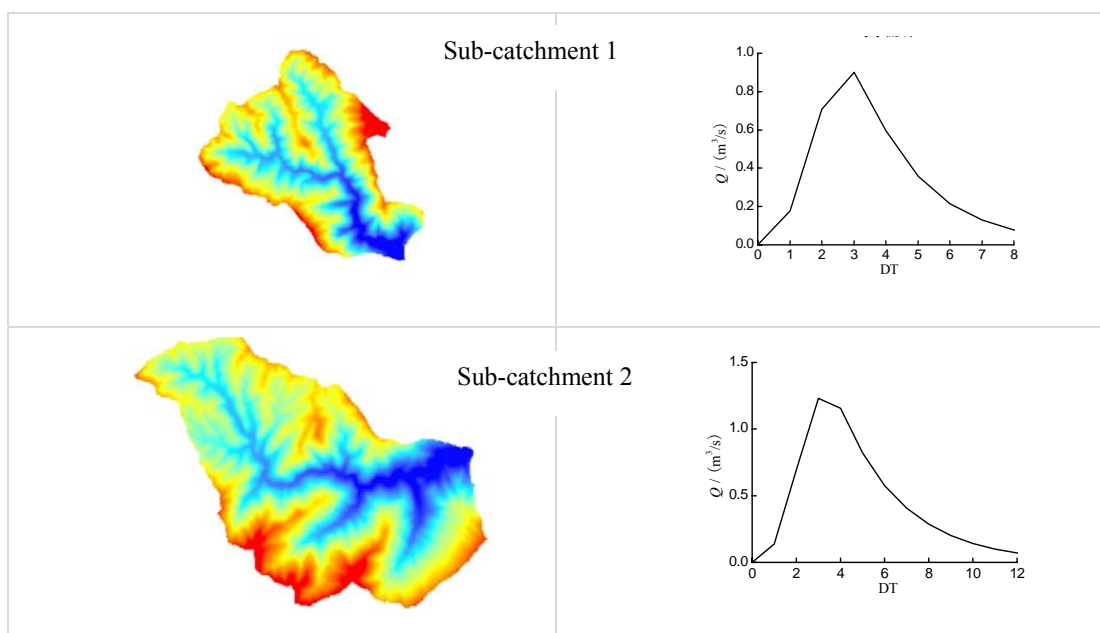


Figure 4. Geomorphologic unit hydrograph based on DEM

The geomorphologic unit hydrograph of each sub-catchment can be calculated based on the DEM data. In this study, the time interval is 1h and after calibration, the overland velocity coefficient  $K$  is taken as 1.1. Considering the sub-catchment storage capacity, the linear reservoir coefficient  $k_1$  of each sub-catchment is defined as 0.92 times of their convergence times. The representative results (sub-catchment 1 and 2) are as shown in Figure 4.

The developed new hydrological model has been carried out using the available datasets of the study area and the results are listed in Table 2 and Figure 5. From the results we can see that the simulated results agree well with the observed data in general. The maximum relative error of peak flow is 13.21%; the discrepancies of time to peak are very small except two flash flood events (940626 and 050626); the Nash-Sutcliffe Efficiency (NSE) coefficients are all greater than 0.62 and can be acceptable. Generally, the new hydrological model performs well and can be treated as a useful tool for flash flood analysis.

Table 2. Simulation results in the Study catchment

Flood No.	Peak flow ( $\text{m}^3/\text{s}$ )			Time to peak(h)	NSE
	Observed	Simulated	Relative error (%)		
940626	299.29	309.03	3.26	-3	0.62
950701	441.11	450.32	2.09	1	0.87
960714	266.00	239.18	-10.08	1	0.62
970902	284.29	321.84	13.21	1	0.87
990521	239.00	214.01	-10.46	0	0.73
020513	264.29	271.74	2.82	1	0.92
030624	252.00	221.75	-12.00	1	0.69
040429	222.38	240.17	8.00	0	0.93
050626	410.00	417.20	1.76	2	0.85
100714	168.00	185.74	10.56	0	0.68

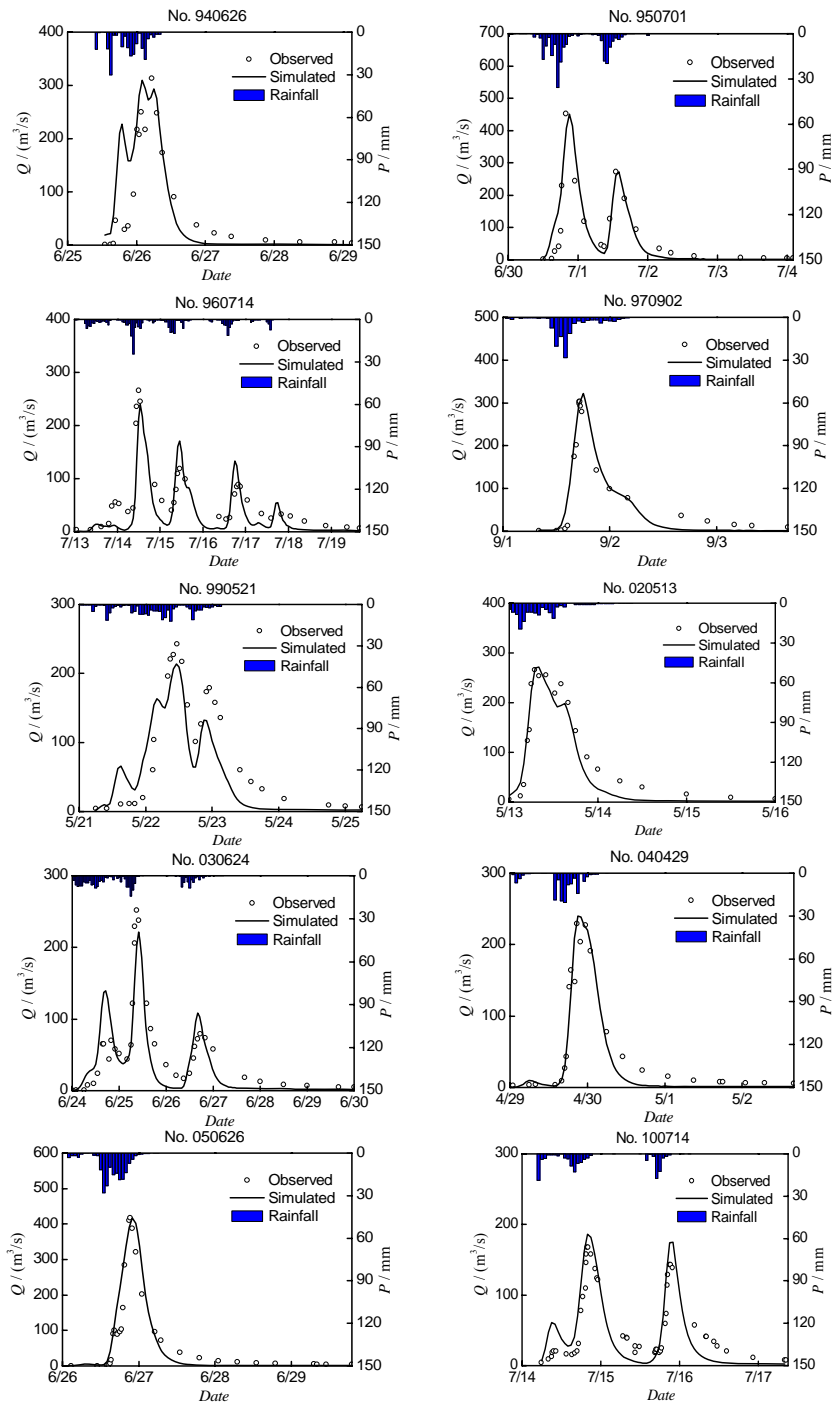


Figure 5. Observed and simulated runoff hydrograph at Dawuchang hydrologic station

## 5. CONCLUSION

This study presents a new hydrological model for flash flood simulation and the novelty is that the geomorphic unit hydrograph based on the grid cell approach is used to model surface runoff, which is directly related to a catastrophic flood event. During the occurrence of a storm event, the traveling time to the outlet of every raindrop on the grid cells is different and the most important parameters that are needed for computing the velocity can be derived from geomorphic data directly without observed rainfall and runoff data, so this model is suitable in ungauged catchment. To verify the model's capabilities when dealing with the flash flood problem, it was used in the headwater catchment of Xiapu River basin, a typical flash flood prone area. The test results show that the proposed hydrological model can deal with the flash flood well and it can be treated as a useful tool for computation of flash flood hydrographs.

## ACKNOWLEDGEMENT

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