6TH INTERNATIONAL CONFERENCE
ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil

FLASH FLOOD EARLY WARNING INDICATORS FOR SOUTH BRANCH OF CENSHUI WATERSHED

Changzhi Li[1], Hong Wang[1], Meihong Ma[1], Xiaotao Cheng[2]
1 China Institute of Water Resources and Hydropower Research, Beijing, China, 100038
2 State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, IWHR, Beijing, China, 100038

ABSTRACT: Using hydrological modeling technique with detailed sub-basin delineation, this study introduces basic concept and methods of analyzing warning indicators for flash flood early warning. Taking South Branch of Censhui watershed in China as an example, 3 typical early warning indicators for flash flood dynamic early warning were investigated. The primary indicator, critical rainfall, was analyzed at 3 early warning stations located inside the watershed, and other two important indicators, warning discharge threshold and warning rainfall duration, were also estimated using the results of critical rainfall. This research illustrates that detailed watershed characteristics can be modeled in-depth by further delineate the watershed into smaller sub-basins to simulate spatial distribution of various basin parameters. The resulted runoff and flood hydrographs show better accuracy at all 3 early warning stations. It further confirms that time of concentration of a watershed is an important factor to warning rainfall duration, and the antecedent soil moisture condition of the watershed has significant impact to the critical rainfall.

Key Words: Small Watershed, Flash Flood Early Warning, Early Warning Indicators, Hydrological Modeling, Critical rainfall

1. INTRODUCTION

As global climate changing and extreme weather events increasing, flash flood disasters are rising and drawing substantial attention around the world. Consequently, flash flood early warning becomes one of the key issues for disaster prevention and mitigation. Flash flood early warning is often conducted through the critical rainfall. Critical rainfall is an estimate of the amount of rainfall required over a given area during a given duration to cause a mountain stream to flood. Critical rainfall method is widely used in the flash flood early warning in China and abroad; however, the determination of critical rainfall value varies significantly. In the United States and European countries, the flash flood guidance system (FFG) developed by the United States is commonly uses as an early warning indicator (U.S. National Weather Service, 1992; Carpenter, T.M. et. al.1993). FFG method and related early warning systems are also used in many countries and regions around globe (FLOODsite.2008; Georgakakos, K. P., 1992; Sperfslage, J. A., 2004; Sweeney, t. l., 1992). At present, this system continues to improve and refine (Konstantine P. Georgakakos. 2006; Carpenter T.M.,1999).

In Japan, the critical rainfall determinations are more focused on the analysis of precipitation and soil moisture content. Commonly used methods include: soil moisture index, effective precipitation, rainfall intensity/time of concentration, and statistics based multi-determination analysis (Japan National Institute for Land and Infrastructure Management.2001). The critical rainfall curve method widely used in Taiwan for debris flow early warning during last century was a reference to the method used in Japan (XIE Z.L.I, et al. 1995; FAN Z. c., 2001). At present, a more mainstream approach is evolved around critical rainfall analysis, mainly focus on rainfall index value for predicting possibility debris flow patterns and early warning (JAN, Cheng Deng, et al, 2004; 2006). In mainland China, climate conditions, geological landforms, vegetation and soil types varies vastly; the availability of precipitation and other hydrological data also varies. As a result, various methods for determining critical rainfall are used around the country.

Typical methods include: statistical analysis of measured rainfall, (CHEN g. y. et al. 2005), warning stage/warning discharge calculation (YE y. et. Al. 2008), rainstorm critical curve method (JIANG j. h. et. Al. 2010), Hydrodynamic method (WANG x. et. Al. 2009).

China has interesting tomography with 2/3 of land as mountains. Many of mountainous areas are flash-flood-prone. Flash flood in China can be characterized as sudden occurrence, wide impact and, destructive damage. The forecasting and early warning of flash flood is full of challenges because of its complexity. Comparing to other countries, flash flood prevention in China initiated relatively late. In recent years, Chinese government has increased the strength of flash flood prevention. At present, majority of mountainous areas have established certain capacity for flash flood prevention at county level, such as data storage, flash flood monitoring, analysis and early warning. Preliminary research indicates that FFG method performs well when continuous information is available, especially the soil moisture content information. It is difficult to apply FFG method in China at present as continuous data is not available in many areas. Remaining methods for determining critical rainfall include statistical analysis of historical disasters, hydrology method or hydrodynamic method which requires intense data and information. These methods are also considered unpractical due to the current condition of the country. This paper, using hydrological modeling, attempts to establish a method for determining critical rainfall value. To demonstrate the method, the South Branch of Censhui watershed was taken as an example. The precipitation, land cover and soil moisture content were considered in the numerical simulation. The results show that the proposed method is practical and applicable in China. It can be used in dynamic early warning for flash flood and can provide .technical support for flash flood disaster prevention in China.

2. RESEARCH CONCEPT AND APPROACH

Basic concept and approach of this study are: using detailed hydrological modeling to simulate flood hydrographs at various early warning stations inside the watershed; determining the lag time based on the peak-precipitation time and peak-flood time, using the lag time to backtrack critical rainfall value at various early-warning stations, as shown in Figure 1. During the development of the detailed hydrological model, special attention should be given to the following: (1) in the process of sub-basin delineation, the geographical locations of the early-warning stations should be appropriately considered as well as the river sections, source and sink points, tributary confluences and diversions; (2) carefully collect and input parameters for each sub-basin such as topographical features, vegetation covers, land uses types, soil types, and river features; (3) utilizing typical precipitation and runoff data in the watershed to calibrate and validate the model.

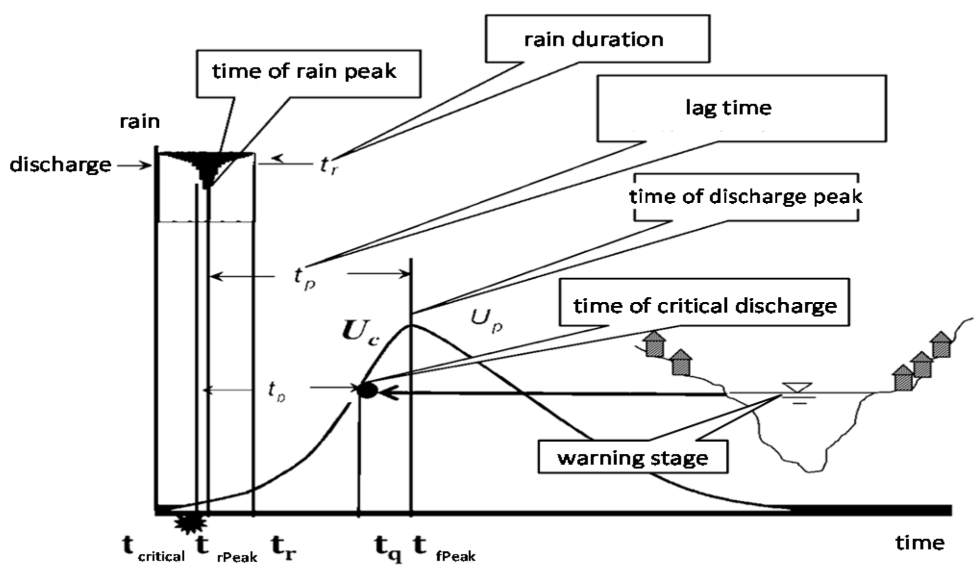

Figure 1. Schematics for Estimating Warning indicators

During hydrological analysis, a hypothetical precipitation series was constructed by assuming an initial total rainfall value and distributing the total rainfall value to each time step based on the rainfall pattern. This hypothetical precipitation series was input into the model, and the resulted flood hydrograph at each early-warning station was compared with pre-determined warning discharge. If computed peak flow differs from warning discharge significantly, the initial total rainfall value will be adjusted accordingly, and the simulation repeats. This iteration process continues until the simulated peak flow at each early warning station matches pre-determined warning discharge within pre-defined tolerance.

3. CRITICAL RAINFALL ANALYSIS

3.1 Description of Study Area

Located in Hunan Province (113° 13´25.3"-113° 29´14.8" E, 29° 43´29.01"-29° 51´27" N) with an drainage area of 223km^2, South Branch of Censhui watershed Is a wettish subtropical monsoon climate region with an annual precipitation of 1200-1900mm. Rainfall concentrates in summers, and heavy storms often triggers flash flood in this area. The watershed is bordered by mountains at south and north, and the elevations descent from west to east. The South Branch of Censhui Creek originates from Yanzi Village, Shimen County. It flows in the valley eastwards through 5 towns and enters into Wangjiachang Reservoir. The creek consists of 3 main tributaries. The tributary 1 is located at the most upstream. It flows mainly through Shimen County. The watershed is predominately wooded mountainous area covered with light to dense trees and grass. The flash flood early-warning stations are marked as A~C. Station A is located near the mouth of the watershed; the recipient of the warning is a business; station B is located at the confluence of the tributary 2 and the main creek. Its recipient is a river pier; station C is located at the confluence of the tributary 1 and the main creek. Its recipient is a corporation. There was a stream gage station, Lianhuayuan Station, located east of warning station B on the main creek (refer to Figure 2).

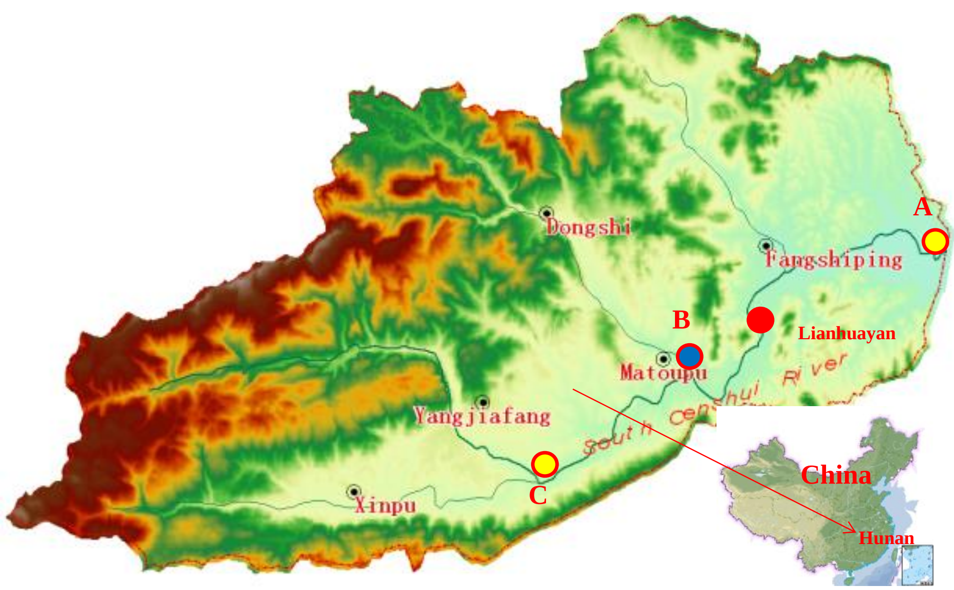

Figure2 Sketch of south branch of Censhui Watershed

In the past, this watershed has been frequently attacked by flash flood. Major flood damage has resulted during the storms of 1909, 1935, 1954, 1963, 1966, 1980, 1983, 1998 and 2003. The hydrologic data of the Lianhuayan Station indicates that during 1909's flash flood event, the recorded peak discharge and river stage reached 1980m^3/s and 94.32m, respectively; during 1935's event, the peak discharge and river stage reached 1290m^3/s, and 93.35m, respectively; during 1966's event, the peak discharge and river stage reached 667m^3/s and 93.11m, respectively.

3.2 Model Development and Calibration

3.2.1 Model Development

HEC-HMS computer software developed by USACE was used to conduct this research. According to river networks and its 3 specific spatial location of the early-warning objects, watershed is divided into 8 sub- basins, 4 river reaches, and 5 junction points. The schetch of the model basics and early-warning objects are illustrated in Figure 3. The SCS curve number method was used to compute the loss before the start of runoff; The SCS unit hydrograph transform method was used to estimate surface runoff; the exponential recession model was used to calculate watershed Baseflow. The major characteristics for each subbasin are listed in Table 1.

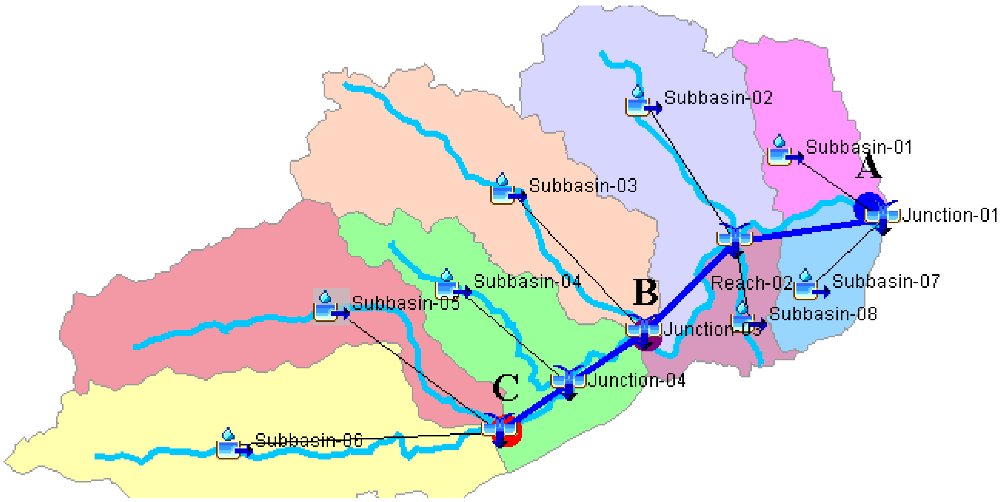

Figure 3 Watershed Delineation and Early Warning Stations

Table 1 Major characteristics for Censhui Watershed Sub-basins

No	Sub-basin	Area (km^2)	CN	Impervious Area (%)	Land Cover	Total Volume	Direct Runoff	Base Flow
1	sub-1	13.90	75	9	Wood/Grassland	SCS CN	SCS UH	Recession
2	Sub-2	38.37	75	8	Wood/Grassland			
3	Sub-3	40.84	75	10	Wood/Grassland			
4	Sub-4	27.80	82	8	Wood/Grassland			
5	Sub-5	38.38	75	8	Wood/Grassland			
6	Sub-6	44.75	75	6	Wood/Grassland			
7	Sub-7	9.74	75	6	Wood/Grassland			
8	Sub-8	9.59	75	5	Wood/Grassland			

The flood flow was routed through river reaches with the kinematic-wave method. Table 2 presents name, length, slope, shape of cross section, side-slope for each river reach.

Table 2. Major Characteristics for Each River Reach

No	River Reach	Length （m）	Slope (‰)	Cross-Section	Bottom Width(m)	Side-Slope (H:V)	Routing Method
1	R-1	2734	4.0	Trapezoidal	50.0	1.9	Kinematic wave
2	R-2	3216	1.6		38.0	1.0	
3	R-3	5626	5.0		50.0	1.3	
4	R-4	5536	4.9		80.0	1.1	

3.2.2 Model Calibration

All parameters used in the hydrological analyses were set according to the reference of HEC-HMS manual, so as the specified conditions concerning the analyses in the watershed. Figure 4 demonstrates the comparison between the computed and field measured flood hydrograph at Lianhuayan Station, during June 26-27, 1966 event. As illustrated in Figure 4, both computed temporal and numeric results of the peak discharge were well agreed with the measured data, which indicates the model was reliable for further analyses.

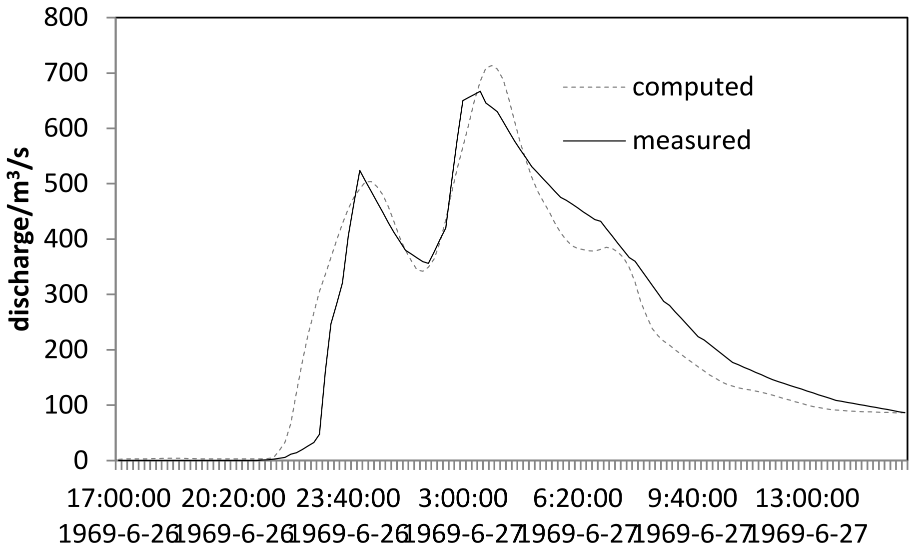

Figure 4 Comparison between the simulated and measured flood process at Lianhuayan Station, on June 26 and 27, 1966

4. CRITICAL RAINFALL ANALYSIS

4.1 Warning Rainfall Duration Determination

Durations of critical rainfall are related to various factors such as: catchment area and shape, rainfall intensity, topography, vegetation, soil type, etc. The rainfall-runoff processes for small basins are largely governed by basin topography and water course characteristics, and the time of concentration of the basin has a significant impact on basin warning rainfall duration. Time of concentration can also be used as the longest warning rainfall duration for early warning. In addition, a series of shorter leading times should also be considered based on factors such as rainstorm characteristics, basin area, basin slope, shape factors, surface conditions, etc.

Using rainfall intensity described in "Storm and Flood Bulletin of Hunan Province" (Department of Water Resources and Hydropower, Hunan, 1984) and Rational Method, the time of concentration for the watershed is estimated to be 5 hours. In this study, the rainfall duration of 1 hour, 3 hours, 6 hours, and 12 hours were chosen as warning rainfall duration.

4.2 Warning Discharge Threshold Calculation

The threshold discharges for early warning at 3 early warning stations (A, B, C) were determined based on the threshold river stage and the river cross section at each location. Manning's Formula was used to convert threshold river stage to threshold discharge. The results are listed in Table 3.

Table 3. Summary of Threshold Discharge at Each Early Warning Stations

Warning Station	River Slope ‰	Manning's n	Ave. Velocity m/s	Cross Section Area m^2	Threshold Flow m^3/s	Local Name
A	0.86	0.035	2.87	470	1347	Long Pond
B	2.5	0.035	2.90	81.4	670	Matou Town
C	4.5	0.045	4.12	120	494	Yanma Border

4.3 Soil Moisture Content Consideration

Soil moisture content has a significant impact on watershed runoff, and consequently, will affect the critical rainfall. Due to lack soil moisture information, 3 scenarios were considered in this study: 1) dry antecedent soil moisture, simulating drought preceding condition; 2) normal antecedent soil moisture, simulating normal preceding condition; and 3) wet antecedent soil moisture, simulating wet preceding condition. Watershed maximum storage capacity (Im) of 100 mm was obtained from "Rainfall-Runoff Bulletin of Hunan province" (Department of Water Resources and Hydropower, Hunan, 1984). Based on the maximum storage capacity of the watershed, the watershed storage capacities are set as 50mm for scenario 1, 75mm for scenario 2, and 90mm for scenario 3. Consequently, the initial loss for 3 scenarios are 50mm, 25mm, and 10mm, respectively.

4.4 Rainfall Pattern and Intensity Analysis

As described in Section 2 of this paper, the 24-hour precipitation series was constructed by assuming an initial total rainfall value and distributing the total rainfall value to each time step based on the rainfall pattern. The warning periods of 1-hour, 3-hours, 6-hours, and 12-hours were converted from 24-hour rainfall (Department of Water Resources and Hydropower, Hunan, 1984). The rainfall pattern used in this study is summarized in Table 4.

Table 4. Rainfall Patterns used in Critical rainfall Analysis

<table>
<tr><td>Δt=15min</td><td colspan="4">t_c=1 hour</td><td colspan="3" rowspan="3">/</td></tr>
<tr><td>Duration</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>Rainfall (%)</td><td>16</td><td>30</td><td>32</td><td>22</td></tr>
<tr><td>Δt=30min</td><td colspan="6">t_c=3 hour</td><td rowspan="4">/</td></tr>
<tr><td>Duration</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>Equivalent to 1H(%)</td><td></td><td></td><td>38</td><td>62</td><td></td><td></td></tr>
<tr><td>Equ. to(H3-H1)(%)</td><td>21.7</td><td>35.5</td><td></td><td></td><td>26.6</td><td>16.2</td></tr>
</table>

Δt=30min	t_c=6 hour											
Duration	1	2	3	4	5	6	7	8	9	10	11	12
Equivalent to 1H(%)							38	62				
Equ. to(H3-H1)(%)					21.7	35.5			26.6	16.2		
Equ. to (H6-H3)(%)	16	17	18	20							15	14
Δt=60min	t_c=12 hour											
Duration	1	2	3	4	5	6	7	8	9	10	11	12
Equivalent to 1H(%)					100							
Equ. to(H3-H1)(%)				49.2		50.8						
Equ. to (H6-H3)(%)							39.8	31.1	29.1			
Equ. to (H12-H6)(%)	11.3	19.1	19.1							29.6	13.9	7

(t_c is total rainfall duration，Δt is rainfall time step，H1 is 1 hour rainfall depth，and so on)

4.5 Results

Using hydrological model, the critical rainfall values at 3 warning stations (A, B, and C) were simulated for above described 3 scenarios. The results are presented in Table 5. The results are summarized as follows:

(1) For drought condition (scenario 1), 1-hour critical rainfall at station A, B, and C are 111mm, 89mm, and 111mm, respectively; 3-hour critical rainfall are 140mm, 112mm, and 126 mm, respectively；6-hour critical rainfall are 151mm, 123mm, 140 mm, respectively；12-hour critical rainfall are 201mm, 167 mm, 191 mm, respectively.

(2) For normal condition (scenario 2), 1-hour critical rainfall at station A, B, and C are 89mm, 69mm, and 80mm, respectively; 3-hour critical rainfall are 116mm, 90mm, and 105 mm, respectively；6-hour critical rainfall are 128mm, 100mm, 115 mm, respectively；12-hour critical rainfall are 170mm, 135 mm, 156 mm, respectively.

(3) For wet condition (scenario 3), 1-hour critical rainfall at station A, B, and C are 77mm, 57mm, and 68mm, respectively; 3-hour critical rainfall are 102mm, 77mm, and 90 mm, respectively；6-hour critical rainfall are 116mm, 88mm, 102 mm, respectively；12-hour critical rainfall are153mm, 118 mm, 139 mm, respectively.

Table 5 Summary of Critical rainfall at Each Early Warning Station

Location		A			B			C		
Warning Discharge (m^3/s)		1347			670			494		
Soil Moisture Content		Mc	Md	Mw	Mc	Md	Mw	Mc	Md	Mw
Critical Rainfall (mm)	1h	89	111	77	69	89	57	80	100	68
	3h	116	140	102	90	112	77	105	126	90
	6h	128	151	116	100	123	88	115	140	102
	12h	170	201	153	135	167	118	156	191	139

（* Md, Mc, Mw represent drought, normal, and wet condition, respectively.）

Table 5 demonstrates the following trends:

(1) For all 3 scenarios, critical rainfall increases as warning duration increases. (2) Antecedent soil condition impacts critical rainfall significantly. Figure 5 depicts the differences of critical rainfall under 3 scenarios. The first graph plots the difference of critical rainfall between normal and wet condition; it shows a difference of 10mm for rainfall durations not exceed 6 hours. The second graph depicts the difference of critical rainfall between drought and normal condition; it indicates a difference of 20mm for rainfall durations not exceed 6 hours. The third graph is the difference of critical rainfall between drought and wet condition; it demonstrates a difference of 30mm for rainfall durations not exceed 6 hours. For rainfall duration of 12-hour, all 3 graphs show a larger difference than shorter rainfall durations. It is concluded that the antecedent soil moisture condition plays an important role in the forecasting of flash flood; and therefore, special attention should be given to it in the early warning determination.

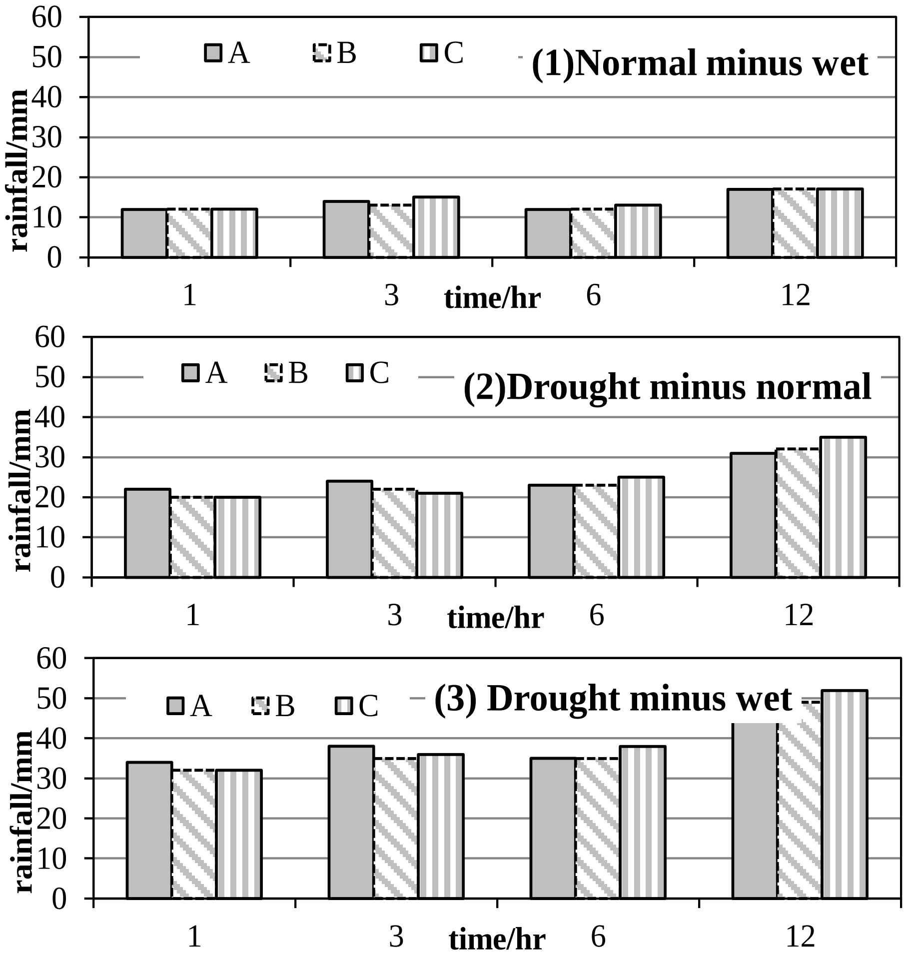

Figure 5. Critical rainfall difference in 3 scenarios

5. RESULTS APPLICATION

As accurate as the tabular format is, it is not most preferred format to real-world application. Graphical format, on the contrary, is more visual and user-friendly. Therefore, the results were plotted in Figure 6. According to a previous research for this region (Department of Water Resources, Hunan, 1984), 80% of time the antecedent soil moisture condition belongs to the normal condition. Therefore, the Scenario 2 –

normal condition results should be used; the results from other 2 scenarios should be considered as references when reaching final warning decisions.

The last graph in Figure 6 is an application schematic. The thick-solid line represents the cumulative rainfall; the dashed line represents critical rainfall. When the cumulative rainfall intersects critical rainfall, a warning should be issued. From this graph, if the cumulative rainfall does not exceed critical rainfall, when an event (as 1h, and 3h, and 6h, and 12h,) is predicted, the cumulated rainfall can be predicted as well, and the results will show whether or not the cumulative rainfall will exceed critical rainfall, and in turn, an early warning decision can be made. In order to achieve dynamic rainfall alert, this information should be updated at regular intervals.

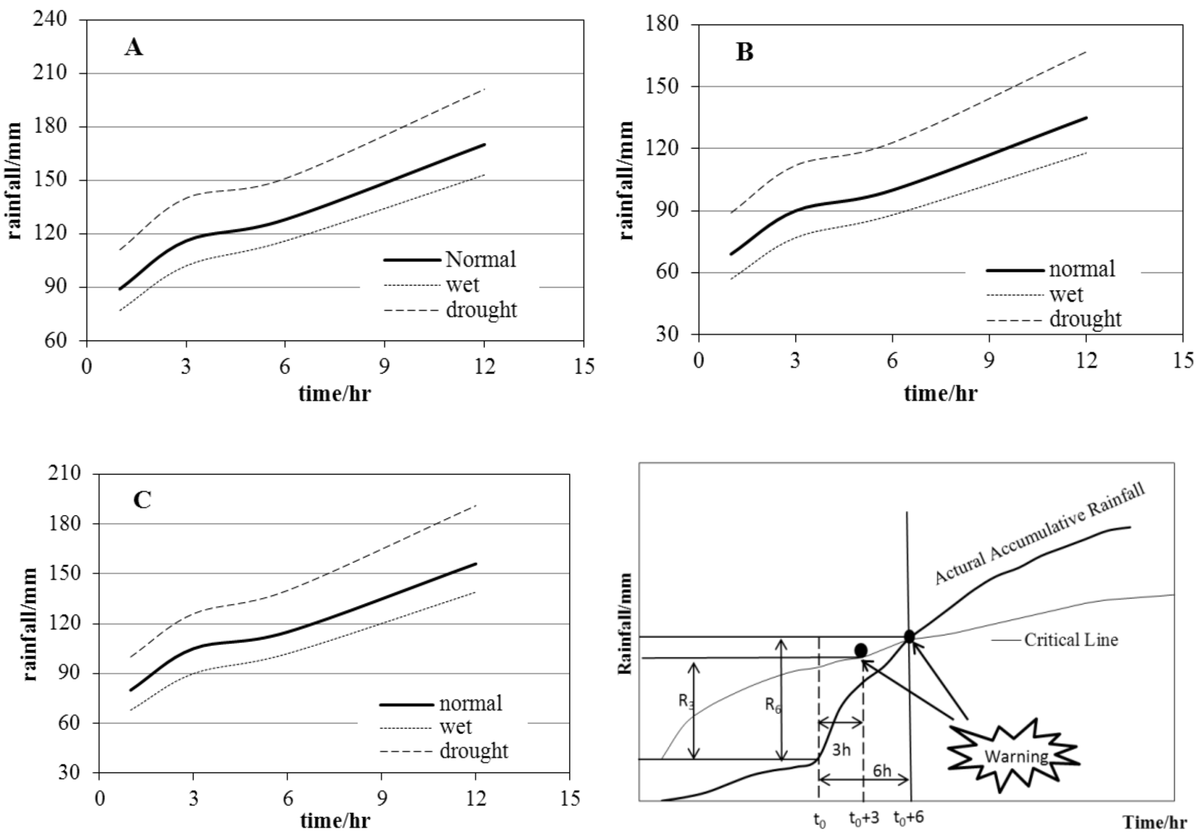

Figure 6 Schematic application of Critical rainfall at 3 Warning Stations

6. CONCLUSIONS

This paper initiated by summarizing critical rainfall analysis methods that are commonly used currently and reviewed flash flood forecasting and early warning progress in China. The research concept and approach using detailed hydrological model to analyze critical rainfall was introduced. Taking the South Branch of Censhui watershed as an example, the method was illustrated by analyzing critical rainfall at 3 early warning stations inside the watershed. The outcomes of this study are as follows:

(1) By delineate watershed into smaller sub-basins, the spatial variation of major watershed characteristics can be considered, and the rainfall-runoff process and flood hydrograph at different locations can be better simulated. For small mountainous watershed with spatial complexity, this method can improve the accuracy of the early warning; (2) in this method, the critical rainfall value is obtained by reverse calculation using simulated flood information. Therefore, the warning discharge and warning

rainfall duration at early warning stations are important. The impact factors include basin topography, land use and land cover, water course characteristics. In addition, the time of concentration of the basin is an important warning rainfall duration; (3) this study utilizes maximum storage capacity of the watershed and the antecedent soil moisture conditions to estimate soil moisture content. The results confirm that soil moisture content at watershed scale has significant impact on critical rainfall estimation. Moreover, the critical rainfall values increase as warning durations increase, regardless the antecedent soil moisture condition.

While the proposed method is promising, there are also needs for improvements. Due to the complexity of the mountainous terrain, data collection and classification need to be refined. Soil moisture estimation method should be further enhanced. The parameter setting for runoff and flood routing process, as well as model calibration and validation need in-depth study. In addition, the rainfall series generation should also be improved with better accuracy. In order to provide dynamic flash flood early warning with better accuracy in China, detailed research should concentrate on real-time access of soil moisture content and dynamic rainfall information.

ACKNOLOGEMENTS

Thanks for finical support of project “Theory and Method on Basin Level Flood and Drought Hazard Risk Management” (Jian No.0101092013), and project “National Flash Flood Hazard Prevention and Control (2013-2015)” and The National Natural Science Foundation project (No. 51021006).

REFERENCES

Carpenter, T.M., Georgakakos, K.P., 1993. GIS-based procedures in support of flash flood guidance [R]. IIHR Report No. 366, Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, IA, November, 170 pp.

CHEN G.Y. YUAN Y. M. Research on critical precipitation amount computation method of mountain torrential flood disaster [J]. Yangtze River. 2005, 36(12):40-43. (In Chinese)

FAN Z. C., WU M. F. 2001. Study on relationship between critical rainfall line and hazard factors of debris flow in first order stream [J]. Journal of Chinese Soil and Water Conservation, vol.32(3): 227-234. (in Chinese)

FLOODsite. Realtime Guidance for Flash Flood Risk Management [R]. March 2008.

Georgakakos, K. P., 1992. Advances in forecasting flash floods [C]. In Proceedings of the CCNAA-AIT Joint Seminar on Prediction and Damage Mitigation of Meteorologically Induced Natural Disasters, 21-24 May 1992, National Taiwan University, Taipei, Taiwan, 280-293.

Hubei Provincial Institute of Water Resources Reconnaissance and Design. 1985. Handbook on Tables and Figures for rainstorm and runoff in Hubei Province, China.（In Chinese）

Hunan Provincial Department of Water Resources and Hydropower. 1984. Handbook on Tables and Figures for Rainfall and Flood in Hunan Province, China.（In Chinese）

JAN, C. D., LEE, M. H., WANG, J. S., WANG, C. L. A Rainfall-Based Debris-Flow Warning Model and Its Application in Taiwan [C]. 2004, International Conference on Slope Disaster Mitigation Strategy, pp.111-119, Taipei.

JAN, C. D., LEE, M. X., GUO F.H. 2006. Rainfall Warning Mode for Spatial and Temporal Characteristics of Debris Flow [J]. Geotechnical technology. vol.110(3): 55-64. (in Chinese)

Japan National Institute for Land and Infrastructure Management. Operating methods of Critical rainfall for Warning and Evacuation from Sediment-Related Disasters [R]. No.5 September 2001.

JIANG J. H. SHAO L. P. 2010. Standard of mountain flood warning based on the precipitation observation data [J]. Journal of Hydraulics. Vol.41(4):458-463. (In Chinese)

Konstantine P. Georgakakos. 2006. Analytical results for operational flash flood guidance [J]. Journal of Hydrology. Vol.317:81–103.

Sperfslage, J. A., Georgakakos, K. P., Carpenter, T. M., Shamir, E., Graham, N. E., Alfaro, R., and L. Soriano. 2004. Central America Flash Flood Guidance (CAFFG) User's Guide [R]. HRC Limited Distribution Report No. 21. Hydrologic Research Center, San Diego, CA, 82pp.

Sweeney, T. L., 1992. Modernized areal flash flood guidance [R]. NOAA Technical Report NWS HYDRO 44, Hydrology Laboratory, National Weather Service, NOAA, Silver Spring, MD, 21 pp.

T.M. Carpentera, J.A. Sperfslagea, K.P. Georgakakosa. et. al. National threshold runoff estimation utilizing GIS in support of operational flash flood warning systems [J]. Journal of Hydrology. Vol.224 (1999) 21–44.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. Modernized Areal Flash Flood Guidance [R]. October, 1992.

WANG X. CAO Z.X. TAN G. M. 2009. Shallow water hydrodynamic modelling of rainfall induced flash flooding [J]. Engineering Journal of Wuhan University. Vol.42(4): 413-416. (In Chinese)

XIE Z.L., LU Y. Z., YOU B. S., et al. 1995. Study on critical rainfall line for soil and debris flow [J]. Journal of Chinese Soil and Water Conservation, Vol.26(3): 167-172. (in Chinese)

YE Y. WANF Z. Y. FAN B. Q. 2008. Flash Flood Critical Rainfall Estimation for small Watershed in Jiangxi Province . [J]. Journal of Hydrology，2008，28(1): 56-58.