Journal of Agricultural Science and Technology A 5 (2015) 646-654
doi: 10.17265/2161-6256/2015.08.002

Effects of Erosion Control Measures on Mountain Floods: A Case Study of the Censhui River South Branch Watershed

Changzhi Li, Hong Wang, Baozhao Yuan, Dongya Sun and Changjun Liu

Department of Water Disaster Reduction, China Institute of Water Resources and Hydropower Research, Beijing 100038, China

Abstract: To investigate the effects of various erosion control measures on mountain floods, a case study was conducted in Censhui River South Branch Watershed using scenario analysis and soil conservation service (SCS) methods. A distributed hydrological model was developed, and watershed parameters were determined based on satellite imagery, digital terrain models, digital maps and field investigations. Two types of erosion control measures were investigated: the variation of vegetation covers and the change of cultivation techniques. Seven scenarios were considered for the test watershed. The results show: (1) while the de-vegetation results in the increase of peak discharge, the improve of vegetation covers decreases peak discharge at watershed scale; (2) by both improving vegetation cover and enhancing terrace-cultivation technology, the peak discharge is reduced and the peak flow arrival time is delayed; (3) attention should be attached to both early warning system and measures changing the underlying surface and conveyance systems.

Key words: Watershed, soil and water conservation, mountain flood, erosion control measures, scenario analysis.

1. Introduction

Mountain flood is often characterized as a sudden occurrence that causes severe threats to lives and properties as well as far-reaching impacts to social and economic developments in mountainous regions. Many efforts for understanding critical rainfall and for conducting early warning had been presented [1-6]. However, the increase of the mountain flood runoff is also related to the changes of the physical features of the watershed or catchment [7]. Altering erosion control measure in mountainous regions is one of the main human actions that may impact mountain flood runoff. Various studies investigated impacts of watershed parameter changes to the runoff characteristics using variety of modeling simulation tools [8, 9]. Other researches presented relationships between catchment vegetation types and variabilities of annual runoff [10, 11]. Efforts were also presented in the area of conjunctive use of surface and groundwater resources [12], as well as the optimization of erosion control measures for minimizing peak discharge in a watershed [13]. Many erosion control measures, such as ecological recovery, restoring farmland to forests or grassland, arbor-shrub-grass compounding and transforming mountain slopes into terraces or check dams, are feasible to alter both the interception and depression features of a catchment, as well as its conveyance systems [14] and infiltration capacities [15].

China has the most interesting topography with vast mountain ranges that occupy two-thirds of the nation's land and cover 56% of the nation's population. Many of these regions are flood-prone. Consequently, mountain flood has been one of the most deadly natural disasters and are taking an increasing roll in claiming lives and causing severe damages each year. In recent years, China has directed its attention to mountain floods and shifted its policy from flood control to flood management with an emphasizing on

Corresponding author: Changzhi Li, Ph.D., research field: flood defense.

the prevention of the disasters, such as preserving and restoring vegetation in mountainous regions. Although the qualitative responses of mountain floods to the changes of watershed parameters have been discussed in many researches [16-18], a few of these presented quantitative responses.

Using scenarios analysis and soil conservation service (SCS) methods (including runoff volume and direct runoff computation), this research presents a quantitative method for the assessment of responses of mountain flood runoff to erosion control measures in the South Branch of Censhui Watershed in Hunan province, China.

2. Research Concepts and Approaches

The basic concepts and approaches for this study are as follows: (1) developing typical design rainstorm and the rainfall pattern in the study area as the input data; (2) establishing various scenarios of parameter changes along with the current parameter in the test watershed; (3) constructing distributed hydrological model to simulate mountain flood runoff at significant points of interests in the watershed; (4) comparing results of different scenarios against the current situation of the test watershed.

Design rainstorm and rainfall pattern were determined according to local hydrological manual [19].

Typical scenarios were established to simulate mountain floods runoff by selecting various erosion control measures in the watershed. In this study, the erosion control measures refer to vegetation covers and the change of cultivation techniques. The vegetation cover change refers to either vegetation improved or deteriorated with increasing and/or decreasing vegetation cover rates; the improvement of cultivation techniques refers to transforming mountain-side croplands into terraces.

The SCS model was used in this study due to its simple structure and wide availability of input data. The key variable, curve number (CN) in SCS model is directly related to the land use, soil type and soil moisture content in a watershed, which can represent various erosion control scenarios.

Distributed hydrological model was chosen to simulate mountain flood at various locations of interests within the watershed. Special attention was attached to the following during the model development: (1) in the process of sub-basin delineation, the geographical locations of the location of interests were appropriately considered as well as the river sections, source and sink points, tributary confluences and diversions; (2) many factors were taken into consideration when estimating input parameters for each sub-basin, such as topographical features, vegetation covers, land uses types, soil types and river channel characteristics; (3) historical precipitation-runoff data and rainstorm event were carefully chosen for model calibration and validation.

3. Mountain Flood Simulations for Erosion Control Measures

3.1 Description of Study Area

Located in Hunan province with a drainage area of 223 km^2 and the longest flow path of 33.6 km, Censhui River South Branch Watershed is a wet subtropical monsoon climate region with an annual precipitation of 1,200-1,900 mm. Rainfall concentrates in summers, and heavy storms often trigger mountain floods in this area. The watershed is bordered by mountains at West, South and North sides, and the elevations descent from West to East. The South Branch of Censhui creek originates from Yanzi village, Shimen county, which flows in the valley eastwards through five towns and enters into Wangjiachang Reservoir. The creek consists of three tributaries with tributary 1 located at the headwater area, the tributary 2 at the middle reach and the tributary 3 at the lower reach. The watershed is predominately wooded mountainous area covered with light to dense trees and grass. The soil structure consists of clay loams and shallow sandy loams. The significant locations of interests are marked as station A and station B in the watershed. Station A is located near the mouth of the watershed, the backwater area of Wanjiachang Reservoir; the recipient of the warning is a business; station B is located near the confluence of the tributary 2. The two sections of the town are connected by a bridge that crosses over the tributary. Based on a preliminary estimation, the maximum flow passing through the bridge opening freely without restriction bears a return period of 50 years approximately [20]. There was a hydrologic station, Lianhuayan station, located between station B and station A on the main creek; this hydrological station was removed after the construction of Wangjiachang Reservoir around 1980 [20]. Fig. 1 presents the sketch of Censui River South Branch Watershed.

The bank-full discharge at station A and station B were estimated using Manning's formula and field investigation data of critical water stages at locations A and B. The results are presented in Table 1.

In the past, this watershed has been frequently attacked by mountain floods. Major flood damages occurred during the storms of 1909, 1935, 1954, 1963, 1966, 1980, 1983, 1998 and 2003. The hydrologic data of the Lianhuayan station indicate that during 1909's flood event, the recorded peak discharge and river stage reached 1,980 m^3/s and 94.32 m, respectively; during 1935's event, the peak discharge and river stage reached 1,290 m^3/s and 93.35 m, respectively; during 1966's event, the peak discharge and river stage reached 667 m^3/s and 93.11 m, respectively [20].

3.2 Model Development and Calibration

3.2.1 Model Development

HEC-HMS computer software developed by United States Army Corps of Engineers (USACE) was used to conduct this research due to its flexibility and commonality for rainfall-runoff simulation. Considering river network and the location of two stations, the watershed is divided into eight sub-basins, four river reaches and five junction points. The sketch of the model basics and the places of interests are illustrated in Fig. 2.

The SCS CN method was used to compute the initial loss before runoff started; the SCS unit hydrograph transform method was used to estimate surface runoff; the exponential recession model was used to calculate watershed base flow. The major characteristics for each sub-basin are listed in Table 2. Table 2 also makes station B as the dividing point of upper and lower reaches for mainstream.

The flood flow was routed through river reaches with the kinematic-wave method for the channel slope of the tributary is considerably steep. Table 3 presents the detailed key information for each river reach, including name, length, slope, shape of cross section and side-slope.

3.2.2 Model Calibration

All parameters used in hydrological analyses were initially set according to the technical reference manual of HEC-HMS [21], so as the specified conditions concerning with the analyses in the watershed. Then, the key parameters were calibrated using historical stream flow data at Lianhuayan hydrological station and the corresponding rainfall data at Liangshuijing rain gauge station, during June 26-27, 1966 flood event. The objective functions provided by HEC-HMS computer software include sum of absolute errors, sum of squared residuals, percent error in peak and peak-weighted root mean square error, which were all used to find the reasonable

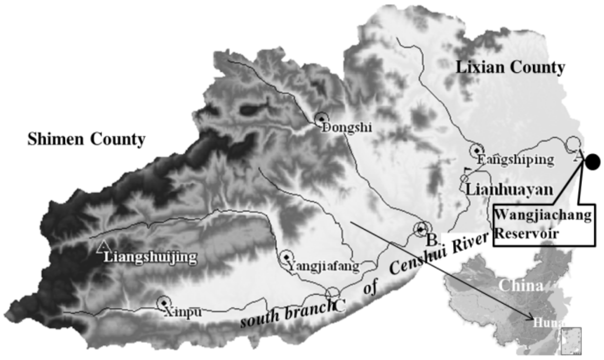

Fig. 1 Sketch of Censhui River South Branch Watershed.

Table 1 Bank-full discharges at stations A and B.

Station	Slope (‰)	Roughness (n)	Average velocity (m/s)	Flow area (m^2)	Discharge (m^3/s)
A	0.86	0.035	2.87	470	1,347
B	2.50	0.035	2.90	231	670

Table 2 Major characteristic of sub-basins in Censhui River South Branch Watershed.

No.	Sub-basin	Area (km^2)	Initial CN	Calibrated CN	Impervious area (%)	Land cover	Total volume	Direct runoff	Base flow	Note
1	Sub-1	13.90	75	/	9	Wood/grassland				Lower reach
2	Sub-2	38.37	75	/	8	Wood/grassland				
3	Sub-3	40.84	75	71	10	Wood/grassland				
4	Sub-4	27.80	82	77	8	Wood/grassland	SCS CN	SCS UH	Recession	Upper reach
5	Sub-5	38.38	75	71	8	Wood/grassland				
6	Sub-6	44.75	75	71	6	Wood/grassland				
7	Sub-7	9.74	75	/	6	Wood/grassland				Lower reach
8	Sub-8	9.59	75	/	5	Wood/grassland				

The sign "/" means the non-calibrated CN value for the sub-basins are in the downstream of Lianhuayan station; SCS CN: curve number of SCS; SCS UH: unit hydrograph of SCS.

Table 3 Major characteristics for each river reach.

No.	Reach	Length (m)	Slope (‰)	Shape of cross-section	Width of cross section (m)	Side slope (H:L)	Routing method	Note
1	Reach 1	2,734	4.0		50.0	1.9		Upper reach
2	Reach 2	3,216	1.6	Trapezoidal	38.0	1.0	Kinematic wave	
3	Reach 3	5,626	5.0		50.0	1.3		Lower reach
4	Reach 4	5,536	4.9		80.0	1.1		

H: depth; L: horizontal distance.

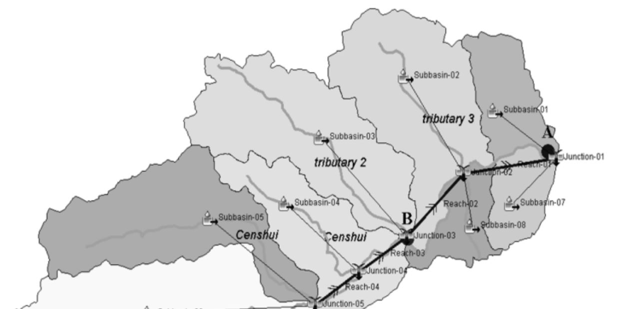

Fig. 2 Watershed delineation and locations of interests.

parameters that yield the minimum value of the objective function. In this study, the best function is the sum of absolute errors. Table 1 presents calibrated CN values, while Fig. 3 demonstrates the comparison between the computed and field measured flood hydrograph at Lianhuayan station. As illustrated in Fig. 3, both computed temporal and numeric results of the peak discharge were well agreed with measured data, which indicates that the model was reliable for further analyses.

3.3 Erosion Control Measure Scenarios

This study considered seven scenarios with various vegetation cover rates and cultivation techniques. These scenarios are as follows:

(1) Using current vegetation cover type and cover rate and current cultivation technique at watershed scale. The current vegetation cover is fair-conditioned woods-grass combination with a cover rate approximately 60%; most of the farmland is slope cropland;

(2) While cultivation techniques remain identical with current condition, the vegetation cover rate degenerating to lower than 50% at watershed scale;

(3) While cultivation techniques remain identical with current condition, the vegetation cover rate improving

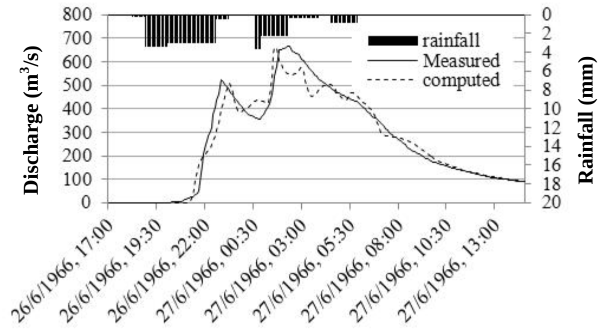

Fig. 3 Comparison between the computed and measured flood process at Lianhuayan station, on June 26-27, 1966.

up to 75% at watershed scale;

(4) While cultivation techniques remain identical with current condition, the vegetation cover rate degenerating to lower than 50% in the upper reach, and maintaining current condition in the lower reach;

(5) While cultivation techniques remain identical with current condition, the vegetation cover rate degenerating to lower than 50% in the lower reach, and maintaining current condition in the upper reach;

(6) While vegetation cover remains identical with current condition, the cultivation techniques improved, that is, most slope croplands were transformed into terraces at watershed scale;

(7) Vegetation cover improves with woods-grass cover rate up to 75%, and most slope croplands were transformed into terraces at watershed scale.

The parameter values in the SCS model were set based on the field investigation and are presented in Table 4. The field investigation information and refinement on CN value in China's recent years study [22-24] were taken into consideration for CN set in this study; and the consideration on parameters for vegetation interception depends mainly on Ref. [25].

3.4 Rainfall Event

Rainfall pattern and intensity-duration are identical for all scenario analyses and were determined according to the manual for rainstorm-runoff analysis in Hunan province [19]. Using rainfall intensity described in the manual and rational method, the time of concentration for the watershed was generally estimated as Eq. (1):

$$\tau = 0.278\frac{L}{V_\tau} = 0.278\frac{L}{mJ^\alpha Q_m^\beta} \qquad (1)$$

where, τ: time of concentration (h); L: the longest distance from the river mouth to the divide of basin (km); J: the mean slope of L; m: empirical parameter for concentration; Q_m: peak discharge at the outlet of a watershed (m^3/s); α, β: experimental exponent, 1/3 and 1/4 for triangular cross section in mountainous and hilly area.

According to Chen and Zhang [22], mean concentration velocity at basin level (v_τ) is used to reflect the characteristics of slope concentration and

Table 4 Typical scenarios setting.

No.	Interception (mm)	Depression (mm)	CN value		Scenarios description
S1	0.50	0	76	All sub-basins	Current situation
S2	0.25	0	82	All sub-basins	Cultivation way has no change, vegetation cover rate lower than 50% at watershed scale
S3	1.25	0	72	All sub-basins	Cultivation way has no change, vegetation cover rate over 75% at watershed scale
S4	0.25	0	82	Sub-basins 4, 5, 6	Cultivation way has no change, vegetation cover rate lower than 50% in upper reach, and maintaining current situation in lower reach
	0.50	0	76	Sub-basins 1, 2, 3, 7, 8	
S5	0.25	0	82	Sub-basins 1, 2, 3, 7, 8	Cultivation way has no change, vegetation cover rate lower than 50% in lower reach, and maintaining current situation in upper reach
	0.50	0	76	Sub-basins 4, 5, 6	
S6	0.50	2	76	All sub-basins	Vegetation cover keeps unchanged, but farming measures improve at watershed scale
S7	1.25	2	72	All sub-basins	At watershed scale, vegetation cover rate over 75% and farming measures improves

Table 5 Time of concentration estimation.

L (km)	J (‰)	m	Q_m (m^3/s)	α	β	τ (h)
33.6	7	1.6	1,347	1/3	1/4	5.05

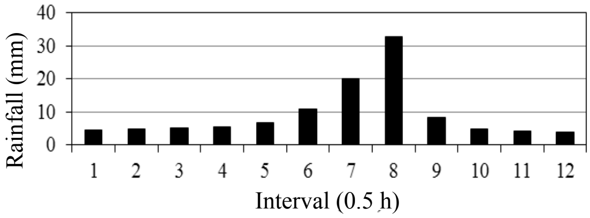

Fig. 4 Design rainstorm pattern.

channel concentration, as Eq. (2):

$$v_\tau = mJ^\alpha Q_m^\beta \quad (2)$$

Table 5 presents parameter values for time of concentration estimation and indicates the time of concentration for this watershed is over 5 h. Hence, the time of concentration of the watershed was estimated as 6 h in this study. Peak discharge Q_m is taken as 1,347 m^3/s, which is also considered as the bank-full discharge at station A and at the outlet of the watershed. This peak discharge is similar to the peak discharge (1,290 m^3/s) in 1935 flood event with a return period of 50 years [20].

As a result, the design rainfall with a return period of 50 years and duration of 6 h ($P_{6,\ 2\%}$) was used in this study to analyze the variation of mountain flood for various scenarios. According to the manual [19], the rainfall intensity of ($P_{6,\ 2\%}$) reaches 169 mm. Fig. 4 illustrates the design rainfall pattern with a time interval of 0.5 h for the studied watershed.

4. Results and Discussion

The simulation results for all scenarios are presented in Fig. 5 and Table 6. While Figs. 5a, 5c and 5e are the rainfall-runoff processes at station A, Figs. 5b, 5d and 5f are those at station B. Table 6 presents the variation of peak discharges for seven scenarios at both stations.

As demonstrate in Figs. 5a and 5b and Table 6, the peak discharge increases when vegetation cover deteriorates; similarly, peak discharge decreases when vegetation cover improves. For scenarios 2 and 3, which simulate vegetation deterioration and improvement, respectively, the increment and the decrement of peak discharges at station A are 258.6 m^3/s and 184 m^3/s, respectively, a 21.62% increase and a 15.38% decrease of peak discharge from current vegetative condition. Similarly, the peak discharge increases and decreases at station B are 187.3 m^3/s and 113.1 m^3/s, respectively, a 21.01% increase and 12.69% decrease from current vegetative condition.

Figs. 5c and 5d present the results from scenarios 4 and 5, which simulate local vegetation cover improving/deteriorating, as well as local vegetation cover remains current condition. As indicate in these two figures, the local vegetation deteriorations also result in considerable effect on peak discharges. Comparing two locations where vegetative cover deteriorating, the peak discharge increment is higher at upper reach than that at lower reach. Table 6 demonstrates that the peak discharges will increase when vegetation cover deteriorates in upper reach and remains current situation in lower reach; the increment of peak discharge at station A is 147.1 m^3/s (12.3%); and 133.5 m^3/s (14.97%) at station B. In addition, Table 6 also indicates that peak discharge decreases when vegetation cover remains current situation in upper reach and deteriorates in lower reach. The decrement at station A is 113.7 m^3/s (9.5%) and 36.6 m^3/s (4.10%) at station B.

Figs. 5e and 5f present the effects of vegetation and cultivation technique to peak flow at stations A and B. These figures show that terrace cultivating (scenario 6) can reduce peak flow, and a combination of both vegetation cover improving and terrace-cultivating (scenario 7) achieve better results.

In general, the peak discharge and the peak arrival time are the key factors for mountain floods. Figs. 5a, 5b, 5c and 5d demonstrate a clear variation of peak discharges; however, the variation of peak arrival times

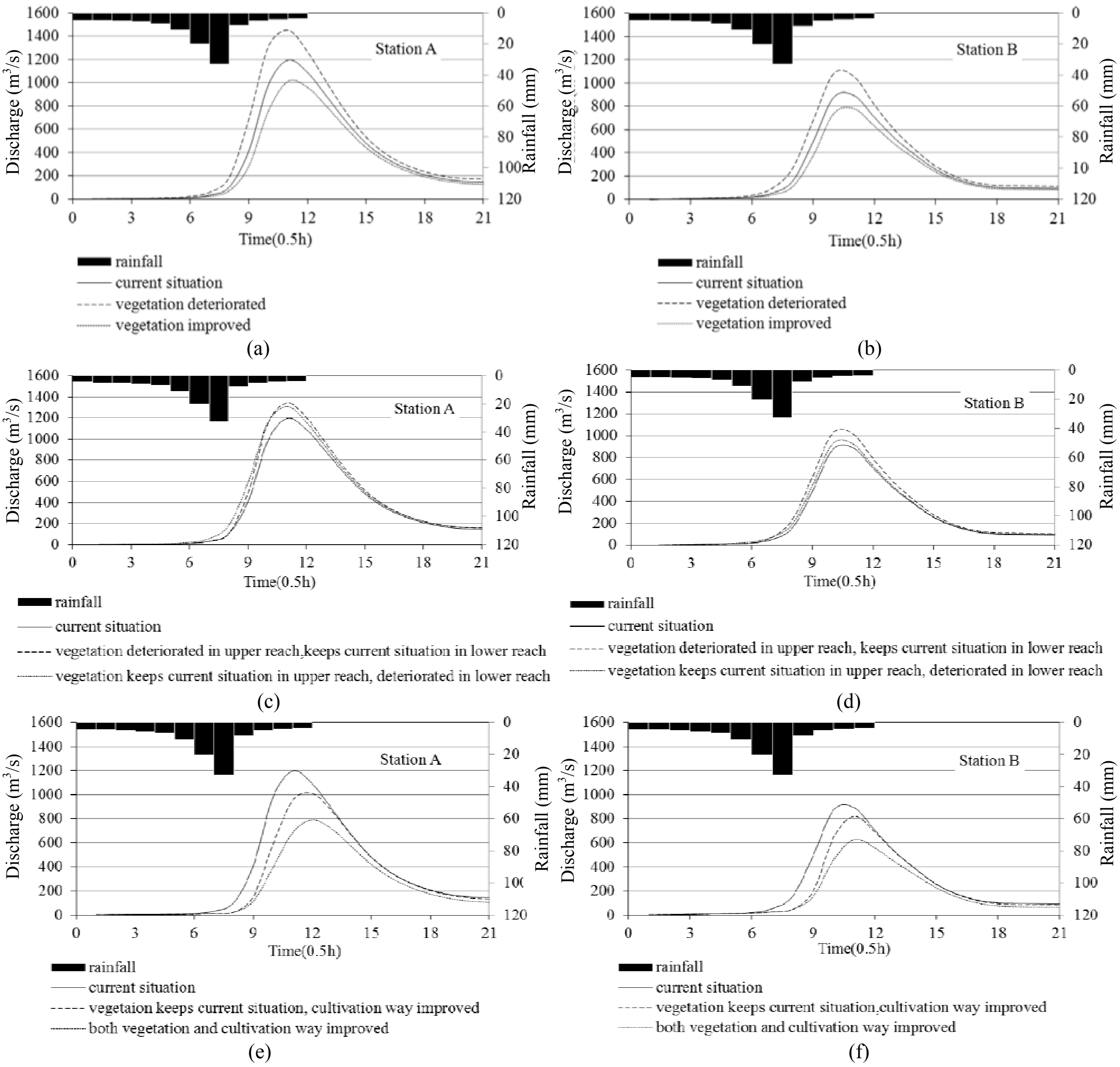

Fig. 5 Rainfall-runoff processes for seven scenarios.

Table 6 Variation of peak discharges for seven scenarios.

No.	Station A			Station B		
	Peak discharge (m^3/s)	Absolute (m^3/s)	Relative (%)	Peak discharge (m^3/s)	Absolute (m^3/s)	Relative (%)
S1	1,196.3	/	/	891.6	/	/
S2	1,454.9	258.6	21.62	1,078.9	187.3	21.01
S3	1,012.3	-184.0	15.38	778.5	-113.1	12.69
S4	1,343.4	147.1	12.30	1,025.1	133.5	14.97
S5	1,310.0	113.7	9.50	928.2	36.6	4.10
S6	1,010.1	-186.2	15.56	820.0	-71.6	8.03
S7	790.6	-405.7	33.91	628.3	-263.3	29.53

Absolute means absolute difference of peak discharge compared to scenario 1, $Q_{S_i} - Q_{S_1}$; relative means relative difference of peak discharge compared to scenario 1, $(Q_{S_i} - Q_{S_1})/Q_{S_1} \times 100$, i = 2-7.

is relatively small for scenarios with only vegetation cover change. Figs. 5e and 5f present the distinct change of peak flood in both magnitude and arrival time.

In natural world, forests and range lands of a mountainous area are components of the steady state, in which every component acts in its complete and ideal capacity. However, when these natural sources were destroyed and changed to the agricultural lands, their texture and drainage and even water retention capacity decreased. Most of the precipitation falling on the surface turns into the surface run off. This, in turn, reduces the concentration time and increases peak discharge, causing the shorter duration torrential floods. This study indicates the powerful capacity of erosion control measures in reducing and delaying peak floods in mountainous regions. As demonstrated by the results, the mountain flood control capacity at Matoupu town, a very important resident area in the watershed, should be expected to reach 50 years protection by a combination of improving vegetation cover and altering cultivation techniques at watershed scale.

5. Conclusions

The results of this study show that erosion control measures in mountainous regions play an important role in managing torrential floods. Increment of peak discharges of torrential floods were resulted from vegetation deterioration at watershed scale, while decrement was occured due to vegetation improvement; the effects of peak discharge decrement and time delay of torrential flood were clearly observed by integrated erosion control measures, for instance, improvement of vegetation cover and cultivation technique. So, for the purpose of integrative torrential flood prevention, attention should be attached not only to early warning system for emergency response, but also to those measures which are able of altering the underlying surface and the conveyance system in a watershed.

Acknowledgments

The authors are grateful to the projects of "China National Flash Flood Hazard Prevention and Control" and project "Theory and Method on Flood and Drought Hazard Risk Management at Basin Level" (Jian No. 0101092013) for their financial supports.

References

[1] Carpenter, T. M., Sperfslage, J. A., Georgakakos, K. P., Sweeney, T., and Fread, D. L. 1999. "National Threshold Runoff Estimation Utilizing GIS in Support of Operational Flash Flood Warning Systems." *Journal of Hydrology* 224 (1-2): 21-44.

[2] Gruntfest, E. 2001. "Beyond Flood Detection: Alternative Applications of Real-Time Data." *NATO Science Series* 77: 167-79.

[3] Georgakakos, K. P. 2006. "Analytical Results for Operational Flash Flood Guidance." *Journal of Hydrology* 317 (1-2): 81-103.

[4] Montesarchio, V., Lombardo, F., and Napolitano, F. 2009. "Rainfall Thresholds and Flood Warning: An Operative Case Study." *Natural Hazards and Earth System Science* 9 (1): 135-44.

[5] Nguyen, P., Sorooshian, S., Hsu, K., AghaKouchak, A., Sanders, B. F., Smith, M. B., and Koren, V. 2012. "Improving Flash Flood Forecasting through Coupling of a Distributed Hydrologic Rainfall Runoff Model (HL-RDHM) with a Hydraulic Model (BreZo)." In *Proceedings of American Geophysical Union Fall Meeting 2012.*

[6] Norbiato, D., Borgaa, M., Espostia, S. D., Gaumeb, E., and Anquetinc, S. 2008. "Flash Flood Warning Based on Rainfall Thresholds and Soil Moisture Conditions: An Assessment for Gauged and Ungauged Basins." *Journal of Hydrology* 362 (3-4): 274-90.

[7] Karalis, S., Katsafados, P., Karymbalis, E., Tsanakas, K., and Valkanou, K. 2014. "Natural and Human Causes of a Flash Flood in a Small Catchment (Rhodes Island, Greece) Based on Atmospheric Forcing and Runoff Modeling Techniques." Presented at EGU General Assembly 2014, Held on April 27-May 2, 2014, Vienna, Austria.

[8] Masoud, A. A. 2011. "Runoff Modeling of the Wadi Systems for Estimating Flash Flood and Groundwater Recharge Potential in Southern Sinai, Egypt." *Arabian Journal of Geosciences* 4 (5): 785-801.

[9] Hooke, J., Mant, J., and Sandercock, P. 2014. "Vegetation Interaction with Runoff and Flash Floods: Implications for Restoration of Drylands." Presented at EGU General Assembly 2014, Held on April 27-May 2,

2014, Vienna, Austria.

[10] Peel, M. C., McMahon, T. A., Finlayson, B. L., and Watson, F. G. R. 2012. "Implications of the Relationship between Catchment Vegetation Type and the Variability of Annual Runoff." *Hydrological Processes* 16 (15): 2995-3002.

[11] Baudena, M., and Provenzale, A. 2008. "Rainfall Intermittency and Vegetation Feedbacks in Drylands." *J. Hydrology and Earth System Sciences* 12 (2): 679-89.

[12] Onta, P. R., Gupta, A. D., and Harboe, R. 1991. "Multistep Planning Model for Conjunctive Use of Surface and Groundwater Resources." *J. Water Res. Plan. Manag.* 6: 662-78.

[13] Dumbrovský, M., and Korsuň, S. 2003. "Optimization of the System of Soil and Water Conservation for Runoff Minimizing in Certain Watershed in the Process of Land Consolidation." In *Research on Soil Erosion,* edited by Godone, D., and Stanchi, S. Publisher: InTech.

[14] Ding, W. F., Zhang, P. C., Ren, H. Y., and Fan, Y. L. 2007. "Effect of Comprehensive Watershed Control on Infiltration Rate in the Qinba Mountain Area." *Bulletin of Soil and Water Conservation* 27 (1): 11-4. (in Chinese)

[15] Zhang, X. M., Cao, W. H., and Yu, X. X. 2009. "Effect of LUCC on Runoff Regulation in Watershed in Loess Gullied-Hilly Region of China." *Shuili Xuebao* 40 (6): 641-50. (in Chinese)

[16] Gao, Y., Zhu, B., and Mu, C. Y. 2006. "Application of SCS Model to Estimate the Volume of Rainfall in Sloping Field of Purple." *Chinese Agricultural Science Bulletin* 22 (11): 396-400. (in Chinese)

[17] Qiao, G. J. 2010. "Analysis on Relationship between Landuse and Runoff." In *Proceedings of 2010 China Society of Water Resources,* 289-94. (in Chinese)

[18] Wang, R. P., Zhang, X., and Sun, C. L. 2012. "Analysis on Response of Landuse to Runoff of a Watershed." *Journal of Production and Management* 31 (12): 92-4. (in Chinese)

[19] Hunan Department of Water Resources and Hydropower (DWRH). 1984. *Manual for Rainstorm-Runoff Analysis in Hunan Province*. Changsha, Hunan: DWRH. (in Chinese)

[20] Hunan Institute of Water Resources and Hydropower Surveying and Design (IWHSD). 1987. *Design Report for Wangjiachang Reservoir Reinforcement*. (in Chinese)

[21] US Army Corps of Engineers. 2000. *Hydrologic Modeling System HEC-HMS Technical Reference Manual*.

[22] Chen, J. Q., and Zhang, G. S. 1984. *Rainstorm-Runoff Computation for Small Watershed*. Beijing: Water Resources and Hydropower Press. (In Chinese)

[23] Li, L., Dong, X. H., Yu, D., Liu, J., and Zhou, Q. P. 2013. "Study on Runoff Simulations on Qingjiang River Basin by SWAT Model." *Yangtze River* 44 (22): 25-9. (in Chinese)

[24] Shi, P. J., Yuan, Y., Jing, Z., and Chen, J. 2001. "The Effect of Landuse on Runoff in Shenzhen City of China." *Acta Ecologica Sinica* 21 (7): 1041-50.

[25] Lee, K. T. 2009. *Hydrology*. Taipei: Wu-Nan Book Company Ltd..