GIS 支持下的小流域设计洪水过程线推求

刘俊萍

(浙江工业大学建筑工程学院,浙江 杭州 310032)

摘　要:浙江省衢州庙源溪为典型的山区河流,庙源溪雨量丰富,河流比降大,源短流急,洪水陡涨陡落,汇流速度快,洪峰流量大。基于 GIS 的不规则三角网和空间分析功能,实现水文特征值等值线的内插。根据 GIS 获取的水文特征值,计算不同历时平均点雨量,考虑点面折算系数,得到平均面雨量。通过频率分析,获得不同频率下的设计雨量。采用瞬时单位线法,进行汇流计算,推求设计洪水过程线及洪峰流量,为制作山洪风险图,建立小流域防洪避洪保障体系提供依据。

关键词:小流域;频率计算;瞬时单位线;设计洪水过程线

中图分类号:P333.2　　**文献标识码**:A　　**文章编号**:1000-0852(2013)03-0056-05

1 引言

浙江省地处中国东南沿海长江三角洲南翼,是热带海洋气团和极地大陆气团交替控制的区域,属亚热带季风气候区,丘陵山地面积占全省国土面积 70%左右,这些地区分布着众多的山溪性河流,形成相对独立的小流域。小流域雨量丰富,河流比降大,源短流急,导致河流水位暴涨暴落,伴随强降雨过程常形成山洪,及滑坡、泥石流等次生灾害,不仅造成人员伤亡,而且造成交通道路、水利工程和农田土地等的损毁,带来巨大的直接和间接经济损失。为保障农村的公共安全,减少山洪灾害损失,建立小流域防洪避洪保障体系,开展小流域设计洪水计算研究,具有重要的理论意义和应用价值。

2 庙源溪概况

庙源溪位于衢州市柯城区,是衢江的支流,属于典型的山区季节性河流,流域面积 83.9km^2,多年平均降雨量 2 012mm,河流长 21.9km,河道平均比降 2.9‰。2002 年 8 月 15 日,在九华乡境内庙源溪流域遭受特大暴雨袭击,引起了特大山洪暴发、山体滑坡、泥石流等灾害,造成农田冲毁、交通、电力、通讯中断、房屋倒塌,损失惨重。庙源溪位置图如图 1 所示。

图 1　庙源溪示意图

Fig. 1 The Miaoyuanxi River basin

3 设计暴雨过程推求

3.1 各历时平均点雨量均值、变差系数 C_v

根据浙江省短历时暴雨[1]有关规定,定点数目选 4,根据各历时 60min、6h、24h、3d 的点雨量均值等值线

收稿日期:2012-04-27
基金项目:国家自然科学基金重大项目(51190093);浙江省级重点科技创新团队项目(2012R10035-11);浙江省重大科技专项重点社会发展项目(2009C13012)
作者简介:刘俊萍(1969-),女,山西太原人,博士,研究方向为水资源系统工程。E-mail: ljp23@163.com

图和 C_v 等值线图，采用地理信息系统，分别产生基于点雨量均值等值线和 C_v 等值线的不规则三角网，利用不规则三角网的空间分析功能[2]，查算所选 4 个点的雨量均值和 C_v 值，见图 2~5。在此基础上，计算点雨量均值的平均值，见表 1。

图集没有年最大 3h 点雨量均值的等值线图，需进行插补计算，计算公式为：

$$\overline{H}_3=\overline{H}_6\left(\frac{1}{2}\right)^{1-n_{1,6}}，其中：n_{1,6}=1+1.285lg\frac{\overline{H}_1}{\overline{H}_6} \qquad (1)$$

式中：$\overline{H}_3$ 为最大 3h 点雨量均值，mm；$\overline{H}_6$ 为最大 6h 点雨量均值，mm；$n_{1,6}$ 为 1~6 小时暴雨衰减指数；$\overline{H}_1$ 为最大 1h 点雨量均值，mm。

3h 点雨量均值计算结果见表 2。

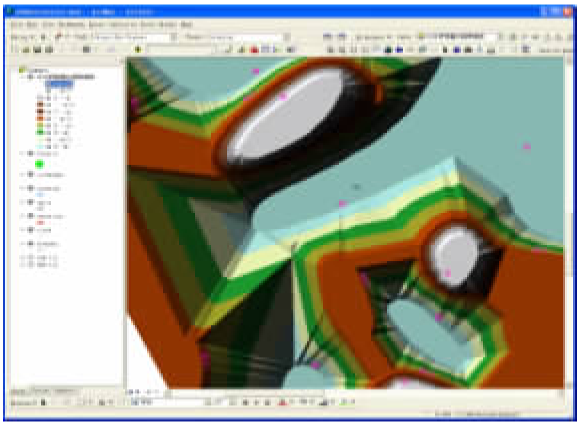

图 2 基于 60min 雨量等值线的不规则三角网

Fig.2 Triangulated irregular network based on 60min rainfall isoline

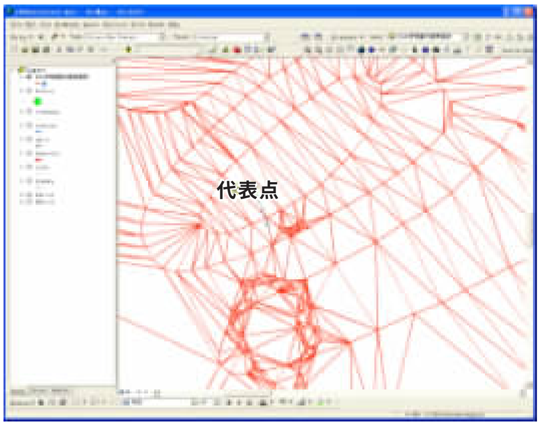

图 3 60min 雨量 TIN 线状平面

Fig.3 Linear plane of triangulated irregular network of 60min rainfall

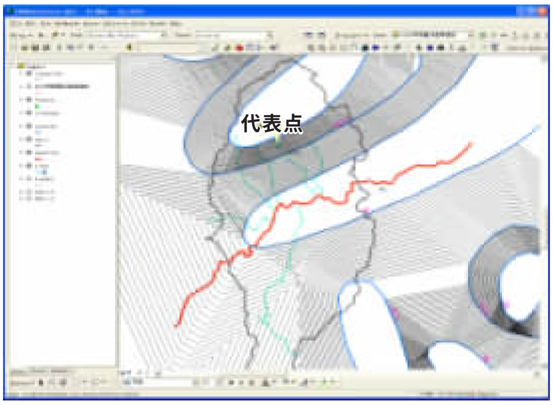

图 4 60min 雨量等值线内插

Fig.4 Interpolation of 60min rainfall isoline

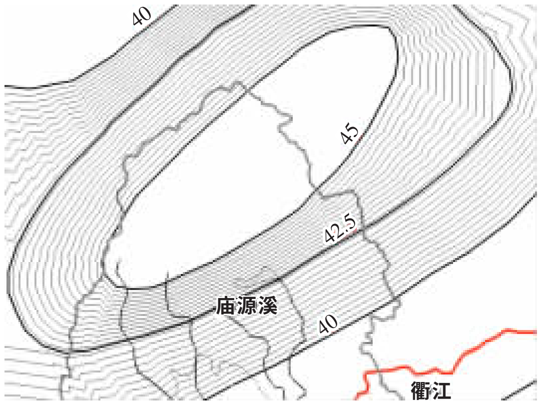

图 5 60min 雨量等值线内插局部放大图

Fig.5 Partial enlarged detail of 60min rainfall isoline interpolation

表1 点雨量均值和 C_v 值

Table 1 Average point rainfall and C_v

历时	第 1 点		第 2 点		第 3 点		第 4 点		平均	
	均值 / mm	C_v	均值 / mm	C_v	均值 / mm	C_v	均值 / mm	C_v	均值 / mm	C_v
60min	43.8	0.406	41.8	0.408	40.4	0.410	40.0	0.411	41.5	0.409
6h	76.5	0.425	72.0	0.435	68.5	0.445	65.0	0.450	70.5	0.439
24h	130.0	0.490	119.4	0.487	115.7	0.484	111.5	0.481	119.2	0.486
3d	179.0	0.491	173.5	0.489	168.5	0.485	163.0	0.482	171.0	0.487

表2 设计面雨量

Table 2 Design area rainfall

历时	点面折算系数 α	面雨量均值 /mm	设计雨量 / mm					
			P=0.5%	P=1%	P=2%	P=5%	P=10%	P=20%
60min	0.810	33.6	86.6	78.9	70.9	60.2	51.9	43.2
3h	0.900	51.7	136.4	123.9	111.2	93.1	80.6	66.8
6h	0.946	66.7	182.3	165.0	147.6	121.4	105.7	87.0
24h	0.984	117.3	349.7	313.8	278.0	227.9	192.6	155.3
3d	0.996	170.2	508.8	456.6	404.3	331.6	279.9	225.5

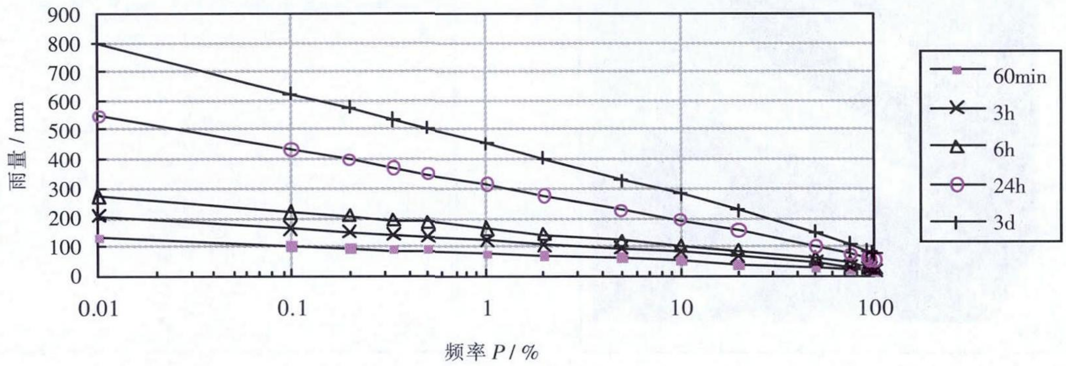

图 6 雨量频率曲线

Fig.6 Frequency curve of rainfall

考虑点面折算系数 α，计算平均面雨量，计算结果见表 2。

3.2 设计雨量计算

根据各历时雨量均值、C_v 值和 C_S/C_v=3.5，查离势系数 ϕ_P 值表或模比系数 K_P 值表，按式(2)计算设计雨量：

$$H_P=K_P\overline{H} \text{ 或 } H_P=(1+\phi_P C_v)\overline{H} \quad (2)$$

式中：H_P 为频率 P 时的设计雨量，mm；$\overline{H}$ 为平均面雨量，mm。

各历时不同频率设计雨量计算成果见表 2。

根据设计面雨量成果，在半对数纸上绘制降雨量和频率的关系曲线，得出不同历时的雨量频率曲线[3-6]，见图 6。

3.3 雨型分配

小流域山洪主要由短历时暴雨形成，历时按 3h 考虑，3h 雨型分配如下：

第一小时雨量

$$H_{first}=(H_{3\,h}-H_{1\,h})\times 0.40 \quad (3)$$

式中：H_{first} 为第一小时雨量，mm；$H_{3\,h}$ 为 3h 设计雨量，mm；$H_{1\,h}$ 为 1h 设计雨量，mm。

第二小时雨量

$$H_{second}=H_{1\,h} \quad (4)$$

式中：H_{second} 为第二小时雨量，mm；其余符号意义同前。

第三小时雨量

$$H_{third}=(H_{3\,h}-H_{1\,h})\times 0.60 \quad (5)$$

式中：H_{third} 为第三小时雨量，mm；其余符号意义同前。

计算不同频率下 3h 雨型分配见表 3。

表 3 不同频率下 3h 雨型分配

Table 3 Distribution of 3h rainfall at different frequency

设计频率 P / %	第一小时雨量 / mm	第二小时雨量 / mm	第三小时雨量 / mm
0.5	19.9	86.6	29.9
1	18.0	78.9	27.0
2	16.1	70.9	24.1
5	13.2	60.2	19.8
10	11.5	51.9	17.2
20	9.4	43.2	14.2

3.4 产流计算

小流域山洪主要由短历时暴雨形成，山洪形成前土壤已饱和，3h 降雨产流计算假定前期土壤已饱和，不再扣除初损，后损为 1.0mm/h。地下径流部分采用斜线分割法，潜流部分按 1.5mm/h 平均入渗率计算，降雨扣除各项损失可得净雨过程，频率=1%的净雨过程为

I_1=15.5mm，I_2=76.4mm，I_3=24.5mm。

3.5 汇流计算

根据庙源溪流域特征，采用浙江省瞬时单位线法进行汇流计算[7-8]。

根据河流长度 L，河道平均比降 J，计算流域特征值

$$J^{\frac{1}{3}} \cdot F^{-\frac{1}{4}}=0.0029^{\frac{1}{3}} \cdot 83.9^{-\frac{1}{4}}=0.0471 \quad (6)$$

$$\theta=\frac{L}{J^{\frac{1}{3}}}=\frac{21.9}{0.0029^{\frac{1}{3}}}=153.6 \quad (7)$$

通过查算流域面积 F 与串连水库的个数 n 的关系 $F\sim n$，得 n=1.5；由浙江省地区综合 $M_1(10)\sim L/J^{1/3}$ 相关图查得，$L/J^{1/3}$=153.6 时，$M_1(10)$=6.5 h；由浙江省地区综合 $b\sim J^{1/3}/F^{-1/4}$ 相关图查得，$J^{1/3}/F^{-1/4}$=0.0471 时，b=0.5。

由以上查算所得的参数，得

$$a=M_1(10)\times 10^b=6.5\times 10^{0.5}=20.6 \quad (8)$$

式中：$M_1(10)$为净雨 I=10mm 时单位线滞时。

则

$$M_1=a\cdot I^{-b}=20.6\cdot I^{-0.5} \quad (9)$$

由各时段净雨及式 $M_1=n\cdot K$，计算各净雨所相应的 M_1 和 K。当频率 P=1%时，净雨过程 I_1 对应 $M_1(I_1)$=5.22，$K(I_1)$=3.48，净雨过程 I_2 对应 $M_1(I_2)$=3.47，$K(I_2)$=2.32，净雨过程 I_3 对应 $M_1(I_3)$=4.15，$K(I_3)$=2.77。

由 n 和 K 两个参数，查瞬时单位线 S曲线查用表，得到各净雨所相应的 1h10mm 单位线 $u(t,10)$，见表4。由各时段净雨 I 及其单位线计算径流过程并错时段叠

表 4 瞬时单位线(P=1%)

Table 4 Instantaneous unit hydrograph(P=1%)

序号	第 1 时段净雨 10mm 单位线 qt_1	第 2 时段净雨 10mm 单位线 qt_2	第 3 时段净雨 10mm 单位线 qt_3
0	0.000	0.000	0.000
1	22.947	0.000	0.000
2	29.999	38.508	0.000
3	32.820	47.386	30.814
4	27.701	40.240	40.136
5	23.684	30.712	36.631
6	19.547	22.640	30.170
7	16.084	16.433	23.899
8	12.701	11.550	18.253
9	10.316	8.054	14.027
10	8.160	5.712	10.456
11	6.472	3.785	7.734
12	5.012	2.612	5.742
13	4.053	1.586	4.238
14	3.061	1.304	3.051
15	2.420	0.944	2.180
16	1.778	0.402	1.489
17	1.474	0.402	1.179
18	0.964	0.244	0.917
19	0.938	0.201	0.642
20	0.706	0.000	0.337
21	0.620		0.337
22	0.268		0.231
23	0.268		0.168
24	0.268		0.000
25	0.182		
26	0.134		
27	0.134		
28	0.000		

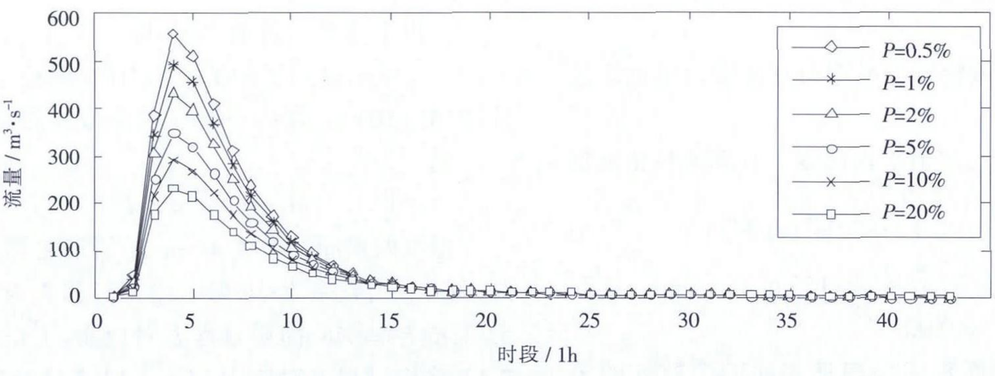

图 7 不同频率 3h 设计洪水过程线

Fig.7 The hydrograph of 3h design flood at different frequency

加，得地表径流过程线。

根据浙江省瞬时单位线的研究成果，基流按 2m^3/s 计算，地下径流过程概化成等腰三角形，地下径流峰现时间原则上为地表径流终止点位置，但为使退水过程光滑，地下径流峰现时间放在退水段 $Q\leqslant$5m^3/s 位置。具体到本文，地下径流峰现时间选择在 T=19h。地表径流过程线与地下径流过程线叠加，得总径流过程线，见图 7。从图中可知，P=1%时洪峰流量为 491m^3/s。

同理，计算不同频率下的洪水过程线及洪峰流量，具体见图 7。根据断面水力计算，可以确定现有堤防的防洪能力和淹没水深，结合实地调查，可划分危险区和警戒区，制作山洪风险图，为小流域防洪规划和当地人民群众防洪避洪提供依据[9-10]。

4 结语

随着经济的快速发展，小流域暴雨洪水灾害造成人民群众和国家财产的损失越来越大。结合地理信息系统，通过频率分析，产汇流计算，对庙源溪小流域设计洪水进行了研究，得到不同频率下的设计洪水过程线及洪峰流量，进一步进行山洪预警等方面的研究工作，以保障农村的公共安全，推进新农村建设。

参考文献：

[1] 王云辉,伍远康,马志鑫,等.浙江省短历时暴雨[R].杭州:浙江省水文勘测局, 2003.(WANG Yunhui, Wu Yuankang, Ma Zhixin,et al. Short Duration Rainstorm in Zhejiang Province [R]. Hangzhou: Hydrology Survey Bureau of Zhejiang Province, 2003. (in Chinese))

[2] 王亚民,赵捧未.地理信息系统及其应用[M].西安:西安电子科技大学出版社, 2006.1-10. (WANG Yaming, ZHAO Pengwei. Geographic Information System and Application [M]. Xi'an: Xidian University Press,2006:1-10.(in Chinese))

[3] SL44-2006,水利水电工程设计洪水计算规范[S].(SL44-2006, Regulation for Calculating Design Flood of Water Resources and Hydropower Projects[S]. (in Chinese))

[4] 叶勇,王振宇,范波芹.浙江省小流域山洪灾害临界雨量确定方法分析[J].水文, 2008, 28(1): 56-58. (YE Yong, WANG Zhenyu, FAN Boqin. An analysis method for ascertain rainfall of mountain flood disaster of small watershed in ZheJiang Province [J]. Journal of China Hydrology, 2008, 28(1):56-58.(in Chinese))

[5] 江锦红,邵利萍.基于降雨观测资料的山洪预警标准[J].水利学报, 2010,41 (4): 458-463. (JIANG Jinhong, SHAO Liping. Standard of mountain flood warning based on the precipitation observation data [J]. Journal of Hydraulic Engineering, 2010,41 (4):458-463.(in Chinese))

[6] 叶凌云,曾小东.小流域洪水计算及防洪措施[J].浙江水利水电专科学校学报,2008,20 (3): 39-42.(YE Lingyun, ZENG Xiaodong. On flood estimation and flood control in small watershed[J]. Journal of Zhejiang Water Conservancy and Hydropower College, 2008,20 (3):39-42. (in Chinese))

[7] 梁瑞驹,潘永新.推求无资料地区设计洪水的一种方法[J].水科学进展,1997,8(2):161-168. (LIANG Ruiju, PAN Yongxin. An approach to estimation of design flood hydrograph based on rainfall data[J]. Advances in Water Science, 1997,8(2):161-168. (in Chinese))

[8] 芮孝芳.流域汇流的概率论体系探讨[J].水科学进展,2004,15(2):135-139.(RUI Xiaofang. Study of mechanism of watershed concentration flow based on probability theory [J]. Advances in Water Science, 2004,15(2):135-139. (in Chinese))

[9] 张平仓,任洪玉,胡维忠,等.中国山洪灾害区域特征及防治对策[J].长江科学院院报,2007, 24 (2):9-12.(ZHANG Pingcang, REN Hongyu, HU Weizhong, et al. Zone characteristics of Chinese mountain torrent disasters and countermeasures [J]. Journal of Yangtze River Scientific Research Institute, 2007,24(2):9-12. (in Chinese))

[10] 汤富平,李满春,秦奋.基于 CA 的小流域分布式降雨径流模拟[J].水科学进展,2010,21 (2): 173-178.(TANG Fuping, LI Manchun, QIN Fen. Distributed rainfall-runoff simulating based on cellular automata for small water sheds [J]. Advances in Water Science, 2010,21(2):173-178.(in Chinese))

（下转第 90 页）

[12] 张鑫,蔡焕杰,尹晓楠. 基于 DFA 的无定河径流长期变化趋势及持续性研究[J]. 生态环境学报, 2010,19(1):208-211. (ZHANG Xin, CAI Huanjie, YIN Xiaonan. Long-term trends and sustainability analysis of runoff in the Wuding River basin [J]. Ecology and Environmental Sciences, 2010,19(1):208-211. (in Chinese))

[13] Kahya, E., Kalayci, S. Trend analysis of streamflow in Turkey [J]. Journal of Hydrology, 2004, 289:128-144.

[14] 曹洁萍. Mann-Kendall 检验方法在降水趋势分析中的应用研究[J]. 农业科技与装备, 2008,(5): 35-40. (CAO Jieping, Mann-Kendall examination and application in the analysis of precipitation trend [J]. Agricultural Science & Technology and Equipment, 2008, (5): 35-40. (in Chinese))

[15] Sergei Rodionov, James E. Overland application of a sequential regime shift detection method to the Bering sea ecosystem [J]. ICES Journal of Marine Science. 2005. 62: 328-332.

[16] 汤奇成,李秀云.径流年内分配不均匀系数的计算和讨论[J].资源科学, 1982, (3):59-65. (TANG Qicheng, LI Xiuyun. Calculation and discussion of annual runoff distribution coefficient of uniformity [J]. Resources Science, 1982,(3):59-65. (in Chinese))

[17] 李艳,陈晓宏,张鹏飞.北江流域径流序列年内分配特征及其趋势分析[J].中山大学学报(自然科学版), 2007,46(5):106-113. (LI Yan, CHEN Xiaohong, ZHANG Pengfei. Research on annual distribution and its trends of runoff in Beijiang River [J]. Acta Scientiarum Naturalium Universitatis Sunyatseni, 2007,46(5):106-113. (in Chinese))

[18] 郑红星,刘昌观.黄河源区径流年内分配变化规律分析[J].地理科学进展, 2003, 22 (6): 585-591. (ZHENG Hongxing, LIU Changguan. Changes of annual runoff distribution in the headwater of the Yellow River basin [J]. Progress in Geography, 2003, 22(6): 585-591. (in Chinese))

Annual Runoff Distribution of Hailiutu River and Its Change Trend

ZHANG Danrong[1], GUO Mianchen[1], XIA Dongmei[2], LI Yahan[1], XIE Yuebo[1], GUAN Yiqing[1]

(1. *College of Hydrology and Water Resources, Hohai University, Nanjing* 210098, *China*;
2. *Hydraulic Research Institute of Anhui Province and Huaihe River Commision, Bengbu* 233000, *China*)

Abstract: This paper analyzed the runoff data of the Hailiutu River, the middle reach of the Yellow River, from 1957 to 2007 with various methods.. According to the analysis by the non-uniform coefficient method of annual streamflow distribution, the annual runoff distribution of the Hailiutu River is quite uniform with a low concentration ratio. The annual runoff series was found to have a significant descending trend by using the Mann-Kendall test. And it was found that the precipitation in the same period has not obvious with non-uniform distribution of the annual precipitation. The precipitation concentrated in July, October and September. With the regime shift index (RSI) method, it was found that the annual runoff change can be divided into the durations as follows: 1957~1967 , 1968~1988 , 1989~2000 , 2001~2007. By comparising the trend and annual distribution of the runoff and precipitation, the conclusoin was made that there is no obvious impact of precipitation on runoff in the Hailiutu River Basin.

Key words: changing point detecting; trend analysis; M-K test; regime shift index method

(上接第 60 页)

Calculation of Design Flood Hydrograph for Small Watershed Based on GIS

LIU Junping

(*College of Civil Engineering and Architecture, Zhejiang University of Technology, Hangzhou* 310032, *China*)

Abstract: The Miaoyuanxi River, located in Quzhou City of Zhejiang province, is a typical mountain stream. The river has characteristics of plentiful rainfall, steep gradient, short source and swift flow, sudden flood rising and sharp dropping, quick travel speed, and great peak discharge. The triangulated irregular network and spatial analysis function of geographic information system(GIS) were analyzed to realize interpolation of the isoline of hydrological statistical parameters. According to the hydrological characteristic parameter derived from GIS, the average point rainfall at different duration was calculated. In view of conversion coefficient of point rainfall into area rainfall, the average area rainfall was obtained. By frequency analysis, design rainfall at different frequency was calculated. The instantaneous unit hydrograph was applied to carry out convergence computation and infer design flood hydrograph and peak flow, which provide basis for drawing mountain flood risk map and establishing security system for small watershed flood control and flood evasion.

Key words: small watershed ; frequency analysis ; instantaneous unit hydrograph ; design flood hydrograph