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THE EFFECT OF LAND USE CHANGE TO THE DEPTH AND AREA OF INUNDATION IN THE BANG SUB-WATERSHED-MALANG-INDONESIA

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ABSTRACT: More than 50% of East Java Province area has the high potential flood disaster, one of them is the Bang sub-watershed**.** The aim of this paper is to analyze the area and depth of inundation on the river of Bank sub-watershed due to the land use change in surrounding it. This study is located in the Bang sub-watershed, Tamban coast, Tambakrejo village, Sumbermanjing Wetan district, East Java Province-Indonesia**.** The methodology consists of predicting the inundation area and flow pattern in the Bang river by using the software of HEC-GeoRAS (Hydrologic Engineering Centre and River Analysis System) version 3.1 which compiling the two main software that are HEC RAS version 4.1.0 and Arc View GIS version 3.3. The result shows that the maximum inundation is 4.99 km^2 on the return period of 50 years based on the land use on 2010. The land use change from 2001 to 2010 indicates that the increasing inundation area is 0.4%, however, the inundation depth is increasing 0.5%.

Keywords: Flood, Simulation, Inundation, Depth

1. INTRODUCTION

Most distributed flood models are very simple representations of reality, as indicated by coefficients as the parameters. Such models require parameter values to be specified for every element in the solution mesh. In terms of the very large number of parameters thereby required, the models are grossly over parameterized with respect to the available data for calibration [1], however, to place great reliance on the *a priori* estimation of the required reach scale or effective parameters required. Thus, as a result of these limitations, it should also be expected that the predictions of flood inundation should be uncertain [2]. In the past this uncertainty has been considered primarily as a function of the uncertainty in the magnitude of an event for a given return period. First define the 100 year event, then predict the inundated areas. This remains an important source of the uncertainty for design problem but it is also clear that these limitations might lead to considerable uncertainty in the forecasting case which will also require updating of the inundation forecasts in real time as the event progresses [1].

The impact of human activities on ecosystems has long been recognized and, now, there is increasing evidence to support the hypothesis that we have entered into an Anthropocene [3] Human activities have been documented as one of the main driving forces changes and simultaneous changes in natural environments [4]. In addition, the spatial pattern of a landscape [5],[6], the availability of ecosystem goods and services [5], and increase vulnerability of regional biomes and human well-being to climate change [7]. The problems of flooding and inundation are more critical due to change in climate in general and change in rainfall pattern/intensity in particular. During the monsoon months from June to September, all these rivers are in spate with bank-full discharges and cause flooding and inundation in several parts [3].

More than 50% of East Java Province area has the high potential flood disaster such as the Bang sub-watershed. This study intends to investigate the area and depth of inundation on the river of Bang sub-watershed due to the land use change in surrounding it. The result is hoped to be used as the base of development and management in surrounding river area. In addition, it can be used as the illustration for the same kind problem in the other area for predicting the inundation due to the flood disaster.

2. MATERIAL AND METHOD

This study is located in the Bang sub-watershed, Tamban coast, Tambakrejo village, Sumbermanjing Wetan district, East Java Province-Indonesia. Geographically, Tamban coast is located in the south longest of 112º38’ and east longest of 112º43’. The available rainfall data is from 1999 to 2008 from the Sitiarjo rainfall station. Map of location is presented as in the Fig. 1.

The procedure of analysis is as follow: 1) hydrological analysis which consists of outlier and consistence test of rainfall data, analysis of area rainfall, testing of goodness of fit (Smirnov-Kolmogorof and Chi Square test), analysis of run-off coefficient, analysis of rainfall intensity covering the daily rainfall and daily net rainfall, and analysis of design flood based on the . Nakayasu Synthetic Unit Hydrograph; 2) Analysis of study location covering ruver flow analysis such as the contour map and analysis of flow and the dimension of river cross section which consists of a) hydraulics analysis by using HEC-RAS version 4.1 for knowing the flow pattern with the input: geometri data, steady flow discharge and boundary condition, running and the result of running data, and b) analysis of flood risk map.

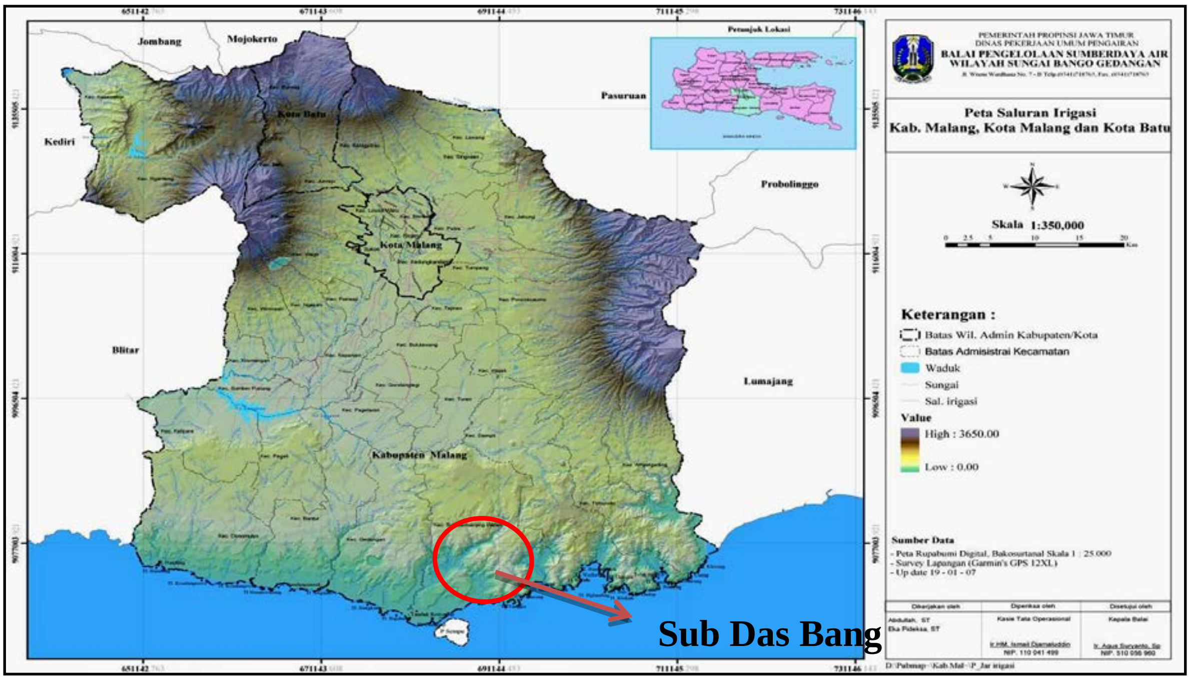

Fig. 1 Map of study location

2.1. Hydrological analysis

The consistence test uses RAPS (Rescaled Adjusted Partial Sums) method. This method is carried out by analyzing the deviation cumulative to the mean value with the formula as follow:

S*o = 0

$$S^{*}k = \sum_{i=1}^{k} (Yi - Y \text{ .... } (1)$$

where:

K = 1,2,3, ... ,n

$$S^{**}k = \frac{S*k}{Dy}$$

$$Dy^2 = \frac{\sum_{i=1}^{k} (Yi - Y)^2}{n}$$

The statistical value of Q and R is as follow:

Q = max │S**k│ for $0 \le k \le n$

R = max S**k – min S**k

Where:

S*o = initial deviation, S*k = absolute deviation, S**k = the value of data consistence, n = number of data, Dy = mean deviation, Q = statistical value of Q for $0 \le k \le n$, R = statistical value (range)

Based on the statistical value as above, it can be found the value of Q/√n and R/√n. The result can be compared with the conditional value of Q/√n and R/√n. If the result is less, it means that the data is still in the consistence boundary. Table 1 presents the value of Q/n0.5 and R/n0.5

Table 1 The value of Q/n0.5 and R/n0.5

n	Q/√n			R/√n		
	90%	95%	99%	90%	95%	99%
10	1.05	1.14	1.29	1.21	1.28	1.38
20	1.10	1.22	1.42	1.34	1.43	1.60
30	1.12	1.24	1.46	1.40	1.50	1.70
40	1.13	1.26	1.50	1.42	1.53	1.74
50	1.14	1.27	1.52	1.44	1.55	1.38
100	1.17	1.29	1.55	1.50	1.62	1.86
∞	1.22	1.36	1.63	1.62	1.75	2.00

Source: Harto [8]

2.2. Design Flood Analysis

The distribution of daily rainfall is determined by using Mononobe formula as follow [9]:

$$I_T = \frac{R_{24}}{t} \cdot \left(\frac{t}{T}\right)^{\frac{2}{3}} \tag{2}$$

where:

I_T =rainfall intensity in T hour (mm/hour)
R_{24} = daily rainfall (mm)
T = rainfall duration from beginning until t (hour)
t = rainfall duration (hour)

2.1.1. Nakayasu Synthetic Unit Hydrograph

The formula of Nakayasu Synthetic Unit Hydrograph is as follow [10]:.

$$Q_P = \frac{A * Ro}{3.6 * (0.3 * T_P + T_{0.3})} \tag{3}$$

where:

Q_P = flood peak discharge (m_3/s/mm),
R_0 = unit rainfall (mm),
T_P = time duration from beginning until flood peak (hour)
$T_{0.3}$= duration time that is needed by the discharge decreasing from the flood peak until 30% of flood peak.

The rising limb formula of unit hydrograph is as follow:

$$Q_a = Q_P \left(\frac{t}{T_P}\right)^{2.4} \tag{4}$$

where:

Qa = discharge before reaching the flood peak (m^3/s/mm),
T = time
Q_p = peak discharge (m^3/s/mm)

The recession limb formula of unit hydrograph is as follow: Untuk, Qd > 0.3 Qp

$$Q_d = Q_P 0.3^{\frac{t-T_P}{T_{0.3}}} \tag{5}$$

For 0.3.Qp > Qd > 0.32Qp

$$Q_d = Q_P 0.3^{\frac{t-T_P+0.5T_{0.3}}{1.5T_{0.3}}} \tag{6}$$

For 0.32Qp > Qd

$$Q_d = Q_P 0.3^{\frac{t-T_P+1.5T_{0.3}}{2T_{0.3}}} \tag{7}$$

$T^{0.3}$ = α. Tg (α: 1.5- 3)
Time lag:
T_p = tg + 0.8 tr
For L < 15 km: tg = 0.21 $L^{0.7}$
For L > 15 km: tg = 0.4 + 0.058 L
Where: L =the length of river (km), tg = time concentration (hour), tr= 0.5 tg until tg.

3. RESULTS AND DISCUSSION

3.1. Outliers and Homogeneity Test

Table 2 Recapitulation of data outliers test

No	year	Max. rainfall (Rmax, mm/day)	Log R
1	2007	32	1.505
2	2008	35	1.544
3	2006	60	1.778
4	2002	85	1.929
5	2001	103	2.013
6	2003	121	2.083
7	2005	136	2.134
8	1999	157	2.196
9	2000	210	2.322
10	2004	210	2.322
Total		1,096	19.7

Note: n = 10; cs = 0.16; mean = 109.6; Sd = 57.83; Ck = 3.3

Table 2 presents the recapitulation of data outliers test. Result shows that there are no rainfall data is out of the upper limit (X_h) as well as the lower limit (X_L), so all of the rainfall data can be accepted for the further analysis. Based on the RAPS method, it can be concluded that the rainfall data in the Sitiarjo Station is consistant enough due to the probability of 95%.

3.2. Rainfall

This study uses the maximum annual series for analizing the yearly maximum rainfall. Table 3 presents the recapitulation of yearly maximum of daily area maximum rainfall. The maximum rainfall data will be used for analyzing the design flood of Bang river.

Table 3 Recapitulation of yearly maximum of daily area maximum rainfall

Year	Rainfall (mm)
1999	157.0
2000	157.0
2001	103.0
2002	85.0
2003	121.0
2004	210.0
2005	136.0
2006	60.0

3.3. Rainfall Distribution

The analysis of rainfall distribution in this study uses the ABM (Alternating Block Method). This method sorts the rainfall starting from the peak one in the middle. Table 4 presents the rainfall distribution based on the ABM for some kinds of return period due to the land use of 2001. Table 4 and 5 present the rainfall distribution based on the ABM due to the land use of 2001 and 2010.

Table 4 Rainfall distribution based on the ABM due to the land use on 2001

Hour to	Ratio	Commutative	Hourly rainfall (mm) due to the return period of							
			2 yr	5 yr	10 yr	25 yr	27 yr	50 yr	100 yr	200 yr
1	6.7 %	6.7 %	4.71	6.83	7.93	9.00	9.07	9.85	10.55	11.17
2	10.0 %	16.8 %	7.04	10.16	11.79	13.38	13.49	14.65	15.69	16.62
3	55.0 %	71.8 %	38.61	55.72	64.68	73.41	73.98	80.37	86.07	91.17
4	14.3 %	86.1 %	10.04	14.48	16.81	19.08	19.23	20.89	22.37	23.70
5	8.0 %	94.1 %	5.60	8.09	9.39	10.66	10.74	11.67	12.49	13.23
6	5.9 %	100.0 %	4.14	5.97	6.93	7.87	7.93	8.61	9.22	9.77
Design rainfall			100.00	158.18	183.62	208.39	210.00	228.15	244.34	258.80
Run-off coefficient			0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
Effective rainfall			70.16	101.25	117.54	133.40	134.43	146.04	16.41	165.66

Table 5 Rainfall distribution based on the ABM due to the land use on 2010

Hour to	Ratio	cumulative	Hourly rainfall (mm) due to the return period of							
			2 yr	5 yr	10 yr	25 yr	27 yr	50 yr	100 yr	200 yr
1	6.7 %	6.7 %	5.00	7.22	8.38	9.51	9.58	10.41	11.15	11.81
2	10.0 %	16.8 %	7.44	10.74	12.46	14.15	14.26	15.49	16.59	17.57
3	55.0 %	71.8 %	40.80	58.89	68.36	77.58	78.19	84.94	90.97	96.35
4	14.3 %	86.1 %	10.61	15.31	17.77	20.17	20.32	22.08	23.64	25.01
5	8.0 %	94.1 %	5.92	8.55	9.92	11.26	11.35	12.33	13.20	13.99
6	5.9 %	100.0 %	4.37	6.31	7.32	8.31	8.38	9.10	9.75	10.32
Design rainfall			109.60	158.18	183.62	208.39	210.00	228.15	244.34	258.80
Run-off coefficient			0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
Effective rainfall			74.15	107.01	124.22	140.98	142.07	154.35	165.30	175.08

3.4. Design Rainfall Due to the Nakayasu Synthetic Unit Hydrograph

Based on the analysis of design rainfall by using Nakayasu synthetic unit hydrograph, the design rainfall is with the return period of 10 years is used for designing the river normalization and dyke. Table 6 and 7 present the design flood due to the land use on 2001 and 2010.

Table 6 Design flood due to the land use on 2001

Return period	Discharge on the section of (m^3s)				
	30	12	8	4	0
2	20.0	39.53	74.93	82.83	87.63
5	28.1	55.65	106.81	118.12	124.82
10	32.3	64.09	123.51	136.61	144.30
25	36.5	72.30	139.76	154.61	163.27
27	38.7	76.80	148.66	164.45	173.64
50	39.8	78.86	152.73	168.96	178.39
100	42.5	84.23	163.36	180.73	190.70
200	44.9	89.02	172.84	191.23	201.86

Table 7 Design flood due to the land use on 2010

Return period	Discharge on the section of (m^3/s)				
	30	12	8	4	0
2	21.0	41.60	79.02	87.36	92.40
5	29.6	58.63	112.71	124.66	131.71
10	34.1	67.55	130.36	144.20	152.30
25	38.4	76.23	147.54	163.22	172.34
27	38.7	76.80	148.66	164.45	173.64
50	41.9	83.16	161.24	178.39	188.32
100	44.8	88.84	172.47	190.82	201.43
200	47.3	93.90	182.50	201.92	213.13

3.5. Simulation with the HEC-RAS Program

Fig. 2 describes many kinds of river reach variation which are interconnected. However, on the HEC-RAS program, the scheme of river system is as the initial data which is needed before entering the other data.

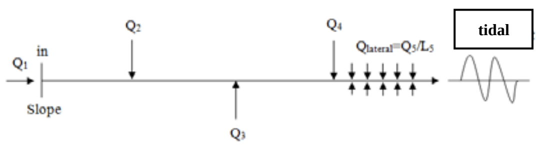

Fig. 2 Scheme of inflow on the hydraulic modeling (HEC-RAS)

3.5.1. Tidal

The tidal data in this study is needed as the input of water level outflow in the downstream of Bang river. The water movement of tidal in Sendang Biru coastal water generally has the mixed tide and it tends to the mixed tide prevailing semi diurnal. The tidal data which is used in this study is the tidal data as the recording result of the previous study in Sendang Biru that is on 1 until 16 October 2005. Due to the objective of this simulation is for knowing the worst possibility of flood condition, so the data which is used in this study is when the highest tide that is on 7th October 2005.

3.5.2. Model calibration

This study uses the high elevation of river cross section that is on the number 30 stakes (elevation +33.15). Based on the survey result (interview to the society) on the rainfall of 2004 which is calibrated with the historical rainfall with the return period of 27 years, the water level is on the 1.02 m over the river cross section (elevation +34.27). The calibration is carried out by changing the "n" value (Manning coefficient), The experiment is carried out on the value of 0.020 until 0.025. The result which is closed to the field condition is 0.023. This value is including the big channel with the clean channel type and less vegetation.

3.5.3. Simulation result

The simulation result by using HEC-RAS and Arc View GIS 3.3 with the extended helping of HEC GeoRAS is presented as in the Fig. 3 until 10. The inundation is expressed as the green color from light to heavy one that indicates that the inundation depth is from shallow (light color) to depth (heavy color) . The brown color is forest, the yellow one is plantation, and the other one is residence.

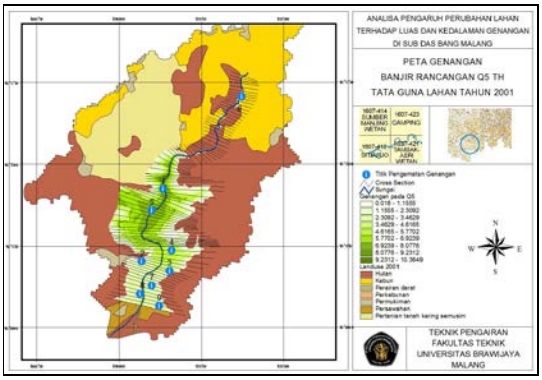

Fig. 3 Simulation result on the inundation depth of Q_5 with the land use on 2001

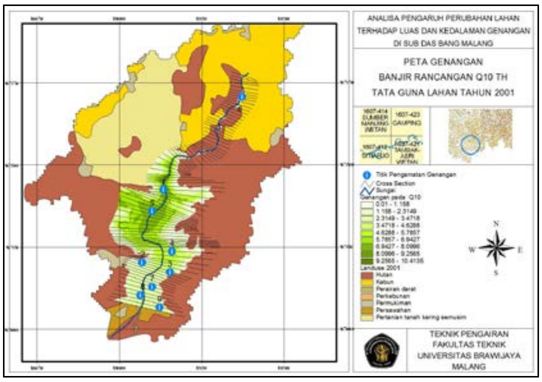

Fig. 4 Simulation result on the inundation depth of Q_{10} with the land use on 2001

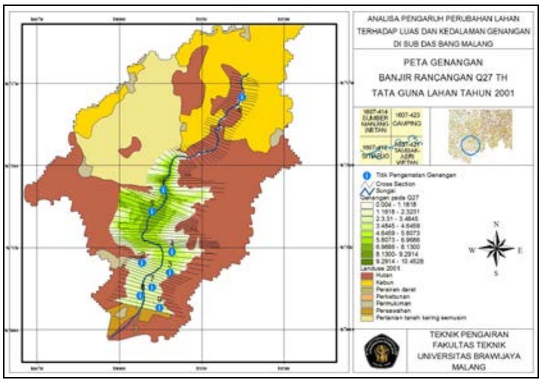

Fig. 5 Simulation result on the inundation depth of Q_{27} with the land use on 2001

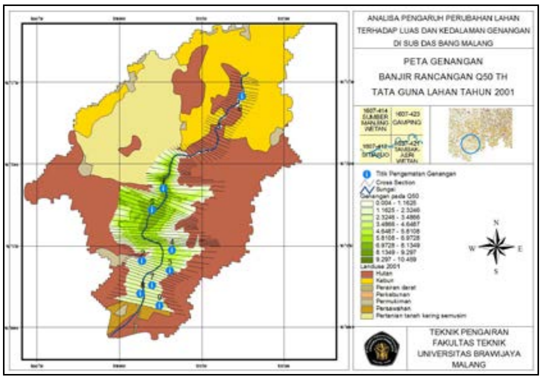

Fig. 6 Simulation result on the inundation depth of Q_{50} with the land use on 2001

3. CONCLUSIONS

The inundation modeling result by using HEC-GeoRAS 3.1 produces that the maximum inundation area is 4.99 km^2 and it is happened on the Q_{50} (discharge with the return period of 50 years) with the land use on 2010. However the average of maximum inundation depth is 4.15 m and it is happened on the Q_{50} too with the land use on 2010. The inundation area is increasing

0.4% and the inundation depth is increasing 0.5% due to the land use change from 2001 to 2010.

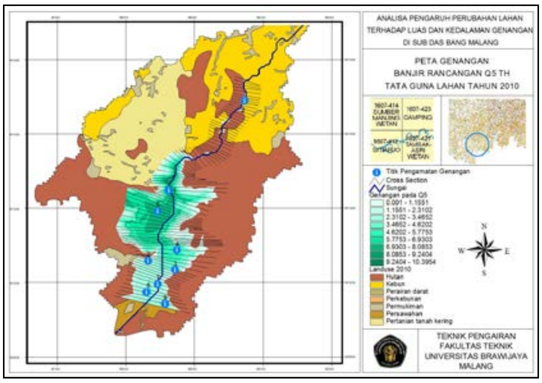

Fig. 7 Simulation result on the inundation depth of Q_5 with the land use on 2010

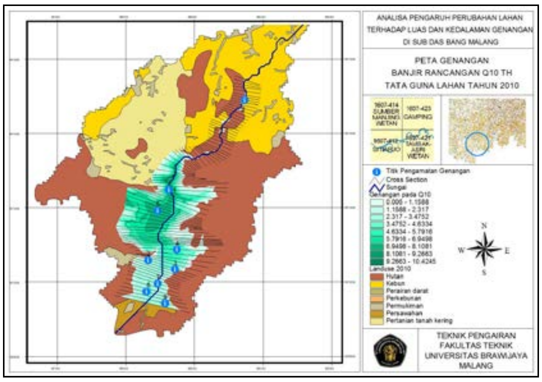

Fig. 8 Simulation result on the inundation depth of Q_{10} with the land use on 2010

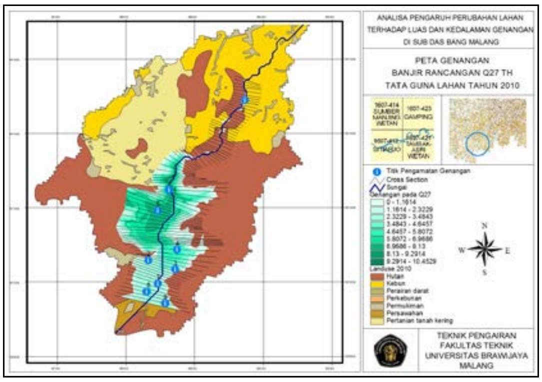

Fig. 9 Simulation result on the inundation depth of Q_{27} with the land use on 2010

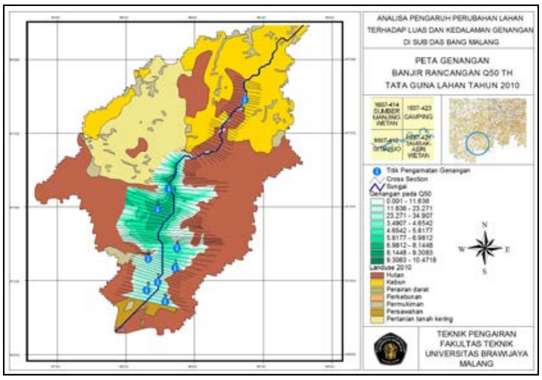

Fig. 10 Simulation result on the inundation depth of Q_{50} with the land use on 2010

Table 8 and 9 present the recapitulation result of flood situation in the Bang river with the land use of 2001 and 2010.

Table 8 Recapitulation result of flood situation with the land use on 2001

No	Design flood (Q_n)	Design flood (m^3/s)	Inundation area (A, km^2)	Mean of inundation depth (H, m)
1	Q_5	124.82	4.18	3.509
2	Q_{10}	144.3	4.19	3.643
3	Q_{27}	173.64	4.20	3.669
4	Q_{50}	178.39	4.25	3.695

Table 9 Recapitulation result of flood control with the land use on 2010

No	Design flood (Q_n)	Design flood (m^3/s)	Inundation area (A, km^2)	Mean of inundation depth (H, m)
1	Q_5	131.71	4.19	3.572
2	Q_{10}	152.30	4.20	3.729
3	Q_{27}	173.64	4.21	3.781
4	Q_{50}	188.32	4.29	3.854

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