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Evaluation of drainage channels capacity in Ambon city: a case study on Wai Batu Merah watershed flooding

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Abstract

Failure of urban drainage capacity to flow surface runoff due to rainfall is possibly to be a factor from many other factors causing flood in urban areas. Big floods in Ambon in 2013 which caused economic loss and loss of human life are the background to conduct a research which is presented in this paper. Ambon is the capital of Maluku Province located in Eastern Indonesia. Recently, the area of the city is developed into settlement area. The research is specifically conducted in Wai Batu Merah Watershed, a watershed in Ambon which severely damage due to floods in 2013. The analysis emphasizes on evaluation of capacity of existing drainage channels (natural and human-made). Daily rainfall data from Pattimura station during 2004 – 2013 is used to be the main data to estimate design rainfall and design flood. Design rainfall is the main data of rainfall-runoff model which is done using Synthetic Unit Hydrograph of SCS. While the fluctuation of water level along the main river is simulated using unsteady flow analyses with an input of 50-year design flood. The result of the simulation shows that one existing tertiary drainage channel cannot accommodate discharge of overland flow and from the upstream to the downstream of Wai Batu Merah River is overflow. Particularly on flood event in 2013, consecutive rainy days occurred since in the beginning of July until mid-August with total depth of rainfall more than triple of 50-year return period of maximum daily rainfall. At that state, flood certainly cannot be avoided in the adjacent of the river.

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Keywords: drainage capacity; design flood; rainfall-runoff model; synthetic unit hydrograph; unsteady flow analysis

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1. Background

Data of floods throughout Indonesia during September 2011 until April 2015 by National Board for Disaster Management of Indonesia [1] shows more than 1200 occurrences of flood at various depths caused economic loss and loss of human live. This paper will specifically discuss floods in Wai Batu Merah Watershed in 2013. Wai Batu Merah Watershed is a watershed in Ambon City, Maluku Province, Indonesia. Floods occurred in two consecutive months in 2013, i.e. July and August. The report [1] shows that flood in July 2013 caused the death of ten people while five people were missing; damage of 95 units of house and damage of three school buildings. Flood also triggered landslide in three villages in the watershed. Whereas flood in August 2013 caused the death of eight people while five people were missing and five people were injured; and also damage of 39 units of house.

From several aspects which may cause flood e.g. land use change, precipitation, physiographic of watershed, natural and human-made drainage channels capacity, and impact of backwater, this paper will specifically evaluate drainage channels capacity in the watershed based on 50-year design rainfall and design flood using available data of ten years daily rainfall during 2004 – 2013.

2. Study area and rainfall in Wai Batu Merah Watershed

Ambon City is the capital of Maluku Province in Eastern Indonesia which is located at 3°42'South latitude and 128°10'East longitude. Ambon City is the largest city in Eastern Indonesia. Ambon City has a total land area of 359.45 km² with the number of population in 2012 is 354,464 (Central Bureau of Statistics of Ambon Regional Office [2]). Wai Batu Merah Watershed is located in Sirimau Sub-district, Ambon. 73 percent of the land area is steep-hilly area, including Wai Batu Merah Watershed. The map of Wai Batu Merah Watershed are presented in Fig. 1.

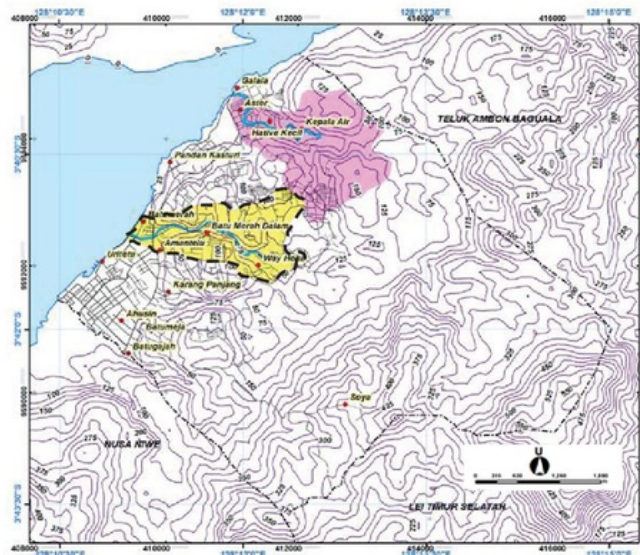


Fig. 1. Map of Wai Batu Merah Watershed [3]

Ambon has tropical monsoon climate when dry season occurs during December – March, while rainy season occurs during May – October. During the last decade, June has the highest average monthly rainfall as much as 672 mm while the average monthly rainfall of the other months during 2004 – 2013 is presented in Fig. 2.

When floods occurred in July and August 2013, rain fell every day during the month of July with total monthly rainfall depth in July 2013 was 1928 mm and maximum daily rainfall was 432 mm. Data of daily rainfall in July and August 2013 is presented in Table 1.

Table 1. Daily rainfall in July and August 2013

July '13	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rainfall depth (mm)	62	33	29	10	2	27	23	3	7	7	42	152	53	6	51	50
July '13	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Rainfall depth (mm)	123	16	4	78	51	4	1	38	432	57	26	2	3	334	200	
Aug '13	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rainfall depth (mm)	54	66	62	70	33	42	8	18	0	5	2	59	7	3	0	6
Aug '13	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Rainfall depth (mm)	0	0	21	23	6	8	0	0	6	4	9	55	42	5	15	

Source: Meteorology Station Class II Pattimura Ambon [4]

Due to that condition, trend of daily rainfall is checked. Analysis stability of mean of monthly rainfall in Ambon which is done using statistical analysis, i.e. t-test [5], reveals a significant increasing mean of monthly rainfall in July by more than 200% during the last decade (2004 – 2013).

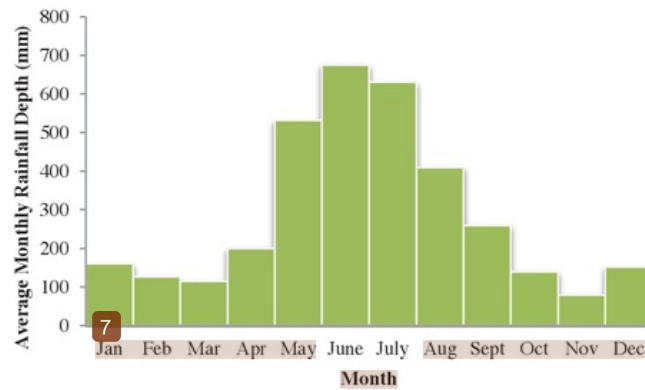


Fig. 2. Average monthly rainfall depth in Ambon (2004 – 2013)

3. Drainage system in Wai Batu Merah Watershed

Wai Batu Merah Watershed has a total area of 35.82 km² with the length of the main river is 3.1 km. Analysis of capacity of drainage system in Wai Batu Merah Watershed covered both natural and human-made drainage channels (the scheme of the drainage system as well as the detail is presented in Fig. 3. (a), (b), (c), and (d)). One important parameter on flood analysis is the magnitude of flood peak discharge which is influenced by rainfall, drainage area, and duration of overland flow (time of concentration) as well as travel time of water through drainage channels. Time of concentration of the watershed is determined by estimating the travel time of overland flow using Hathaway formula [6] and obtained as long as 10.959 hours.

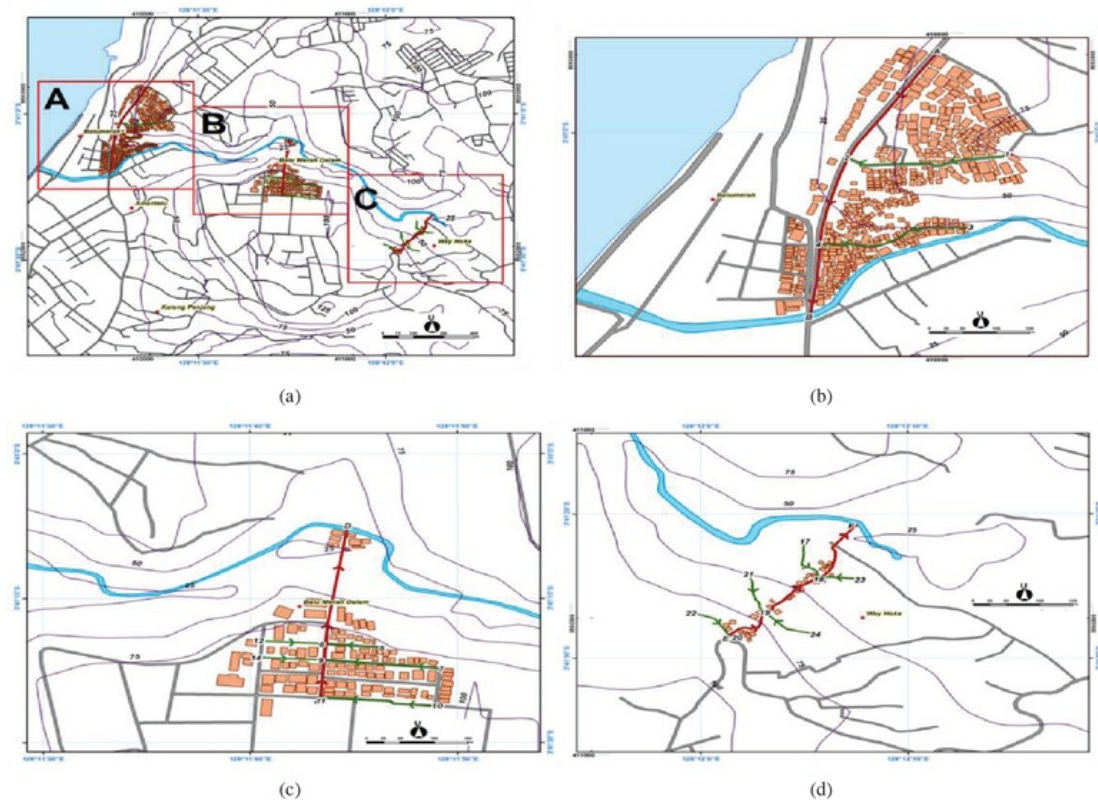


Fig. 3. (a) Scheme of drainage system in Wai Batu Merah Watershed; (b) Detail A; (c) detail B; (d) detail C [3]

4. Design rainfall and design flood

The distribution of maximum daily rainfall data in Ambon during 2004 – 2013 is assumed to follow distribution of Log Pearson Type III [7] with the calculated coefficient of variety is equal to 1.05. Validation of the assumption is done using test of Chi-Squared [7] goodness of test. The calculated X^2Cr (5.3) is less than critical Chi-Squared X^2Cr (5.991), which means the assumption is correct. Therefore, the next calculation of design rainfall is following equation in Log Pearson Type III distribution. Design rainfall is calculated for four different return periods, i.e. 2, 5, 25, and 50-year. The complete results are tabulated in Table 2.

To determine the most suitable method to estimate design flood, a measurement of actual discharge had been conducted in the main river. The field measurement recorded the discharge was $60.07 \text{ m}^3/\text{s}$. That magnitude is close to the calculated discharge using Rational Method [8] as much as $61.96 \text{ m}^3/\text{s}$. Therefore, the design flood at various return periods is determined using Rational Method and presented in Table 2.

Table 2. Design rainfall and design flood for Wai Batu Merah Watershed

Return period (T, years)	Maximum daily rainfall depth (mm)	Design flood (m^3/s)
2	184.5	61.96
5	285.8	95.97
25	477.4	160.35
50	572.3	192.22

The main input data of unsteady flow analysis in the main river besides geometric data of the channels is continuous discharge. In this study, continuous discharge is obtained by transforming rainfall into runoff in the watershed using Synthetic Unit Hydrograph (SUH) [7]. The application of SUH for flood analysis in this study is mainly due to unavailable data of flow discharge in Wai Batu Merah River to derive representing unit hydrograph. After several trials, using different types of commonly used of SUH, i.e. SUH Snyder and SUH Soil Conservation Service (SCS), SUH SCS provides closest magnitude to the observed magnitude of peak and time to peak of flood discharge. Synthetic Flood Hydrograph of SCS is then constructed based on SUH SCS and presented in Fig. 4.

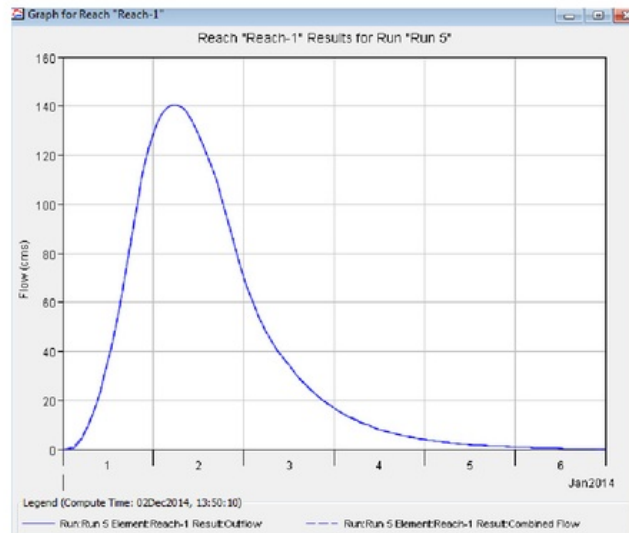


Fig. 4. Synthetic Flood Hydrograph SCS for flood analysis in Wai Batu Merah Watershed

5. Evaluation of drainage channels capacity and unsteady flow analysis of the main river

Evaluation of drainage channels capacity is done by calculating the capacity of each channel to flow water and compare it to discharge of overland flow. Drainage channels capacity are calculated using Manning formula [9], flow through open channel. While the overland flow is estimated using Rational Method [7]. Important data as input variables in Rational Method, i.e. rainfall intensity and time of concentration are not available in the related watershed, therefore data of rainfall depth is used to estimate rainfall intensity using Mononobe Formula [7] while the time of concentration is calculated using Hathaway formula [6,8]. A complete calculation of drainage channel capacity as well as the magnitude of overland flow is presented in Table 2.

Drainage channels in the watershed were constructed following the land topography. Data of slope of each drainage channel as presented in Table 2 indicates that most of the land area in Wai Batu Merah Watershed is steep. This condition causes the time of concentration of overland flow as well as the travel time of water through drainage channel is very short.

Time of concentration has inversely proportional relation with rainfall intensity based on Mononobe Formula [7]. It causes the shorter time of concentration results the higher rainfall intensity. Due to limited data, the duration of rainfall in a day is assumed to be equal to the time of concentration which is then used to calculate rainfall intensity. Further, the higher rainfall intensity causes the bigger peak flood discharge. The analysis shows that most of existing drainage channels has much bigger capacity compared to discharge of overland flow due to rainfall and only one drainage channel has insufficient capacity to flow discharge of overland flow, i.e. tertiary channel of 1-2 (refer to Fig. 3).

Table 2. Comparison of drainage channel capacity and discharge of overland flow in Wai Batu Merah Watershed

Type of drainage channel	Code	Service area (ha)	Slope (m/m)	Flow velocity in the drainage channel, V (m/s)	Existing drainage capacity, Q (m ³ /s)	Overland flow, Q' (m ³ /s)	Remarks
Secondary	A-B	2.5972	0.08	11.167	112.506	1.41	Sufficient
Tertiary	1-2	2.1069	0.04	3.620	0.724	0.91	Insufficient
Tertiary	3-4	0.4903	0.04	3.620	0.724	0.21	Sufficient
Secondary	E-F	1.9332	0.25	18.95	317.028	1.6	Sufficient
Tertiary	17-18	0.2065	0.125	7.373	2.21	0.12	Sufficient
Tertiary	24-19	0.3717	0.06	5.108	1.532	0.16	Sufficient
Tertiary	23-18	0.786	0.07	5.517	1.655	0.36	Sufficient
Tertiary	21-19	0.235	0.125	7.373	2.212	0.17	Sufficient
Tertiary	22-10	0.3394	0.57	15.744	4.723	0.25	Sufficient
Secondary	C-D	4.6518	0.14	11.948	11.948	3.74	Sufficient
Tertiary	5-6	3.4193	0.03	4.988	3.991	1.4	Sufficient
Tertiary	12-6	0.1653	0.125	7.373	2.212	0.11	Sufficient
Tertiary	14-9	0.8963	0.04	4.171	1.251	0.4	Sufficient
Tertiary	7-9	0.1709	0.03	3.612	1.084	0.09	Sufficient

Evaluation of river capacity as primary drainage channel is different with evaluation of human-made drainage channels capacity as discussed earlier. Unsteady flow analysis is used to evaluate it. Continues data of runoff throughout the watershed which is obtained from Synthetic Flood Hydrograph SCS from earlier analysis as shown in Fig.4 is used as the input data. The flood simulation results overflow occurred along the river as in Fig. 5. While the figure of water level above river bank in the upstream and downstream is presented in Fig. 6.a and 6.b.

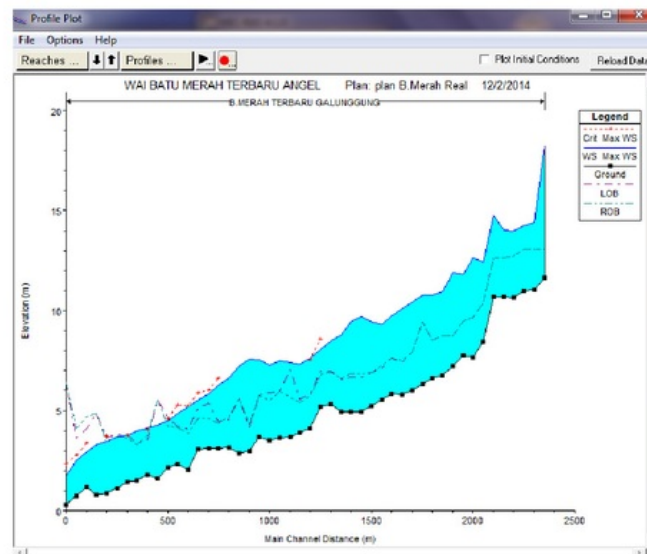


Fig. 5. Unsteady flow analysis at 50-year return period of flood at Wai Batu Merah Watershed

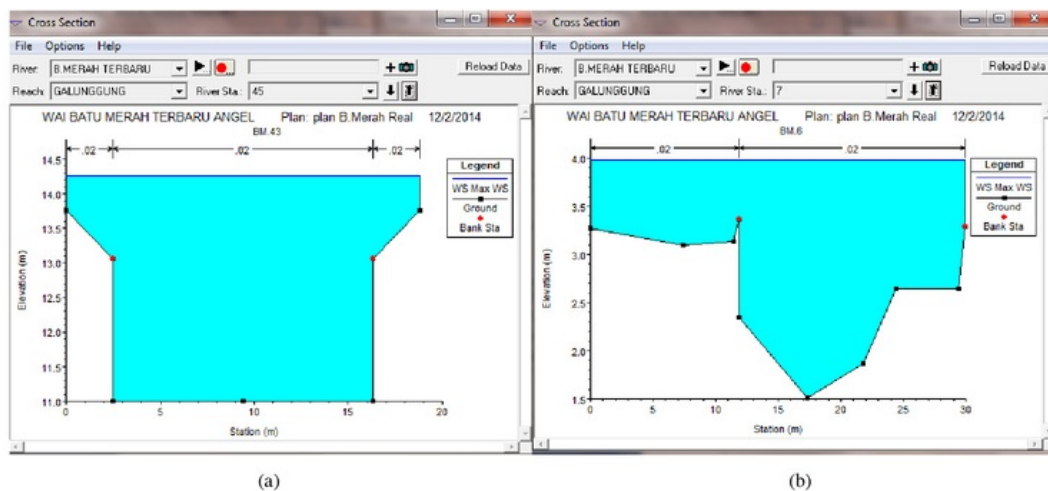


Fig. 6. Cross section of Wai Batu Merah River for analysis of 50-year return period of flood at: (a) upstream; (b) downstream

6. Conclusion

The flood simulation shows from the upstream to the downstream of Wai Batu Merah River is overflow due to maximum daily rainfall depth at 50-year return period. The recorded data of daily rainfall reveals rain fell during the month of July 2013 until mid of August 2013. The rainfall depth reached more than triple of maximum daily rainfall at 50-year return period. At that state, flood certainly cannot be avoided in the adjacent area of the river.

On the contrary, at 50-year return period of maximum daily rainfall, most of the secondary and tertiary drainage channels have capacity much more than discharge of overland flow. It happens due to the channels were designed and constructed following the contour of the area which is very steep. It makes the flow velocity through the drainage channels is very fast. This condition is unfavorable for the river to flow overland flow into the final outlet (sea) as quickly as possible.

Finally, it can be concluded that flood in 2013 in Wai Batu Merah Watershed was occurred in the close proximity of the main river due to insufficient river's capacity as well as the extreme rainfall. In the past, when the watershed was less developed, overflow along the river may not be a problem. However, the present situation as the area has been developed to satisfy human needs, overflow along the river is considered as a hazard. Therefore, a good city development and management must be done by considering the natural capacity of the river as well as future rainfall condition.

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