Performance Analysis of Long Storage and Tidal Controlling Gate on the Flood of Kemuning River

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Abstract. Kemuning river flood is caused by watershed (DAS) quality factor, river capacity, and tidal influence. Effort of controlling that has been done is by making reservoir in upper stream, river normalization in the urban area, and pump installation in the mouth of river. Yet those efforts are not significantly decreasing the frequency of flood. In this paper, it proposed the installation of controlling gate in the downstream of the pump location as a means of controlling, so the current can only move one direction to the downstream of the river. The gate design is planned according to the topography of the local riverbed and utilized it as a long storage. To know the effectiveness of the plan, the performance analysis of long storage and the gate on flood of Kemuning river is conducted. The result of analysis shows that the peak of maximum hydrograph discharge Q2; Q5; Q10; Q25; Q50, is (m³/second): 121.608; 192.720; 220.258; 241.605; 263.558. The combination of long storage and one direction gate cannot control the discharge of flood for two years, therefore to control flood it needs additional water reservoir and/or flood pump.

1. Introduction

The performance of the flood control system in the Kemuning river must continue to be improved, because the condition of the watershed (DAS) is increasingly damaged and sedimentation occurs at the river mouth. Kemuning river is crossing the urban area of Sampang and floods occur every year so that it becomes one of the centers of attention in flood control efforts in Indonesia [1]. The problem of flood and the causes that occur at Kemuning river are often found in some regions, with a larger scale. Thus, Kemuning river flood control is potential as a model in Indonesia, even in general it can also be applied anywhere.

The causes of flood in Kemuning river are: (1). Conditions of watersheds (DAS); (2). River flow conditions in urban areas, and (3). Influence of tidal water. The concept of flood control by improving watershed conditions has been exposed in previous papers, while in this paper it focuses on controlling the influence of tide [2-5]. Kemuning River watershed is shown in Figure 1.
At the time of maximum tide, the influence of sea level elevation spreads to the river in Sampang urban area. Therefore, efforts to control floods by increasing the capacity of water distribution at the mouth of the river must be done carefully, especially against the emergence of back water.

The use of long storage in flood control system is intended as an effort to increase the effect of water storage from riverbed [6]. This is considered to be quite profitable if the cost of making water reservoirs outside the riverbed is relatively expensive related to land acquisition. In hydraulic analysis, to determine the response of the storage capacity of the flood discharge hydrograph that enters the river system is by using the Muskingum concept. The use of this concept has been applied in various construction planning. Increasing accuracy has been carried out by adding storage parameters [4,3].

The efforts to improve the performance of temporary reservoirs [7] and water pumps in the control system of the tidal water influence, one-way water gates are used which in this case are called valve gate. The valve gate is one of the water gates that operate automatically, that is, the opening and closing doors use energy due to the changes in water level of upstream and downstream of the door. Valve gate applications have been carried out in the water management system plan in oil palm plantations [8,9] [10]. The use of the gate is described in Figure 1. In the applied test, it shows very good performance in terms of operation and accuracy of discharge capacity.

Maximizing the performance of the tidal influence control system is done by making: (1). temporary water reservoir, (2). water gate, and or (3). pump.

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**Figure 1.** Kemuning river watershed.

**Figure 2.** The use of valve gate.
2. Method
The method used is by analyzing the influence of the use of auxiliary facilities (reservoirs, gate, and pumps) from the hydraulics review. Activities in the form of simulations with several pair scenarios, focusing on the analysis of the effectiveness of controlling the influence of tidal water with the use of river channels as long storage and equipped with water gates.

As input, flood discharge is used with various times, starting from 2 years. The river is dredged, with 2 assumptions: (1) the riverbed elevation is as low as tide surface and (2) the elevation of the riverbed below the level of low tide, with consequence it is necessary to always have a water pump. The flood water level due to back water is limited to 50 cm below the surrounding ground level.

3. Data analysis
The flood water level in up stream’s water gate that is installed at the river mouth is carried out by searching the flood. In this activity, water storage capacity is calculated without additional water reservoirs outside the riverbed. The search is carried out using the Muskingum method, with the means of output in the form of box culvert. Output capacity is calculated in two conditions, namely free flow and compressive flow.

3.1. Artificial rain
The flood hydrograph was analyzed by the method of variance in rain to flood discharge. In Kemuning watershed area there are 2 influenced rain stations (STA) into Kemuning river flood discharge, namely Kedundung STA and Torjun STA. The maximum annual rainfall data for the last 10 years is presented in table 1. The average height of regional rainfall is calculated by 2 methods, namely Thiessen Algebra and polygon averages. The highest daily rainfall from the analysis results is generated from the Thiessen polygon method. This happens because the distribution of station locations is uneven. Thus, for the next calculation, the results of the rainfall analysis of the Thiessen polygon method (table 2) are used.

| Table 1. Maximum annual daily rainfall data. |
|---------|---------|---------|---------|
| No | Year | Maximum Rainfall Kedundung STA | Torjun STA |
| 1 | 2008 | 75 | 67 |
| 2 | 2009 | 30 | 110 |
| 3 | 2010 | 65 | 210 |
| 4 | 2011 | 69 | 64 |
| 5 | 2012 | 33 | 70 |
| 6 | 2013 | 82 | 73 |
| 7 | 2014 | 80 | 78 |
| 8 | 2015 | 75 | 65 |
| 9 | 2016 | 64 | 88 |
| 10 | 2017 | 64 | 25 |

| Table 2. Maximum annual average rainfall. |
|---------|---------|---------|---------|---------|
| No | Year | Maximum Rainfall | d (mm) |
| 1 | 2008 | 75 | 67 | 72.42 |
| 2 | 2009 | 30 | 110 | 55.82 |
| 3 | 2010 | 65 | 210 | 111.81 |
| 4 | 2011 | 69 | 64 | 67.39 |
| 5 | 2012 | 33 | 70 | 44.94 |
| 6 | 2013 | 82 | 73 | 79.09 |
| 7 | 2014 | 80 | 78 | 79.35 |
| 8 | 2015 | 75 | 65 | 71.77 |
| 9 | 2016 | 64 | 88 | 71.75 |
| 10 | 2017 | 64 | 25 | 51.41 |
Artificial rain was calculated by the Gumbel method and Log Pearson Type III. The suitability test of the two methods was carried out with the smirnov-kolmogov test. The smallest deviation is used as a determinant of the selected frequency distribution. The results of the analysis show the Log Pearson Type III distribution. The artificial rain analysis results are shown in Table 3. Thus, even though the calculation results show that the artificial rain of the Gumbel EJ method is larger, but because the test results show that the more suitable distribution is Log Pearson Type III then the results of Log Pearson type III analysis are used (Table 3).

3.2. Flood hydrograph
The flood hydrograph that was used as input in the flood trace analysis was carried out using the Nakayasu Synthetic Unit (HSS) hydrograph model. The use of Nakayasu HSS is done with the consideration that this model is very suitable [3]. The results of the flood discharge hydrograph analysis with various times are shown in Table 4.

| Year | E J Gumbel | Log Person |
|------|------------|------------|
| 5    | 100.876    | 89.823     |
| 10   | 120.229    | 105.804    |
| 20   | 139.038    | 128.346    |
| 50   | 163.347    | 146.903    |
| 100  | 181.647    | 167.045    |
| 1000 | 241.763    | 248.724    |

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| Time (hour) | Q-5 | Q-10 | Q-20 | Q-50 | Q-100 | Q-1000 |
|------------|-----|------|------|------|-------|--------|
| 0          | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000   |
| 1          | 19.393 | 22.843 | 27.710 | 31.716 | 36.065 | 53.699 |
| 2          | 89.463 | 105.380 | 127.831 | 146.313 | 166.375 | 247.726 |
| 3          | 79.540 | 93.692 | 113.652 | 130.085 | 147.921 | 220.250 |
| 4          | 66.878 | 78.777 | 95.560 | 109.377 | 124.374 | 185.188 |
| 5          | 57.059 | 67.211 | 81.530 | 93.318 | 106.113 | 157.999 |
| 6          | 48.147 | 56.714 | 68.796 | 78.743 | 89.540 | 133.322 |
| 7          | 33.513 | 39.475 | 47.885 | 54.809 | 62.324 | 92.798  |
| 8          | 23.906 | 28.160 | 34.159 | 39.098 | 44.459 | 66.198  |
| 9          | 17.693 | 20.841 | 25.282 | 28.937 | 32.905 | 48.994  |
| 10         | 13.619 | 16.041 | 19.459 | 22.273 | 25.327 | 37.710  |
| 11         | 10.601 | 12.488 | 15.148 | 17.338 | 19.716 | 29.356  |
| 12         | 8.340  | 9.824  | 11.917 | 13.640 | 15.510 | 23.094  |
| 13         | 6.630  | 7.810  | 9.474  | 10.843 | 12.330 | 18.359  |
| 14         | 5.306  | 6.250  | 7.581  | 8.677  | 9.867  | 14.691  |
| 15         | 4.246  | 5.001  | 6.067  | 6.944  | 7.896  | 11.757  |
| 16         | 3.398  | 4.002  | 4.855  | 5.577  | 6.318  | 9.408   |
| 17         | 2.719  | 3.203  | 3.885  | 4.447  | 5.056  | 7.528   |
| 18         | 2.176  | 2.563  | 3.109  | 3.558  | 4.046  | 6.025   |
| 19         | 1.741  | 2.051  | 2.488  | 2.847  | 3.238  | 4.821   |
| 20         | 1.393  | 1.641  | 1.991  | 2.279  | 2.591  | 3.858   |
| 21         | 1.115  | 1.313  | 1.593  | 1.823  | 2.073  | 3.087   |
| 22         | 0.892  | 1.051  | 1.275  | 1.459  | 1.659  | 2.470   |
| 23         | 0.714  | 0.841  | 1.020  | 1.168  | 1.328  | 1.977   |
| 24         | 0.311  | 0.366  | 0.444  | 0.208  | 0.0578 | 0.860   |
3.3. Long storage capacity
The capacity of long storage is calculated based on topographic data at the location of the prospective box culvert building. The results of the analysis of the storage capacity of each water level are shown in Figure 3.

![Figure 3. Long storage capacity.](image)

3.4. Box culvert output capacity
The box culvert capacity is calculated in 2 conditions, when the water level in the reservoir is 0.0 m to 1.2 m x the box culvert height with the free flow equation, whereas if the water level is more than 1.5 x the box culvert height it uses the press flow approach. Whereas when the water level between (1,2 to 1,5) is considered the transition part. In an effort to get the number and dimensions of the box culvert, simulations were carried out. In this paper, 3 (three) choices are displayed as follows:
- Number of boxes culvert 1, with a size of 1m x 1m;
- Number of box culvert 1, with a size of 2 m x 2 m;
- Number of box culvert 3, with a size of 1.5 m x 1.5 m. The box culvert size selected is already on the market, so if it is implemented it will be easy to get in the field. The results of the analysis are stated in table 5.

**Table 5. Box culvert capacity (m³/second).**

| ELEV | NUMBER OF BOX CULVERT (DIMENSION) | 1 (1 m x 1 m) | 1 (2m x 2 m) | 3 (1.5 m x 1.5 m) |
|------|-----------------------------------|--------------|--------------|-----------------|
|      |                                   | 0            | 0            | 0               |
| 3.69 |                                   | 3.507005     | 1.189487     | 9.250218        |
| 3.93 |                                   | 9.232588     | 3.131459     | 24.35225        |
| 4.17 |                                   | 15.68146     | 5.318751     | 41.36204        |
| 4.41 |                                   | 22.47099     | 7.62159      | 59.2704         |
| 4.65 |                                   | 47.62823     | 5.371493     | 33.88935        |
| 5.69 |                                   | 48.04972     | 5.442642     | 34.11453        |
| 5.73 |                                   | 48.46755     | 5.512873     | 34.33823        |
| 5.77 |                                   | 48.88181     | 5.58222      | 34.56049        |
| 5.81 |                                   | 49.29259     | 5.650716     | 34.78132        |
| 5.85 |                                   | 49.69997     | 5.718391     | 35.00077        |
| 5.93 |                                   | 50.10404     | 5.785275     | 35.21884        |
| 5.97 |                                   | 50.50888     | 5.851395     | 35.43558        |
| 6.01 |                                   | 50.90526     | 5.916776     | 35.65099        |
| 6.05 |                                   | 51.29716     | 5.981442     | 35.86511        |
| 6.09 |                                   | 51.68875     | 6.045416     | 36.07796        |
| 6.13 |                                   | 52.07739     | 6.108721     | 36.28957        |
| 6.17 |                                   | 52.46316     | 6.171376     | 36.49994        |
| 6.21 |                                   | 52.8461      | 6.233401     | 36.70911        |
| 6.25 |                                   | 53.2263      | 6.294816     | 36.9171         |
| 6.27 |                                   | 53.41538     | 6.352599     | 37.02685        |
| 6.29 |                                   | 53.60379     | 6.355637     | 37.12992        |
| 6.31 |                                   | 53.79155     | 6.38583      | 37.2269         |
| 6.33 |                                   | 53.97865     | 6.415881     | 37.32959        |
| 6.35 |                                   | 54.1651      | 6.445792     | 37.43201        |

Source: calculation results
3.5. Flood search

The response of long storage to inflow debit and output capacity was analyzed by tracing the flood, which in this case uses the Muskingum method. Flood tracing was carried out on 3 output capacities. The results of the analysis were presented in the form of a discharge hydrograph, in Figure 3, while the water level in the reservoir (long storage) in the simulation I was presented in Figure 3.

The water level in the reservoir (long storage) of the three simulations obtained an illustration that alternative 3 is the best choice, considering the height of the right and left cliffs of the river is about 7 meters. The water level elevation graph in Alternative 1 is shown in Figure 5.

4. Discussion

Regional average rainfall analysis, with the number of rain stations 2 (two) pieces, until now there are still incorrect assumptions, that is always use the algebraic mean method. This opinion is supported by the explanation that with only 3 points, polygons cannot be made to determine the area of influence. However, in this study, it proved that if the location of the rain station was not evenly distributed, the teissen polygon method was still more appropriate. This also agrees with CD Soemarto [6].

The results of flood trace analysis with several alternative means of output indicate that:
- By using 1 (one) box, the most profitable size culvert is 2 x 2 (m);
- By using 3 (three) boxes the most optimal size culvert is 1.5 x 1.5 (m).
Design selection is done with a large review of the maximum control, namely the maximum storage effect and flood water level not exceeding the limit.

Thus, the use of long storage by combining water gate and box culverts is not enough to control the influence of high tide water. It is recommended to add a pool of water outside the river trough or use a pump.

5. Conclusion
The use of Long storage is not effective for controlling the influence of tidal water in Kemuning River floods, so it needs to support Box culvert, water gates, and or water pumps. Box culvert 3 holes with 1.5 x 1.5 (m) designs most optimal with the aim of maximizing the reservoir effect with the maximum flood water elevation limit.

References
[1] Kustamar K, F Handoko and A Soetedjo 2018 Flood Control Strategy In Sampang City, East Java, Indonesia. International Journal of GEOMATE 00 52 186-2990
[2] Kustamar K, T H Nainggolan, A Witjaksono, A Utomo and L M Limantara 2018 Development of the Conservative Village Model in the Upstream Brantas River International Journal of GEOMATE 15 50 82 – 188
[3] Weng Chan N 1997 Increasing flood risk in Malaysia: causes and solutions Disaster Prevention and Management: An International Journal 6(2) 72-86
[4] Kustamar K, T H Nainggolan, Lilia D S and A Witjaksono 2017 Flood Control Based on Conservation of Water Resources Research Report. PUPT. Not published.
[5] Rode S, Guevara S and Bonnefond M 2018 Resilience In Urban Development Projects In Flood-Prone Areas: A Challenge To Urban Design Professionals (Liverpool: Liverpool University Press)
[6] Harmani E 2015 Controlling The Flood Caused By The Sedimentation In Kemuning River, Sampang City, Madura Journal Of Civil Engineering 11 29-34
[7] Muqoddas Z 2017 Flood Is Occurred Frequently - Sampang City Constructs The Reservoir (Madura: Portal Madura News)
[8] R Hendrayana 2018 Sawit Coconut Plant Development Plan Proceedings of the National Seminar on Science and Technology Faculty of Engineering, University of Muhammadiyah Jakarta
[9] W Chung and Y-L Kang 2004 Flood Routing In Long Channels: Alleviation Of Inconsistency And Discharge Dip In Muskingum-Based Models 29 1
[10] Frendi I 2013 Normalization Planning Of Kemuning River, Sampang, Madura (Undergraduate Thesis, Faculty of Civil Engineering and Planning, University of National Development “Veteran”, East Java, Indonesia)