Flow Behavior of Boyong River as Revealed by Long-term Hydro-monitoring System

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Abstract. Boyong River is one of many rivers originating from Mt. Merapi, flows across three autonomy administrative of Sleman Regency, Yogyakarta City, and Bantul Regency. The river experiences flood in the form of lava flow several times, and the 1994 and 2010 occurrences were considered the biggest ones along with the river history. In line with the rapid development of information and communication technology, efforts to develop the early warning system due to the Mt. Merapi disaster have been implemented by the Hydraulic Laboratory of Gadjah Mada University 2006. This paper presents the study results of Boyong River flow behavior by analyzing the data obtained from the monitoring system. The Gemawang Weir at Boyong River was selected as the river control point understudy; those include the catchment boundary, the catchment characteristics, and the hydraulic features. Monitoring equipment consists of an automatic water level recorder (AWLR), the flow visualization using a Brinno camera, and the hydrophone monitoring system. The flow hydrograph characteristics and its corresponding sediment transport rate are considered two parameters for identifying the flow behavior. The results show that the precursive and recession times of the flood hydrograph are about 1-3 hours and 3.5-5 hours, respectively.

Keywords: Flow behavior, early warning system, hydrophone, flow hydrograph.

1. Introduction
Gemawang Weir is one of several water structures located on the Boyong River. The complementary infrastructure in Gemawang Weir is quite complex, including Automatic Water Level Recording (AWLR), Hydrophone, Turbidity, and Monitoring Cameras that can record data and information related to natural events the Boyong River.

Information related to the Boyong River is essential because this river is a river that crosses the administrative center of the Special Region of Yogyakarta. The Boyong River originates at Mount Merapi and empties into Opak River, administratively located in Sleman Regency, Yogyakarta City, and Bantul Regency. The river flows, a reasonably large discharge, high utilization around its flow, and investment in water resources infrastructure buildings are quite a lot. Over time these changes occur pretty effectively in their contribution to the destructive power of water.
As the most active volcano in Indonesia, Merapi has about seven years of eruption occurrences that produce relatively large amounts of sediment [5]. Eruptions that have occurred in recent years have resulted in changes in the morphology of the river.

This study aims to determine the flow behavior and sediment transport rate in the Boyong River by studying the performance of hydrological and hydraulic monitoring equipment at the Gemawang Weir, which is expected to be helpful in the development of the future research.

2. Research Methods

2.1 Research Location
The research location is at Gemawang Weir on the Boyong River with coordinates X: 430679.69 and Y: 9142514.69 (see Figure 1). Gemawang weir is located at an elevation of +125.00 m above sea level with a spillway width of 28 meters. The main dam height is 4 meters, and the building condition is good.

![Figure 1. Location of Gemawang Weir and Catchment Area of Boyong River.](image)

2.2 Sediment Control Infrastructure
Distribution of the flood-prone lahars of Mount Merapi, one of which is towards Kali Boyong, where the river flows into the urban area of Yogyakarta.

As a volcanic disaster-prone area, the Boyong River flows require integrated and sustainable management by applying appropriate technology, including the Sabo Dam sediment control building.

The Sabo Dams in Boyong River are arranged in a single river management unit, and there are approximately 57 Sabo Dams along the Boyong River (see Figure 2). The sediment control system of the Boyong River has a total capacity of 2,338,668 m³.
2.3 Methods
This research begins with a previous study related to the Boyong River and takes an inventory of spatial data along the river section as additional information. The next step is to collect water level data at the spillway, data obtained in meters (m) or millimeters (mm) from automatic water level recorder (AWLR) readings. The flow data obtained from the hydro-monitoring system is then processed to obtain a flow hydrograph with units of m$^3$/s.

2.4 Flow Data Processing
The automatic water level recorder (AWLR) on the Gemawang Weir reads the water level above the overflow. Then, the amount of discharge that overflows above the weir crest is calculated using the Equation of discharge coefficient ($C_d$) of the standard type of weir written as follows [8]:

$$C_d = 2.20 - 0.0416 \left( \frac{H_d}{W} \right)^{0.9900}$$  \hspace{1cm} (1)

The Equation used to calculate the flow over the top of the weir crest is written as follows:

$$Q = C_d \cdot B \cdot H^{3/2}$$  \hspace{1cm} (2)

where:

- $Q$ = discharge that passes through the overflow, m$^3$/s
- $C_d$ = overflow discharge coefficient
- $B$ = spillway effective width, m

Figure 2. Sabo Dams along Boyong River.
\[ H = \text{water level above the spillway, m} \]
\[ W = \text{spillway height, m} \]

The recording obtained by AWLR is a hydrograph of water level and then processed into a discharge hydrograph using Equation (2). The hydrograph consists of three main parts; the initial stage is the rising limb, crest, and recession limb [9].

### 2.5 Flash Flood
Flash floods are flood events that occur quickly or suddenly with large flood volumes. In addition to carrying water, flash floods also bring other materials mixed in, ranging from fine to coarse materials in the form of sand, gravel, gravel, stones, and fallen trees. This disaster is hazardous and has high destructive power due to its high speed and mixing [4].

### 2.6 Bed Load Transport
Coarse particles that move along the river bed as a whole are called bed load [7]. Bedload occurs in sediments with larger sizes, such as gravel, sand, boulders, and gravel. The particles in the bedload move by rolling or sliding on the riverbed. The bottom sediment load generally occurs in large-diameter sediment grain sizes. The movement of the bed formation causes degradation and aggradation along with the flow, which is called riverbed alteration.

### 2.7 Hydrophone
The hydrophone is a Japanese steel pipe that monitors bottom sediment by recording sediment particles with a microphone [6]. When a bottom sediment particle hits the iron pipe at the bottom of the channel, the microphone will detect the impact and then convert it into a wave or pulse. Hydrophones can monitor sediment transport in rivers with steep slope conditions—measurement of bottom sediment transport discharge following the increase in the number of pulses recorded.

A study entitled "Basic study on sediment rate measurement with a hydrophone based on sound pressure data" [10]. In this study, a hydrophone has been used to measure the intensity of bedload transport. The method used calculates the amount of thrust generated by hitting sand and gravel into a steel pipe. However, this method has several obstacles. If the sediment rate is high, the sound level increases continuously, so the number of thrusts will decrease or become zero. This problem can be solved by integrating and recording proper pressure.

In collaboration with Kyoto University, the Hydraulic Laboratory of Universitas Gadjah Mada installed the hydrophone monitoring system at Gemawang Weir, Mlati Regency, Sleman. As a result, hydrophone data in the Gemawang Weir segment can be accessed on the website https://data.hydraulic.lab.cee-ugm.ac.id/bo-awlr-02/ for free.

### 2.8 Flowchart of research
The research of the flow behavior of Boyong River was carried out according to the flow chart as shown in Figure 3.
Figure 3. Flowchart of the research.

3. Results and Discussion

3.1 Measured Flood Hydrograph
Photo of the situation of Gemawang Weir and the sketch of hydrophone geometry is shown in Figure 4 (a) and Figure 4 (b), respectively. Data on water level readings by means of Automatic Water Level Recorder (AWLR) and hydrophone readings are available starting on December 11, 2015, at 18:00 Western Indonesian Time until this manuscript is prepared (July 10, 2021).

Figure 4 (a). Situation of Gemawang Weir [2].
Figure 4 (b). Geometry of pipe hydrophone main components [1].
The analysis of the measured flow rate and the pulse recording in this study was carried out on several flood occurrences, i.e., November 30 thru December 1, 2016, and November 16-17, 2017. The first occurrence is shown in Table 1 and Figure 5, whereas the second occurrence is shown in Table 2 and Figure 6.

**Table 1.** Measured flow depth and discharge on November 30 – December 1, 2016

| Date       | T (hours) | H (m) | Q (m³/s) | Date       | T (hours) | H (m) | Q (m³/s) |
|------------|-----------|-------|----------|------------|-----------|-------|----------|
| 11/30/2016 |           |       |          | 12/1/2016  |           |       |          |
| 0          | 0.26      | 7.93  |          | 24         | 0.46      | 19.45 |          |
| 1          | 0.25      | 7.89  |          | 25         | 0.40      | 15.81 |          |
| 2          | 0.29      | 9.53  |          | 26         | 0.36      | 13.28 |          |
| 3          | 0.29      | 9.59  |          | 27         | 0.32      | 11.36 |          |
| 4          | 0.27      | 8.60  |          | 28         | 0.30      | 9.93  |          |
| 5          | 0.25      | 7.65  |          | 29         | 0.27      | 8.80  |          |
| 6          | 0.23      | 6.96  |          | 30         | 0.25      | 7.80  |          |
| 7          | 0.22      | 6.16  |          | 31         | 0.24      | 7.04  |          |
| 8          | 0.19      | 5.10  |          | 32         | 0.23      | 6.71  |          |
| 9          | 0.18      | 4.68  |          | 33         | 0.23      | 6.58  |          |
| 10         | 0.17      | 4.39  |          | 34         | 0.20      | 5.67  |          |
| 11         | 0.16      | 3.94  |          | 35         | 0.18      | 4.89  |          |
| 12         | 0.15      | 3.73  |          | 36         | 0.17      | 4.46  |          |
| 13         | 0.15      | 3.50  |          | 37         | 0.15      | 3.72  |          |
| 14         | 0.14      | 3.37  |          | 38         | 0.16      | 3.95  |          |
| 15         | 0.14      | 3.26  |          | 39         | 0.16      | 3.87  |          |
| 16         | 0.14      | 3.23  |          | 40         | 0.16      | 3.94  |          |
| 17         | 0.14      | 3.12  |          | 41         | 0.41      | 15.89 |          |
| 18         | 0.13      | 3.02  |          | 42         | 0.36      | 13.35 |          |
| 19         | 0.72      | 37.30 |          | 43         | 0.33      | 11.49 |          |
| 20         | 1.00      | 61.58 |          | 44         | 0.29      | 9.75  |          |
| 21         | 0.82      | 45.64 |          | 45         | 0.29      | 9.56  |          |
| 22         | 0.69      | 34.87 |          | 46         | 0.27      | 8.70  |          |
| 23         | 0.56      | 25.60 |          | 47         | 0.28      | 9.16  |          |

**Figure 5.** Hydrograph of flow and number of pulses on November 30 – December 1, 2016.
Table 2. Measured flow depth and discharge on November 17-18, 2017

| Date   | T (hours) | H (m) | Q (m³/s) | Date   | T (hours) | H (m) | Q (m³/s) |
|--------|-----------|-------|----------|--------|-----------|-------|----------|
| 0      | 0.15      | 3.44  |          | 24     | 0.55      | 25.05 |          |
| 1      | 0.14      | 3.20  |          | 25     | 0.46      | 19.48 |          |
| 2      | 0.14      | 3.09  |          | 26     | 0.40      | 15.56 |          |
| 3      | 0.13      | 2.94  |          | 27     | 0.36      | 13.17 |          |
| 4      | 0.13      | 2.85  |          | 28     | 0.33      | 11.64 |          |
| 5      | 0.13      | 2.79  |          | 29     | 0.30      | 10.17 |          |
| 6      | 0.13      | 2.81  |          | 30     | 0.28      | 9.09  |          |
| 7      | 0.12      | 2.70  |          | 31     | 0.26      | 8.03  |          |
| 8      | 0.12      | 2.56  |          | 32     | 0.24      | 7.16  |          |
| 9      | 0.11      | 2.39  |          | 33     | 0.22      | 6.48  |          |
| 10     | 0.11      | 2.34  |          | 34     | 0.20      | 5.68  |          |
| 11     | 0.11      | 2.28  |          | 35     | 0.20      | 5.39  |          |
| 12     | 0.11      | 2.32  |          | 36     | 0.19      | 5.07  |          |
| 13     | 0.11      | 2.22  |          | 37     | 0.18      | 4.82  |          |
| 14     | 0.10      | 2.09  |          | 38     | 0.17      | 4.49  |          |
| 15     | 0.10      | 2.06  |          | 39     | 0.17      | 4.32  |          |
| 16     | 0.10      | 2.04  |          | 40     | 0.16      | 4.04  |          |
| 17     | 0.46      | 19.06 |          | 41     | 0.16      | 3.93  |          |
| 18     | 0.51      | 22.16 |          | 42     | 0.15      | 3.62  |          |
| 19     | 0.76      | 40.85 |          | 43     | 0.15      | 3.42  |          |
| 20     | 0.75      | 40.21 |          | 44     | 0.14      | 3.40  |          |
| 21     | 0.91      | 52.80 |          | 45     | 0.14      | 3.20  |          |
| 22     | 0.84      | 47.15 |          | 46     | 0.14      | 3.16  |          |
| 23     | 0.67      | 34.03 |          | 47     | 0.14      | 3.10  |          |

Figure 6. Hydrograph of flow and number of pulses on November 17–18, 2017.

The shape of the hydrograph in Figures 3 and 4 shows that at the initial time, there is the only base flow that constantly flows continuously all the time. After the rain, there is surface runoff so that the value reaches its peak at a particular time. When the rain starts to disappear, then the surface runoff will decrease until it ends.
3.2 Measured Sediment Transport
The hydrophone is quite good at reading the number of collisions caused by sediments with a diameter greater than 4 mm (see Figure 7). The reading for each level of gain or wave gain will be different. HP1 has the highest amplification level (x 1024), producing the most significant pulse value than HP2, HP3, HP4, HP5, or HP 6. In addition to sediment diameter, hydrophone sensitivity is also affected by river flow rate and sediment grain density [3].

![Figure 7](image7.png)

**Figure 7.** The relationship between pulse magnitude and particle diameter on HP1.

The relationship between the number of pulses and the relative frequency of two different flood events are shown in Figure 8 and Figure 9 for November 30-December 1, 2016, and November 17-18, 2017 events, respectively. The figures show that the relative frequency is much influenced by the flood characteristics (i.e., the discharge and duration of the flood). The higher number of pulses with a longer duration produced the higher relative frequency. Further study requires more data to investigate the behavior of such a relationship.

![Figure 8](image8.png)

**Figure 8 (a).** The relative frequency and the duration of each class of pulses on the hydrophone on November 30, 2016.

![Figure 8](image9.png)

**Figure 8 (b).** The relative frequency and the duration of each class of pulses on the hydrophone on December 1, 2016.
4. Conclusion

Based on the analysis carried out to obtain hydraulic parameter values at Gemawang Weir, the flow hydrograph with components in the form of precursive time and recession time in the flood event are presented. The precursive time of 1-3 hours and recession time of 3.5-5 hours is obtained. A flood with a high discharge will carry sediment with a large grain diameter, where the higher the diameter of the grains hitting the hydrophone, the higher the pulse readings.

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