STUDY ON THE PERFORMANCE OF WONOGIRI RESERVOIR AS FLOOD CONTROL STRUCTURE

Alexander Armin Nugroho
Disaster Risk Reduction Office of Central Java Province, Semarang, Indonesia
alex_nugroho07@yahoo.com

ABSTRACT

The Wonogiri reservoir was built with a primary function as flood control, especially in areas prone to flooding along the Bengawan Solo River. To find out the performance of the Wonogiri reservoir in flood control of Bengawan Solo, a study was conducted on flood hydrograph characteristics of the reservoir inflow by considering the contribution inflow from all sub-watersheds in the reservoir catchment area, at the end of December 2007. Calculation analysis flood hydrograph of Wonogiri Reservoir inflow is done with the calibration of Wuryantoro and Keduang sub-watersheds. Results of the calibration were then used as reference to simulate flood hydrograph inflow in each sub-watershed catchment areas. Flood routing in the reservoir was done with the assumption that the inflow of the reservoir was left to face up a height of water in the reservoir 135.3 m (the lower flood control limit) and 138.3 m (the upper flood control limit) and then the spillway gates full-opening. Results of this research indicated that the maximum discharge inflow into the reservoir on the event of Wonogiri flood at the end of December 2007 was ranged from 3,331 to 4,993 m^3/s; and it was occurred on December 26, 2007 at between 04:00 - 06:00 am. The most dominant flood hydrograph contribution into the reservoir was derived from Keduang sub-watershed. The flood in the reservoir was simulated as that the spillway gates were closed until water level of reservoir reached the minimum height of 135.3 m and 138.3 m and only until then the spillway gates full-opening. The reservoir water level reached 135.47 m on December 26, 2007 at 6:00 am and outflow was generated when the gates opened to reach 550 m^3/s and then increased up to 642 m^3/s at 14:00 after then it gradually decreases. The water level simulation was unable to reach 138.3 m because up to December 27, 2007 at 23:00 the water level reservoir reaches only 136.44 m. The Wonogiri reservoir flood control function still can run well and able to reduce the peak flood of 85%.

Keywords: Flood hydrograph inflow, Wonogiri Reservoir, flood control.

1 INTRODUCTION

One of the attempts in controlling flood is by installing reservoir/dam. The reservoir principle as a flood control is to detain high peak flow (Q_p) of the incoming flood (inflow) in the reservoir and released (outflow) with lower Q_p, so it will not inundate the downstream area. Wonogiri Reservoir is built with the main aim as a flood control, particularly in the flood-prone area alongside the Bengawan Solo River, while other functions are as irrigation water supply and hydroelectric power plant.

To discover Wonogiri Reservoir performance in Bengawan Solo flood control in the end of December 2007, a study was conducted towards flood hydrograph characteristics of the reservoir inflow by considering the contribution inflow from the entire sub-watersheds in the reservoir catchment area. This research was intended to study dominant factor of the flood discharge flowing to the Wonogiri Reservoir, and also to evaluate Wonogiri Reservoir performance on flood control in the end of December 2007.

2 RESERVOIR OPERATION

Reservoir is built generally for the development of river water resource by containing water on the rainy season, and improves the river stream condition particularly on the dry season. The reservoir could change the inflow-outflow hydrograph pattern. Outflow hydrograph change in the reservoir downstream is usually beneficial for the flood control, with its lower flood discharge and decelerating flood arrival time. Points should be noted are the deceleration of the flood arrival time, the reduction of the amount of flood discharge being released to the downstream, and the ratio of the allocation of reservoir volume for flood control and the volume for the development of the water resource (Kodoatie & Sjarief, 2006)

Wonogiri Reservoir operation is divided to three categories, i.e. (Nippon Koei Co. Ltd, 1984):

a) Non-Flood Period Operation (May 1st – October 31st). The reservoir water level gauge is planned to reach the highest normal high water level (NHWL), El. 136.00 m. During the dry season, the spillway gate is always closed. The spillway gate of Wonogiri reservoir can be seen in Figure 2(b) and Figure 2(c).

b) Flood Period Operation (Flood Control Operation) (November 1st – April 15th) reservoir water level gauge was only being increased to El. 135.30 m (controlled water level/CWL). Above the CWL is the space provided for the flood control. The spillway gate opening is measured with criteria as follows: On minor flood, Q_p < 400 m^3/s, outflow released < 400 m^3/s by setting the spillway gate opening (partial opening) until the flood stops, Q outflow is equal to Q inflow. On standard flood (moderate flood and major flood), 400 $m^3/s < Q_p <$ 4000 m^3/s, outflow released continuously is 400 m^3/s (partially opened) until the flood stops. On massive flood, $Q_p > 4000$ m^3/s, which is Design Flood condition or Probable Maximum Flood (PMF) that being used as review on reservoir detailed-design stage. On the terms of flood control, similar to the standard flood control operational, in the beginning the outflow is released continuously which is about 400 m^3/s (preceding release).

c) Reservoir Impounding Period Operation (April 15th – April 30th), for 15 days, the water level gauge is expected to increase from *CWL* (El. 135.30 m) to *NHWL* (E1. 136.00 m) that can be seen in Figure 2(a).

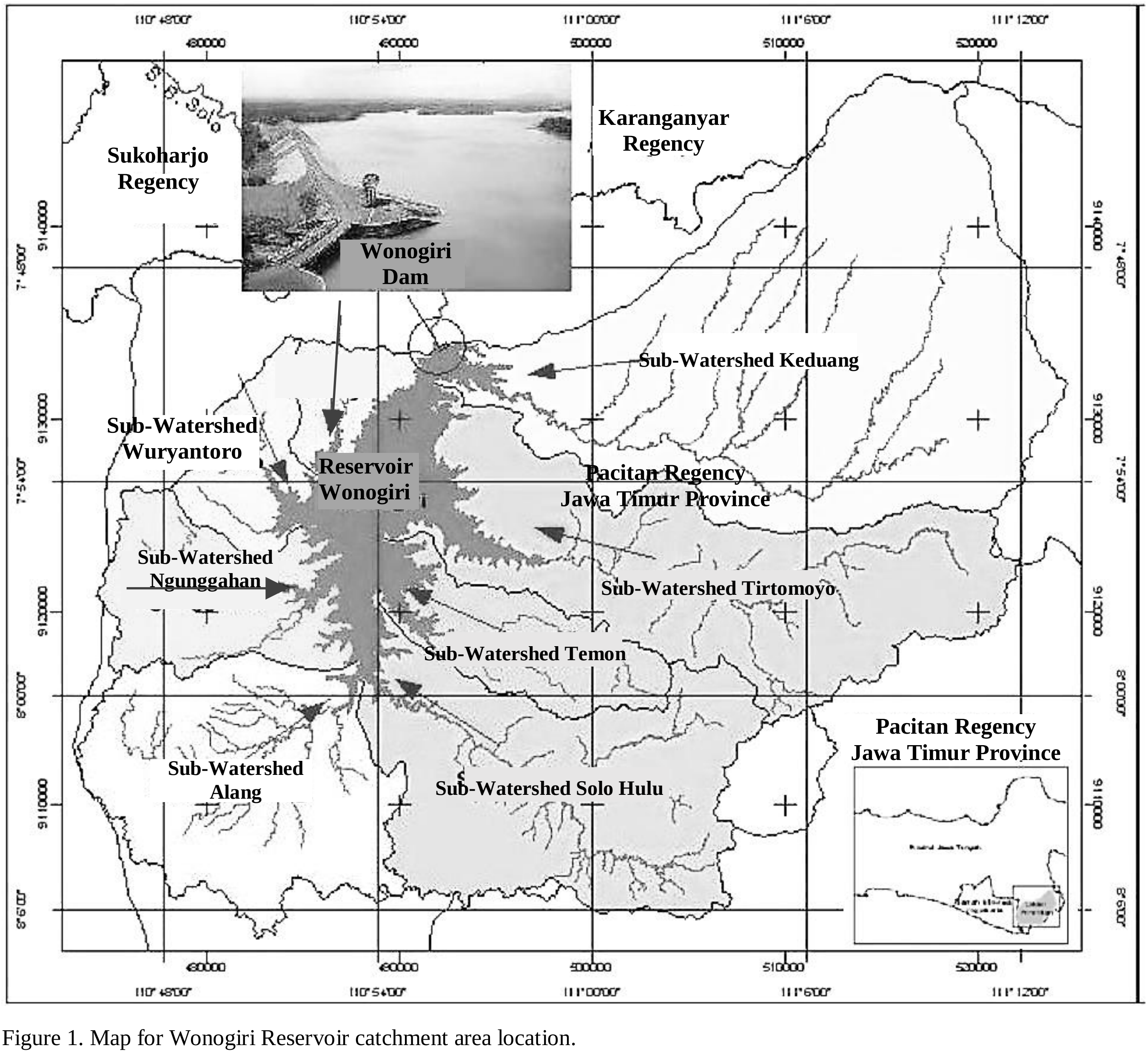

Figure 1. Map for Wonogiri Reservoir catchment area location.

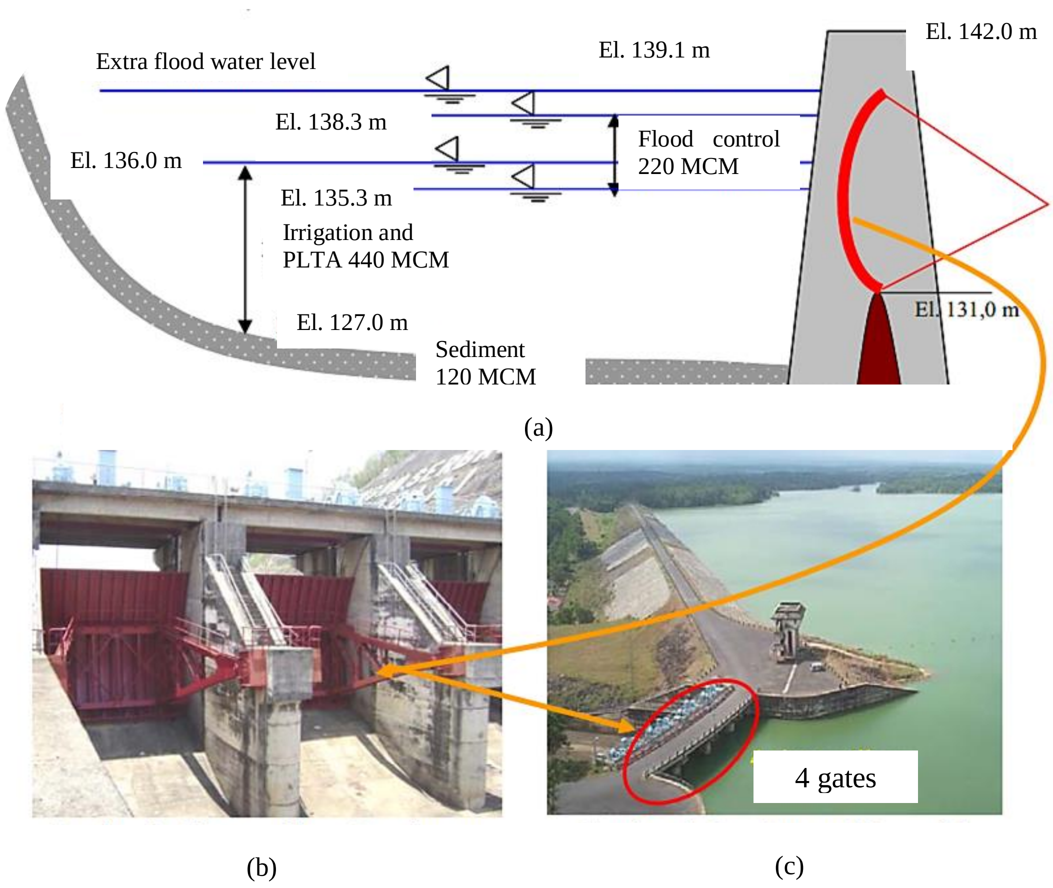

Figure 2. (a) Sketch of water level, volume, and spillway gate of Wonogiri Reservoir; (b) Spillway gate of Wonogiri Reservoir; Wonogiri Reservoir (Perum Jasa Tirta, 2008)

3 RESEARCH METHOD

3.1 Data Availability

The data successfully collected were as follows:

a) Digital map of Wonogiri Reservoir catchment area and land use in 2005, obtained from Forestry Research Office of Solo City as can be seen in Figure 1.
b) Digital map of soil type and Bengawan Solo watershed soil infiltration, obtained from Watershed Management Office of Solo City.
c) Hourly discharge of sub-watershed of Keduang, Temon, Alang, Wuryantoro, obtained from Forestry Research Office of Solo City.
d) Hourly rainfall data of Sambiroto Station, Ngancar and Tumpang, Pulutan Wetan and Kedunguling, obtained from Forestry Research Office of Solo City.
e) Daily rainfall data obtained from Public Works Office of Wonogiri Regency.
f) Position of the rainfall station of the Wonogiri Reservoir catchment area, obtained from Water Resource Management Office of Solo City.
g) Data resulted from operational monitoring on Wonogiri Reservoir, obtained from Perum Jasa Tirta I.

3.2 Watershed Parameter Identification

The watershed parameter identification was conducted by measuring each sub-watershed area and each land use area, based on the present map. To determine the state of the land use on year 2007, the map resulted from satellite imagery interpretation year 2005 was used. The composite curve number (CN) value of each sub-watershed was determined based on CN value of each land use type and soil group.

3.3 Rainfall Analysis

Average rainfall in the watershed area was calculated with Thiessen polygon method. The calculation was based on daily rainfall record from the rainfall stations on Wonogiri Reservoir catchment area and surrounding area. Distribution of daily rainfall to hourly rainfall on each sub-watershed used the measured typical hourly rainfall of nearest station.

3.4 Flood Hydrograph Simulation with HEC-HMS Software

The process of calibration with HEC-HMS model was done with recorded rainfall and discharges hourly data of Wuryantoro sub-watershed on December 26, 2007 and April 14th to April 15th, 2007; and the Keduang sub-watershed on April 20th, 2007.

The measurement of the watershed parameter gained from the calibration was used to calculate the peak flow, flood volume and peak time, based on the composite CN value of each sub-watershed on Wonogiri Reservoir catchment area.

The flood routing in the reservoir was intended to discover the inflow and outflow changes on the reservoir. The Wonogiri Reservoir inflow-outflow calculation was based on the hydraulic spillway design guide and 2005 echo-sounding result on the stage storage.

4 RESULT AND DISCUSSION

4.1 Watershed Parameter Identification

The area of Keduang sub-watershed is 421 km2, Tirtomoyo 231 km^2, upstream Solo 206 km^2, Alang 169 km^2, Ngunggahan 82 km^2, Temon 63 km^2, Wuryantoro 44 km^2 and others is 28 km^2. The Wonogiri Reservoir catchment area was utilized for dry field by the percentage of 38%, 25% of rice field, 22% of settlement, 14% of plantation, and others below 1%. The river stream discharge was the adequately large inflow discharge for Wonogiri Reservoir.

4.2 Curve Number (CN) and Composite CN

The composite CN value of Keduang sub-watershed was 83, Tirtomoyo was 80, Temon was 79, upstream Solo was 75, Alang was 71, Ngunggahan was 74, Wuryantoro was 82, and for others it was 77.

4.3 Watershed Rainfall

The watershed rainfall on December 25th, 2007 in Keduang sub-watershed was 166 mm, Tirtomoyo was 148 mm, upstream Solo was 143 mm, Alang was 137 mm, Ngunggahan was 117 mm, Temon was 155 mm, Wuryantoro was 133 mm, and in others it was 132 mm. On December 25th, 2007 a quite high intensity rain occurred on each sub-watershed. This then triggered accumulation of the runoff and the river stream discharge that became a rather large inflow discharge to Wonogiri Reservoir.

4.4 Hourly Rainfall Distribution

The hourly rainfall distribution on December 25th to December 27th, 2007 of Wonogiri reservoir catchment area can be seen in Figure 5.

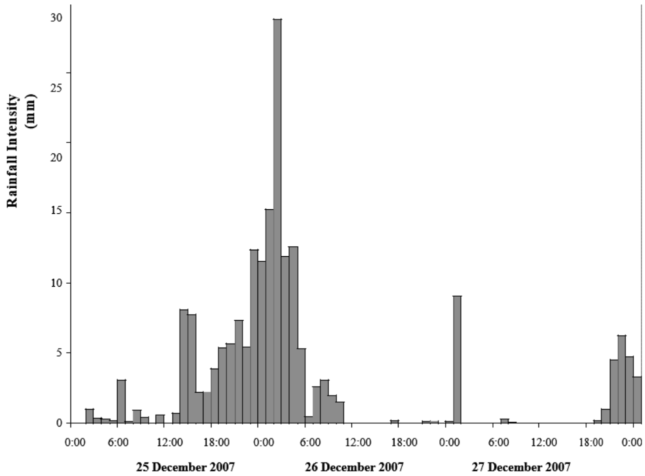

Figure 3. Hourly rainfall distribution on Wonogiri Reservoir catchment area on December 25th to December 27th, 2007.

4.5 Simulation

The watershed parameter used in the simulation process was the parameter resulted from calibration. The flood hydrograph simulation process of each sub-watershed was conducted with alternatives as follows:

a) Simulation 1 used the calibration result of Wuryantoro sub-watershed on December 26th, 2007 as the reference to simulate flood hydrograph of each sub-watershed in Wonogiri Reservoir catchment area.
b) Simulation 2 used the calibration result of Wuryantoro sub-watershed on April 14th to April 15th, 2007 as the reference to simulate flood hydrograph of Alang sub-watershed, Ngunggahan, Wuryantoro, and others. The simulation was also using the calibration result of Keduang sub-watershed on April 20th to April 21st, 2007 as the reference to simulate flood discharge of Keduang sub-watershed, Tirtomoyo, upstream Solo, and Temon.
c) Simulation 3 used calibration result of the Wuryantoro sub-watershed on April 14th to April 15th, 2007 as the reference to simulate flood hydrograph of each sub-watershed in Wonogiri Reservoir catchment area.
d) Simulation 4 used the calibration result of Keduang sub-watershed on April 20th to April 21st, 2007 as the reference to simulate flood hydrograph of each sub-watershed in Wonogiri Reservoir catchment area.

Based on Simulation 1 result, the maximum inflow discharge value that entered Wonogiri Reservoir which occurred on December 26th, 2007 at 05:00 was 4,303 m^3/s. The recapitulation result of Simulation 1 flood hydrograph can be seen in Table 1.

Table 1.Recapitulation result of Simulation 1 with hourly rainfall input on December 25th to December 27th, 2007

No	Hydrology Element	Peak Flow Discharge (m^3/s)	Peak Time
1	Keduang	1,666	Dec 26 2007, 02:00
2	Tirtomoyo	759	Dec 26 2007, 02:00
3	Solo Hulu	600	Dec 26 2007, 05:00
4	Alang	556	Dec 26 2007, 05:00
5	Ngunggahan	348	Dec 26 2007, 07:00
6	Temon	218	Dec 26 2007, 02:00
7	Wuryantoro	272	Dec 26 2007, 05:00
8	Others	156	Dec 26 2007, 05:00

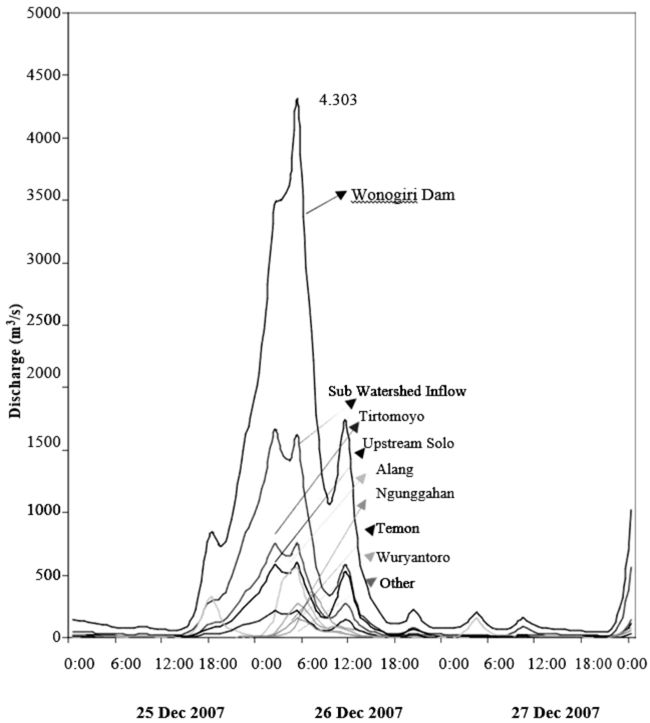

Figure 4. Each sub-watershed hydrograph that calculated with reference from flood hydrograph of Wuryantoro sub-watershed on December 26th, 2007.

Based on the Simulation 2 result, the maximum inflow discharge value that entered Wonogiri Reservoir which occurred on December 26th, 2007 at 04:00 was 3,756 m^3/s. The recapitulation result of Simulation 2 flood hydrograph can be seen in Table 2. Based on the Simulation 3 result, the maximum inflow discharge that entered Wonogiri Reservoir which occurred on December 26th, 2007 at 04:00 was 4,993 m^3/s. The recapitulation result of simulation flood hydrograph can be seen in Table 3.

Table 2. Recapitulation result of Simulation 2 with hourly rainfall input on December 25th to December 27th, 2007

No	Hydrology Element	Peak Flow Discharge (m^3/s)	Peak Time
1	Keduang	1,340	Dec 26 2007, 06:00
2	Tirtomoyo	629	Dec 26 2007, 06:00
3	Solo Hulu	507	Dec 26 2007, 06:00
4	Alang	691	Dec 26 2007, 04:00
5	Ngunggahan	380	Dec 26 2007, 06:00
6	Temon	180	Dec 26 2007, 06:00
7	Wuryantoro	290	Dec 26 2007, 04:00
8	Others	164	Dec 26 2007, 04:00

Table 3. Recapitulation result of Simulation 3 with hourly rainfall i nput on December 25th to December 27th, 2007

No	Hydrology Element	Peak Flow Discharge (m^3/s)	Peak Time
1	Keduang	1,938	Dec 26 2007, 04:00
2	Tirtomoyo	898	Dec 26 2007, 04:00
3	Solo Hulu	708	Dec 26 2007, 10:00
4	Alang	691	Dec 26 2007, 04:00
5	Ngunggahan	380	Dec 26 2007, 06:00
6	Temon	257	Dec 26 2007, 04:00
7	Wuryantoro	290	Dec 26 2007, 04:00
8	Others	164	Dec 26 2007, 04:00

Based on the Simulation 4 result, the maximum inflow discharge that entered Wonogiri Reservoir which occurred on December 26th, 2007 at 06:00 was 3,459 m^3/s. The recapitulation result of Simulation 4 flood hydrograph can be seen in Table 4.

Table 4.Recapitulation result of Simulation 4 with hourly rainfall input on December 25th to December 27th, 2007

No	Hydrology Element	Peak Flow Discharge (m^3/s)	Peak Time
1	Keduang	1,340	Dec 26 2007, 06:00
2	Tirtomoyo	629	Dec 26 2007, 06:00
3	Solo Hulu	507	Dec 26 2007, 06:00
4	Alang	375	Dec 26 2007, 06:00
5	Ngunggahan	252	Dec 26 2007, 08:00
6	Temon	180	Dec 26 2007, 06:00
7	Wuryantoro	185	Dec 26 2007, 06:00
8	Others	109	Dec 26 2007, 06:00

The result from Simulation 2, Simulation 3, and Simulation 4 can be seen in the graph in Figure 7. If the rainfall analysis on Wonogiri Reservoir catchment area was valid, which is 149 mm on December 25th, 2007; these conditions (Simulation 1, 2, 3, and 4) then indicated a significant change on watershed response. As a comparison is the heavy rain in 1966 flood on Wonogiri Reservoir catchment area, with 215 mm it caused maximum stream discharge 3,950 m^3/s with 60 years return period (Overseas Technical Cooperation Agency of Japan (OTCA), 1974). Based on this comparison, it then could be known that even with lighter rain than the 1966 event, a larger maximum discharge still could occur.

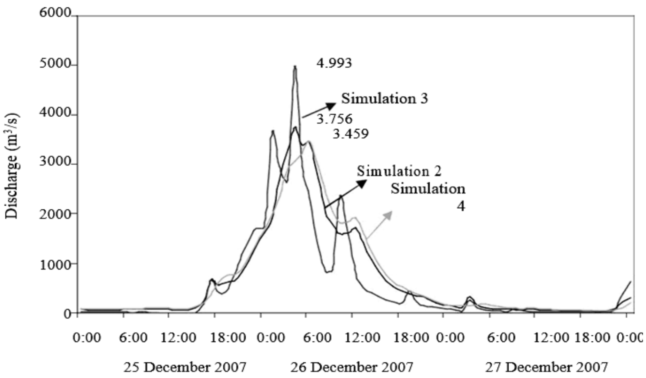

Figure 5. Wonogiri reservoir inflow based on result of Simulation 2, 3, and 4.

4.6 Flood Routing on Reservoir

Flood routing on the reservoir was intended to find how much influence does the reservoir has on the flood discharge at the reservoir downstream, and also to find the characteristic of the outflow hydrograph, which is very essential for flood control. Hence the flood routing on the reservoir was intended to discover the change on inflow and outflow of the reservoir.

The principle of flood period operation in Wonogiri Reservoir was to maintain the water level elevation on Control Water Level (CWL) height, which is elevation 135.3 m. As for the water release through the spillway, it was based on large inflow discharge to the reservoir storage with its maximum discharge (Q_p) could be estimated with flood forecasting system.

Based on operational monitoring result data on Wonogiri Reservoir on December 25th to December 27th, 2007; the water release operation on flood event at the end of December 2007, was started at 08:00 when the water level elevation has reached CWL, which at elevation (El.) 135.75 m with gradual outflow discharge from 100 to 175 m^3/s. This water release through the spillway then continued until it reached the peak on outflow 200 m^3/s on December 27th, 2007 at 01:30 when the reservoir water elevation reached 136.57 m. The dischagre outflow of 200 m^3/s did not cause the stream overflow on the river downstream of Wonogiri Reservoir to reach Nguter, for as the stream storage capacity is 400 m^3/s (Perum Jasa Tirta I, 2008).

The data used as input for flood routing Simulation 1 was the inflow data resulted from flood hydrograph simulation with watershed referenced on Wuryantoro sub-watershed at December 25th to December 27th, 2007, early water elevation 133.63 m (refer to operational monitoring result of Wonogiri Reservoir); spillway gate closed until the water level height in the reservoir reached 135.3 m (lower flood control limit) then the spillway gate was completely opened, as can be seen in Figure 8.

The result of flood routing 1 for flood event on December 25th to December 27th, 2007, can be seen in Table 5 and Figure 9.

Table 5. Recapitulation of flood routing Simulation 1 on December 25th To December 27th, 2007

No	Elevation	Outflow Discharge (m^3/s)	Date	Time
1	133.63 (El. Early)	-	Dec 25	00:00
2	135.48 (El. Gate opened)	550	Dec 26	06:00
3	135.94 (El. Maximum)	642	Dec 26	14:00

Outflow of 550 m^3/s reached to peak of 642 m^3/s at 14:00 would cause stream overflow on the river downstream of Wonogiri Reservoir, because the storage capacity of the stream is only 400 m^3. These showed that the operational guide on spillway gate opening is really significant on the downstream flood control. The flood event on end of December 2007 described the reliability of Wonogiri Reservoir flood reduction step by holding the maximum discharge that enter the reservoir, to be released to the spillway gate in order to not exceed the storage capacity in the downstream.

The data used as input for flood routing Simulation 2 was the inflow data resulted from flood hydrograph simulation with watershed referenced on Wuryantoro sub-watershed at December 25th to December 27th, 2007 with early water elevation 133.63 m (refer to operational monitoring result of Wonogiri Reservoir); spillway gate closed until the water level height in the reservoir reached 138.3 m (upper flood control limit) then the spillway gate was completely opened. The scheme can be seen in Figure 10(a). The recapitulation of flood routing 2 for flood event on December 25th to December 27th, 2007, can be seen in Table 6 and the inflow – outflow hydrograph can be seen in Figure 10(b).

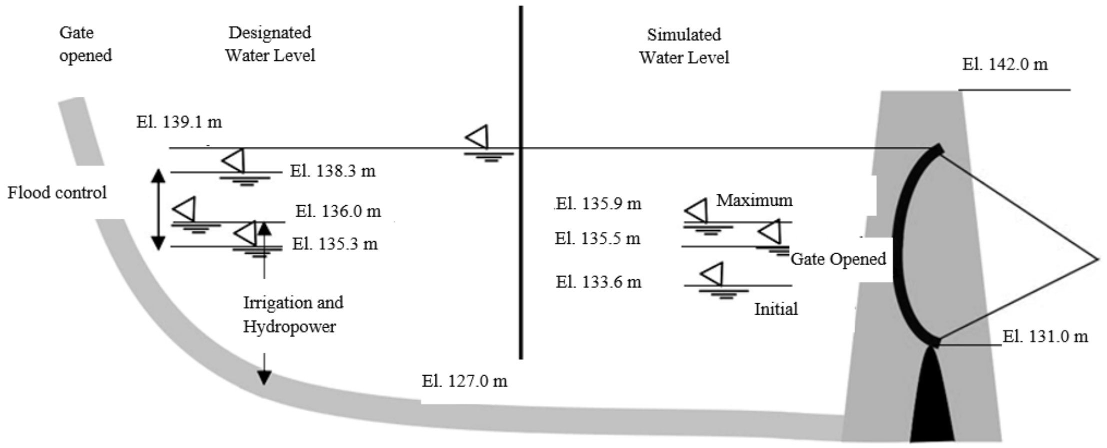

Figure 6. Scheme of Gate Opening on Flood Routing Simulation 1.

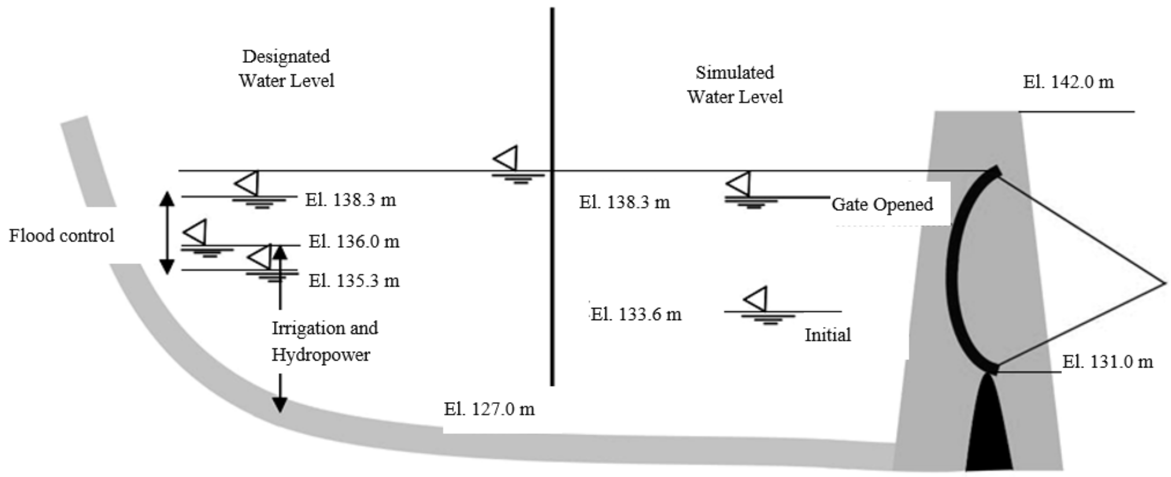

Figure 7. Scheme of gate opening on flood routing Simulation 2.

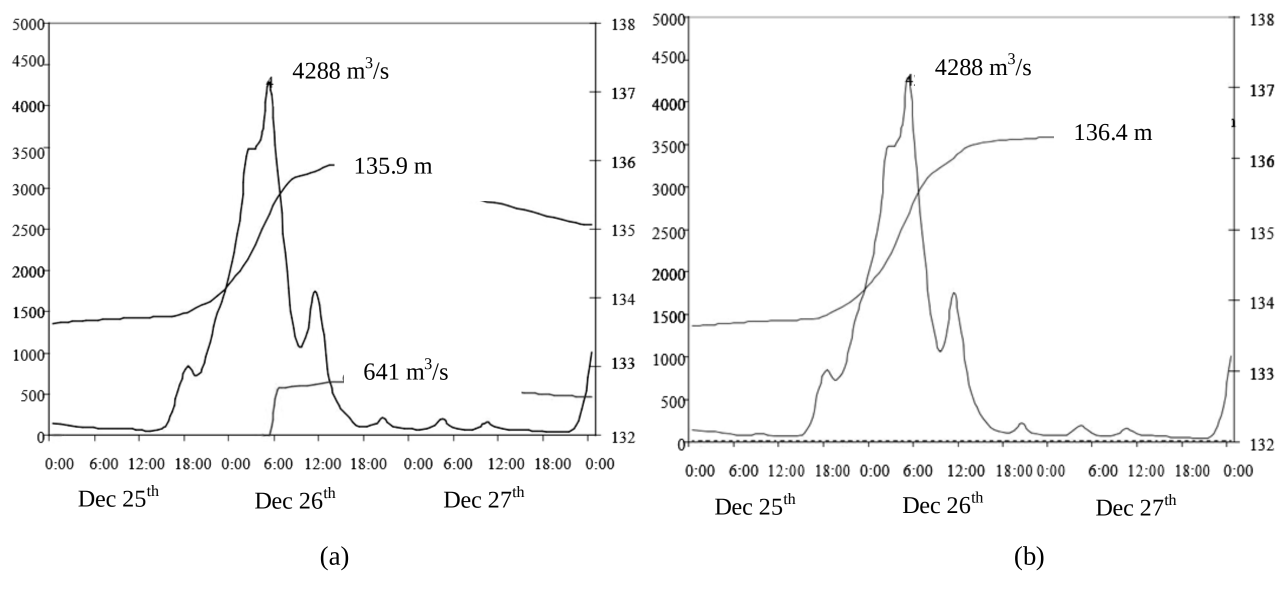

Figure 8. Wonogiri reservoir inflow - outflow hydrograph on December 25th to December 27th, 2007 (a) with flood routing Simulation 1; (b) with flood routing Simulation 2.

Table 6. Recapitulation of flood routing Simulation 2 on December 25th To December 27th, 2007

No	Elevation (m)	Outflow Discharge (m^3/s)	Date	Time
1	133.63 (Initial Elevation)	-	Dec 25	00:00
2	136.44 (Maximum Elevation)	-	Dec 27	23:00

5 CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

The conclusions that came from result of this research are as follows:

a) Based on the four simulations, the maximum discharge that entered the Wonogiri Reservoir was ranging from 3,331 to 4,993 m^3/s which occurred on December 26th, 2007 between 04:00 to 06:00.
b) The most dominant flood hydrograph contribution that entered Wonogiri Reservoir came from Keduang sub-watershed.
c) The flood routing Simulation 1 showed that the water level elevation exceeded the CWL (Control Water Level, El. 135.3 m), which occurred on December 26th, 2007 at 6:00, with the water level gauge reached 135.48 m and the outflow produced when the gate opened was 550 m^3/s, then increased until it reached the peak 642 m^3/s at 14:00 and gradually decreased.
d) The flood routing Simulation 2 showed that until December 27th, 2007 at 23:00, the water level elevation just reached 163.44 m and not yet exceed the design flood water level of 138.3 m. The flood control function of Wonogiri Reservoir still could run well, with 85% flood reduction level.

5.2 Suggestions

The following are several suggestions for development of next research:

a) Further research and management are needed on changes at Wonogiri Reservoir catchment area land use, as the highly influential factor to the inflow discharge that enter the Wonogiri Reservoir.
b) This research did not conduct simulation with variation on Wonogiri Reservoir spillway gate opening; therefore an advanced study on spillway gate opening guide is needed, in the term of condition changes in the reservoir catchment area.
c) The reading system of the water level elevation still manually conducted; in order to support the Wonogiri Reservoir operational activity at flood season, enhancement to the supporting facility are needed, such as digital sensor for water level elevation reading system, and information network system for early warning system.
d) The quality and quantity of the data used in the research really influenced the obtained result; therefore enhancement for the quality and quantity of data on rainfall data, AWLR/ARR data, land use data, and soil type data, are very much expected.

6 REFERENCES

Kodoatie, R. J. & Sjarief, R., 2006. *Pengelolaan Bencana Terpadu [Integrated Management of Flood].* Jakarta: Yarsif Watampone.

Nippon Koei Co. Ltd, 1984. *Manual for Operation and Maintenance*, Tokyo: s.n.

Overseas Technical Cooperation Agency of Japan (OTCA), 1974. *Hydrology, Sporting Record Part One, Colombo Plan expert K. Nobe (Hydrologyst),* Japan: s.n.

Perum Jasa Tirta I, 2008. *Banjir Bengawan Solo Desember 2007 dan Operasi Pengendalian Banjir Bendungan Wonogiri [Bengawan Solo River Flood on December 2007 and Operation of Wonogiri Reservoir as Flood Control],* Surakarta: Perum Jasa Tirta I.