

Integrated Simulation of Spillway and Diversion Structure in Flood Risk Assessment of Upper Solo River

Saraswati Renaningsih

Agency of Public Housing and Settlement Area, Bangka-Belitung Province, Pangkal Pinang, INDONESIA
ayas_27@yahoo.com

ABSTRACT

Wonogiri Reservoir is a multi-purpose hydraulic structure that is used for water supply service and flood control in the watershed area of Upper Solo River. Inflow of the Wonogiri Reservoir comes from 10 rivers in the watershed's catchment area. As for the purpose of reservoir's sediment controller, a new spillway is constructed; and also closure dike is being built, which influenced the change on reservoir storage characteristic, and then means that a new reservoir operation guideline is necessary. Therefore, study on flood routing on the watershed of Upper Solo River at the new condition of the reservoir operation is needed. The analysis was conducted to acquire detailed information on flood characteristics of Wonogiri Reservoir and Upper Solo River started from the downstream of the reservoir until the downstream control point in the Jurug Water Level Recorder including the flood discharge and the maximum water level. The analysis procedure was performed by four components, which are flood forecasting, reservoir flood routing, rainfall-runoff lateral inflow, and hydraulic channel routing. The analysis result was integrated into a software package which was arranged by using the Microsoft Visual Studio Express 2012, Microsoft Access, and HEC-RAS. With the support of the software, it was expected that the decision making in the spillway operational is more quickly and more accurate (rapid assessment) in order to improve the flood control performance in the area of Upper Solo River.

Keywords: Wonogiri Reservoir; characteristic change; reservoir storage; reservoir operational guidelines; flood routing

1 INTRODUCTION

Solo River (Bengawan Solo) is the longest river in Java Island, with the main course is up to ± 600 km, as seen in Figure 1. Flood disaster occurs almost every year, especially at rainy season. The government built Wonogiri Reservoir as one of the efforts for flood control in Solo River, particularly the upstream part.

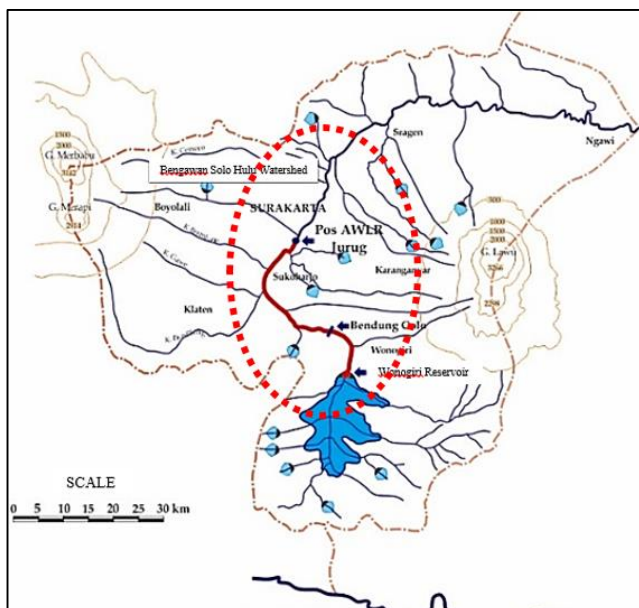


Figure 1. Map on research area.

Wonogiri Reservoir as the multi-purpose reservoir has functions for flood control, irrigation, and hydropower. The capacity of Wonogiri Reservoir is decreasing because of the sedimentation problem, which then leads to the decreasing of the reservoir function. As a reservoir sedimentation controller, a new spillway is built, and a closure dike is also being built, which influenced the change on reservoir's storage characteristic, and then means that a new reservoir operation guideline is necessary.

Wijaya (2014) has developed software in form of hydrology-hydraulic model for flood routing simulation in Solo River and reservoir up to the Jurug AWLR (Automatic Water Level Recorder) Station. Further development of the software is necessary, particularly on the component of flood flow from the Wonogiri Reservoir outlet up to the Jurug AWLR Station by hydraulics, in order to discover the flood characteristic at a certain control point that is located in the reservoir downstream.

The purposes of this research are to conduct study on flood characteristic in Upper Solo River after closure dike and new spillway was built, by taking into account the lateral inflow weight of the tributary in the reservoir downstream and to conduct software development that was resulted from previous research (Wijaya, 2014), by

hydraulic calculation of flood routing from Wonogiri Reservoir outlet up to the Jurug AWLR Station.

2 RESEARCH LOCATION

2.1 Wonogiri Reservoir

The catchment area of Wonogiri Reservoir has 10 watersheds with total area of 1,343 km² (Oktavia, 2013). The catchment area of Wonogiri Reservoir is illustrated in Figure 2, while detail of each area is listed in Table 1.

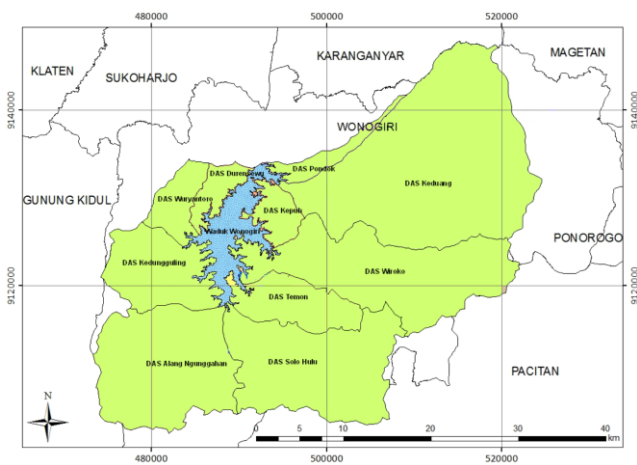


Figure 2. Catchment area of Wonogiri Reservoir.

Table 1. Watershed area of Wonogiri Reservoir

No	Watershed Name	Area (km ²)	Percentage (%)
1	Alang Ngunggahan	193.02	15.05
2	Durensewu	26.15	2.04
3	Keduang	397.36	30.97
4	Kedungguling	96.05	7.49
5	Kepuh	29.86	2.33
6	Pondok	24.17	1.88
7	Solo Hulu	193.62	15.09
8	Temon	68.08	5.31
9	Wiroko	216.95	16.91
10	Wuryantoro	37.60	2.93
Total		1,282.86	100.00

To overcome the sedimentation problem in Wonogiri Reservoir, a new spillway has been built and at the moment, a closure dike is currently being constructed. With the closure dike, water storage in Wonogiri Reservoir is separated into 2 (two), which is main reservoir (MR) and sediment storage reservoir (SSR). The scheme of Wonogiri Reservoir water storage after

construction of closure dike could be seen in Figure 3 (Nippon Koei Co. Ltd, 2007). The construction of closure dike and new spillway changed the operational pattern of the reservoir spillway (Gupitakingkin, 2014). The new guideline is shown in Table 2.

Table 2. New guideline on Wonogiri Reservoir spillway gate operation at flood period

Maximum Flood Discharge (m ³ /s)	Operational Pattern	
	New Spillway	Old Spillway
4,400 (Q60)	If inflow < 400 m ³ /s then outflow = inflow If inflow > 400 m ³ /s then outflow = 400 m ³ /s If TMA > Elevation 138.20 m then spillway gate completely opened a = 5.6 m	Not operated
6,500 (Q500)	If inflow < 800 m ³ /s then outflow = inflow If inflow > 800 m ³ /s then outflow = 800 m ³ /s If TMA ≥ Elevation 138.20 m then gate completely opened a = 5.6 m	Not operated
9,600 (Q5,500)	If inflow < 800 m ³ /s then outflow = inflow If inflow > 800 m ³ /s then outflow = 800 m ³ /s If TMA ≥ Elevation 138.20 m then gate completely opened a = 5.6 m	Operated according spillway gate operational manual table

2.2 Upper Solo River Watershed

In Upper Solo River watershed Wonogiri Reservoir – Colo Weir, there are 12 sub-watersheds with total area of 183 km² (Amalia, 2014). On the watershed of Upper Solo River Colo Weir up to the Jurug AWLR Station, there are 14 sub-watersheds with total area of 1,738 km² (Gunawan, 2009), as shown in Figure 4.

2.3 Colo Weir and Jurug AWLR Station

Colo Weir is located in Pengkol Village, Nguter Sub-district, Sukoharjo Regency, Central Java Province. This construction is aimed to regulate the water level of Solo River, so it could be used for irrigation purpose. The Jurug AWLR Station is located in Jurug Village, Pucang Sawit Sub-district, Surakarta City.

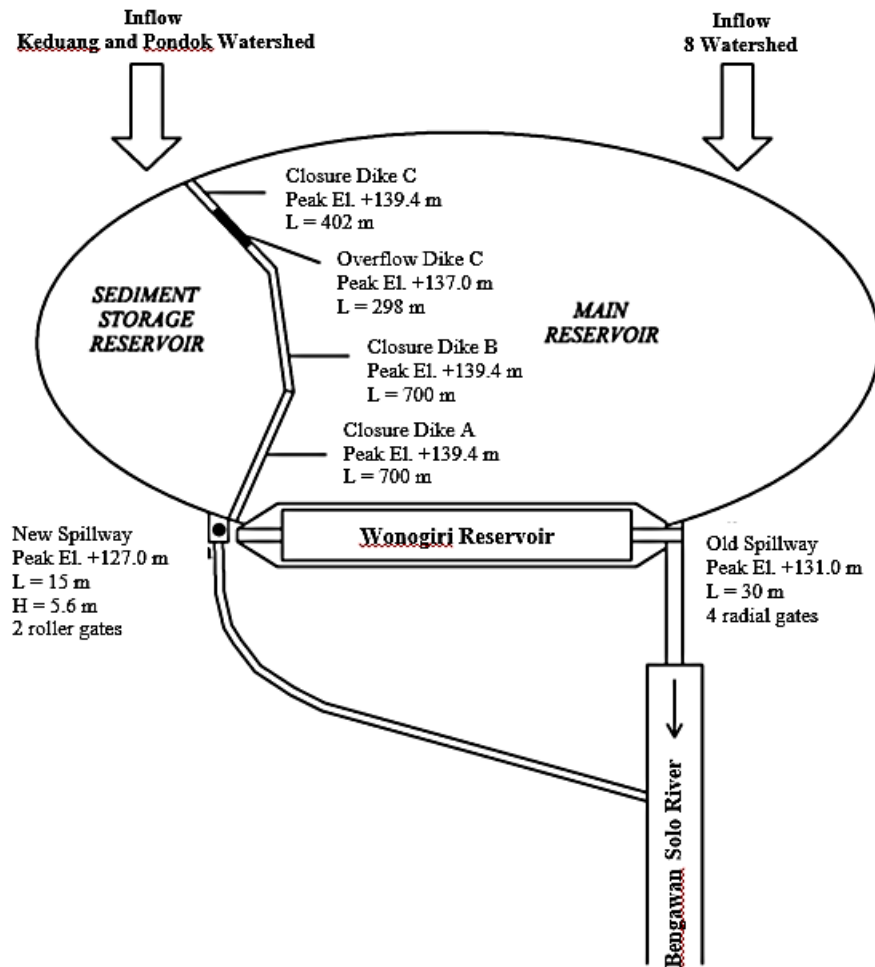


Figure 3. Scheme for the reservoir water storage after the construction of closure dike.

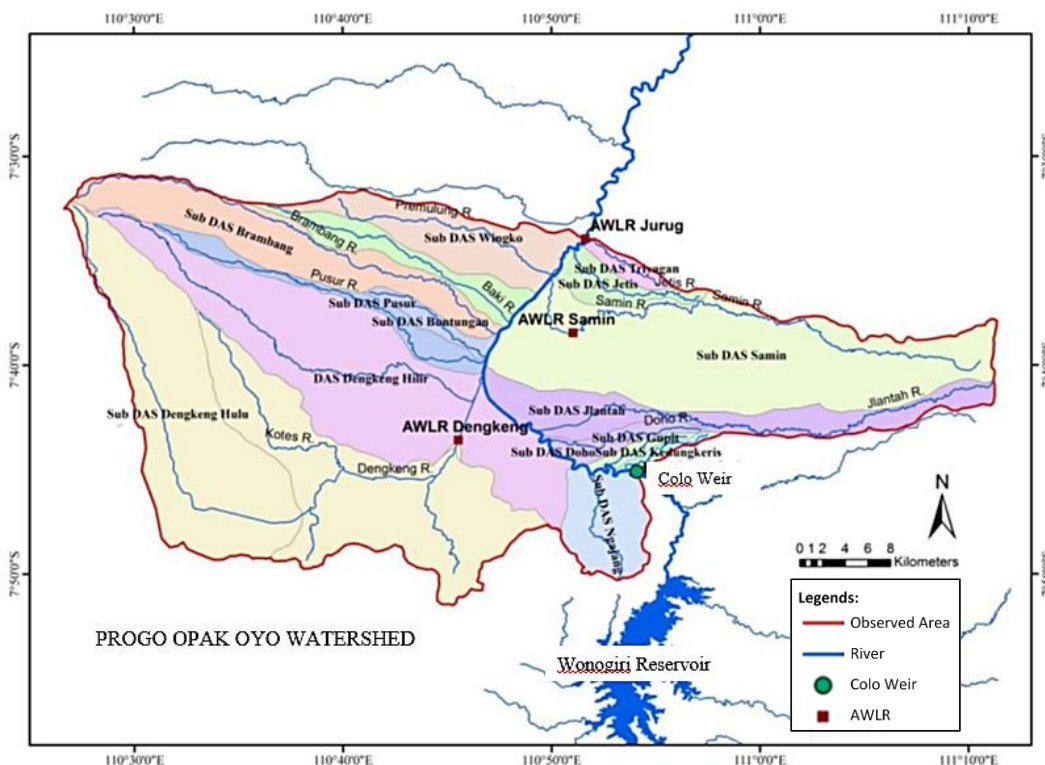


Figure 4. Area of upper Solo River watershed Colo Weir - Jurug AWLR station.

3 PREVIOUS RESEARCH ON SOLO RIVER

Amalia (2014) conducted research about calculation on simulation of lateral inflow contribution to flood discharge in Colo Weir. The conclusion of this research was that the Wonogiri Reservoir operational in flood period at old condition (before construction of closure dike and new spillway) is safer compared to at the new condition.

Hanova (2014) developed visual basic-based software that modeled rain transformation into flow, for the purpose of tributary flood hydrograph and flood routing in Solo River. The arrangement of the software program was based on procedure of calculation and hydrology analysis formulations that Amalia (2014) generated.

Amalia (2014) conducted research on flood characteristic in Solo River Colo Weir – Surakarta City. The result of this research showed that the flood characteristic is affected by lateral inflow from the watershed’s tributaries; with the biggest contribution comes from Dengkeng River.

Wijaya (2014) developed software to support flood routing in Upper Solo River watershed, in the form of hydrology-hydraulic model. This software was developed by integrated hydrology-hydraulic monitoring system, which consisted of 3 components: flood forecasting, reservoir flood routing and hydrologic channel routing.

4 THEORETICAL BASIS

4.1 Water Balance in Reservoir

The water balance in the reservoir meets the following equation.

$$\frac{\Delta S}{\Delta t} = \sum_{i=1}^i \frac{I_i}{\Delta t} - \sum_{j=1}^j \frac{O_j}{\Delta t} \quad (1)$$

in which ΔS denotes storage change in reservoir (m^3), I_i is inflow discharge at time i to reservoir (m^3/s), O_j is outflow discharge from reservoir (m^3/s) at time j , Δt is interval of routing time (s).

4.2 Flood Routing in Reservoir

Flood routing in reservoir used the level pool routing method, with following equations.

$$I - O = \frac{dS}{dt} \quad (2)$$

whereas dS is storage change in reservoir (m^3) and dt is interval of routing time (hour).

Equation (1) showed that storage change between time intervals dt is the same with inflow minus the outflow. If the interval of routing time is Δt , the Equation (1) could be written as:

$$\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} = \frac{S_1 + S_2}{\Delta t} \quad (3)$$

where S_1, S_2 are storage at the first and second time, respectively.

Equation (3) could be written in form of:

$$\frac{2S_2}{\Delta t} - O_2 = I_1 + I_2 + \frac{2S_1}{\Delta t} - O_1 \quad (4)$$

4.3 Storage through Overflow Dike and Closure Dike

Common equation used in hydraulic of broad-crested spillway is as follows:

$$Q = CLH^{\frac{3}{2}} \quad (5)$$

whereas Q id storage that goes through broad-crested spillway (m^3/s), L is length of broad-crested spillway perpendicular to the direction of flow (m), H is depth of water surface above the crest of broad-crested spillway at downstream (m).

Front-view sketch of the overflow and closure dike is shown in Figure 5. (Nippon Koei Co. Ltd, 2007).

Note:

Elevation of overflow dike	= +137 m
Elevation of closure dike peak	= +139.4 m
Bottom width of overflow dike (B)	= 250 m
Top width of overflow dike (T)	= 250 m
Normal depth (ND)	= 2.4 m
Total length (CW)	= 2,100 m
Slope angle of overflow dike	= 84.29°
Discharge coefficient (C_d)	= 1.69

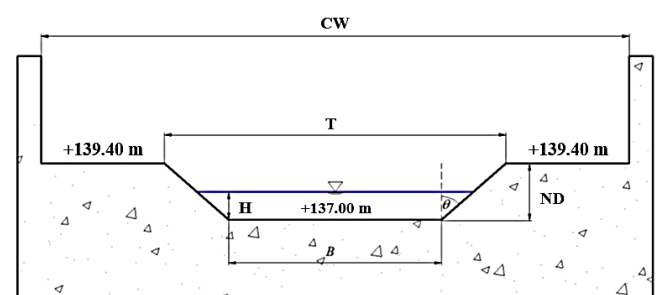


Figure 5. Front-view sketch of the overflow and closure dike.

4.4 Storage through Overflow Dike on Overflow Dike

Equation that enters the Main Reservoir (MR) on the condition of:

Zero Flow (no flow between discharge), $Q = 0$

Free Flow

$$Q = C_d(BH^{1.5} + \tan\theta H^{2.5}) \tag{6}$$

Submerged Flow

$$Q = C_d[BH^{1.5} + \tan\theta H^{2.5}] \left(1 - \left(\frac{h}{H}\right)^{1.5}\right)^{0.385} \tag{7}$$

in which h is water height above the overflow dike on MR and SSR is Sediment Storage Reservoir.

Equation that enters the SSR on the condition of:

Zero Flow (no flow between discharge), $Q = 0$

Free Flow

$$Q = C_d(Bh^{1.5} + \tan\theta h^{2.5}) \tag{8}$$

Submerged Flow

$$Q = C_d[Bh^{1.5} + \tan\theta h^{2.5}] \left(1 - \left(\frac{H}{h}\right)^{1.5}\right)^{0.385} \tag{9}$$

4.5 Flood Routing in River Course

Flood routing in the river course was conducted with HEC-RAS 4.1.0 software. The basic formula/calculation of flow in unsteady flow is as follows.

Continuity equation (mass conversion principal)

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - qt = 0 \tag{10}$$

Momentum equation (momentum conversion principal)

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + q_A \left(\frac{\partial z}{\partial x} + S_f\right) = 0 \tag{61}$$

in which A means total area of flow section (total of flow section area in main channel and overbank channel) (m^2), qt is lateral discharge per length unit (m^3/s), v is flow velocity (m/s), g is gravitational acceleration (m/s^2), x is distance, measured in the direction of flow (m), z is water level (m), and S_f is energy gradient (friction slope) which is defined as follows:

$$S_f = \frac{n^2 |Q| |Q|}{A^2 |R^2} \tag{7}$$

whereas n denotes Manning coefficient roughness and R is hydraulic radius (m).

5 RESEARCH METHOD

5.1 Concept of Model Development

The main components in developing the hydrology-hydraulic model in flood routing of Upper Solo River watershed are the flood forecasting, reservoir flood routing, rainfall-runoff lateral inflow and hydraulic flood routing. Scheme of the model can be seen in Figure 6.

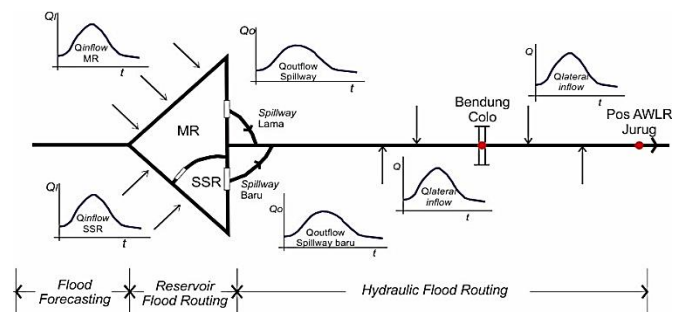


Figure 6. Scheme on software development.

5.2 Software Arrangement

The software was arranged by using Microsoft Visual Studio Express 2012 software. The main structure of the software was arranged with 4 main components, which are flood forecasting, reservoir flood routing, rainfall-runoff lateral inflow, and hydraulic flood routing. The simulation stages are presented as shown in Figure 7.

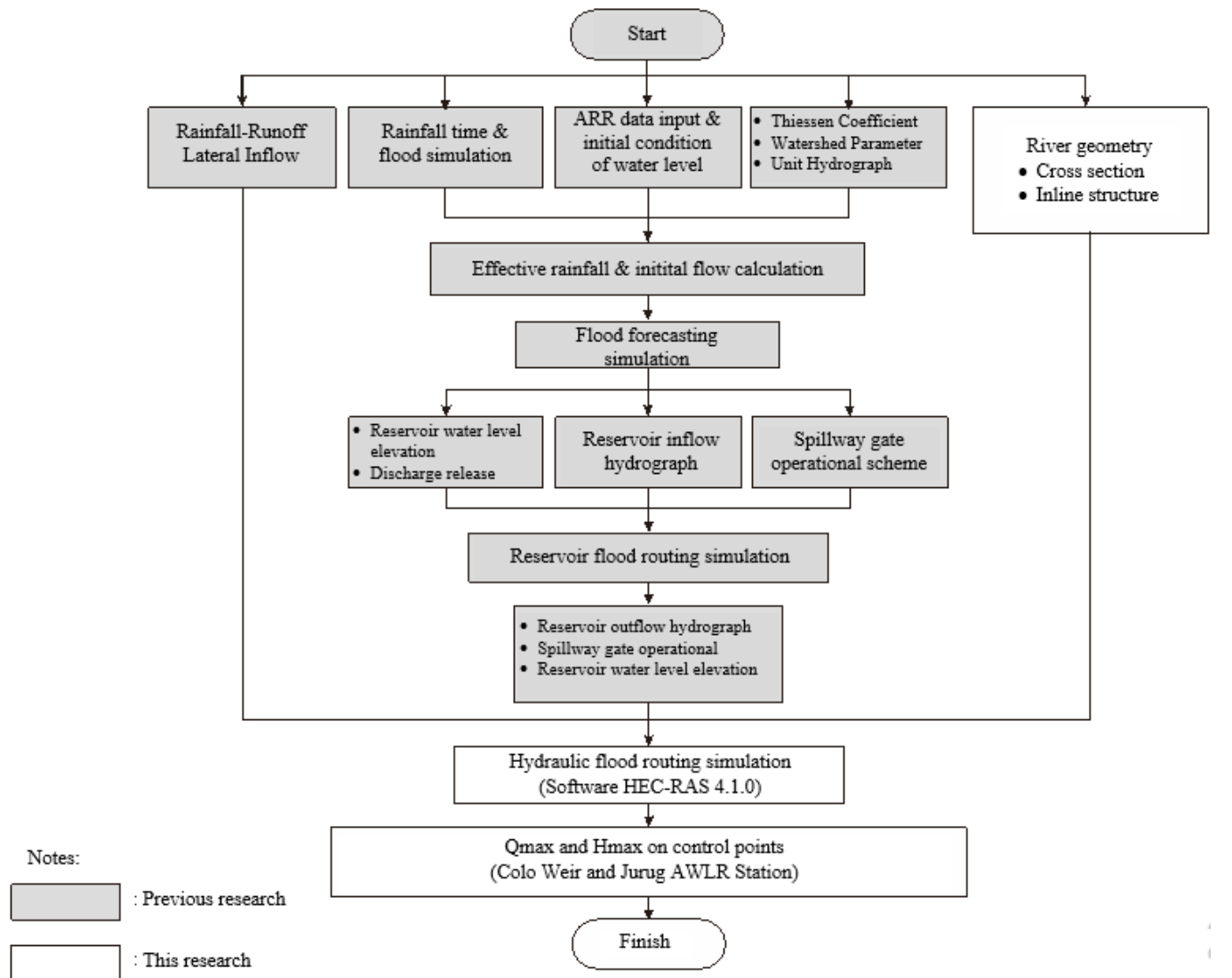


Figure 7. Chart of software main structure.

5.3 Database Arrangement of Software

Database of flood routing software for Upper Solo River was arranged with the Microsoft Access software. The input and output of each simulation is presented in Table 3.

Table 3. Input and output of simulation data in software

Component	Input	Output
Flood Forecasting	Real-time rainfall data, Thiessen coefficient, Initial Flow, and hydrograph of watershed outlet unit	Flood hydrograph of Wonogiri Reservoir inflow
Reservoir Flood Routing	Flood hydrograph of Wonogiri Reservoir inflow, reservoir water level gauge, spillway gate initial opening, operational pattern of Wonogiri Reservoir at flood period and discharge release	Spillway gate opening height, outflow discharge Wonogiri Reservoir (Main Reservoir and Sediment Storage Reservoir)
Rainfall-Runoff Lateral Inflow	Real-time rainfall data, Thiessen coefficient, Initial Flow, and hydrograph of watershed outlet unit	Lateral flood hydrograph Wonogiri Reservoir -Jurug AWLR Station inflow
Hydraulic Flood Routing	Outflow discharge of Wonogiri Reservoir (Main Reservoir and Sediment Storage Reservoir), lateral flood hydrograph Wonogiri Reservoir-Jurug AWLR Station and river geometry	Discharge, water level gauge, velocity on control point (Colo Weir Jurug AWLR Station)

a) Hydrology Station

The hydrology data that was used for data input was based on the result of hourly monitoring which was recorded on 10 Automatic Rainfall Recorder Stations (ARR) and 6 AWLR in the watershed of Upper Solo River, which was managed by Perum Jasa Tirta I.

b) Curve Number Value

Curve Number (*CN*) value that was used as a constant in this simulation program, which was based on the previous research result. *CN* values of Wonogiri watershed are shown in Table 4, while *CN* values in Upper Solo River watershed are shown in Table 5 which was based on research of Amalia (2014).

Table 4. *CN* value in Wonogiri Reservoir catchment area (Oktavia, 2013)

No	Watershed	Composite <i>CN</i>	<i>CN</i> (AMC III)
1	Pondok	63.56	80.05
2	Keduang	71.62	85.31
3	Kepuh	73.46	86.42
4	Wiroko	81.64	91.09
5	Temon	83.06	91.85
6	Solo Hulu	82.91	91.78
7	Alang	83.29	91.98
	Ngunggahan		
8	Kedungguling	84.68	92.71
9	Wuryantoro	80.01	90.20
10	Durensewu	75.12	87.41

Table 5. *CN* value in Upper Solo River Watershed, Colo Weir– Jurug AWLR Station (Amalia, 2014)

No.	Watershed	Composite <i>CN</i>	<i>CN</i> (AMC III)
1	Kedungkeris	92.26	83.82
2	Gupit	92.38	84.06
3	Ngajang	93.90	87.00
4	Doho	91.66	82.69
5	Jlantah	88.85	77.60
6	Dengkeng Hulu	82.67	72.57
7	Dengkeng Hilir	85.87	72.54
8	Pusur	82.83	67.72
9	Buntungan	81.37	65.51
10	Brambang	83.40	68.59
11	Kembangan	82.66	67.45
12	Samin	87.68	75.57
13	Wingko	84.90	70.97
14	Jetis	89.31	78.42
15	Triyagan	88.10	76.30

c) Rating Curve

Estimation calculation for initial flow used the water depth that was measured in 6 AWLR which was located in Upper Solo River watershed, with the rating curve that was available in each AWLR.

d) Unit Hydrograph

The unit hydrograph that was used as database on the watershed at Wonogiri Reservoir catchment area was based on research of Gupitakingking (2014), which was an update from the unit hydrograph on the research of Oktavia (2013). For the unit hydrograph in watershed of Upper Solo River, Wonogiri Reservoir until Colo Weir was based on research of Hanova (2014); whereas for unit hydrograph Colo Weir until Jurug AWLR Station was based from research of Amalia (2014).

5.4 Flood Routing Simulation

Simulation of reservoir flood routing was conducted to find the characteristic of Wonogiri Reservoir at flood at return period of 60 years, 500 years, and PMF. The flood characteristic in Upper Solo River Wonogiri Reservoir until Jurug AWLR Station was acquired by validity test on result of software simulation with the hydrology-hydraulic monitoring data that was present in the Solo River for certain flood condition.

6 RESULT AND DISCUSSION

6.1 Result of Software Development

The data input menu consisted of four tabs, which are time, real-time monitoring, Thiessen coefficient, and loss parameter. To find out the flood characteristic in Upper Solo River Wonogiri Reservoir until Jurug AWLR Station (see Figure 4), the software simulation used data input of real-time rainfall monitoring on January 25th 2014 (Table 7). This data was chosen because rain occurred for 12 hours, from 13:00 up to 24:00; therefore, at that time the Wonogiri Reservoir spillway released outflow discharge of 100 m³/s and increased into 140 m³/s, in which this condition lasted for 73 hours.

Table 6. Data of hypothetical water level on AWLR station

Water Depth (m)					
Keduang	Wiroko	Temon	Solo Hulu	Walikan	Dengkeng
1.76	1.52	1.36	1.21	1.14	0.10

The flood forecasting menu consists of 5 tabs which are unit hydrograph, effective rainfall, initial flow, reservoir inflow hydrograph, and total inflow hydrograph. From the simulation result, the reservoir

inflow hydrograph can be obtained as shown in Figure 8, which was the maximum discharge of 479 m³/s occurred at January 25th 2014 at 20:00, and was categorized as standard flood.

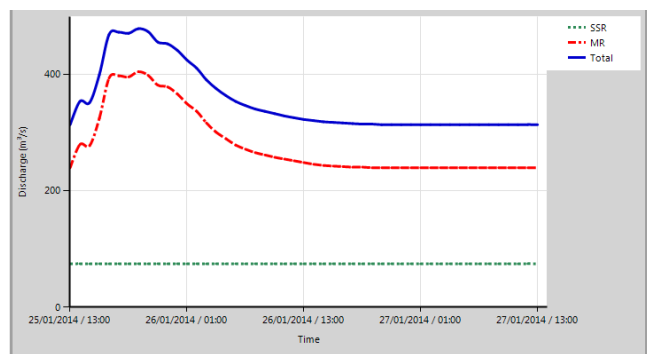


Figure 8. Flood forecasting simulation result.

On the menu reservoir flood routing, there are two tabs, which are tab initial condition of reservoir and outflow hydrograph. Result of reservoir flood routing simulation showed that the reservoir outflow discharge tends to be constant, which was 145 m³/s (Figure 9). This is in accordance with the function of the reservoir as flood controller, which is controlling outflow discharge through the spillway so that it is equal with the inflow discharge. From Figure 10, it could be seen that the inflow discharge on SSR tends to be constant, with the largest discharge is of 80 m³/s.

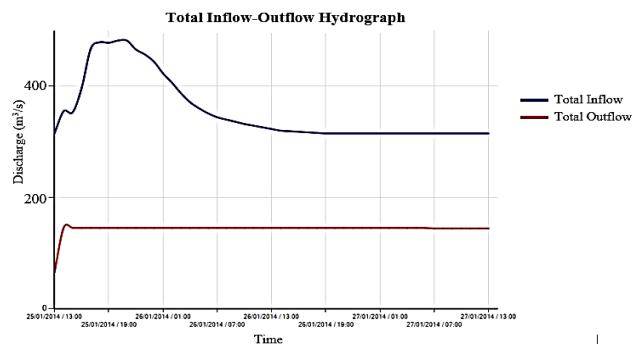


Figure 9. Reservoir outflow hydrograph

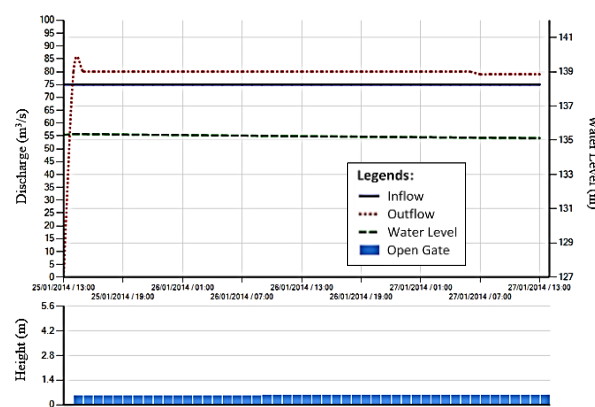


Figure 10. Outflow hydrograph of SSR resulted from reservoir flood routing simulation.

Table 7. Rainfall monitoring data on January 25th 2014

Hour	Rainfall depth (mm)										
	Pracimantoro	Batuwarno	Tirtomoyo	Jatisrono	Wonogiri	Colo	Klaten	Matesih	Ngargoyoso	Boyolali	
1	0.5	14	0	0	0	0	0	1	0	0	
2	0	0	0	0	0	0	0	4.5	0	0	
3	0.5	2	24.4	0	11.5	0	0.5	1.5	0	0	
4	0	0	9.8	0	3.5	0	0	1.5	0	0	
5	0.5	0	3.9	1	0	2.24	0	0	0	0	
6	0.5	0	1.4	0	0	1.12	0	0	0	0	
7	0.5	0	4.8	0	0	0.28	0	0	0	0	
8	0.5	0	2.2	0.5	0	0	0	0	0	0	
9	0.5	0	3.4	0	0	0	0	0	0	0	
10	0	0	3.1	0	0	0	0	0	0	0	
11	0	0	0	0	0	0	0	0	0.5	0	
12	0.5	0	0	0	0	0	0	0	0	0	

Table 8. Simulation final result summary

Start Simulation Time	January, 25 th 2014 – 13:00
Maximum Water Level of SSR	135.35 m
Maximum Water Level of MR	135.86 m
Maximum Total Inflow of Wonogiri Reservoir	479 m ³ /s
Maximum Total Outflow of Wonogiri Reservoir	145 m ³ /s
Maximum Discharge of Colo Weir	157.00 m ³ /s at January 26 th 2014 – 15:00
Maximum Water Level of Colo Weir	104.67 m at January 26 th 2014 – 13:00
Maximum Discharge of AWLR Jurug	249.00 m ³ /s at January 27 th 2014 – 04:00
Maximum Water Level of AWLR Jurug	80.70 m at January 26 th 2014 – 18:00

Table 9. New spillway gate operation and old spillway gate operation

Date - Time	Time (hour)	New Spillway Gate Operation		Old Spillway Gate Operation	
		Gate Opening (m)	Gate 1&4 Opening (m)	Gate 2&3 Opening (m)	
25/01/2014 – 13:00	0	0	0	0	
25/01/2014 – 14:00	1	0.56	0	0	
25/01/2014 – 15:00	2	0.56	0	0	
25/01/2014 – 16:00	3	0.56	0	0	
25/01/2014 – 17:00	4	0.56	0	0	
25/01/2014 – 18:00	5	0.56	0	0	
25/01/2014 – 19:00	6	0.56	0	0	
25/01/2014 – 20:00	7	0.56	0	0	
25/01/2014 – 21:00	8	0.56	0	0	
25/01/2014 – 22:00	9	0.56	0	0	
25/01/2014 – 23:00	10	0.56	0	0	
25/01/2014 – 00:00	11	0.56	0	0	
26/01/2014 – 01:00	12	0.56	0	0	
26/01/2014 – 02:00	13	0.56	0	0	
26/01/2014 – 03:00	14	0.56	0	0	
26/01/2014 – 04:00	15	0.56	0	0	
26/01/2014 – 05:00	16	0.56	0	0	
26/01/2014 – 06:00	17	0.56	0	0	
26/01/2014 – 07:00	18	0.56	0	0	
26/01/2014 – 08:00	19	0.56	0	0	
26/01/2014 – 09:00	20	0.57	0	0	
26/01/2014 – 10:00	21	0.57	0	0	
26/01/2014 – 11:00	22	0.57	0	0	
26/01/2014 – 12:00	23	0.57	0	0	
26/01/2014 – 13:00	24	0.57	0	0	
26/01/2014 – 14:00	25	0.57	0	0	

Data input of the hydraulic calculation was river geometry in form of the cross-section that was resulted from measurement, followed with inline structure (Figure 11), and boundary condition as the requirement of unsteady flow simulation on HEC-RAS 4.1.0 software. The data were already saved in the software database, which then able to facilitate the users when running the software. Technical data of Colo Weir gate operational pattern which was used in this simulation are:

- Gate operational operate two gate openings,
- Using the overflow gate type (open air),
- The gate is opened maximum at 5 m height.

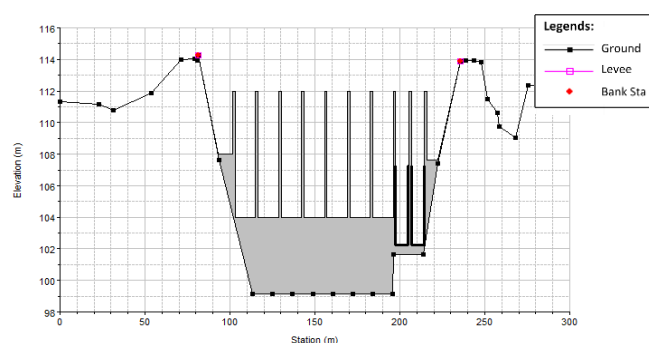


Figure 11. Inline structure of Colo Weir di RS. 746.10.

Next step was conducting the unsteady flow simulation. The time interval in simulation calculation was recommended at 2-minutes time interval for computation interval, 1 hour for hydrograph output interval and detailed output interval. The result of hydraulic flood routing simulation showed the flood characteristics at the control points, which are as follows.

a) Colo Weir

Maximum flood discharge of 157 m³/s was occurred on January 26th 2014 on 15:00, with volume of 26,020.31 m³. Maximum water level of 104.67 m was occurred at January 26th 2017 at 13:00.

b) Jurug AWLR Station

Maximum flood discharge of 249 m³/s was occurred on January 27th 2014 on 04:00, with volume of 39,014.31 m³. Maximum water level of 80.70 m was occurred at January 26th 2017 at 18:00. The final result of this simulation was presented in Table 8 in which showed the information about the amount of inflow and outflow discharge of the reservoir, fluctuation of reservoir water level in both SSR and MR, spillway gate operation (Table 9), and also the flow condition in Colo

Weir and Jurug AWLR Station. This simulation gave the information on the flood characteristic, in the form of flood discharge and maximum water level gauge on control points of Colo Weir and Jurug AWLR Station.

6.2 Flood Performance

6.2.1 Flood Performance in Wonogiri Reservoir

The reservoir flood routing simulation was conducted with entering hydrograph input of Wonogiri Reservoir inflow in return period of 60 years, 500 years, and PMF, which was a research result from Ansita Gupitakingkin (2014). Based on the design of Nippon Koei Co. Ltd, (2007), for the 60-years and 500-years return period floods, reservoir outflow operation use new spillway, whereas for PMF, the operation uses new and old spillways. The result of reservoir flood routing for 60-years return period is shown in Figure 12.

Based on Figure 12, the water level at SSR and MR are still below the closure dike peak elevation (+139.4 m). There was no runoff from SSR to MR and vice versa, because each elevation did not exceed the overflow dike elevation (+137 m). Based on the maximum water level, the reservoir condition is safe from the potency of overtopping, since it is still below the critical water level limit (+139.1 m). Further then, reservoir flood routing simulation was conducted for the 500-years return period flood (Figure 13).

Based on Figure 13, the maximum water level at SSR is +138.77 m, and at MR is +138.03; whereas both are still below the closure dike peak. On the 500-years return period flood simulation, full opening gate was conducted, started from the 7th hour because the reservoir water level exceeded +138.2 m. This was conducted to avoid the overtopping on Wonogiri Reservoir.

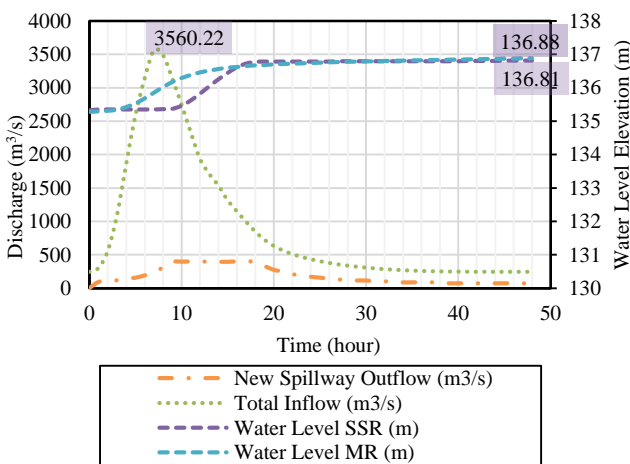


Figure 12. Reservoir flood routing for 60-years return period flood.

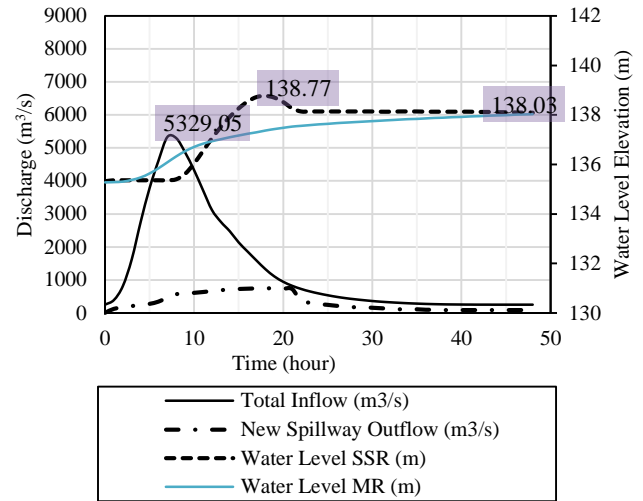


Figure 13. Reservoir flood routing for 500-years return period flood.

Further, reservoir flood routing simulation was conducted for the PMF (Figure 14). Reservoir flood routing simulation for PMF operated simultaneously on new and old spillways; and the outflow from the old spillway was 400 m³/s. From the result of reservoir flood routing for PMF, it was known that the SSR maximum water level was +139.92 m (52 cm above the closure dike), and for the MR was +137.12 m (below the closure dike peak). This condition is compatible with the Nippon Koei (2007) design, in which at condition of PMF, the reservoir water level is allowed to overtopping through the closure dike.

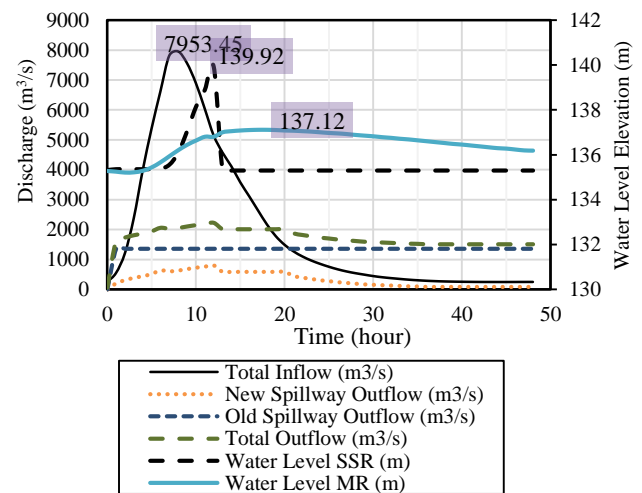


Figure 14. Reservoir flood routing for PMF.

Recapitulation of the results from reservoir flood routing on Nippon Koei design and on simulation result is presented in Table 10. It is known that by the presence of a closure dike, the maximum outflow discharge and the reservoir maximum water level were increased. The increase of maximum outflow discharge

for 500-years return period was 66.67% and 73.99% at PMF. The increase of outflow discharge also increases the risk on Wonogiri Reservoir downstream. On the other hand, there was also an increase in maximum water level, which are 0.01 m for 60-years return period, 0.97 m for 500-years return period, and 1.32 m for PMF.

6.2.2 Flood Characteristic on Downstream of the Reservoir

To obtain the flood characteristic that occurs on the downstream of reservoir, simulation based on certain rain event was conducted. As an example, simulation with real-time rainfall data input on January 25th 2014 was conducted. The result of the simulation was compared with the data from observation that was conducted by Perum Jasa Tirta I.

From the software simulation, it was seen that the maximum outflow discharge was of 80 m³/s until January 27th 2014 at 06:00; and next was of 79 m³/s until the end of simulation (see Figure 15). The difference between result from simulation and observation was that the outflow discharge that the old spillway released was of 100 m³/s until January 25th 2014 at 09:00, and 140 m³/s for so forth.

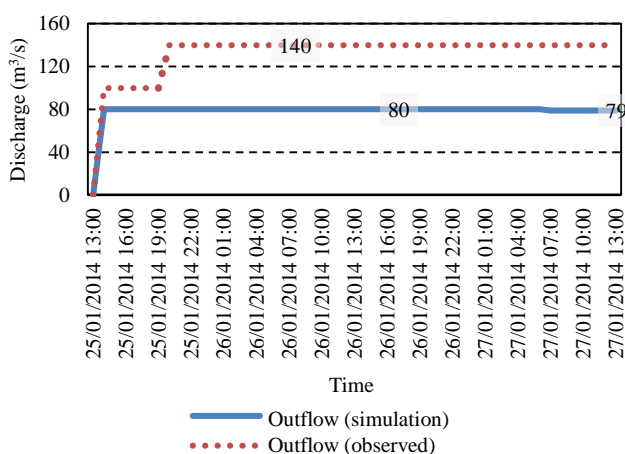


Figure 15. Reservoir outflow.

The flood characteristic on control points of Colo Weir and Jurug AWLR Station was obtained from the result of hydraulic flood routing simulation. The simulation result showed that the maximum water level in Colo Weir was 3.92 m lower than the result of field observation (Figure 16). The water level on Jurug AWLR Station showed the difference, in which the simulation result was 0.41 m lower (see Figure 17).

The water level fluctuation difference in simulation and field observation results was due to several possibilities. First is the difference in reservoir operational guideline, in which when the simulation used new reservoir operation, old guideline was used at flood in January 25th 2014 (was only operating old spillway). The second possibility was due to the decrease of the unit hydrograph, which still using synthetic unit hydrograph that caused the calculated lateral inflow discharge was still less accurate, also the input unsteady flow data only calculated 5 tributaries that give the biggest contribution to flood discharge in Upper Solo River Wonogiri Reservoir until the Jurug AWLR Station. The third possibility was the calibration of watershed parameter was only conducted on one flood event; therefore lead to the calibration of watershed parameters was not yet optimal.

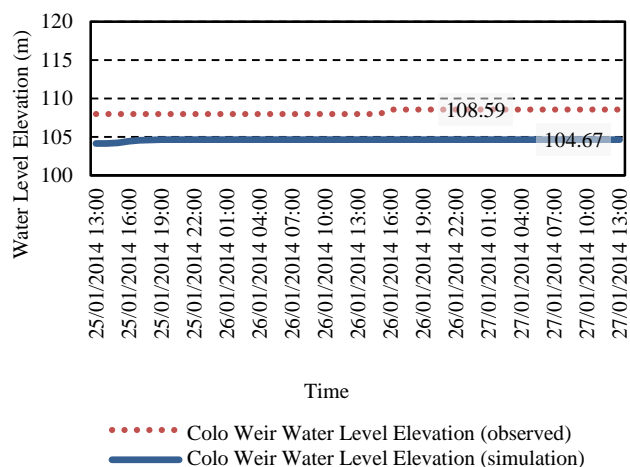


Figure 16. Water level elevation on Colo Weir.

Table 10. Recapitulation of comparison from reservoir flood routing results

Return Period (year)	Maximum Inflow Discharge (m ³ /s)	Maximum Outflow Discharge (m ³ /s)			Δ Maximum Outflow Discharge (%)	Maximum Water Level Elevation (m)			Δ Maximum Water Level (m)
		Old Condition	New Condition Old Spillway	New Condition New Spillway		Old Condition	New Condition MR	New Condition SSR	
60	3,560.22	415	-	405	-2.41	136.80	136.88	136.81	0.01
500	5,329.05	447	-	745	66.67	137.80	138.03	138.77	0.97
PMF	7,953.44	1,242	1,360	801	73.99	138.60	137.12	139.92	1.32

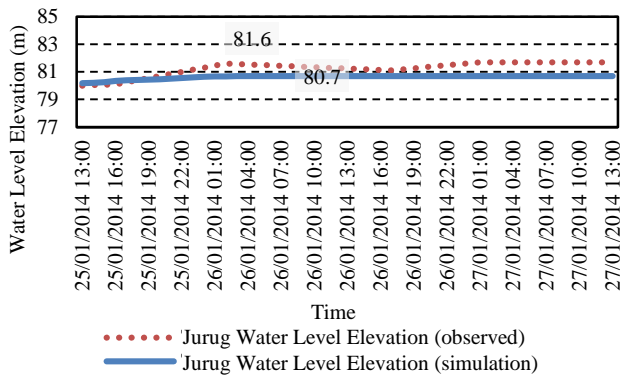


Figure 17. Water level elevation on Jurug AWLR station.

7 CONCLUSIONS

The simulation results can be summarized as follows:

- There were significant changes on the simulation result of flood hydrograph Wonogiri Reservoir outflow when compared with the operating rule that the Nippon Koei Co. Ltd (2007) arranged, in the form of outflow discharge increase of 66.67% for 500-years return period and 73.99% for PMF. The water level elevation increased 0.97 m for 500-years return period and 1.32 m for PMF.
- Characteristic of flood hydrograph of January 25th 2014 flood event simulation result was that the water level elevation was lower than the observation result. This was because the flood routing simulation based on the new condition of the reservoir operation, whereas only the new spillway was being operated; while the outflow real operational data was only came from old spillway (still using the old operational guide).

REFERENCES

Amalia, A., 2014. *Studi Pengaruh Pembangunan Closure Dike Waduk Wonogiri Terhadap Kondisi*

Banjir di Hilir Waduk, Yogyakarta: Master Thesis Report. Universitas Gadjah Mada.

Amalia, B. A. R., 2014. *Analisis Karakteristik Banjir Sungai Bengawan Solo Ruas Bendung Colo - Kota Surakarta*, Yogyakarta: Undergraduate Thesis Report. Universitas Gadjah Mada.

Gunawan, 2009. *Studi Banjir Bengawan Solo 2007 untuk Peningkatan Kinerja Mitigasi Bencana Banjir*, Yogyakarta: Master Thesis Report. Universitas Gadjah Mada.

Gupitakingin, A., 2014. *Studi Pengaruh Pembangunan Closure Dike Waduk Wonogiri Terhadap Pola Operasi Waduk Periode Banjir*. Tesis, Yogyakarta: Master Thesis Report. Universitas Gadjah Mada.

Hanova, Y., 2014. *Pengembangan Perangkat Lunak Model Simulasi Hidrologi untuk Pengendalian Banjir Wilayah Sungai Bengawan Solo Hulu*, Yogyakarta: Master Thesis Report. Universitas Gadjah Mada.

Nippon Koei Co. Ltd, 2007. *The Study on Countermeasures for Sedimentation in Wonogiri Multipurpose Dam Reservoir in The Republic of Indonesia. Final Report*, The Republic of Indonesia: Ministry of Public Works.

Oktavia, S. R., 2013. *Pengembangan Model Hidrologi untuk Estimasi Hidrograf Inflow Waduk Wonogiri*, Yogyakarta: Master Thesis Report. Universitas Gadjah Mada.

Wijaya, A. P., 2014. *Pembuatan Perangkat Lunak Untuk Mendukung Pengendalian Banjir DAS Bengawan Solo Hulu*, Yogyakarta: Master Thesis Report. Universitas Gadjah Mada.