ANALYSIS OF HYDRAULIC FLOOD CONTROL STRUCTURE AT PUTAT BORO RIVER

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ABSTRACT

Putat Boro River is one of the main drainage systems of Surakarta city which drains into Bengawan Solo river. The primary problem when flood occur is the higher water level of Bengawan Solo than Boro River and then backwater occur and inundates Putat Boro River.
The objective of the study is to obtain operational method of Putat Boro River floodgate to control both inflows and outflows not only during flood but also normal condition. It also aims to know the Putat Boro rivers floodgate operational function to reduce inundation. Putat Boro river water level variation and Bengawan Solo river water level variation were used for simulation of Boro river floodgate routing. The simulation used 10-year inflows, 50-year inflows, and 100-year inflows return period and Boro water level variation are +82.50 m, +83.00 m and +84.00 m.
The results of the study show that the effective opening of floodgate are 0.35 m - 0.55 m for +82.05 m of Bengawan Solo water level, 0.50 m – 0.65 m for +82.55 m of Bengawan Solo water level and 0.70 m – 0.85 m for +83.48 m of Bengawan Solo water level, for reducing water level of Boro river flooding.

Keywords: Flood, drainage systems, floodgate and flow routing.

1 INTRODUCTION

Flood that occurs periodically in dense populated area, particularly in urban area has caused damages and losses to physical structures, even loss of human lives. Flood in 1966 inundated almost 2/3 of Surakarta city including urban area. Inundation attained 1 m up to 2 m depth and caused 90 people died.

Boro River is one of many drainage canals flowing into Bengawan Solo River. Its catchment comprises Sewu, Pucang Sawit, Jagalan, Purwodiningratan, and Tegalharjo sub district, Jebres district, Surakarta city. Flood that occurs almost every year is affected by backwater phenomena. It occurs when water level of Bengawan Solo River is higher than ground level of catchment of Boro River. The flood control of Putat Boro River has three gates.

2 FLOOD ROUTING AND FLOW OVER GATE SYSTEM

Flood routing is used to determine flood hydrograph at a point based on monitored hydrograph at another point upstream on a watercourse. Flood hydrograph can be traced from riverbed or a dam (Soemarto, 1989). There are some flood routing methods, a well-known one is Muskingum developed by Mc Carthy (1938 in Ven Te Chow, 1989) as shown in Equation (1)

$$\Delta S = \sum I.\Delta t - \sum Q.\Delta t \tag{1}$$

where ΔS is storage change in the *i*-th time interval (m^3), $\sum I$ is volume of inflow (m^3), $\sum Q$ is volume of outflow in the *i*-th time interval (m^3), and Δt is interval of duration (second, hour, day).

The foregoing equation can be elaborated as follows.

$$\frac{1}{2}(I_n + I_{n+1}) = \frac{1}{2}(Q_n + Q_{n+1}) + \frac{\Delta S}{\Delta t} \tag{2}$$

$$\frac{1}{2}(I_n + I_{n+1}) = \frac{1}{2}(Q_n + Q_{n+1}) + A\frac{\Delta H}{\Delta t} \tag{3}$$

$$\frac{1}{2}(I_n + I_{n+1}).\Delta t = \frac{1}{2}(Q_n + Q_{n+1}).\Delta t + A.\Delta H \tag{4}$$

where I_n is inflow in the beginning of Δt (m^3), I_{n+1} is inflow in the end of Δt (m3), Q_n is outflow in the beginning of Δt (m^3), Q_{n+1} is outflow in the end of Δt m^3), A is the water surface area at an observed time (m^2), and is change in water elevation during Δt (m).

The following equation is used for flood routing analysis through sliding floodgate.

$$Q = K.\mu.a.b\sqrt{2gh_1} \tag{5}$$

where Q is discharge (m^3/s), K is sinking flow factor, μ is discharge coefficient, a is floodgate-opening (m), b is floodgate width (m), g is acceleration due to gravity (m/s^2), and h_1 is depth of water in front of floodgate above threshold (m).

Value of K and μ for sinking flow factor and discharge coefficient (Ministry of Public Works, 1986) are provided in Figure 1 and Figure 2, respectively. Peak discharge is analyzed by using rational method (Sri Harto, 2000), (Chow, 1964) as follows

$$Q_p = k\ C\ I\ A \tag{6}$$

where Q_p is peak discharge (m^3/s), k is 0.278, C is runoff coefficient which depends with characteristic of the catchment area ($0 \leq C \leq 1$) (Chow, 1988), I is rainfall intensity during time concentration (mm/hour), and A is watershed area (km^2).

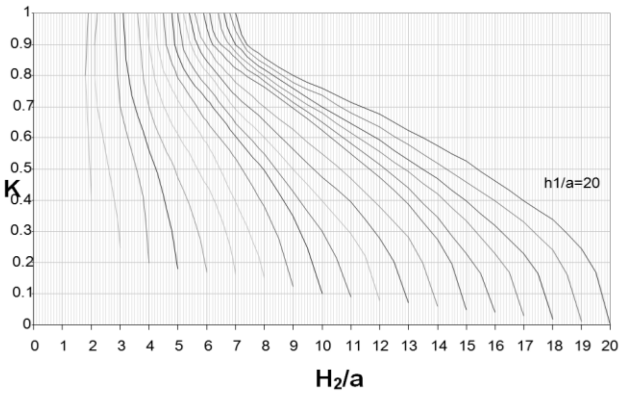

Figure 1. Value of K for sink flow factor.

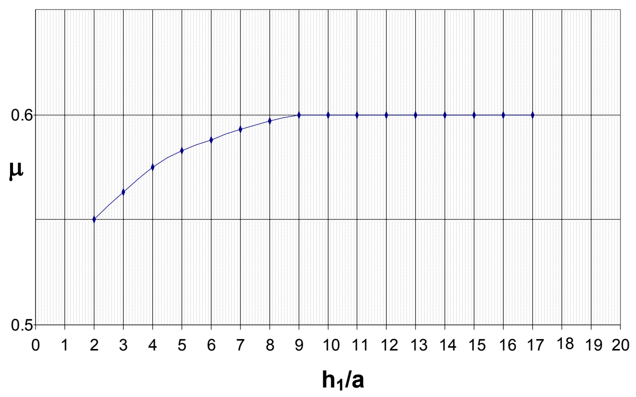

Figure 2. Value of μ for discharge coefficient.

Kirpich (1940) developed a formula to analyze time concentration (Chow et al, 1988) as follows.

$$t_c = \left[\frac{0.87.L^2}{1000.S}\right]^{0.385} \tag{7}$$

where t_c is time concentration (hour), L is river length (km), and S slope of the river (m/m).

3 METODOLOGICAL APPROACH

The research uses some secondary data obtained from several source, there are Main Project of Bengawan Solo River Region Development, Bengawan Solo River Basin organization, and Public Works Office of Solo (see flowchart in Figure 3).

a) Watershed map is gained from visual earth map with scale of 1:25.000 that is resulted storage characteristic as shown in Figure 4.
b) Daily rainfall maximum data which is used to analyze design rainfall with specified return period, then flood hydrograph can be presented as in Figure 5.
c) Putat Boro watershed characteristic
d) Daily water level maximum in Jurug obtained from AWLR.

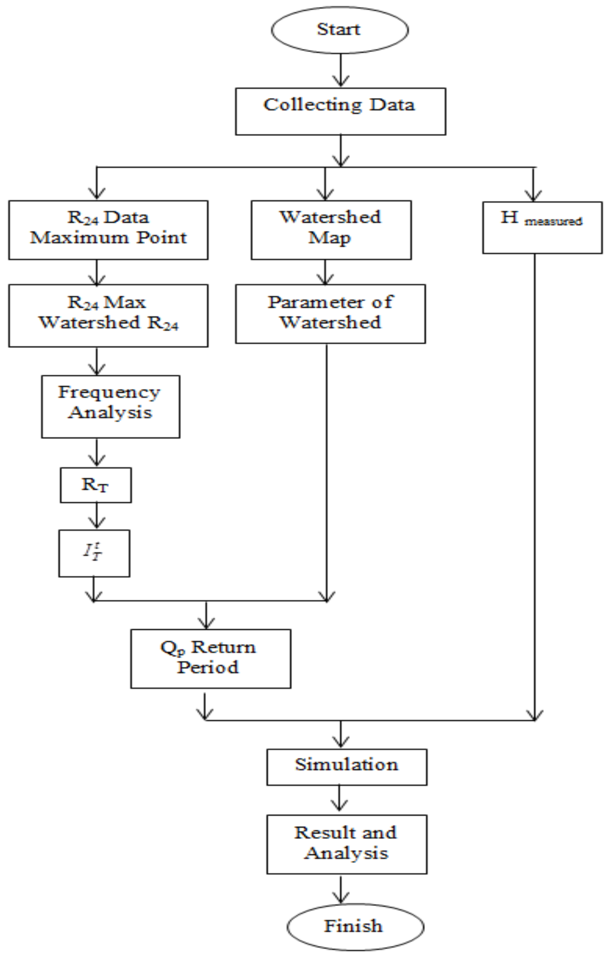

Figure 3. Research flow chart.

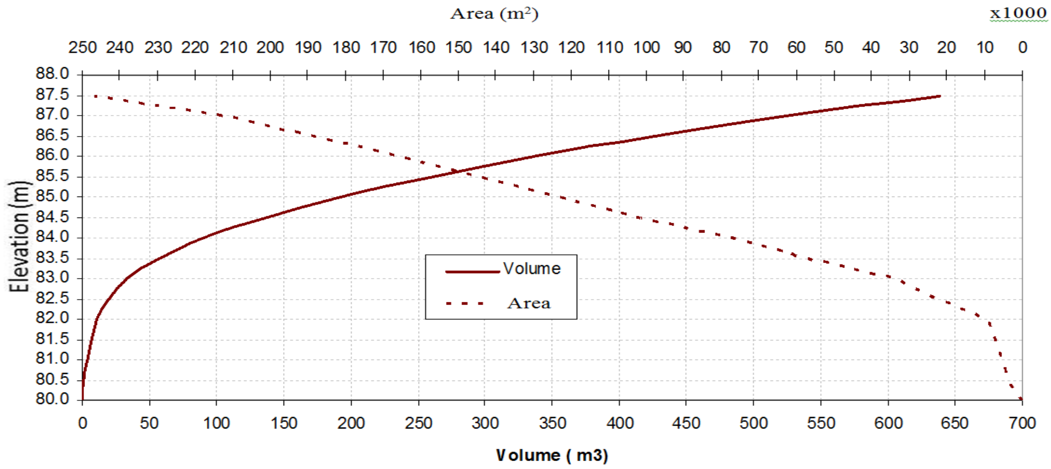

Figure 4. Inundated area and storage volume of Boro River.

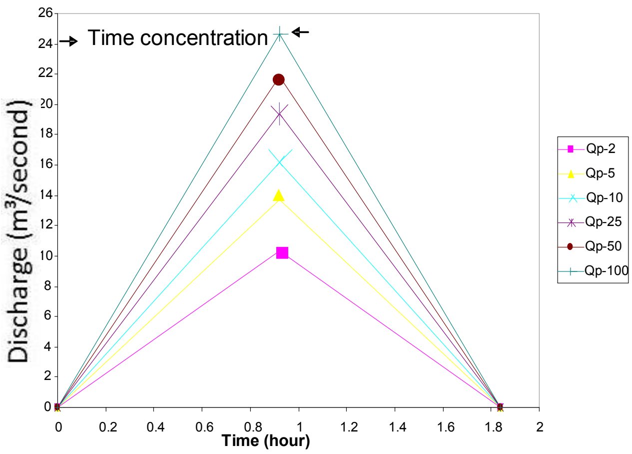

Figure 5. Flood hydrograph of Boro River with several return periods.

4 RESULTS AND DISCUSSIONS

Simulation of flood analysis through Putat floodgate applies return period of 10, 50, and 100 years and +84.00 m maximum water level in Boro River ($H_{upstream}$). If it is exceeded, there will be the overflow from Boro River). Peak discharges are presented below.

4.1.1 Inflow with a return period of 10 years

Based on 16.14 m^3/s *Qp* Boro, + 82.50 m, + 83.00, and + 84.00 m Boro River level, and + 82.05 m, + 82.55, + 83.48 m Bengawan Solo ($H_{downstream}$) River level, varying results of Putat floodgate-opening are obtained as shown in Table 1.

Table 1. Simulation result with Qp-10 years

$H_{downstream}$ \ $H_{upstream}$	+ 82.50 m	+ 83.00 m	+ 84.00 m
+ 82.05 m	0.20 m - 0.40 m	0.20 m - 0.50 m	0.20m - 0.50 m
+ 82.55 m	-	0.20 m - 0.55 m	0.20 m - 0.60 m
+ 83.48 m	-	-	0.20m - 0.75 m

Graphic results are depicted from Figure 6 to Figure 11

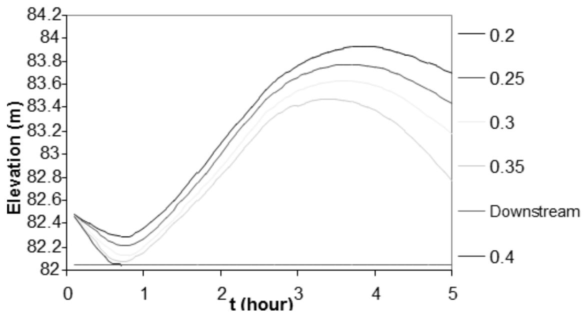

Figure 6. Q_{10}-$H_{upstream}$=82.5 m and $H_{downstream}$=82.05 m with variation in floodgate-opening.

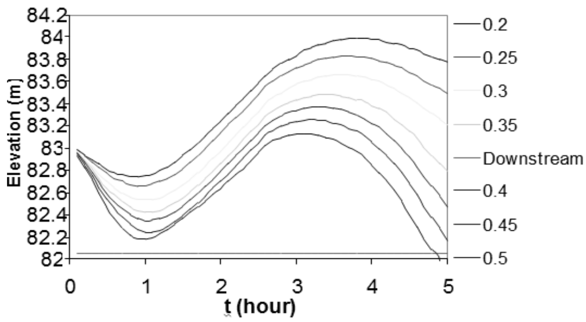

Figure 7. Q_{10}- $H_{upstream}$ =83.00 m and $H_{downstream}$ =82.05 m with variation in floodgate-opening.

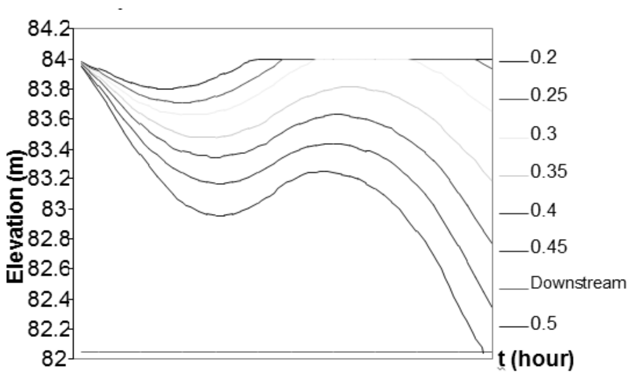

Figure 8. Q_{10}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =82.05 m with variation in floodgate-opening.

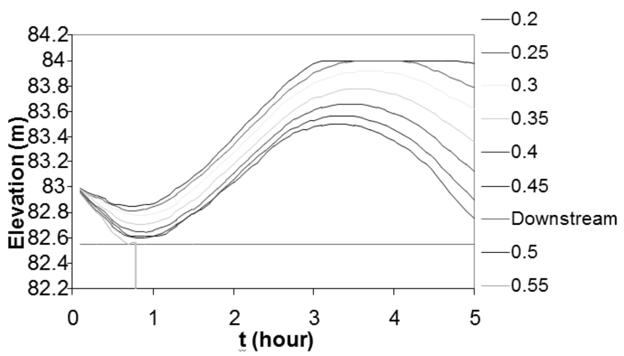

Figure 9. Q_{10}- $H_{upstream}$ =83.00 and $H_{\text{downstream}}$ =82.55 m with variation in floodgate-opening.

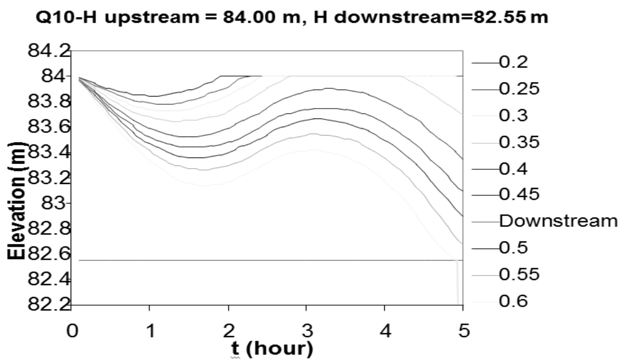

Figure 10. Q_{10}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =82.55 m with variation in floodgate-opening.

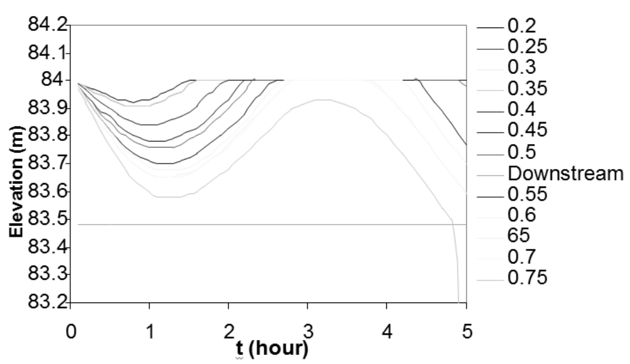

Figure 11. Q_{10}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =83.48 m with variation in floodgate-opening.

4.1.2 Inflow with a return period of 50 years

From 21.87 m^3/s *Qp* Boro, + 82.50 m, + 83.00, and + 84.00 m Boro River level, and + 82.05 m, + 82.55, + 83.48 m Bengawan Solo ($H_{\text{downstream}}$) River level, varying results of Putat floodgate-opening are obtained as shown in Table 2.

Table 2. Simulation result with Qp-50 years

$H_{upstream}$ / $H_{\text{downstream}}$	+ 82.50 m	+ 83.00 m	+ 84.00 m
+ 82.05 m	0.2 m - 0.45 m	0.2 m - 0.55 m	0.2 m - 0.55 m
+ 82.55 m	-	0.2 m - 0.60 m	0.2 m - 0.70 m
+ 83.48 m	-	-	0.2 m - 0.90 m

Graphic results can be seen from Figure 11 to Figure 17

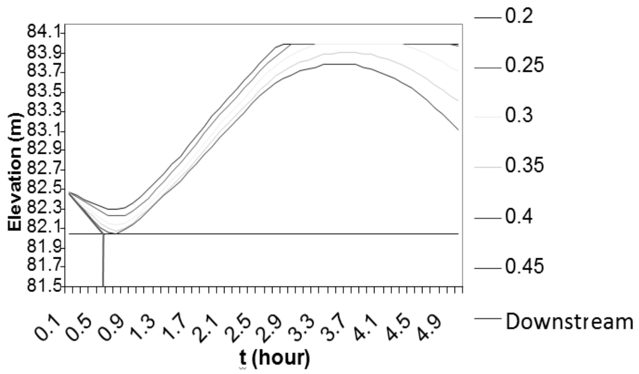

Figure 12. Q_{50}- $H_{upstream}$ =82.50 m and $H_{\text{downstream}}$ =82.05 m with variation in floodgate-opening.

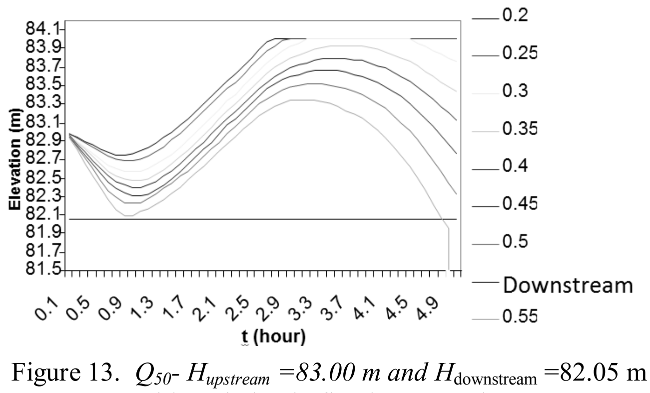

Figure 13. Q_{50}- $H_{upstream}$ =83.00 m and $H_{\text{downstream}}$ =82.05 m with variation in floodgate-opening.

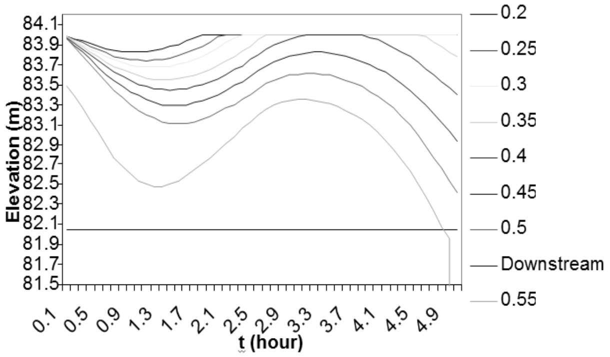

Figure 14. Q_{50}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =82.05 m with variation in floodgate-opening.

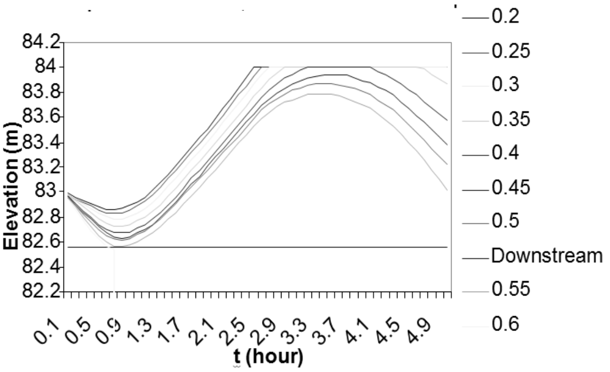

Figure 15. Q_{50}- $H_{upstream}$ =83.00 m and $H_{\text{downstream}}$ =82.55 m with variation in floodgate-opening.

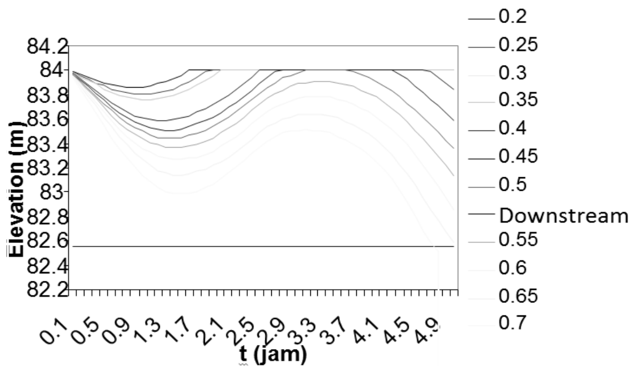

Figure 16. Q_{50}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =82.55 m with variation in floodgate-opening.

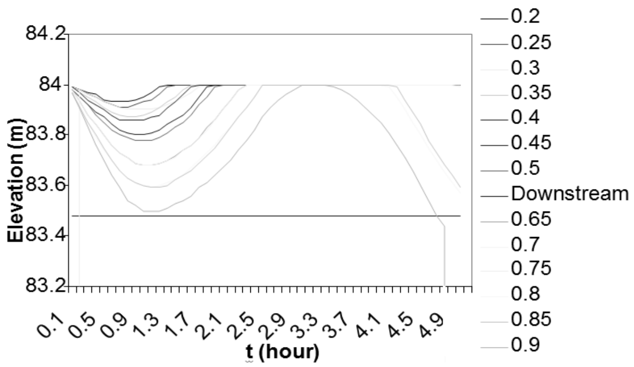

Figure 17. Q_{50}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =83.48 m with variation in floodgate-opening.

4.1.3 Inflow with a return period of 100 years

From 24.63 m^3/s *Qp* Boro, + 82.50 m, + 83.00, and + 84.00 m Boro River level, and + 82.05 m, + 82.55, + 83.48 m Bengawan Solo ($H_{\text{downstream}}$) River level, varying results of Putat floodgate-opening are obtained as shown in Table 3.

Table 3. Simulation result with Qp-100 years

H_{upstream} / $H_{\text{downstream}}$	+ 82.50 m	+ 83.00 m	+ 84.00 m
+ 82.05 m	0.2 m - 0.45 m	0.2 m - 0.45 m	0.2 m - 0.60 m
+ 82.55 m	-	0.2 m - 0.60 m	0.2 m - 0.70 m
+ 83.48 m	-	-	0.2 m - 0.90 m

Graphic are depicted from Figure 18 to Figure 23

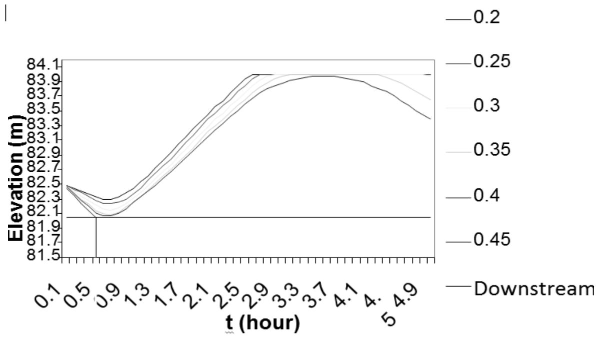

Figure 18. Q_{100}- $H_{upstream}$ =82.50 m and $H_{\text{downstream}}$ =82.05 with variation in floodgate-opening.

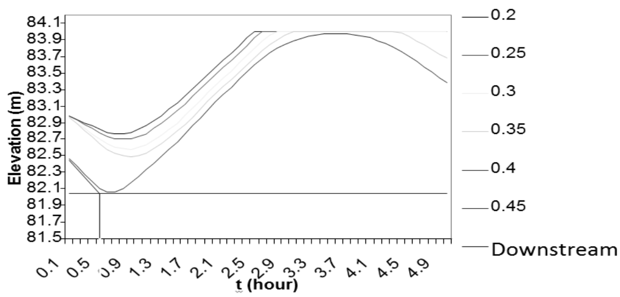

Figure 19. Q_{100}- $H_{upstream}$ =83.00 m and $H_{\text{downstream}}$ =82.05 m with variation in floodgate-opening.

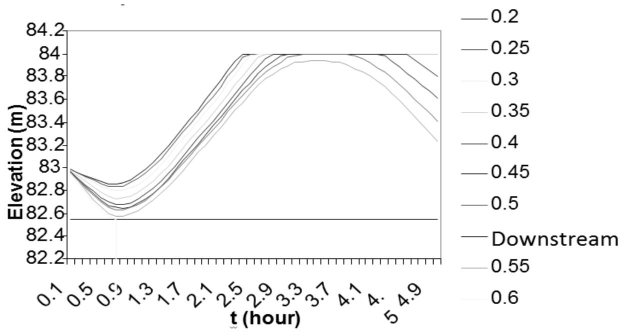

Figure 20. Q_{100}- $H_{upstream}$ =84.00 m and $H_{\text{downstream}}$ =82.05 m with variation in floodgate-opening.

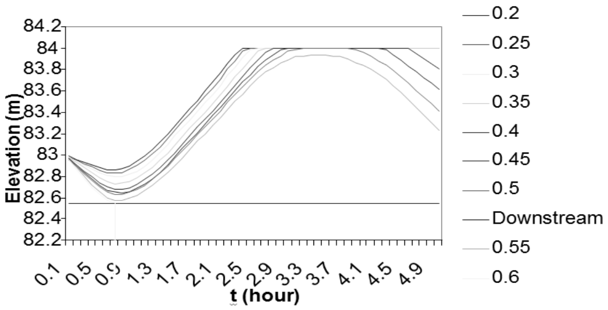

Figure 21. *Q_{100}- $H_{upstream}$ =83.00 m and* $H_{\text{downstream}}$ =82.55 m with variation in floodgate-opening.

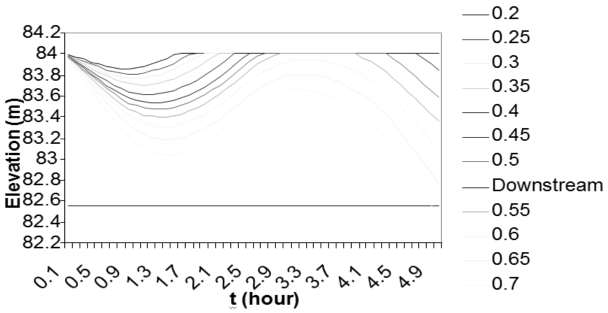

Figure 22. *Q_{100}- $H_{upstream}$ =84.00 m and* $H_{\text{downstream}}$ =82.55 m with variation in floodgate-opening.

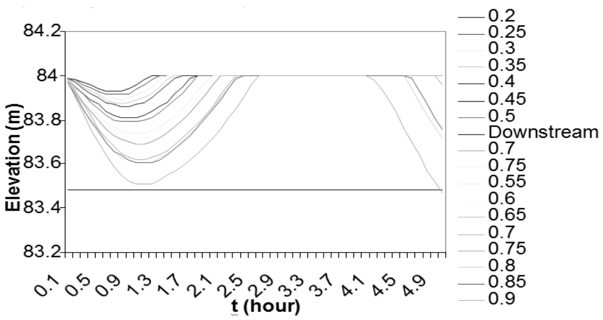

Figure 23. *Q_{100}- $H_{upstream}$ =84.00 m and* $H_{\text{downstream}}$ =83.48 m with variation in floodgate-opening.

The results of simulation show that for water level of Bengawan Solo River ($H_{\text{downstream}}$) + 82.05 m and 10 years of Q_p , the floodgate-opening that can lower water level of Boro River maximally is 0.35 m - 0.45 m (can be seen at Figure 6, Figure 7, and Figure 8),while the floodgate-opening for 50 years of Q_p is 0.40 m - 0.5 m (can be seen at Figure 12, Figure 13, and Figure 14), and about 0.40 m - 0.55 m for 100 years of Q_p (can be seen at Figure 18, Figure 19, and Figure 20).

When Bengawan Solo elevation ($H_{\text{downstream}}$) rises up to + 82.55 m due to 10 years of Q_p, the floodgate-opening for maximum level reduction is approximately 0.50 m - 0.55 m (can be seen at Figure 9 and Figure 10), 0.55 m - 0.65 m for 50 years of Q_p(see Figure 15 and Figure 16), and 0.55 m - 0.65 m for 100 years of Q_p (see Figure 21 and Figure 22).

For + 83.48 m $H_{\text{downstream}}$ and 10 years of Q_p , the floodgate-opening that can result maximum reduction of Boro River level is approximately 0.70 m (see Figure 11), 0.85 m for 50 years of Q_p, (see Figure 17), and 0.85 m for 50 years of Q_p (see Figure 23). If the floodgate is opened more than those values, it may cause backwater from Bengawan Solo River ($H_{\text{downstream}}$).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

According to the result of flood routing simulation towards Putat Floodgate using 10 years, 50 years, and 100 years of return period of flood hydrograph with variation in water elevation of Boro River, +82.50 m, +83.00 m dan +84.00 m, it can be concluded that :

a) For +82.05 m Bengawan Solo Rivel level, the effective floodgate-opening is 0.35 m – 0.55 m
b) For +82.55 m Bengawan Solo Rivel level, the effective floodgate-opening is 0.50 m – 0.65 m
c) For +83.48 m Bengawan Solo Rivel level, the effective floodgate-opening is 0.70 m – 0.85 m
d) Putat Floodgate can be operated with the maximum floodgate-opening as long as no backwater occurs

5.2 Recommendations

The followings are some recommendations to optimize flood control system as the main goal.

a) Operating management of Putat Floodgate should be improved by referring to the gate operational guide.
b) Procurement of pump needs to be realized to prevent backwater occurrence due to the overflow from Bengawan Solo River.

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