Investigation and modelling of the flood control system in the Aerotropolis of Yogyakarta International Airport

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Abstract. The New Yogyakarta International Airport has become one of Indonesia's National strategic projects and potentially support the development of the Aerotropolis area around the airport. Located on the southern coast of Yogyakarta with rivers at the airport's upstream, flooding can be a threat to the Aerotropolis area and the Yogyakarta International Airport. This research aims to investigate and model the flood review of the existing design of the flood control system of the Aerotropolis area and find out the possible option of better flood control in the area. The one-dimensional Hydrologic Engineering Center-River Analysis System (HEC-RAS) 4.1 was used to simulate the flood and its control in the Aerotropolis area. Simulation of flood control options includes river normalization, optimization of flood gates, retarding basin, and flood pumps. The present study proposed adjustment of performing in the use of a flood control alternative. Alternative flood control at each flood-prone area was adjusted to the level of flooding risk in the area. In conclusion, the use of retarding basin and flood pumps highly recommended to prevent flooding at the Aerotropolis area of Yogyakarta International Airport.

Keywords: Aerotropolis, flooding, investigation, modelling, flood control, HEC-RAS

1. Introduction
The New Yogyakarta International Airport has become one of Indonesia's National strategic projects [1]. It will be the central hub for international flights to and from Yogyakarta [2] and potentially support the development of the Aerotropolis area around the airport [3]. Aerotropolis is a metropolitan sub-region whose infrastructure, land use, and economy are centered on the airport [4]. As a new urban development paradigm of the 21st century, Aerotropolis has increasingly become a portal to national and regional economic growth [5-7].

Located at the southern coast of Yogyakarta, in the Temon district of Kulon Progo regency, with rivers at the airport's upstream, flooding can be a threat to the Aerotropolis area and the Yogyakarta International Airport [8,9]. Floods is one of a natural disaster frequently occurs there. Based on the data in the regional Disaster management Agency (BPBD) Kulon Progo, Temon district has a high flood...
The flood is an overflow of water that submerges the land that is usually dry and inundated in many ways [11]. On 17th March 2019, a flood happened in the Temon sub-district and caused 344 people to evacuate. The New Yogyakarta International Airport has affected the condition, physical capacity, and morphology of the airport's rivers.

Based on these conditions, the investigation and the existing design review are necessary to find out the possible option of better flood control in the area. Due to its complexity and risk, the flood system modeling in the Aerotropolis area needs to do. Many software has been developed to predict future floods and possible affected areas. One of the most commonly used software for hydraulic flood modeling is one-dimensional Hydrologic Engineering Center-River Analysis System (HEC-RAS).

There have been several previous studies related to flood inundation in the Kulon Progo area, both individually and by institutions. In 2018, PT. Angkasa Pura researched flood inundation simulation using MIKE 21 and HEC-RAS software. The alternative flood control proposed includes normalization, construction of river dike, and the use of four retarding basins, but retarding basins have not been simulated with HEC-RAS [9]. Aditya K et al. (2019) analyzed the land-use changes in the Temon sub-districts after YIA construction with the study area is in the West Carik channel, the Sindutan channel, the Poncol channel and the Lawang channel [12].

Alternative flood control proposed is river normalization. In 2019, PT. Virama Karya In this work, PT Virama Karya simulated the flood occurrence using HEC-RAS. The simulation was modelled by dividing into three major systems, namely the Carik Barat System, the Ledeng System and the Carik Timur System. For existing conditions, the system simulated using steady flow. While for the redesign, the system simulated using unsteady flow analysis [8]. In 2020, Akhyar Fahrizal et al. analyzed the effect of land-use changes on the runoff potential in the Serang watershed, Kulon Progo Regency, which is the Yogyakarta International Airport [13]. In the same year of 2020, Festi and Novi analyzed the estuary conditions for flooding occurrence in the Serang River, Kulon Progo Regency. This study focused on the behaviour of the Serang River estuary using HEC-HMS and HEC-RAS to determine the effectiveness of the existing section of the estuary [14].

In this research, flood control was simulated using HEC-RAS 4.1 software with unsteady flow analysis for a whole of drainage and river systems. Simulation of flood control options includes river normalization, optimization of flood gates, retarding basin, and flood pumps. The present study proposed adjustment of performing. Alternative flood control at each flood-prone area was adjusted to the level of flooding risk in the area. This research was more detailed than previous studies, so that the result of the simulation will be better than others.

2. Study of Literature
2.1. Hydraulic flood modelling
Flood hydraulic modelling is a mathematical model used to evaluate the main elements of fluids flow to predict flooding. The model can simulate the 1D, 2D, or 3D forms depending on the user's needs. Flood hydraulic modelling was used to determine the ability of the river to drain flood discharge [15]. In hydraulic flood modelling, the model analyzes the input data such as boundary conditions, channel geometry, forces, and other channel parameters into output data, including flow velocity, flow discharge, water surface level, flow pressure, and others [16], so that the modelling results highly dependent on input data [17].

The nature of flooding causes the flood modelling simulation cannot be modelled precisely as in reality but just close to it [18]. Even though a model has been calibrated to get optimal results, it does not guarantee that the results are the same as a real condition [17]. Many software has been developed to simplify the calculation of flood hydraulics such as HEC-RAS, LISFLOOD, MIKE, and others. Those have their advantages and disadvantages. One of the well-known and widely used software is HEC-RAS[19].
2.2. Overview of HEC-RAS software

HEC-RAS is a free software designed by M. Gary W. Brunner in 1995 and was developed at the Hydrologic Engineering Center (HEC) to perform hydraulic behaviour of flood in one-dimensional (1D), two-dimensional (2D) or a combined of 1D and 2D calculation for permanent (steady) or non-permanent flow (unsteady) both in the natural and constructed channels [20,21]. HEC-RAS also enables users to perform quasi unsteady and full unsteady flow sediment transport-mobile bed modelling, water temperature analysis, and generalized water quality modelling (nutrient fate and transport) [20].

The choice of steady or unsteady flow analysis simulation depends on the analysis's objectives; for example, to simulate the flood routing in a river, a non-permanent flow simulation is needed. HEC-RAS applies conservation laws to the basis of its hydraulic calculations. Conservation laws divide into three are mass conservation law, momentum conservation law, and energy conservation law [22]. The mass conservation law in open-channel flow states that the volume of liquid entering a flow system will be proportional to that comes out as in equation 1 [20,23-24].

\[
d\frac{A_T}{dt} + \frac{dQ}{dx} = q_i \tag{1}
\]

Where \(dA_T/dt\) is the rate of storage change, \(dQ/\)dx is the flow rate, and \(q_i\) is lateral inflow (m³). The momentum conservation law is expressed as the momentum equation. The momentum conservation law in a control volume is equal to the amount of momentum flux entering and leaving the control volume plus the sum of forces acting on the control volume that causes a change momentum on the control volume, defined as equation 2 [25].

\[
\frac{\partial Q}{\partial t} + \frac{d(Qv)}{dx} + gA\left(\frac{\partial v}{\partial x} + S_f\right) = 0 \tag{2}
\]

The law of energy conservation in the hydraulic system is stated according to the Bernoulli equation, as equation 3. Bernoulli's law states that the amount of water energy from each flow through a channel cross-section is equal to the sum of elevation head, pressure head, and velocity head.

\[
H = z + d \cos \theta + \frac{v^2}{2g} \tag{3}
\]

Where \(H\) is the total head (m), \(z\) is the elevation of the channel bottom (m), \(\theta\) is slope channel (rad,°), \(d\) is depth (m), \(v\) is the velocity (ms⁻¹), \(g\) is the gravitational force (ms⁻²), and \(\zeta\) is coefficient of kinetic correction. If the channel slope is small, then the value of \(\theta\) can be assumed to be 0, so that the value of \(d\) is proportional to the value of \(h\) measured vertically. Therefore, the Bernoulli equation changes to equation 4.

\[
H = z + h + \frac{v^2}{2g} \tag{4}
\]

If the energy in is equal to the sum of the energy out and friction energy, equation 4 can be written as equations 5 and 6.

\[
H_{in} = H_{out} + H_f \tag{5}
\]
\[
z + h + \frac{v^2}{2g} = z + h + \frac{v^2}{2g} + H_f \tag{6}
\]

The open channel flow velocity in HEC-RAS is calculated using one of the empirical formula, a widely used and very versatile formula in water resources, the manning equation. Robert Manning first presented the manning formula in 1889. The manning equation was originally developed for uniform
channels with a uniform steady state. However, in reality, no flow can be uniform and stable so that the manning equation can ultimately be applied to unsteady flow with non-prismatic channels. Equation 5 is a widespread and useful form of the Manning equation [26].

\[ V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \]  

(7)

Where \( V \) is the flow rate (m\(^3\)/s\(^1\)), \( n \) is the Manning's roughness coefficient (unitless), \( R \) is the hydraulic radius (m), and \( S \) is slope energy gradient (unitless). Manning's roughness coefficient value is a function of the wall material. According to [27], \( n \) value of manning of the channel is classified into several classes, as in Table 1.

**Table. 1. Manning’s roughness coefficient value [27]**

| No | Type of channel and description | \( n \) Manning’s value |
|----|---------------------------------|------------------------|
|    |                                 | Minimum | Normal | Maximum |
| 1  | Concrete                        |         |        |         |
|    | -Culvert, straight and free of debris | 0.010  | 0.011  | 0.013   |
|    | -Culvert with bends, connections, and some debris | 0.011  | 0.013  | 0.014   |
|    | -Finished                        | 0.011   | 0.012  | 0.014   |
|    | -Sewer with manholes, inlet, etc., straight | 0.013  | 0.015  | 0.017   |
| 2  | Earth, straight and uniform      |         |        |         |
|    | -Clean recently completed        | 0.016   | 0.018  | 0.02    |
|    | -Clean, after weathering         | 0.018   | 0.022  | 0.025   |
|    | -Gravel, uniform section, clean | 0.022   | 0.025  | 0.03    |
|    | -with short grass, few weeds    | 0.022   | 0.027  | 0.033   |
| 3  | Natural streams                 |         |        |         |
|    | -Clean, straight, full stage, no rifts or deep pools | 0.025  | 0.03   | 0.033   |
|    | -Clean, winding, some pools and shoals | 0.033  | 0.04   | 0.045   |
|    | -Sluggish reaches, weedy, deep pools | 0.05   | 0.07   | 0.08    |

3. **Materials and Methods**

3.1. **Study Area**

The research location is in Temon District, Kulon Progo Regency, Special Region of Yogyakarta Province. Based on the topography, the research location area was dominated by gardens, rice fields, and residential areas. It is located between the Bogowonto River and the Serang River. During the rainy season, the two rivers affect the airport drainage area's flow system and its surroundings. The figure of the research location shown in Figure 1.
3.2. Data Resources and Analysis

Primary data in this study were obtained from the investigation at the research location. Those data are including flood information data, documentation of photographs at the research location, and inventory of buildings along the river/channel. Flood information data is obtained from the investigation at the research location, through interviews with stakeholders and residents affected by flooding in the Aerotropolis Yogyakarta International Airport area. Flood information data will be used as a calibration so that it becomes a reference in modelling flood control using HEC-RAS 4.1.

Secondary data required in this study were obtained from related agencies and previous studies. This research uses secondary data consisting of Map of the RBI, river profile data, tidal data, and hydrologic analysis data.

The analysis of this research was a hydraulic analysis using HEC-RAS software with unsteady flow analysis. The primary and secondary data were used as input data for simulation using the HEC-RAS. The simulation was divided into two steps, both the existing simulation and the simulation with flood control. In the existing simulation, the flood system was simulated to determine which locations were affected by flooding and needed to apply for flood control. The simulation with flood controls was performed by trying various flood control options, including river normalization, optimization of flood gates, retarding basin, and flood pumps. The present study proposed adjustment of performing. Alternative flood control at each flood-prone area was adjusted to the level of flooding risk in the area.

4. Result and Discussions

4.1. Evaluation of existing channel capacity

Existing channels system was simulated using one-dimensional HEC-RAS with an unsteady flow analysis. The unsteady flow analysis was appropriate to use in this hydraulic analysis because the type of simulation is flood routing. Based on investigation, most of the channel modelled is still a natural channel and there is a tidal influence from the sea in the downstream of both Bogowonto river and Serang river. There are two boundary conditions used in the simulation using HEC-RAS are stage hydrograph and flow hydrograph. At the downstream boundary condition, a stage hydrograph was applied with tidal data. A flow hydrograph was applied at the upstream boundary conditions with a
discharge resulting from the hydrological analysis. The water level conditions strongly influence floods in the Aerotropolis area of Yogyakarta International Airport downstream of the Serang and Bogowonto Rivers. The downstream of those rivers causes backwater.

The stage and flow hydrograph conditions downstream of the Bogowonto and Serang rivers in Figure 2. In the Bogowonto River, the stage hydrograph adjusted to the tide observations. At the beginning of the simulation, the flow hydrograph increases until the end of the simulation. On the contrary, the height of the tides' level is decreasing. In the Serang river, the tide level is constant at 1 m. The sea level in the Serang river was kept constant at a maximum of 1 m because there is a tourism object in that area.

![Figure 2](image)

**Figure 2.** Stage and flow hydrograph condition at downstream (a) Bogowonto river (b) Serang river

The simulation result of the existing conditions, as shown in Figure 3, explains that several channels are overflowing, causing flood inundation around the area. The overflow channel was represented as the red line symbol, while the result of HEC-RAS simulation shown in Figure 4. Based on investigation, there were water structures existing in the existing conditions, such as gate, culvert, bridge, and weir. All existing floodgates cannot function optimally, and some were broken. It is highly recommended to repair the floodgates so that the floodgate's function in preventing flooding can operate optimally. Each water structure has different hydraulic characteristics which will have a direct influence on hydraulics along the open channel, such as decreasing the flow rate, increasing the water surface level, and others.

![Figure 3](image)

**Figure 3.** Existing scheme of the channel system
Figure 4. Overflow existing simulation result
4.2. Evaluation of redesign channel system

Simulation of the redesign channel system is a simulation of floods with channel conditions different from existing conditions. Overflow channels in the existing simulation were normalized with the new dimensions in each path as needed, as shown in Figure 5 with the green line. Normalization aims to normalize or restore drainage conditions as before, carried out when the channel dimensions are not uniform, or there is a narrowing in several sections, which results in a reduction in capacity and inhibits river flow rates [28].

The floodgate in the redesign channel system was fully functionalized, as shown in figure 4, with the blue colour gate symbol. A new floodgate was applied in the junction between Carik Timur channel (number 22) and Ledeng channel (number 27), as shown in Figure 5 with the red colour gate symbol. It was carried out to reconnected both channels. It makes different from previous studies.

![Figure 5. Scheme of the redesign channel system](image)

The result of the simulation with the river flow conditions that had been normalized and completed by the floodgates shows that there are still flooded areas, especially in channel number 18 and number 19 (Plumbon area) and in channel number 29 and number 30 (Jelantoro area). Therefore, as a solution, a retarding basin was built and modelled in the location area between channel number 18 and number 19 and in the area between channel number 29 and 30. The planning of retarding basin was equipped with flood pumps. Pumps are greatly optimum in overcoming flood problems, especially in areas downstream of river flows such as estuaries [29]. The pump will release floods in the retention pond/reservoir out to the channel or sea. In this simulation, the pump only operates when the water level is at a certain level, according to the pump’s elevation-discharge function.

5. Conclusions

Based on the simulation results, it can be concluding that Aerotropolis area needs some flood handling. The first is the normalization in some channels to handle the floods around the Aerotropolis drainage. The second is the existing floodgate needs to repair and need a new flood gate between channel number 22 and number 27 to connect the Carik Timur channel to the Ledeng channel. The third is the use of
retarding basin and flood pumps highly recommended to prevent flooding at the Aerotropolis area of Yogyakarta International Airport. For further research, the flood simulation can be re-simulated using different discharge from the updated hydrological analysis with predictive land use change information.

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