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Modeling the Yogyakarta International Airport (YIA) Area Flood Control System Using EPA SWMM 5.1

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ABSTRACT

Yogyakarta International Airport (YIA) is a new airport in the Special Region of Yogyakarta, located in Temon District, Kulon Progo Regency. The presence of the airport will undoubtedly bring various benefits, such as increasing economic activities in the area around the airport. However, the location has a problem, namely the risk of flooding. Flooding can affect activities around the airport, such as freight forwarding activities and access to or from the airport. Based on this problem, preventive measures are needed to minimize the flood impact on the activities of YIA airport and the surrounding area. In this case, the EPA SWMM program is used to model the drainage system in the study area. Modelling the point of occurrence of flooding will make it easier to normalize and add embankments to the channel. Modelling with EPA SWMM 5.1 requires input data such as rainfall distribution data, watershed characteristics, and the transverse appearance of the drainage channel. The results showed an overflow in the 15 drainage channels studied. The overflow causes high surface runoff and sedimentation based on channels and backwaters. Efforts to overcome by normalizing and adding embankments are sufficient to overcome flooding in several channels. Meanwhile, for channels that are still experiencing flooding, other countermeasures, such as retention ponds, are needed.

Introduction

Yogyakarta International Airport (YIA) is a new airport that has been operating since 2020. YIA is located in Temon District, Kulon Progo Regency. The YIA area is on the coast of the South Coast of Java, between the Serang River on the east and the Bogowonto River on the west. The decree was established based on Governor's Decree No. 68 / KEP / 2015, dated March 31, 2015, concerning the Determination of Construction Sites for the Development of New Airports in DIY [1].

The presence of YIA certainly has various benefits and significantly improves the community's economy. However, there are flooding problems that can hamper airport activities and the activities of the surrounding community. A flooding incident once hit the YIA area on March 17th, 2019, which required hundreds of residents to be displaced and hampered the airport construction process. [2] The flooding inundated the area around the airport, with water levels reaching 60 cm in the eastern area of the airport. The problem of flooding is susceptible to airports because the airport system is very complex and pays excellent attention to thee-duration of its operations [3].

Temon Subdistrict, the airport's location, has 105 basins at risk of becoming flood points [4]. According to BPBD, Kulon Progo Regency is one of the districts with a high risk of flooding, which was 27% in 2019. Given their impact on airport operations, such risks must undoubtedly be considered [5].

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The problem of flooding in the airport area is closely related to the drainage system around the airport. Figure 1 show the drainage channel map in the YIA Airport. The channel's condition and capacity need to be considered to determine the risk of flooding. This research is carried out to examine flood management efforts from the technical side by conducting hydrological and hydraulic analysis using hydrologic and hydraulic modelling so that flood problems within the scope of the drainage system around YIA can be known and appropriate treatment alternatives can be determined.

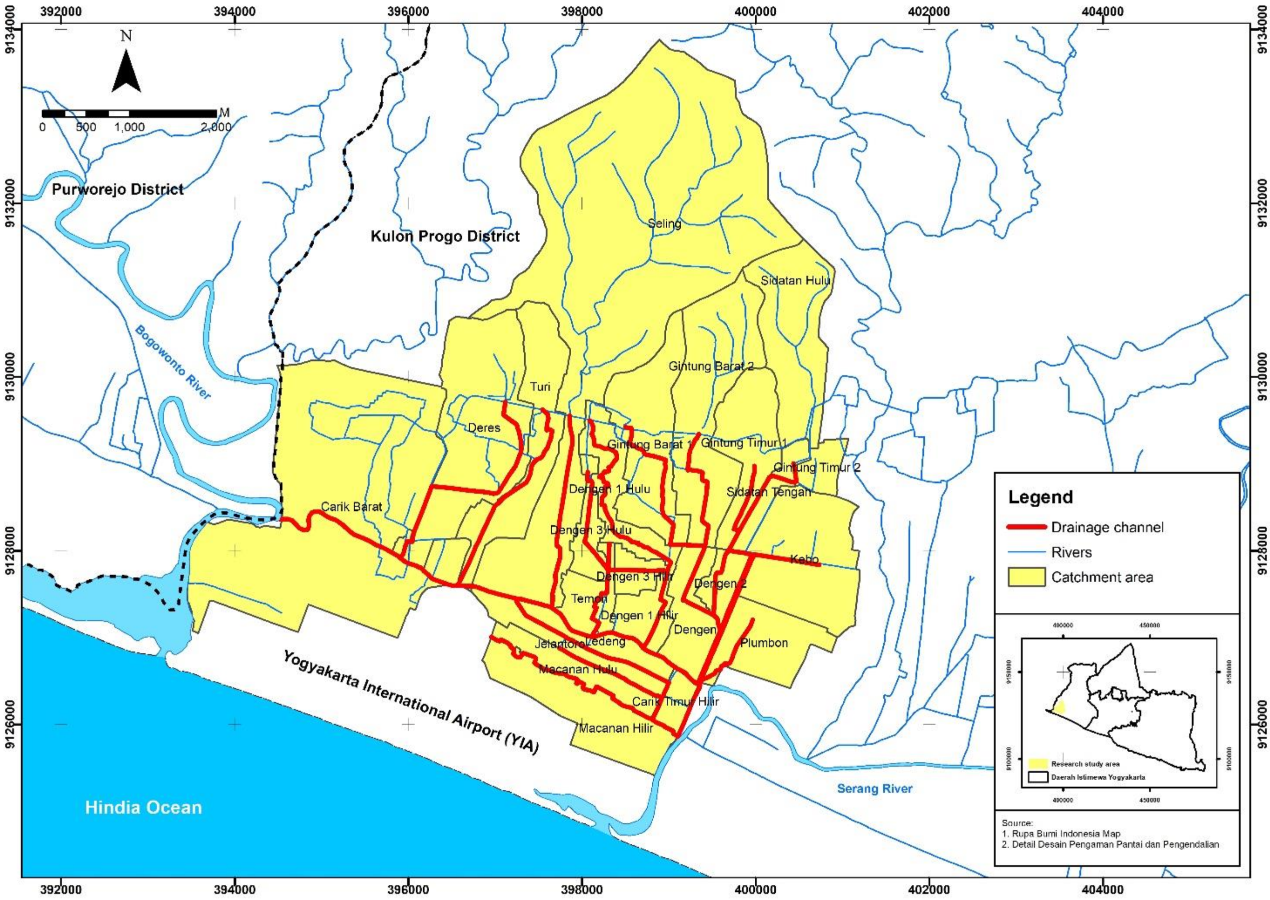

Figure 1. Map of the research site

1. Method

This research consists of two analyses: hydrological analysis and hydraulics analysis. The hydrological analysis is used to obtain design rainfall following the Minister of Public Works Regulation 12/PRT/M/2014 concerning Urban Drainage Systems, as shown in Table 1. The initial step of hydrological analysis is the design of rainfall calculation. The rainfall probability was estimated by frequency analysis using 20-year annual maximum rainfall data from the Hargorejo rainfall station. Several frequency distributions are considered-Normal Distribution, Normal Log Distribution, Gumbel Distribution, and Person III Log Distribution. The goodness of fit was tested using Smirnov-Kolmogorov and Chi-Squared [6]. Then, the rainfall distribution pattern is analyzed using 5-year rainfall data. Only rainfall data with a depth of > 50mm is used or categorized as heavy rain. The final rainfall design is then used as an input for hydraulic analysis. The hydraulic analysis was carried out as flood routing using the EPA SWMM 5.1.

Table 1. Rainfall return period design for various city typologies[7]

City Typology	Catchment Area (Ha)			
	<10	10-500	100-500	>500
Metropolitan cities	2 th	2-5 th	5-10 th	10-25 th
Major cities	2 th	2-5 th	2-5 th	5-20 th
Medium city	2 th	2-5 th	2-5 th	5-10 th
Small towns	2 th	2 th	2 th	2-5 th

Analysis of hydraulics was performed using the EPA SWMM 5.1 application. EPA SWMM 5.1 is an application to model surface runoff in a *sub-catchment* area that flows through pipelines, open channels, pumps, reservoirs, and so on [8].

SWMM can model drainage systems in four main parts: atmospheric, ground level, underground surface, and drainage networks. The parts are described in three forms: visual objects, *non-visual objects*, and computational models [9]. *Visual objects* describe the drainage system in the field to the SWMM work yard. Some *of the visual objects* used are rain gages, subcatchments, junction nodes, outfall nodes, conduits, orifices, and weirs

Then-Visual Object describes the characteristics and processes of additional areas of study in SWMM. There are various types of *non-visual object* data, but this study only uses three types of data, namely *transect, curves, and ice time series*. *A transect* is used to describe the cross-section of a natural channel. In contrast, *curves* serve to describe the functional relationship between two magnitudes. *The curves* used are *shaping curves* describing channels over bridges and time series used as rainfall data inputs. SWMM can model various discrete-time simulations based on physical conditions by applying mass, momentum, and energy conservation principles [10]. This study will model surface runoff, infiltration, and flow tracing, as presented in Figure 3.

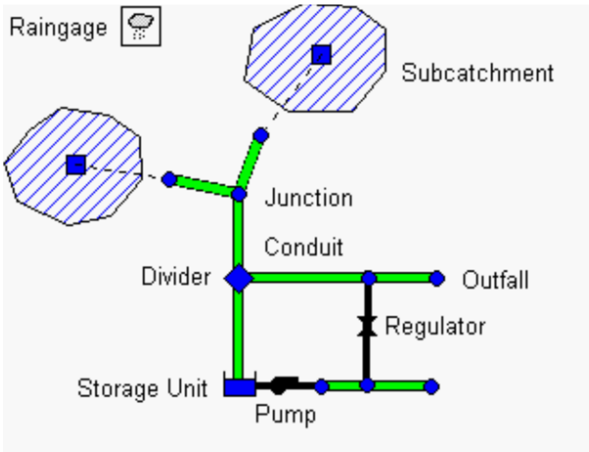

Figure 2. *Visual Objects* in SWMM [10]

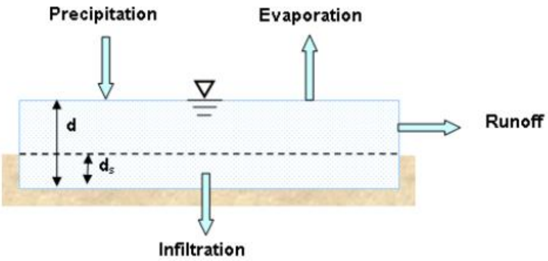

Figure 3. SWMM Inner Surface Runoff Concept[10]

Based on this explanation, the input data needed to simulate rain data *sub-catchment* data, transverse channel appearance, longitudinal appearance, transverse channel building, and tides. The initial simulation was carried out using existing data to determine the distribution of floods at the research site. For the existing simulation to describe flood events in the field, verification is carried out by interviewing residents to find out the points of flooding. The following simulation is a simulation of flood control by normalizing and providing embankments in channels that experience overflow or flooding.

2. Result

3.1 Hydrological analysis

In this study, a rain design was needed as input in the simulation in SWMM 5.1. Rain data was obtained from the Hargorejo rain station (Figure 1). The rainfall data is the maximum daily rainfall for 20 years (1999-2018). The data is presented in Table 2.

The data is then used to determine the amount of design rain by conducting a frequency analysis. Frequency analysis uses probability distributions such as Normal distribution, Normal Log, Gumbel, and Person III Log. The distribution will show the relationship between the frequency of rain events with the magnitude of the extreme rain event. The draft is presented in Table 3.

Table 2. Hargorejo Station Annual Maximum Daily Rainfall data of Hargorejo Station

Year	Maximum rain (mm)	Year	Maximum rain (mm)
1999	95.5	2009	64.5
2000	245	2010	105
2001	135	2011	91.4
2002	74	2012	81.5
2003	86.5	2013	88
2004	81	2014	97.5
2005	165	2015	69.5
2006	73	2016	231
2007	125	2017	190
2008	96	2018	71

Table 3. Rain Re-Designed Various Distributions

T (year)	Normal (mm)	Normal Log (mm)	Gumbel (mm)	Pearson III log (mm)
1.1	45	62	54	66
2	113	104	104	97
5	158	146	152	141
10	182	174	183	178
20	201	201	213	220
50	223	237	252	289
100	238	264	281	352

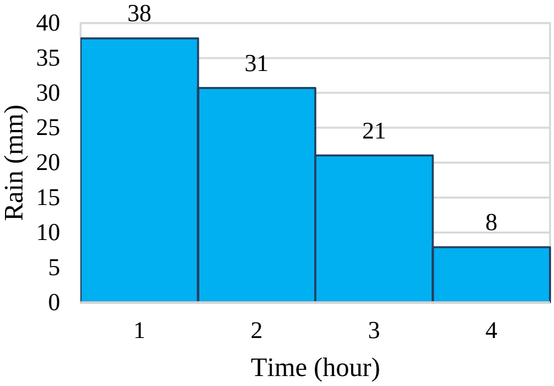

Figure 4. 2-year rainfall distribution pattern

The distribution used, namely Log Person III, because it has the smallest Chi-Square (X^2) value of 1.5 and $_{a\ max}$ value Δ of 0.118. The re-kala used is a 2-5 year anniversary because the research location is classified as a small city with an area of > 500 ha. The design used is a 2-year return period of 97 mm and a 5-year return period of 140 mm.

The rain distribution pattern was calculated using data on the dominant rain event whose depth was > 50 mm. The rain data used is the rain of the clocks from the Hargorejo rain station. There were 15 rain events with 4 hours of dominant rain 4 times. This study used to rain for 2 years because the simulation results showed flood points in the simulation according to flood points in the field situation. The pattern of the distribution of rain on re-time is presented in Figure 4.

3.2 Rain catchment area

The rainfall area is an area that collects and stores rainwater and drains it through channels or rivers to the sea with regional boundaries in the form of mountain ridges. There are 230 rain catchment areas studied, as shown in Figure 5. The determination of the boundary of the rain catchment area was carried out using *Google Earth* and a survey field. The initial step is to determine the outlet point of the rain catchment area along the drainage channel studied, then from that point, the boundary of the rain catchment area is determined, which in this study will use the road as the boundary. The reason the road is used as the boundary of the rain catchment area is because of its higher elevation compared to the elevation of the surrounding area.

After the boundaries of the rain catchment area are determined, identify the land use and soil type in each rain catchment area. The identification is used to determine the impervious and *pervious* area and the curve number (CN) value as input for the infiltration model in SWMM 5.1. The *residential area represents the impervious or watertight* area, and the rest will represent the *pervious* area. In addition, there is %Zero impervious, defined as the area of *impervious* areas that do not have *depression storage* or areas that cannot withstand rainwater runoff so that rainwater directly becomes surface runoff. *%Zero impervious* is represented by residents' homes within the rain catchment area.

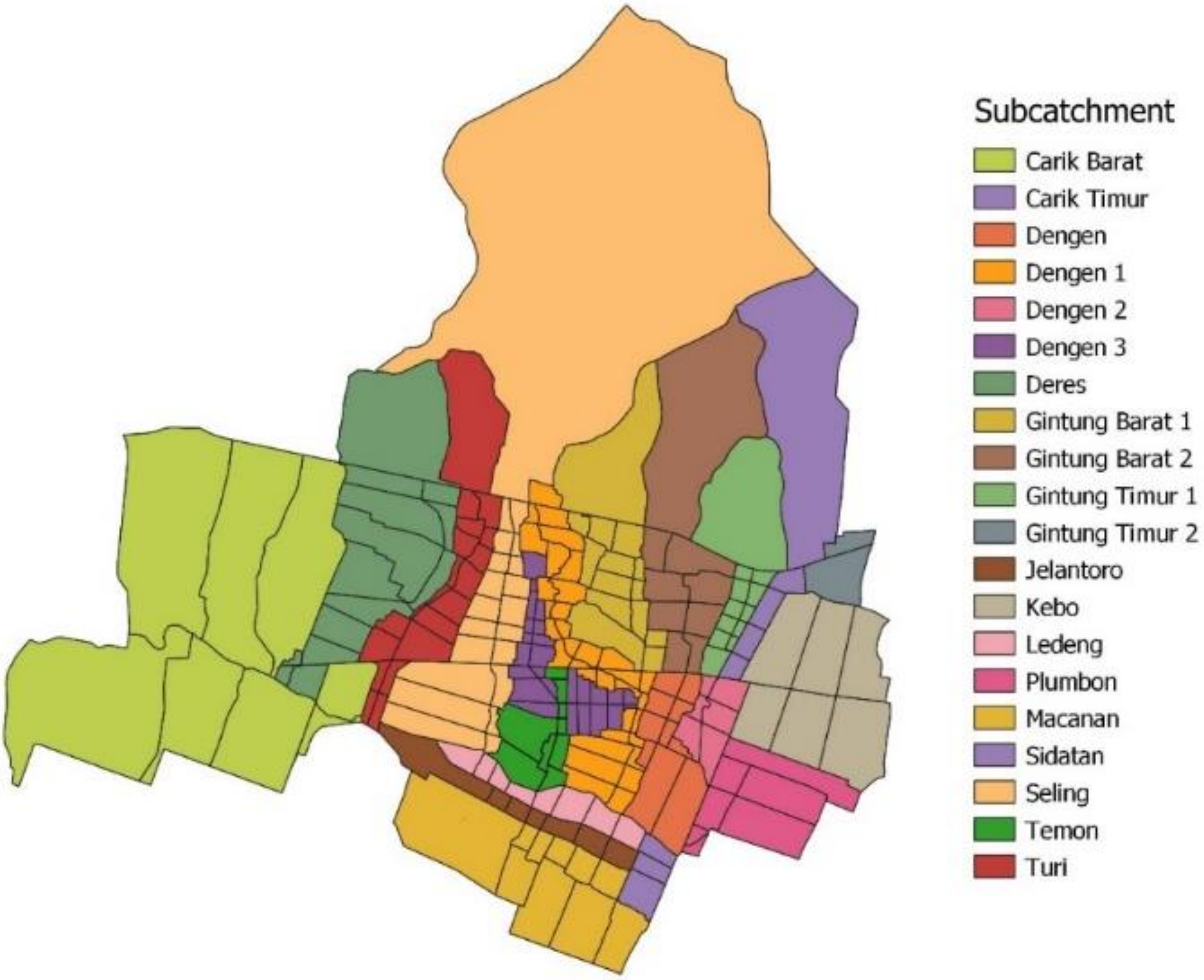

Figure 5. Division of rain catchment areas

3.3 Modeling with EPA SWMM 5.1

Modeling using EPA SWMM 5.1 has the advantage that hydrological and hydraulic modeling can be done simultaneously. This study used two modeling scenarios: modeling the existing drainage system and modeling after normalization and adding embankments. The initial scenario begins by drawing a research site scheme with a schematic approach complete with *sub-catchments*, *conduits, junctions, outfalls,* and some buildings across channels such as culverts, sluices, and bridges. The depiction of the sub-catchment is made following a background image or *backdrop* filled with the characteristic data of *the sub-catchment* itself. For drainage, channels are drawn using *conduits* and *junctions. conduit* represents charaterictic shape of the channel with data on the length and the coefficient of the roughness of the channel. The channel roughness uses the Manning coefficient value adjusted to the conditions of the channel in the field. A*uction* is used to connect the conduit with other *conduits* with input data of the base elevation of the channel and the maximum depth describing the distance of the channel from the base to the bank or ground level.

Several approaches depict inline structures such as bridges, sluices, and groundsels. Most bridges are described as culverts according to the conditions in the field by drawing them like *culvert boxes*. Some bridges do not use *culvert boxes,* so the approach used is to use *shape curves*. Pintu water is described as *an orifice* or spillway. The use of an *orifice* is considered sufficient to describe the sluice because there are many sluices equipped with valve doors or flap gates in the field. The screw sluice is only modeled without a valve door or door operation control and is considered to remain open when conducting simulations. *Groundsil* is depicted using a weir or weir by inserting the dimensional shape of the upper cross-section of the *groundsil* itself, which is trapezoidal. The overall depiction of the model described earlier can be seen in Figure 6.

EPA SWMM 5.1 modeling requires that there be a boundary requirement that is downstream of the channel modeled. The downstream point is the downstream part of the channel from the West Carik channel and the Lower East Carik channel, and the Tiger. The lower reaches of the West Carik channel itself empty into the Bogowonto River in the western part, while the lower reaches of the East Carik channel and the Tigers empty into the Serang River in the eastern part. The boundary terms in question use tidal data at the downstream point that has been described. The tide height used is +2 m high, the average height downstream of the simulation. *The routing model* used in this study is *a dynamic wave* because it can show changes in flow over time with the most theoretically accurate results and can take into account channel storage, *backwater*, and pressurized flow [10].

Hasil simulation shows overflow at some point of the channel. There are fifteen overflowing channels: Deres, East Carik, Dengen, Dengen 1, Dengen 2, Dengen 3, West Gintung 1, Temon, East Gintung 1, Sidatan, Kebo, Plumbon, Ledeng, Jelantoro, and Macanan channels. Only four channels do not overflow, namely the West Carik, Turi, Seling, and West Gintung 2 channels. These results were obtained using rain on a 2-year return period with an average tide level of +2 m. The results follow the flood event on March 17, 2019, because the flood points were simulated according to the flood points in the field. The location of the overflowing and non-overflowing channels is shown in Figure 7. For an overview of the profile of the overflowing channel water level and how to overcome it with normalization can be seen in Figure 8 to Figure 13.

Auto-Length: Off
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Figure 6. Simulation Depiction Schema IN EPA SWMM 5.1.

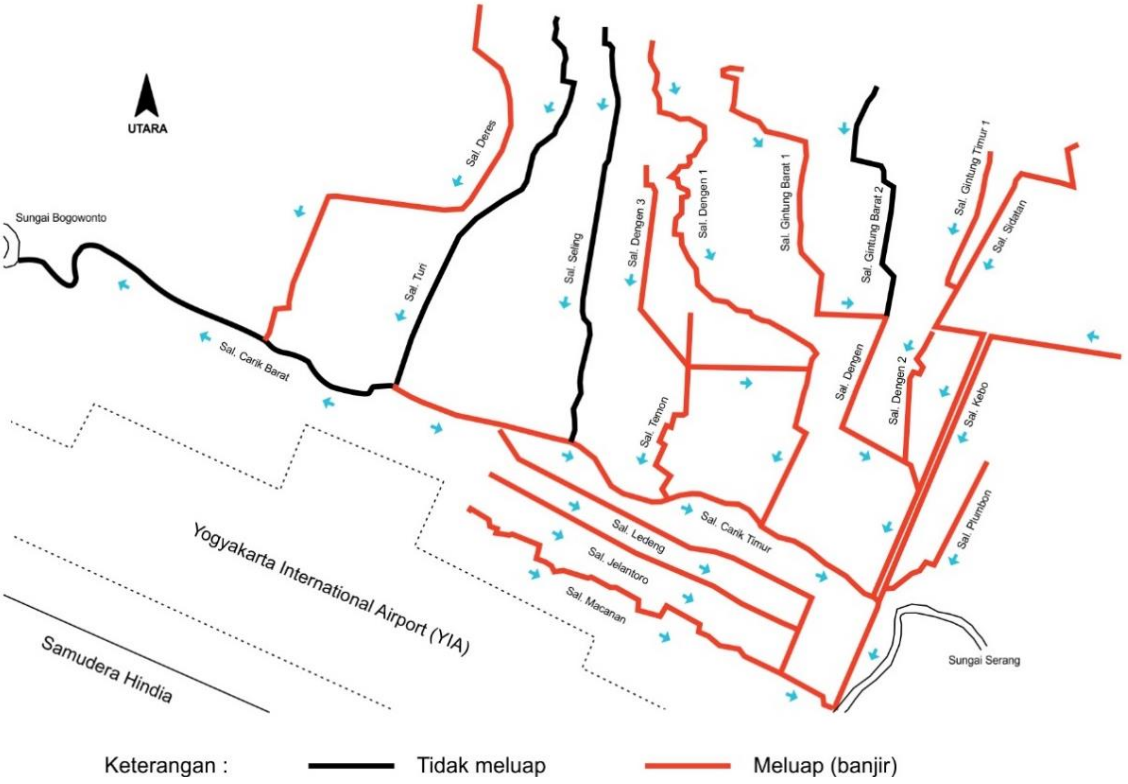

Figure 7. Existing Channel Schema

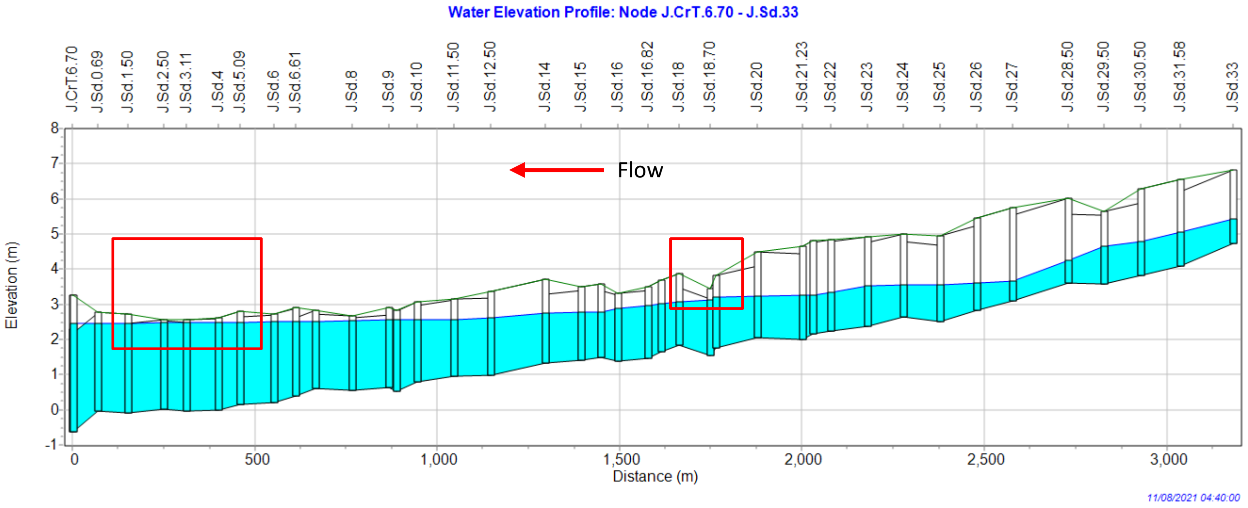

Figure 8. Profile of the Water Level of the Sidatan Channel in existing conditions

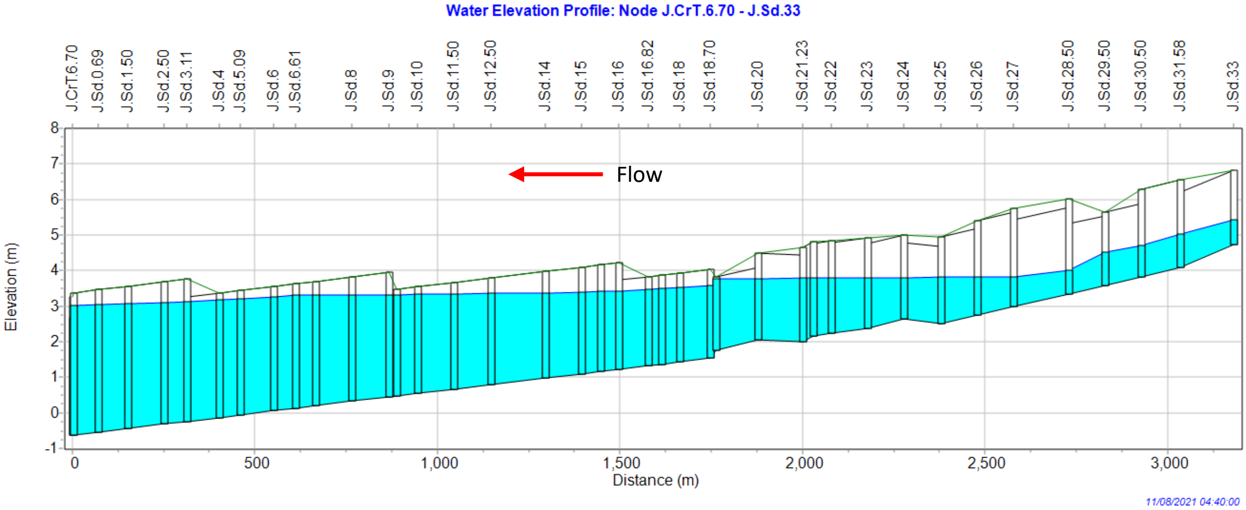

Figure 9. After normalization

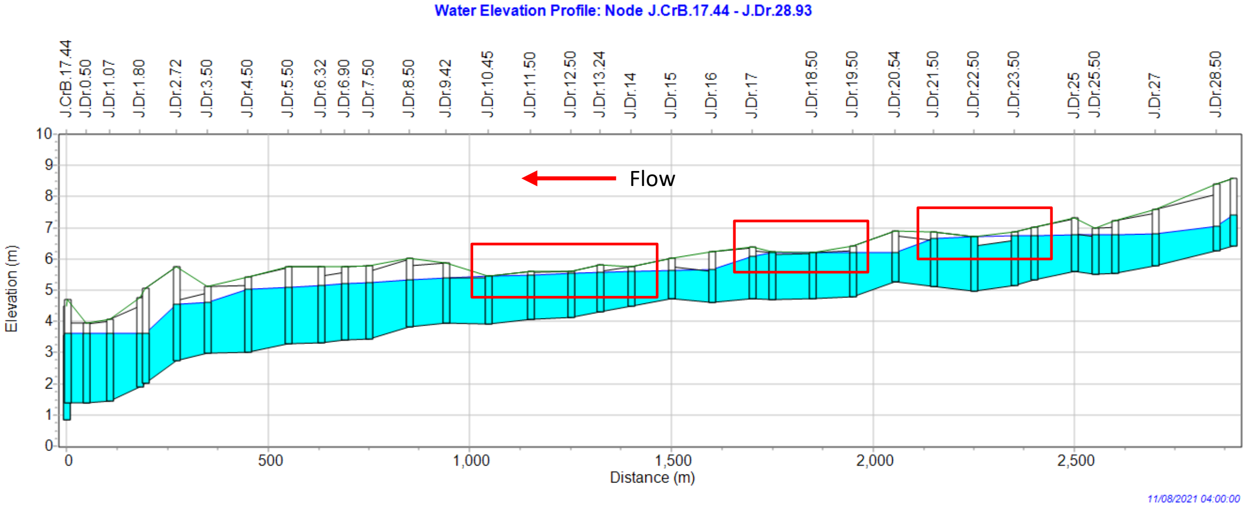

Figure 10. Deres Channel Water Level Profile existing conditions

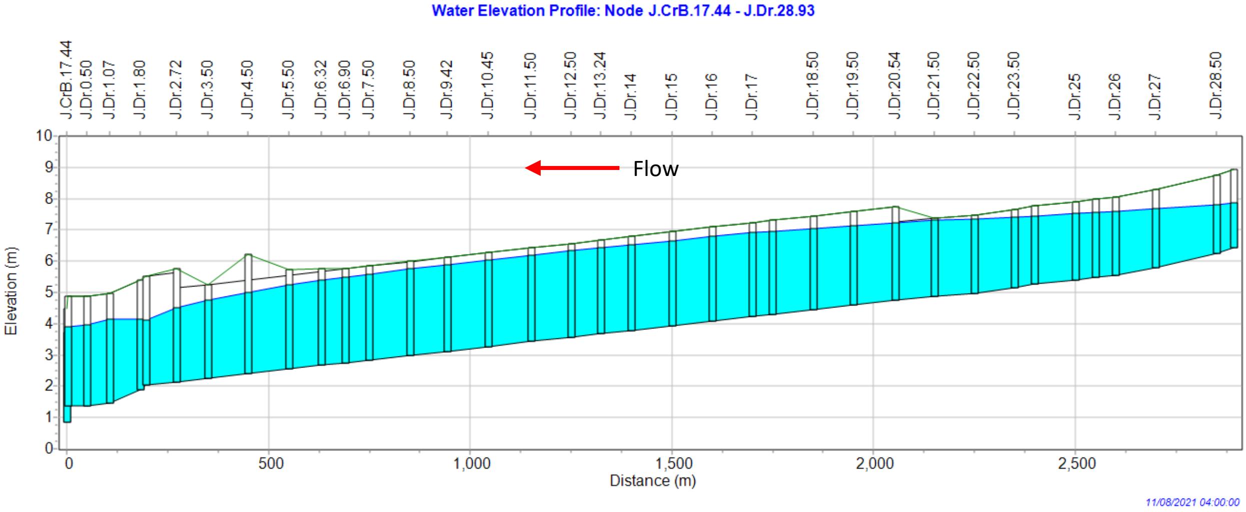

Figure 11. After normalization

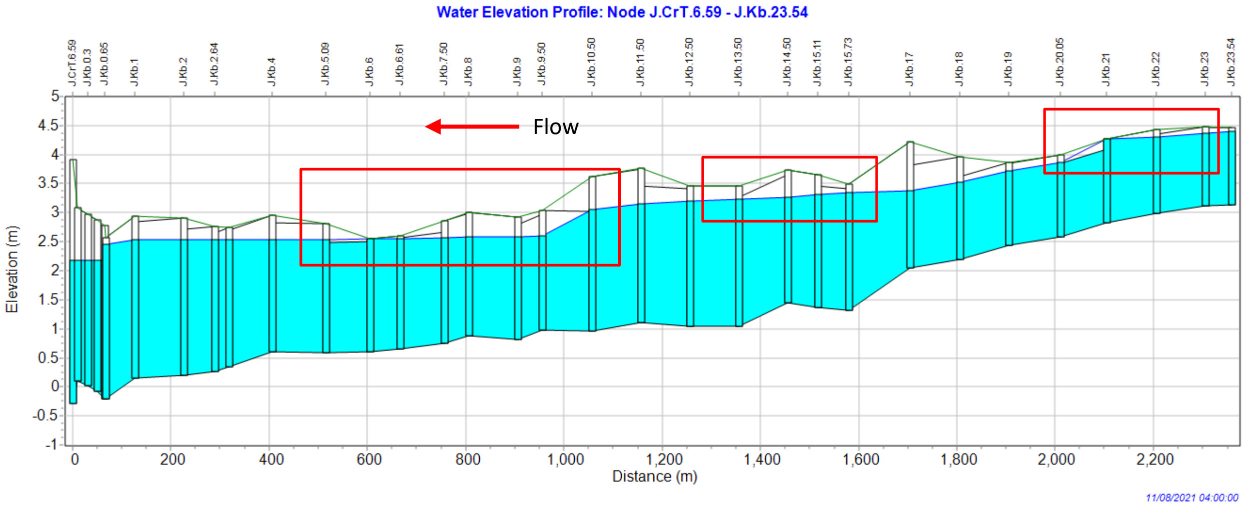

Figure 12. Kebo Channel Water Level Profile existing conditions

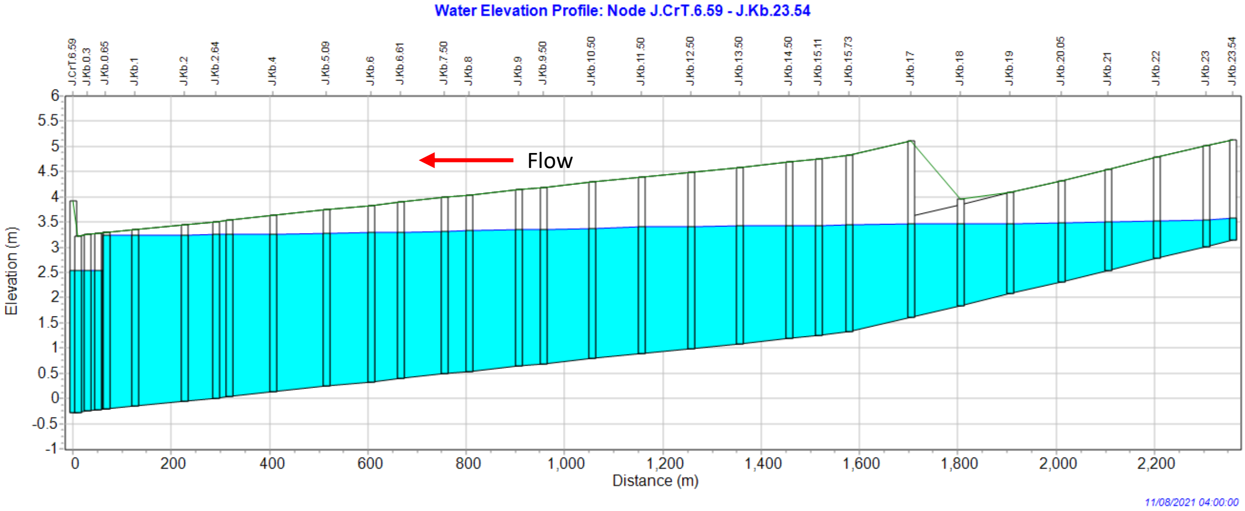

Figure 13. After normalization

Based on the Image of the longitudinal cross-section of the existing channel with an average tidal of +2m, it can be seen that there is an overflow at several points of the channel. The causes of overflow are several factors, such as surface runoff, the physical condition of the channel itself, and the *backwater*. Surface runoff is not supported by drainage channel reservoirs, a common occurrence in some channels such as in East Gintung 1, Temon, Deres, Plumbon, Plumbon, Jelantoro, and Tiger channels. It is also possible that the condition of the lowest elevation of the lower end of channel Dengen 3 is higher than the previous channel so that the flow of water is blocked and backwater occurs. *Backwater* occurs due to the high flow at the downstream end of the channel, so the flow from upstream cannot multiply can also be caused by a narrowing in the downstream part of the channel where there are buildings across the channel, such as sluices.

After it is known that the channel is experiencing overflow or flooding, normalization is then carried out in the channel. Normalization serves to normalize the condition of the drainage channel as it was and is carried out when the dimensions of the channel are not uniform, or a narrowing occurs in some parts of the channel. Normalization is carried out by changing the dimensions of the channel, dredging the channel from sedimentation, and making the channel walls into masonry.

Normalization of the channel is created by following the initial or existing form of the channel itself. There are two forms used, namely trapezoidal and square. Trapezoidal shapes are made in the channels Dengen, Dengen 1, Gintung Barat 1, Jelantoro, Kebo Hilir, Ledeng, Tiger Hilir, Plumbon and Sidatan. The square-shaped channels are made in Temon, Macanan Hulu, Kebo Hulu, Gintung

Timur 1, Dengen 2, and Dengen 3. The height of the embankment used is between 0.5 m and 1.2 m.

Flood control efforts with normalization and the addition of levees are considered sufficient to overcome flooding at several flood points at the study site, although some channels are still experiencing flooding even though they have been normalized and added embankments. These channels require other flood control alternatives, such as the creation of retention ponds.

3. Conclusions

The 2-year rainfall design was deemed sufficient to represent the flood event on March 17th , 2019. The causes of overflow or flooding in the area around the airport are high surface spleen as a result of land use changes due to the presence of *Yogyakarta International Airport* (YIA) airport, the condition of drainage channels filled with vegetation, and sedimentation to inhibit water flow, and the occurrence of *backwater* due to the ebb and flow of the Serang and Bogowonto rivers as outlet drainage channels.

Flood management by normalizing and adding dikes is considered sufficient to solve the problem of flooding for the time being in some channels. As channels are still experiencing flooding even though they have been normalized, they can use other countermeasures alternatives such as retention ponds considering that the presence of the airport will make the surrounding area turn into a residential area from what was previously still a rice field.

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