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Numerical Modeling for Flood Hazard Mapping of Kedurus River Basin

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Abstract— *Kedurus River serves to drain flood discharge from Gresik Regency and empties into Mas River Surabaya. In the rainy season, the West Surabaya area is often submerged by floods due to high rainfall and Kedurus River runoff. According to the results of the Surabaya City inundation monitoring survey by Public Works Agency for Highways at the end of 2017, the total area of flooding in Rayon Wiyung is 274.93 hectares. The biggest number contributors came from the Kedurus River area. So that a flood analysis of the downstream Kedurus watershed is needed to create a flood hazard map. Flood analysis in Kedurus River using HEC-RAS software, Flood simulation uses flow hydrograph as an upstream boundary condition with 5 years, 10 years and 50 years return periods. Meanwhile, rainfall is simulated as precipitation. In addition, secondary channels are simulated as lateral flows and reservoirs as storage areas. Flood simulation was carried out with three scenarios, the results of the three scenarios were compared with the results of the flood survey. From the simulation results obtained depth, velocity, area and duration of flooding, then mapping the flood map using ArcGIS software. The results of the HEC-RAS flood simulation with all three scenarios can be concluded that the flood depth is maximal 1.1 meters , the velocity in the inundation area is between 0.05 m / s to 0.21 m / s, the widest flood bank is 28.61 hectares. Subdistricts that have a high threat level are Wiyung District, especially in the Karangan Jaya area.*

Keywords— *Flood, HEC-RAS 2D, Kedurus river, hazard map.*

I. INTRODUCTION

Kedurus River watershed covers the area of Surabaya City and Gresik Regency. Population growth has caused this region to change from agricultural land to residential land [1]. So that the flow coefficient becomes large and the volume of runoff entering the Kedurus River increases. Kedurus River serves to drain flood discharge from the city of Gresik into Mas River Surabaya. The research location is presented in the picture below. Blue map is the area of West Surabaya and including the downstream Kedurus watershed.

Fig. 1. Research sites

The Surabaya City Government has tried to minimize the occurrence of flooding by increasing drainage capacity, even by combining pumps, retentions basin, sluice gates and infiltration wells [2]. However, flooding in the West Surabaya area has not been fully resolved. In the rainy season, the West Surabaya area is often submerged by floods due to high rainfall and Kedurus River runoff. According to the results of the Surabaya City inundation monitoring survey by Public Works Agency for Highways at the end of 2017, the total area of flooding in Rayon Wiyung is 274.93 hectares [3]. In the final report on structuring of the Surabaya drainage channel in 2015, it was explained that the biggest contributor to this figure came from the Kali Kedurus area [4].

Fig. 2. Map of the Surabaya flood area
(Source: Surabaya City Government, 2014)

The losses due to the flooding are not small, because the western Surabaya area is a densely populated area equipped with several facilities such as offices, education, industry. To reduce the negative impact of the flood, it is necessary to analyze the floods of western Surabaya.

The purpose of this study is to produce a flood hazard map that can be used for early prevention and warning planning. In addition, this study is expected to be able to analyze depth, velocity, area and duration of flooding, so that it can identify priority handling.

II. METHODOLOGY

Hydrological data, land use maps, DEM maps and calibration data are used as hydrological and hydraulic analyzes. The results of the analysis are depth, velocity, area and duration of flooding as a guide in making flood hazard maps.

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A. Calibration

Calibration aims to make modeling result close to field conditions. The calibration in this study is useful as an initial condition used for flood simulation. The results of measurements in field are velocity and depth, then the results are simulated to determine the value of manning roughness. Calibration is successful if the depth of the simulation results is close to the depth of the field.

B. Hydrological Analysis

Hydrological analysis is needed to process hydrological data (rain data) into design flood. This design flood is used as a boundary condition in flood simulation using the HEC-RAS software.

Determination of regional rainfall in the Kali Kedurus watershed using the Thiessen Method. The following is equation of Thiessen [5]:

$$\bar{P} = \frac{A_1P_1 + A_2P_2 + \cdots + A_nP_n}{A_{total}}$$

$\bar{P}$ is average rainfall (mm), P_1 and P_2 are the height of rain at each rainfall post (mm), while A_1 and A_2 are the area bounded by the polygon line (km^2).

Design rainfall can be calculated using the Normal, Gumbel, Log Normal and Log Pearson III distributions which are then tested using the Chi-Square Test and the Kolmogrov Smirnov Test. From these calculatios generate average annual rainfall. After that, the hourly rain distribution can use the following formula [6].

$$R'_t = t.R_t - (t-1)R_{(t-1)}$$

$$R_t = \frac{R_{24}}{t}\left(\frac{t}{T}\right)^{\frac{2}{3}}$$

Rt is the average rainfall until the hour to t (mm), *R24* is the height of rain in 24 hours (mm), *R't* is the height of rain at the hour to t (mm), for *t* is the time of rain or t-hour (hour), while *T* is the duration of rain (hours).

$$R_{eff} = C \times Rt$$

Effective rain (*Reff*) can be calculated by multiplying the flow coefficient with the design rainfall (mm). The average flow coefficient (*Ck*) can be known by the formula as follows, where *A* is the area of land (hectares) [5].

$$C_k = \frac{C_1A_1 + C_2A_2 + \cdots + C_nA_n}{A_{total}}$$

To determine the flood discharge can use the Nakayasu method unit hydrograph. The Nakayasu synthesis hydrograph formula is:

$$Q_p = \frac{C.A.R_o}{3.6\,(0.3T_p + T_{0.3})}$$

The peak flood discharge (*Qp*) can be calculated by the formula above, for Ro is unit rain (mm), *Tp* is a grace period from the beginning of the rain until the flood peak (hours), *T0.3* is the time required by reducing the discharge from peak to 30% of peak discharge, *A* is the catchment area to the outlet, and *C* is the flow coefficient [7].

Nakayasu method is used on the main river, Kedurus River. While the secondary channel is lateral flow, the calculation of the flood discharge uses the Rational Method.

$$Q = 0.278 \times C \times I \times A$$

From the formulation above, the calculation of flood discharge (*Q*) is the multiplication of the flow coefficient (*C*) with the rainfall intensity in mm / hour (*I*) and the area of the drainage area in km^2 (*A*).

C. Hydraulic Analysis

Hydraulics analysis is needed to determine the ability of the cross section to accommodate the flood discharge. In this study flood simulation using HEC-RAS software. River water level calculations use the Saint Venant equation. This equation is used for flow modeling in 1 dimension, the Saint Venant formula consists of continuity equations and momentum equations [8].

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_l = 0$$

The equation above is a continuity equation, *A* is cross sectional area, *Q* is discharge, and q_1 is lateral flow per unit length. And for the momentum equation it can be written as follows [8]:

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + g\ A\left(\frac{\partial z}{\partial x} + S_f\right) = 0$$

Where *Q* is discharge, *V* is flow velocity, *g* is the acceleration of gravity, *x* is the distance measured after flow, *z* is water level, *t* is time, and S_f is slope of energy line calculated by the manning equation. This equation is used in 1D hydraulic modeling. While for 2D hydraulic modeling using 2D continuity equations, and 2D momentum equation [9].

Assuming that the flow is incompressible, the unsteady differential form of the mass conservation (continuity) equation is:

$$\frac{\partial H}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} + q = 0$$

Where *t* is time, *u* and *v* are the velocity components in the x- and y- direction respectively, *V* is velocity $\sqrt{v^2 + u^2}$, *H* is water surface above the reference, *h* is the depth of water surface H+d, where *d* is depth under reference (m) and *q* is a sources/sink flux term.

The 2D momentum equation is divided into 2, namely the direction of the y-axis and the x-axis. X-axis 2D flow momentum equation [9]:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial H}{\partial x} + v_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - c_f u + fv$$

Y-axis 2D flow momentum equation [9]:

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial H}{\partial y} + v_t\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - c_f v + fu$$

Where *u* and *v* are the velocities in the Cartesian directions, g is the gravitational acceleration, V_t is the horizontal eddy viscosity coefficient, c_f is the bottom friction coefficient, *R* is the hydraulic radius and *f* is the Coriolis parameter.

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III. Result and Discussion

A. Calibration

Calibration measurements produce velocity and depth. To measure velocity of the existing conditions, the Flowatch / Flow Meter is used in this calibration. The measurement data is then simulated to determine the value of manning roughness.

Calibration is used by giving an initial estimate for the value of manning roughness based on river conditions, so this initial estimate is corrected repeatedly until the depth of simulation results is the same as depth in existing conditions. In this study, calibration location was carried out in three locations, namely Jl. Royal Residence (-7.319013, 112.677745) at RS 81-RS 80, Jl. Raya Wiyung Pratama (-7.320039, 112.686098) at RS 71-RS 70 and Jl. Raya Menganti (-7.313385, 112.702605) at RS 32 – RS 31.

TABLE I. Depth Comparison Results between Existing Conditions and Simulation

Location	Depth of Survey Results (m)- h1	Manning Value	Depth of Simulation (m) - h2	Δh = |h1-h2|
Upstream (RS 81- RS 80)	6.09	0.035	5.774	0.316
		0.04	5.839	0.251
		0.05	5.962	0.128
		0.052	5.991	0.099
		0.054	6.027	0.063
		0.056	6.047	0.043
		0.058	6.067	0.023
		0.06	6.086	0.004
		0.061	6.096	0.006
Midstream (RS 71- RS 70)	5.83	0.017	5.588	0.242
		0.025	5.743	0.087
		0.027	5.778	0.052
		0.03	5.829	0.001
		0.031	5.845	0.015
Downstream (RS 32- RS 31)	6.5	0.018	6.229	0.271
		0.02	6.309	0.191
		0.023	6.422	0.078
		0.024	6.459	0.041
		0.025	6.495	0.005
		0.026	6.531	0.031

From the table above, depth of the simulation results is close to depth of measurement if Δh has the minimum difference. From several analyzes, it can be concluded that the use of manning values for cross section RS 127- RS 75 is 0.060, this cross section consists of short grass land. For cross section RS 74 - RS 34 has a cross section made of stone pairs, so that the results of the analysis obtained using manning value is 0.035. While in the downstream of Kedurus River in the cross section RS 33- RS 0 has a section of concrete, so that results of the analysis obtained using manning value is 0.025.

In figure 3 is comparison of depth at the calibration location, between simulation results and calibration results. The difference in depth of simulation with calibration is not so far. The following is comparison chart of the depth at calibration location:

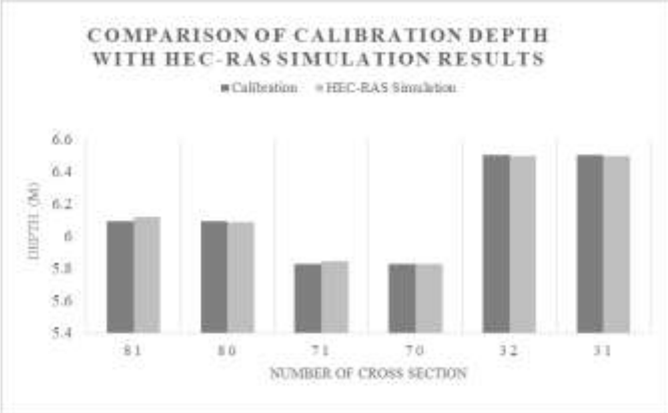

Fig. 3. Chart comparison of existing water level with simulation results.

Calibration approaches field conditions if the model simulation results (depth) are close to depth in field conditions. From the results of analysis obtained difference between depth of the calibration results with depth of the simulation results has an average error of 0.143%, this can be concluded that the manning value for the Kedurus River flood simulation can be used.

B. Hydrological Analysis

The purpose of hydrological analysis is to process rainfall data into flood discharge data which is used as boundary conditions in flood simulation. In this study hydrological analysis was carried out in the upstream, downstream, Kedurus watershed on secondary channels as the lateral flow and on the retentions basin in the downstream Kedurus watershed as storage area.

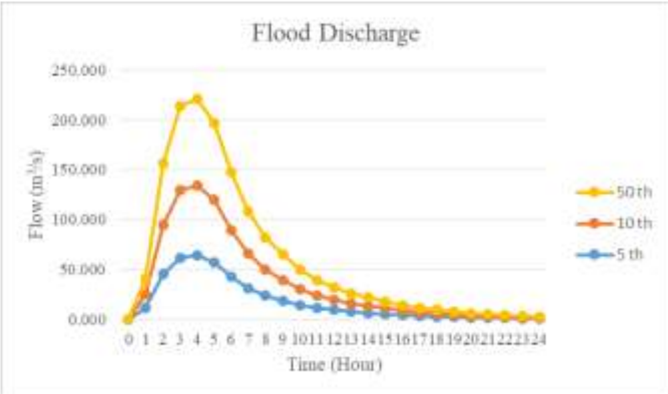

Fig. 4. Upstream Kedurus River flood discharge

In Figure 4 is the result of the design flood discharge in the upstream Kedurus watershed using the Nakayasu method. The hydrograph data is used as the upstream boundary conditions of the Kedurus River when conducting a flood simulation. Meanwhile, for the downstream Kedurus watershed, the calculation will get an hourly rain value. This hourly rain distribution is used as input data precipitation during flood simulations. The following is the rainfall data for the downstream Kedurus watershed.

TABLE 2. Rain distribution in lower Kedurus watershed

Hour to-	PUH		
	5	10	50
1	62.40	69.23	85.08
2	16.22	17.99	22.11
3	11.38	12.62	15.51
4	9.06	10.05	12.35

Analysis is also needed to analyze the design flood discharge in secondary channels as lateral flow. Calculation of flood discharge using the Rational method. This discharge is required for the upstream secondary channel conditions when simulating floods. Following is the hydrograph of secondary channels for 10 years return period.

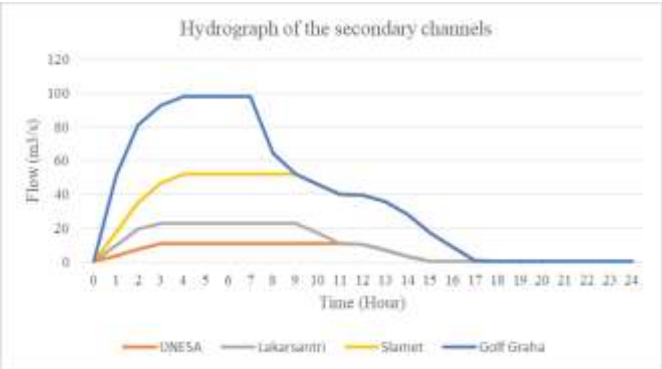

Fig. 5. Hydrograph of secondary channels for 10 years return period.

In the same way, the 5 years and 50 years return period flood discharge can be known. In addition, hydrological calculations are used on sub-bases or channels that enter retentions basin in the downstream Kedurus watershed. This is used to determine the lateral inflow used in flood simulations.

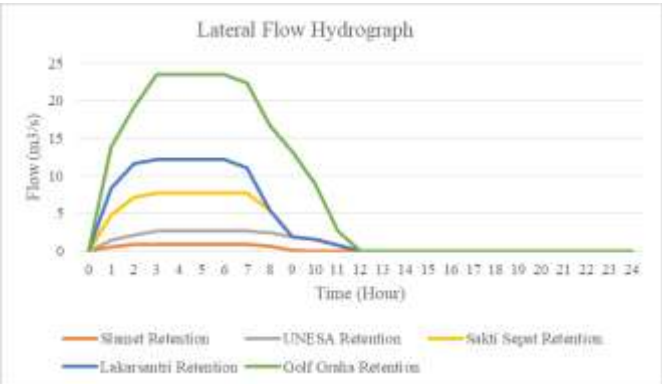

Fig. 6. Hydrograph on the retention basin

In Figure 6 is a hydrograph used as a lateral inflow in the downstream retentions Kedurus watershed. The hydrograph with a 10-year return period was analyzed using the Rational Method, in the same way the design flood discharge for the 5 year and 50 year return periods can be known.

C. *Hydraulic Analysis*

The flood simulation in this study used HEC-RAS 5.0.5 software in 1 dimension and 2 dimensions. The 1D hydraulic model aims to determine the propagation of flood flow in the river or channels, while for 2D hydraulic models it is used to propagate flood flows in floodplain areas.

In this study, the flooding that occurred in the downstream Kedurus watershed was caused by the overflowing of Kedurus River and the high rainfall in the area. In flood simulations, high rainfall is simulated as Precipitation, then for the upstream boundary conditions of Kedurus River using flow hydrograph, while the downstream boundary conditions use a stage hydrograph. For upstream boundary conditions on secondary channels using flow hydrograph.

In this study the flood simulation was carried out with three scenarios, where each scenario uses return period of 5 years, 10 years and 50 years. The three flood simulation scenarios are:

1. First Scenario
   In this first scenario the simulation is only in the main river (Kedurus River) without any influence from the secondary channels (lateral flow) or retention basin (storage area). The following is the first scenario scheme:

Fig. 7. First scenario scheme

2. Second Scenario
   The difference between first scenario and second scenario is this scenario flood simulation in addition to main river (Kedurus River) also calculates the lateral flow in secondary channels that affect the Kedurus River. The following is the second scenario scheme:

Fig. 8. Second scenario scheme

3. Third Scenario

   The third scenario is simulating Kedurus River, secondary channel as lateral flow, and retention basin as storage area. This third simulation aims to determine the effect of retention basin in downstream Kedurus watershed to reduce flooding that occurs in the area. The following is the third scenario scheme:

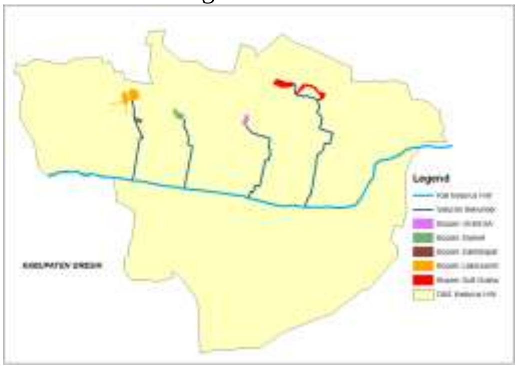

Fig. 9. Third scenario scheme

One result of the three scenarios is presented in the figure below. The following figure is an examples of 1D simulation on the Kedurus River.

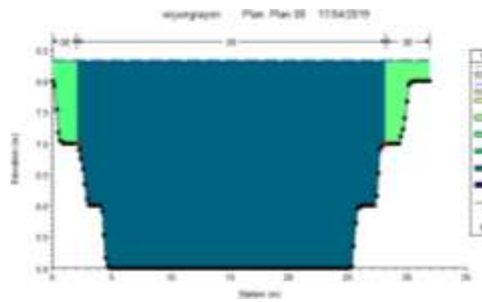

Fig. 10. Cross section at RS 82 with a 10 years return period in scenario 1

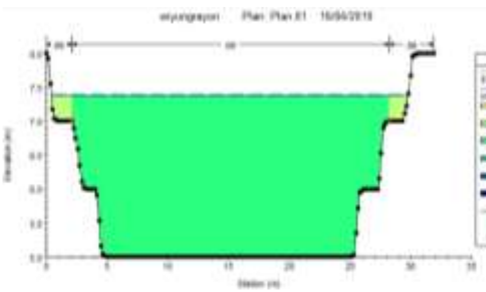

Fig. 11. Cross section at RS 82 with a 10 years return period in scenario 3

In Figure 10 and Figure 11, results of first and third scenario flood simulations with 10 years return period. From the same cross section, cross section 82 produces different depths, the depth of the first scenario is higher than the third scenario. For the first scenario the water level is at 8.32 m while the third scenario is 7.38 m. The color in the image shows the velocity distribution, dark blue shows the greater the velocity. The biggest velocity distribution is in the main channel, while on the riverbank the velocity is getting smaller. The results of the third scenario show that secondary channels and reservoirs are influential in reducing flood discharge.

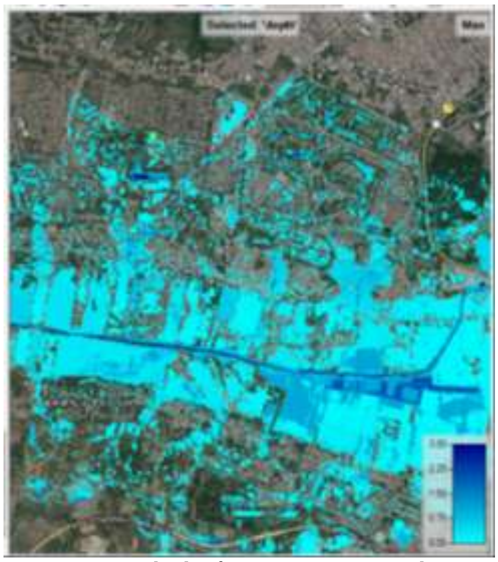

Fig. 12. RAS Mapper display for 10 year return period in scenario 1

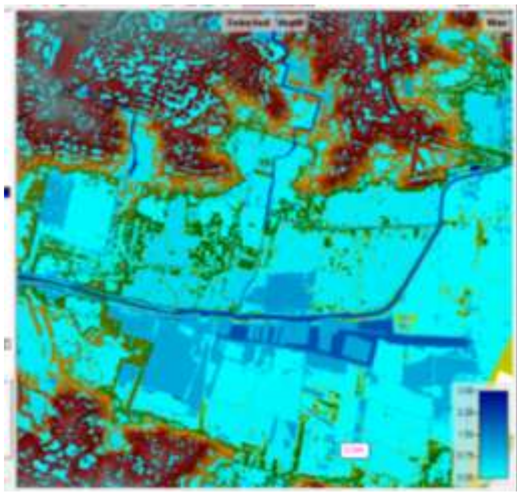

Fig. 13. RAS Mapper display for 10 year return period in scenario 2

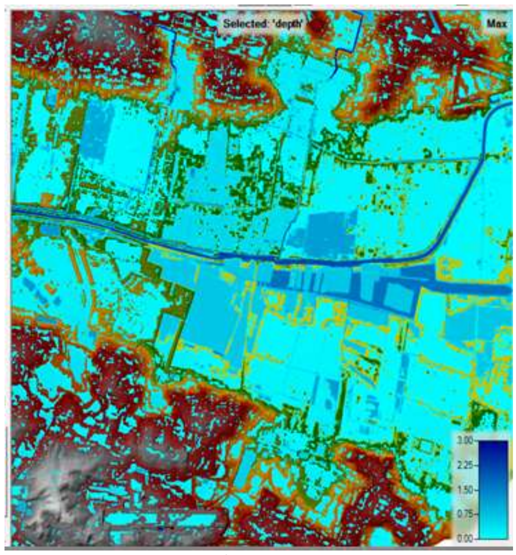

Fig. 14. RAS Mapper display for 10 years return period in scenario 3

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Figures 12-Figure 14 are the results of 2D flood simulation, from these results can determine the direction of flooding in inundation area. Display on the RAS Mapper in first, second and third scenarios is different. Map layer in the first scenario using Google Satellite / Google Hybrid, while the third and second scenario uses terrain.

Results of three scenarios can be concluded with table below. The table below is only an example when comparing with the 10 year return period, but research still uses a return period of 5 year, 10 year and 50 year. The depth difference of three scenarios is presented in the following table.

TABLE 3. Comparison between Depth of Simulation Results with Survey Results

LOCATION	DEPTH OF SURVEY RESULTS	DEPTH OF SIMULATION RESULTS (m) 10 years return period		
		First Scenario	Second Scenario	Third Scenario
Bozem Kedurus	-	2.03	2.03	1.65
Jl. Wiyung V	0.5-0.7	0.41	0.21	0.2
Jl. Wiyung VI	0.5-0.7	0.35	0.22	0.21
Jl. Raya Bangkingan	0.3-0.7	0.36	0.3	0.29
Jl. Babatan UNESA	0.3-0.7	0.53	0.31	0.31
Dukuh Karangan Jaya	0.5-0.6	0.57	0.24	0.23
SMP 40 Surabaya	0.1-0.2	0.13	0.22	0.09
Perum Pondok Rosan	0.1-0.2	0.21	0.12	0.11

Table 3 is a comparison between depth of survey results and simulation results. The survey results were obtained from the Public Works Agency of Highways and Surabaya City Government at the end of 2017. The location is representative of other locations affected by the flood. The 1D and 2D simulation results show that retentions basin and secondary channels (third scenario) in the Kedurus watershed have an effect on decreasing flood discharge.

While to find out the velocity of simulaion results, click the velocity menu on Ras-Mapper Result. And for the flood area can be obtained from Arc-GIS software, so the result is:

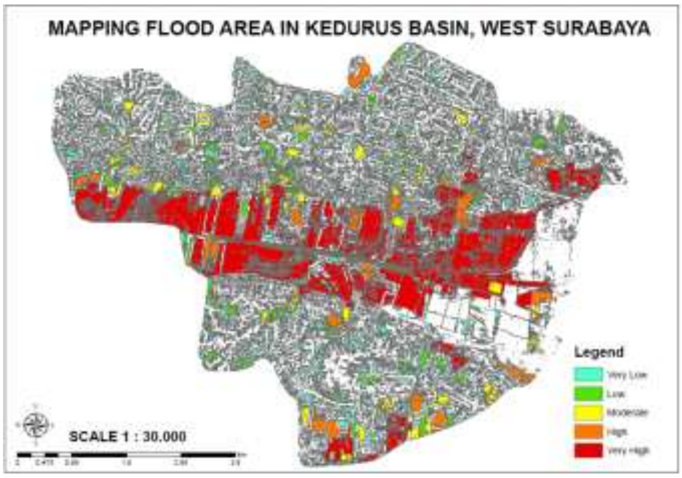

Fig. 15. Flood area in Kedurus Basin

The area of flood parameters used is referring to P Public Works Government Regulation number 12/PRT/ year 2014 as presented in the following table:

TABLE 4. Inundations Parameter

Number	Inundations Parameter	Percentage Score	Criteria
1	High Inundation	35%	
	> 0.5 m	100	Very High
	0.3 m - 0.5 m	75	High
	0.2 m - < 0.3 m	50	Moderate
	0.1 m - < 0.2 m	25	Low
	< 0.1 m	0	Very Low
2	Area Inundation	25%	
	> 8 ha	100	Very High
	4 -8 ha	75	High
	2 - <4 ha	50	Moderate
	1 - 2 ha	25	Low
	< 1 ha	0	Very Low
3	Duration of Inundation	20%	
	> 8 hour	100	Very High
	4 -8 hour	75	High
	2 - <4 hour	50	Moderate
	1 - 2 hour	25	Low
	< 1 hour	0	Very Low
3	Velocity of Inundation	20%	
	> 0.8 m/s	100	Very High
	0.4 -0.8 m/s	75	High
	0.2 - 0.4 m/s	50	Moderate
	0.1 - 0.2 m/s	25	Low
	< 0.1 m/s	0	Very Low

D. Flood Risk Analysis

Flood risk analysis aims to find out the most flood-prone locations, so that priority handling can be identified. Flood parameter criteria based on Public Works Government Regulation Number. 12 / PRT / year 2014.

Flood parameters consist of depth, area, duration and velocity of flooding. Then the total value of the flood parameters is summed with the value of the flood loss parameter. Then, parameter of flood loss consists of economic losses, then social disturbances and public facilities, transportation losses, losses in residential areas, and loss of personal property. For more details, can be seen in the table below:

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TABLE 5. Flood criteria value

Sub-district	Location	Depth (m) = 35 %		Area (Ha) = 25 %		Duration (Hour) = 20 %		Velocity (m/s) = 20 %		Total Flood Parameter
		Depth	Score	Area	Score	Duration	Score	Speed	Score	
Wiyung	Jl. Wiyung	0.41	75	4.2	75	>8	100	0.032	0	65
Wiyung	Raya Wiyung Indah	0.15	25	24.86	100	>8	100	0.115	0	53.75
Wiyung	Dukuh Karangan Jaya	0.57	100	9.27	100	>8	100	0.033	0	80
Wiyung	Raya Karang Klumprik	0.19	25	28.61	100	>8	100	0.012	0	53.75
Wiyung	Jl. Golf VI-X	0.51	100	5.99	100	>8	100	0.074	0	80
Wiyung	Griya Babatan	0.53	100	9.35	100	>8	100	0.021	0	80
Lakarsantri	Jl. Raya Bangkingan	0.36	75	2.72	50	>8	100	0.134	25	63.75
Lakarsantri	SMP 40 Surabaya	0.13	25	8.9	100	>8	100	0.012	0	53.75
Lakarsantri	Perum Pondok Rosan	0.21	50	8.61	100	>8	100	0.029	0	62.5
Lakarsantri	Lidah Wetan	0.67	100	3.78	50	>8	100	0.066	0	67.5
Lakarsantri	Lidah Kulon	0.81	100	1.78	25	>8	100	0.108	25	66.25
Karangpilang	Bogangin Baru	0.63	100	0.33	0	>8	100	0.01	0	55
Karangpilang	Perum. Gunungsari Indah	0.33	75	2.1	50	>8	100	0.142	25	63.75

TABLE 6. Value of flood loss in some locations

Sub-district	Location	Total Flood Parameter	Economic Loss		Social and Facilties Loss		Transportation Loss		Residential Areas		Personal loss		FINAL SCORE
			Effect	Score	Effect	Score	Effect	Score	Effect	Score	Effect	Score	
Wiyung	Jl. Wiyung	65	small	30	small	30	moderate	65	high	100	small	30	320
Wiyung	Raya Wiyung Indah	53.75	small	30	small	30	moderate	65	high	100	small	30	308.75
Wiyung	Dukuh Karangan Jaya	80	small	30	small	30	small	30	high	100	high	100	370
Wiyung	Raya Karang Klumprik	53.75	small	30	small	30	small	30	high	100	small	30	273.75
Wiyung	Jl. Golf VI-X	80	small	30	small	30	very small	0	moderate	65	small	30	235
Wiyung	Griya Babatan	80	small	30	small	30	small	30	high	100	high	100	370
Lakarsantri	Jl. Raya Bangkingan	63.75	small	30	small	30	moderate	65	small	30	very small	0	218.75
Lakarsantri	SMP 40 Surabaya	53.75	small	30	moderate	65	moderate	65	high	100	very small	0	313.75
Lakarsantri	Perum Pondok Rosan	62.5	small	30	small	30	high	100	small	30	very small	0	252.5
Lakarsantri	Lidah Wetan	67.5	small	30	small	30	moderate	65	high	100	very small	0	292.5
Lakarsantri	Lidah Kulon	66.25	small	30	small	30	moderate	65	high	100	very small	0	291.25
Karangpilang	Bogangin Baru	55	small	30	small	30	small	30	moderate	65	small	30	240
Karangpilang	Perum. Gunungsari Indah	63.75	small	30	small	30	small	30	high	100	small	30	283.75

Depth, velocity, area and duration of floods in the table above are obtained from the results of flood simulations. For the time of flooding until low tide (dry) takes more than 8 hours, this is because in this study using HEC-RAS 5.0.5 software where this version has not been able to simulate rainwater infiltration, so that the length of time flooding to dry has not been identified optimally.

The total value of flood parameters is obtained from the sum of the percentages in each criterion as in Table 5. The total parameter values are then summed up with other loss criteria as in Table 6. The highest value of the table above is the area with the highest priority, If the total value gets lower then the priority gets smaller. Based on the results of flood analysis, then the sub-districts that have flood vulnerability are in Wiyung District especially in the Karangan Jaya and Griya Babatan regions.

The results of the analysis are used to create a flood risk map. The flood risk map is presented in Figure 16. Maximum depth generated in the inundation area from 10 years flood is 0.81 meters located in Lidah Kulon village. Maximum area generated in the inundation area from 10 years flood is 28.61 hectares located in Raya Karang Klumprik.

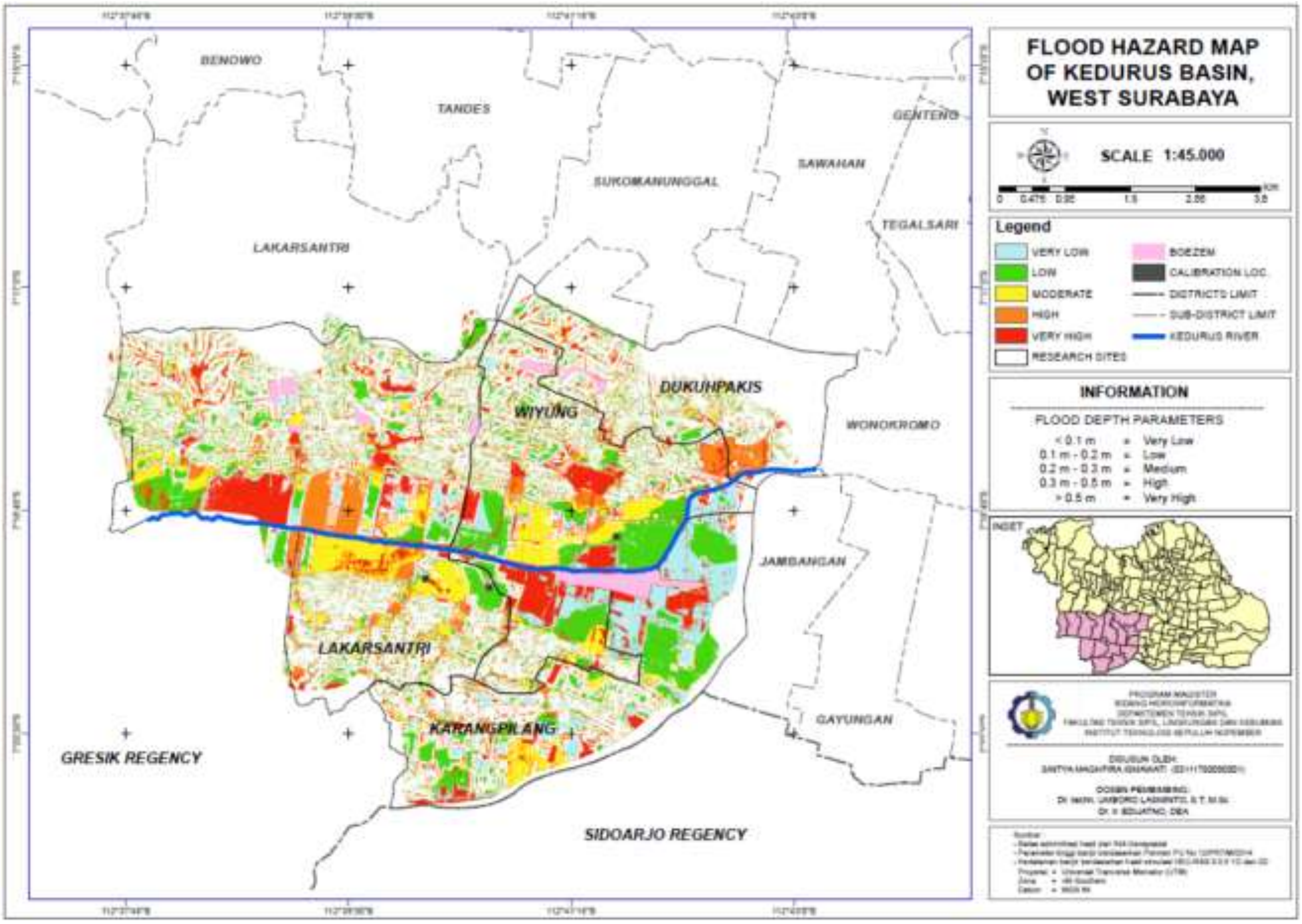

Fig. 16. Kedurus watershed flood hazard map with a 10th return period.

IV. Conclusion

Based on the calculation and analysis of floods in the West Surabaya area, it can be concluded as follows:

1. The results of flood simulation using HEC-RAS software with three scenarios can be concluded that the maximum flood depth is 0.81 meters, the velocity in the inundation area is between 0.012 m / s to 0.21 m / s, the widest area of flooding is 28.61 hectares.
2. Boezem and secondary channels in the third scenario are influential to reduce flood discharge by 19%.
3. Maximum depth generated in the inundation area from 10 years flood is 0.81 meters located in Lidah Kulon village. Maximum area generated in the inundation area from 10 years flood is 28.61 hectares located in Raya Karang Klumprik. The biggest velocity of 0.134 m/s occurred in the Raya Bangkingan area. So, sub-districts that have flood vulnerability are in Wiyung District especially in the Karangan Jaya and Griya Babatan regions.

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