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Flood Disaster Mitigation Using the HEC-RAS Application to Determine River Water Levels in the Old City Area of Jakarta

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Abstract

The old city area is a tourist area strategically located in the heart of the capital city of DKI Jakarta. The Krukut River is one of the rivers that often overflows, which is one of the causes of flooding in Jakarta. This study aims to determine the water level of the Krukut river so that it can be used as a reference in handling flood disaster mitigation. This study uses the Nakayasu and Snyder methods to calculate flood discharge, with a return period of up to 100 years. Meanwhile, for modeling the river water level using the HEC-RAS 5.0.07 application. The contribution of this study is to examine the upstream cross-section up to 300 meters after the TMA is relatively high with the first plan, which is 3 m deep from the bottom of the channel. However, the track still has a sufficient guard height of about 1.5 m. In other words, no overflow/river water does not overflow in the upstream area with a return period of 10 years and 25 years. However, due to the narrower channel section, the upstream area is more prone to flooding than the downstream middle region. From the modeling results, the channel prone to erosion is section 10, which is widening while the track is not filled with CONCRETE channels, so it is not easily eroded. For this reason, it is recommended to repair the walls of the river/channel so that scouring does not occur, especially if there is a high/extreme discharge.

Keywords: *Krukut River, Flood, HEC-RAS*

1. Introduction

In planning the field of water resources, many factors must be considered, one of which is knowing the danger of flooding that will occur in the area [1]. In planning, the flood discharge value is needed, which is the basis for designing water structures as a value that affects planning related to the strength of the building structure, and the efficiency and economic value of the building to be planned [2]. For this reason, it is necessary to know hydrological data, the primary basic material in carrying out hydrological analysis used to design water structures such as flood control buildings, irrigation buildings, river management, and others. The hydrological analysis is an essential parameter to carry out careful and precise handling in the planning of water structures.

In predicting the magnitude of the design flood discharge for a watershed (DAS), it can be done using several methods, such as the Rational Method and the mathematical

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method of diverting rainfall flows which are pretty complex [3] [4]. [5] One of the most widely used methods in Indonesia is the unit hydrograph method.

A hydrograph is a method for estimating measured river flows and unmeasured watersheds by simulating rainfall into the runoff in a rainfall-runoff model [6][7]. The first rainfall model used is in the form of an empirical equation developed from one area to several other regions [8] [9]. The hydrograph can show the overall response of the watershed (DAS) to specific inputs, which are by the nature and behavior of the watershed concerned [10] [11]. The flow hydrograph constantly changes according to the magnitude and time of the input [12] [13]. Flow hydrographs are an essential part of overcoming problems related to hydrology because flow hydrographs can describe the time distribution of surface runoff in a measurement area and determine the diversity of physical characteristics of the watershed [14] [15].

The unit hydrograph is a direct runoff hydrograph produced by rain that occurs evenly throughout the watershed (DAS) and with a fixed intensity in a specified time unit [16] [17]. Unit hydrograph (unit hydrograph) is the watershed response (DAS) in the hydrology concept. The response nature of the watershed (DAS) is formed from the relationship between the flow hydrograph and the physical condition of the watershed (DAS). The unit hydrograph is a typical hydrograph for a watershed. [18] States that a unit hydrograph is a direct flow hydrograph produced by one rainfall excess spread evenly throughout the watershed with a fixed intensity for a particular time.

The problem that occurs in the process of converting rain into flooding by the watershed system is that it always gives different answers. To overcome this problem, an approach in the form of a flood hydrograph is presented. The presentation of the flood hydrograph can use the unit hydrograph reduction method from the measured flood hydrograph if available. If no data is available, then the empirical formula can be used, namely the Synthetic Unit Hydrograph (HSS), which is a hydrograph based on the parameters of the Watershed (DAS). Long rainfall data is required for a watershed from a rain recording post where rainfall and discharge data are often limited [19] [20].

Hydrologists have found many methods with the suitability of the data, the type of data, and the amount of data required from each of these methods, as is the case with the Synthetic Unit Hydrograph Method (Snyder, Nakayasu, Gama I, Limantara) [21] [22]. Synthetic Unit Hydrograph (HSS) is an artificial hydrograph used to create a unit hydrograph modeling based on watershed characteristics. To obtain information about unit hydrographs, the Synthetic Unit Hydrograph (HSS) approach is used to estimate the use of the unit hydrograph concept in a plan for direct observation data on flood hydrographs in watersheds (DAS) are not available.

The presentation of the flood hydrograph can use the unit hydrograph derivation method from the measured flood hydrograph if data is available and use the empirical formula, namely Synthetic Unit Hydrograph (HSS), which is a hydrograph based on synthetic watershed parameters. One of the Synthetic Unit Hydrographs often used in calculating flood discharge in Indonesia is Nakayasu's Synthetic Unit Hydrograph (HSS).

The Nakayasu Synthetic Unit Hydrograph (HSS) method is a popular method used in water resource planning, especially in the analysis of unmeasured watershed (DAS) flood discharges. The Nakayasu Synthetic Unit Hydrograph (HSS) method is increasingly widespread. Still, in reality, many difficulties are often encountered, especially in determining the value of, where the importance of indicates the characteristics of the watershed (DAS), namely the area of the watershed (A), the length of the main river (L), the coefficient of flow (C), the average slope of the river (s), the coefficient of bottom roughness (n), the length of the river from the center of gravity of the watershed to the outlet (Lc) and the alpha parameter (α) itself. The history of Nakayasu's Synthetic Hydrograph Unit (HSS) was researched in the Japanese region, which has different characteristics from the Indonesian area, often giving inaccurate and precise results. The value generated by the Synthetic Unit Hydrograph (HSS) of Nakayasu will significantly affect the results obtained in the calculation of peak flood discharge, which usually experts estimate the parameter only by looking at the characteristics of the Watershed (DAS). Meanwhile, parameters are only estimates for areas that have never been analyzed from the condition of existing watershed characteristics [23].

States that the synthetic unit hydrograph has five watershed parameters that dominantly affect the peak discharge, namely the length of the river/mainstream (L), the area of the watershed (A), the length of the main river (Lc), roughness coefficient (n) and slope. river (S) [24] Stated that the modeling of the variable on the Nakayasu synthetic unit hydrograph (comparative study with the GAMA I synthetic unit hydrograph) is influenced by watershed characteristics in the form of watershed length and watershed area [3] who examined the study of the Nakayasu synthetic unit hydrograph to calculate the design flood discharge in the Kodina river basin. From the results of the study that the unit hydrograph measured the deviation rate of the Nakayasu synthetic unit hydrograph. Modifying the Nakayasu HSS Equation is carried out by deriving the basic formula for peak time (Tp) from the value of Tr and peak discharge (Qp) from the T03 equation in the form of the value of. The results showed a significant deviation for the basic hydrograph unit, namely for Tp = 26% and Qp = 22.40%.

An important factor in water building planning is knowing the amount of flooding that occurs, where this quantity determines the dimensions of the building, which are closely related to the risk, and the economic value of the planned building [25] [26]. The synthetic unit hydrograph (HSS) method is a popular method used in preparing water resources, especially in the analysis of unmeasured watershed flood discharges. The use of the Nakayasu HSS method is increasingly widespread. Still, in reality, many difficulties are often encountered, especially in determining the value, so this study aims to overcome these problems.

In hydrological research, it has been widely used by previous researchers in both districts and cities. The previous study used the SCS-CN method. While the update of this research will examine the hydrology of river water level modeling using the HEC-RAS 5.0.07 program, which has not been used in previous studies.

2. Literature Review

The unit hydrograph is defined by [27] as a direct runoff hydrograph produced by adequate rain with a height of one unit, which is spread evenly throughout the watershed with a constant intensity for one team of time [5].

2.1 Flow

Coefficient Flow coefficient or often abbreviated C is a number that shows the ratio between the amount of water that runs over to the amount of rainfall. This flow coefficient number is one indicator to determine whether a watershed has experienced (physical) disturbance [28] [29].

2.2 Rain

Intensity Rain Intensity In estimating the amount of discharge, data on the maximum hourly rainfall and adequate rainfall are needed [30] [31]. Based on the distribution of rain, the amount of rain every hour will fall during the concentration-time of the rainy period. As the concentration of rain in one day is 6 hours, then the division of the amount of rain will fall in each hour. Rain intensity is the rain or water level rate per unit of time. The rainfall intensity is denoted by the letter I with units of mm/hour [32] [33]. Rain intensity can be formulated as follows:

$$I = \frac{R24}{24} + \left[\frac{24}{T}\right]^{2/3}$$

2.3 Concentration

Concentration time is the time required to drain water from the most distant point in the flow area to the critical control point downstream of a stream [34][35].

2.4 Effective Rainfall

Rain is the portion of the total rain that results in direct runoff. The amount of adequate rainfall can be expressed as follows:

$$R_n = C . I$$

2.4 Nakayasu Synthetic Unit Hydrograph

Analyzing the design flood hydrograph based on the Nakayasu Synthetic Unit Hydrograph Method, it is necessary to know the flow area's characteristics, which are expressed in parameters. The parameters in question are [21]:

- The time lag from the beginning of the rain to the peak of the hydrograph *(time to peak magnitude)*
- From the center of rainfall to the center of gravity of the hydrograph (*time lag)*
- The hydrograph (*time base of hydrograph*)
- Size of catchment area the
- The length of the most extended main river channel (*length of the longest track*)
- Hydraulic*Runoff coefficient analysis*

2.4 Method with HEC RAS software

HEC-RAS is a program/software that functions to model flow in rivers, River Analysis System (RAS), created and developed by Hydrologic Engineering Center (HEC) under the auspices of the US Army Corps of Engineers (USACE). HEC-RAS can model the steady and unsteady one-dimensional flow model. Based on previous studies, HEC RAS is a fairly good and representative tool for river/channel hydraulics analysis, besides the results of HEC RAS analysis can also be integrated into the hydraulics modeling stages using HEC RAS including:

- Preparation of input data and boundary conditions.
- Making longitudinal and transverse river cross sections (river reach and cross section).
- Determination of model boundary conditions.
- Running program.
- Analysis of program results (flow parameters: velocity, water level, flow overtopping).
- Validation/verification of model results with field conditions.

3. Data And Methodology

This research was conducted on the Krukut River, a large river located in the western part of Jakarta. In this study, the HEC-RAS 5.0.7 program was used to analyze the flood water level on the overflowing river's cross-section and calculate the flood discharge, with a return period of up to 100 years.

3.1 Data

The data used in this study are as follows:

- Topographical
- Data Daily rainfall data for ten years (2011-2020).

3.2 Methodology

- Collect data, namely the study of related literature such as rainfall and river topographic data.
- Perform data analysis by analyzing the frequency of rainfall to obtain the value of the planned rain. Then the frequency distribution test is carried out to determine the distribution equation used for the statistical distribution of the analyzed data.
- Calculate the magnitude of the planned flood discharge using a Synthetic Hydrograph Unit (HSS) based on river data using the Nakayasu HSS method.
- Analysis of river hydraulics using the HEC-RAS 5.0.7 program to analyze the flood water level on the overflowing river cross-section.

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4. Results And Discussion

4.1 Topographic Measurements

Results of topographic measurements can be seen in the following table:

No. STA		Tool Height (m)	Tool Target (m)	Arah Horisontal			Azmt. First (der)	Azmt. (der)	Vertical Angle (Z')			Distance		Coordinate		
STA	Target			deg	mnt	sec			deg	mnt	sec	Miring (m)	Datar (m)	X (m)	Y (m)	Z (m)
1	2	3	4	5			6	7	8			9	10	11	12	13
P.3	P.3													400,178	774,258	53,005
	P.2	1,38	1,30	0	0	0	160,0000	160,0000	90	34	21	[redacted]	291,870	500,004	499,990	50,168
	P.KALI-A	1,38	1,30	346	57	8		146,9522	90	50	6	[redacted]	75,336	441,262	711,110	51,987
	P.KALI-B	1,38	2,15	339	36	55		139,6153	93	26	0	[redacted]	50,535	432,921	735,765	49,203
	P.KALI-A	1,38	1,30	269	2	4		69,0344	90	58	55	[redacted]	21,793	420,529	782,055	52,711
	P.KALI-A	1,38	1,30	154	47	43		314,7953	92	14	7	[redacted]	8,666	394,029	780,364	52,746
	P.KALI-B	1,38	2,45	155	3	54		315,0650	92	21	46	[redacted]	9,416	393,528	780,923	51,546

Figure 1. Result Topographic Measurements
(Source: measurement results)

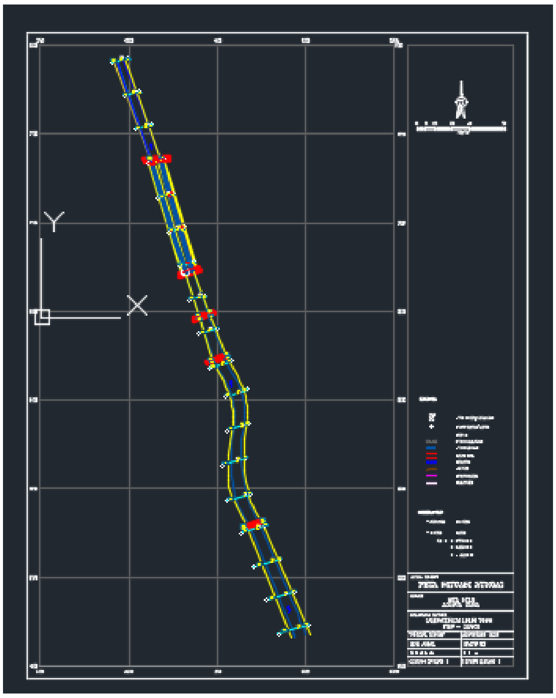

Figure 2. Situation Map of the Krukut River

4.2 Rainfall Planned

HEC-RAS is a program/software that functions to model flow in rivers. River Analysis System (RAS) was created and developed by Hydrologic Engineering Center (HEC) under the auspices of the US Army Corps of Engineers (USACE). HEC-RAS can model the steady and unsteady one-dimensional flow model. Based on previous studies, HEC RAS is a relatively good and representative tool for river/channel hydraulics analysis. Besides, the results of HEC RAS analysis can also be integrated into the hydraulics modeling stages using HEC RAS, including:

Rainfall can be calculated by compiling the maximum annual rainfall data from the most significant to the minor data. The results calculation of planned rain can be seen in the table below:

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Table 1. Results of Planned Rainfall

Year	Rainfall			
	Normal	Log Normal	Gumbel	Log Pearson III
2	155,727	143,808	146,260	137,839
5	213,684	202,538	226,888	199,018
10	243,970	242,330	280,271	247,320
20	268,955	289,941	331,477	292,533
25	274,476	327,661	347,720	318,183
100	315,830	371,800	447,426	446,119

4.3 Calculation of Planned Flood Discharge

In calculating the planned flood discharge of the Krukut river, the Nakayasu and the Snyder methods are used.

Table 2. Recapitulation of Nakayasu design flood discharge at 100th

Tr	Q (m^3/second)
2	90,05
5	113.96
10	130.16
25	148.98
50	166.54
100	182.87

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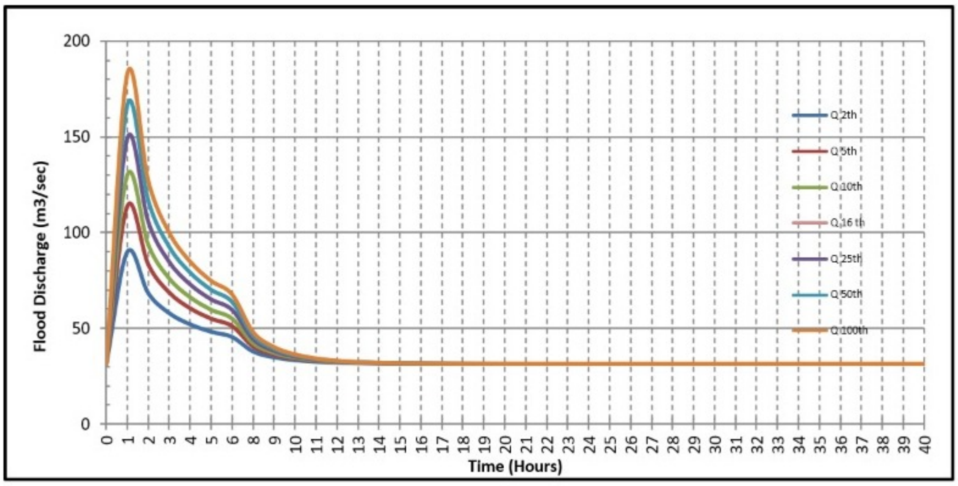

Figure 3. Nakayasu Flood Hydrograph

Table 3. Recapitulation of Snyder design flood discharge at 100th

Tr	Q (m^3/second)
2	55.10
5	64.74
10	71.27
25	78.86
50	85.94
100	92.52

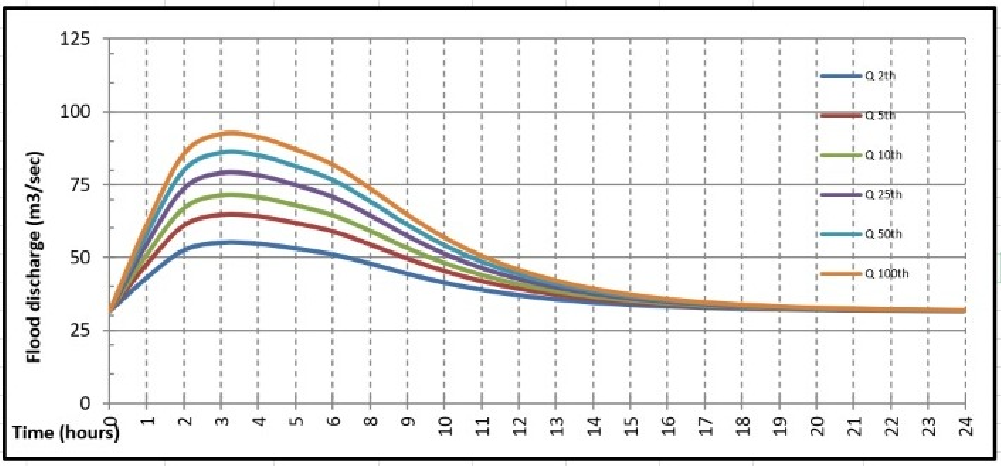

Figure 4. Snyder Flood Hydrograph

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4.4 High SimulationKrukut River Water Level Using HEC-RAS

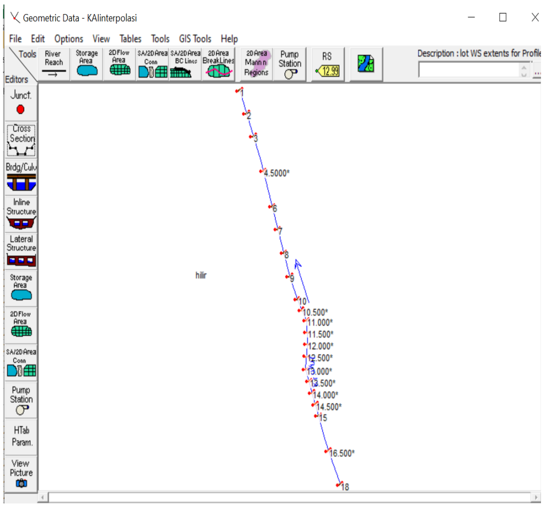


Figure 5. Krukut River Network Through HEC-RAS

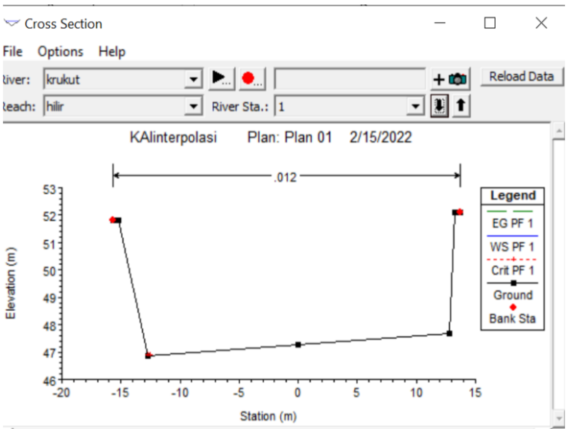


Figure 6. Cross section model of the river cross section 6

Figure 7. Condition of the Krukut River

The Cross-section of the river modeled is a cross-section of the river as a result of refining the modeling results.

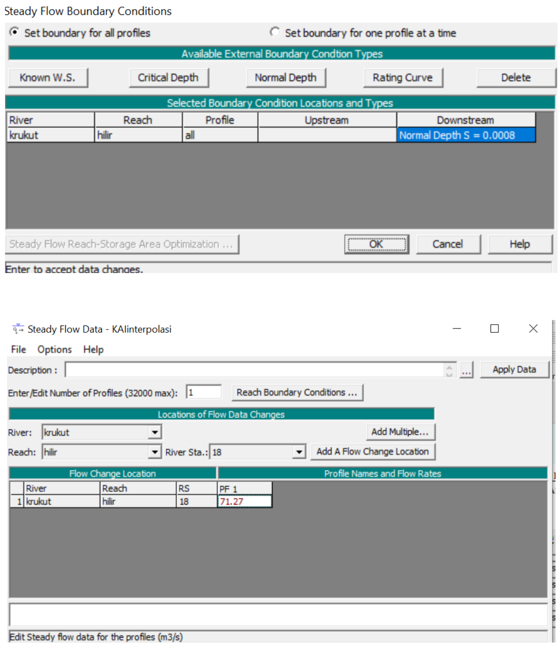
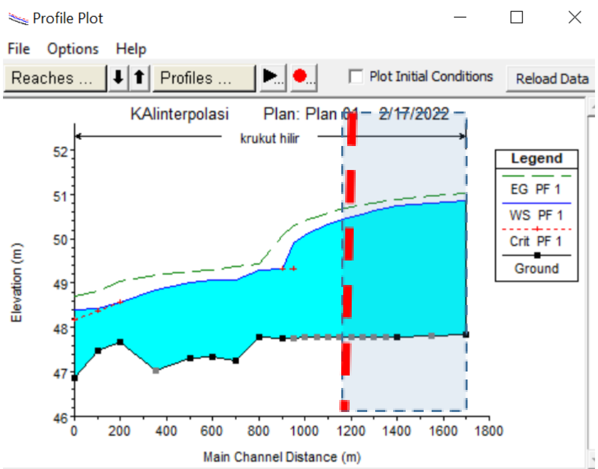


Figure 8. River Plan 1

4.5 Analysis of River Hydraulics Modeling Results

The results from HEC-RAS that must be analyzed include whether there is overtopping along the river, how the river speed is compared to the cross-sectional speed limit and how the river water level profile is formed. Analysis of the HEC-RAS model results is divided into two plans: plan 1 with a discharge period of 10 years and plan 2 with a discharge period of 25 years. From the upstream section until 300 meters after that, the TMA is relatively high with plan 1, which is 3 m deep from the bottom of the channel. However, the track still has a sufficient guard height of about 1.5 m. In other words, no overtopping/river water does not overflow in the upstream area with a return period of 10 years.



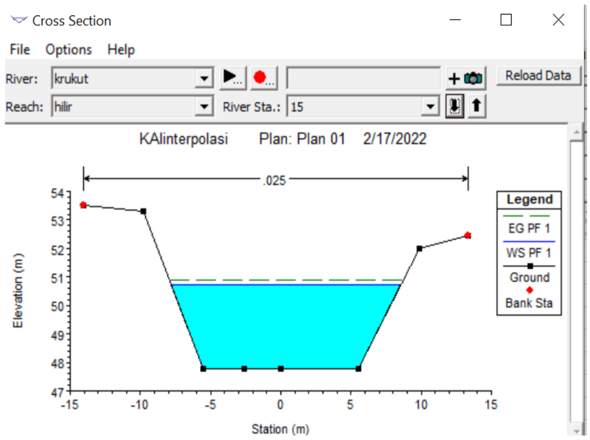


Figure 9. Results of Modeling River Plan 1 (10th Return Period)

The Collins method of Observational Hydrograph (HSO) was used for calibration. Calibration is carried out to check the accuracy of the parameter in the calculation.

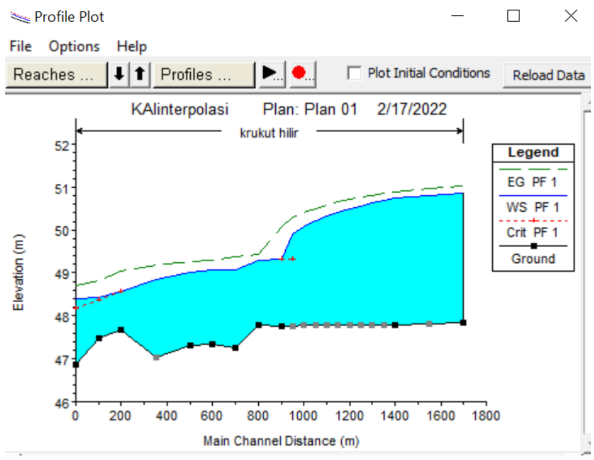
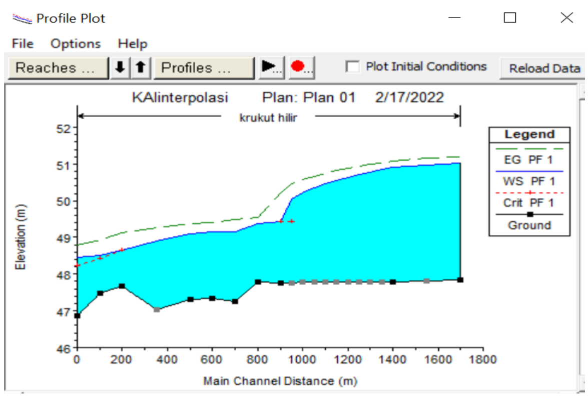


Figure 10. River Plan 2 Modeling Results (10th Return Period)

In the middle section, the channel width is slightly wider than the upstream section but with the type of channel is a channel. Some are still in the form of natural media. The water level begins to decrease following the expansion of the track that will occur afterward. The water depth from the bottom is around 2.5 m, and there is a guard height of 2-3 m.



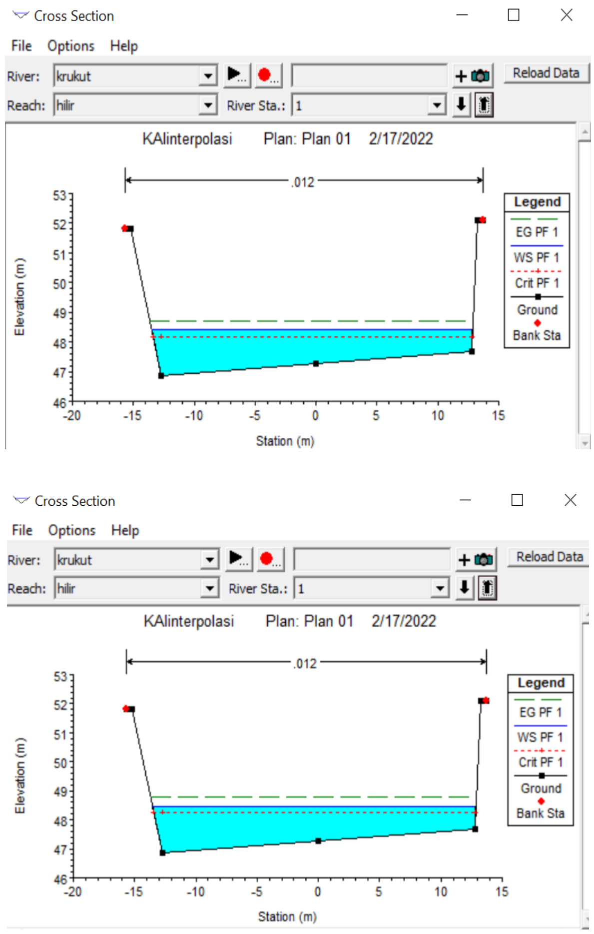


Figure 11. Results of Modeling River Plan

Profile Output Table - Standard Table 1

File Options Std. Tables Locations Help

HEC-RAS Plan: Plan 01 River: krukut Reach: hilir Profile: PF 1

Reach	River Sta	Profile	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
hilir	18	PF 1	78.86	47.84	51.01		51.20	0.000183	1.92	41.10	14.22	0.36
hilir	16.500*	PF 1	78.86	47.81	50.98		51.16	0.000445	1.90	41.60	14.96	0.36
hilir	15	PF 1	78.86	47.79	50.90		51.07	0.000727	1.83	43.02	16.63	0.36
hilir	14.500*	PF 1	78.86	47.79	50.85		51.03	0.000813	1.91	41.34	16.22	0.38
hilir	14.000*	PF 1	78.86	47.79	50.78		50.99	0.000911	1.99	39.66	15.75	0.40
hilir	13.500*	PF 1	78.86	47.78	50.72		50.94	0.001023	2.08	38.00	15.21	0.42
hilir	13.000*	PF 1	78.86	47.78	50.64		50.88	0.001147	2.17	36.38	14.61	0.44
hilir	12.500*	PF 1	78.86	47.78	50.56		50.82	0.001279	2.26	34.84	13.94	0.46
hilir	12.000*	PF 1	78.86	47.78	50.46		50.75	0.001435	2.36	33.39	13.51	0.48
hilir	11.500*	PF 1	78.86	47.78	50.35		50.67	0.001649	2.48	31.83	13.28	0.51
hilir	11.000*	PF 1	78.86	47.77	50.22		50.57	0.001959	2.63	30.03	13.06	0.55
hilir	10.500*	PF 1	78.86	47.77	50.04	49.43	50.46	0.002488	2.85	27.71	12.86	0.62
hilir	10	PF 1	78.86	47.77	49.43	49.43	50.23	0.006720	3.96	19.91	12.46	1.00
hilir	9	PF 1	78.86	47.80	49.38		49.55	0.000299	1.83	43.18	27.45	0.46
hilir	8	PF 1	78.86	47.25	49.15		49.49	0.000736	2.58	30.60	22.77	0.71
hilir	7	PF 1	78.86	47.35	49.16		49.41	0.000433	2.20	35.89	22.84	0.56
hilir	6	PF 1	78.86	47.30	49.11		49.36	0.000459	2.24	35.21	22.84	0.58
hilir	4.5000*	PF 1	78.86	47.04	48.91		49.27	0.000619	2.67	29.49	18.27	0.67
hilir	3	PF 1	78.86	47.68	48.64	48.64	49.12	0.001558	3.07	25.67	26.94	1.00
hilir	2	PF 1	78.86	47.48	48.50	48.44	48.92	0.001266	2.88	27.37	26.97	0.91
hilir	1	PF 1	78.86	46.88	48.47	48.25	48.79	0.000800	2.53	31.19	26.36	0.74

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Profile Output Table - Standard Table 1

File Options Std. Tables Locations Help

HEC-RAS Plan: Plan 01 River: krukut Reach: hilir Profile: PF 1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
hilir	18	PF 1	71.27	47.84	50.85		51.02	0.000177	1.84	38.78	14.09	0.35
hilir	16.500*	PF 1	71.27	47.81	50.81		50.98	0.000432	1.82	39.16	14.77	0.36
hilir	15	PF 1	71.27	47.79	50.74		50.90	0.000715	1.77	40.33	16.34	0.36
hilir	14.500*	PF 1	71.27	47.79	50.68		50.86	0.000798	1.84	38.74	15.91	0.38
hilir	14.000*	PF 1	71.27	47.79	50.62		50.81	0.000894	1.92	37.17	15.43	0.39
hilir	13.500*	PF 1	71.27	47.78	50.56		50.76	0.001001	2.00	35.64	14.89	0.41
hilir	13.000*	PF 1	71.27	47.78	50.49		50.71	0.001118	2.09	34.16	14.31	0.43
hilir	12.500*	PF 1	71.27	47.78	50.41		50.65	0.001237	2.17	32.78	13.65	0.45
hilir	12.000*	PF 1	71.27	47.78	50.32		50.58	0.001397	2.27	31.44	13.40	0.47
hilir	11.500*	PF 1	71.27	47.78	50.21		50.50	0.001606	2.38	29.98	13.18	0.50
hilir	11.000*	PF 1	71.27	47.77	50.09		50.41	0.001911	2.52	28.28	12.98	0.55
hilir	10.500*	PF 1	71.27	47.77	49.92	49.32	50.30	0.002433	2.73	26.08	12.79	0.61
hilir	10	PF 1	71.27	47.77	49.32	49.32	50.07	0.006843	3.85	18.52	12.40	1.01
hilir	9	PF 1	71.27	47.80	49.29		49.44	0.000300	1.76	40.50	27.42	0.46
hilir	8	PF 1	71.27	47.25	49.07		49.38	0.000743	2.49	28.64	22.74	0.71
hilir	7	PF 1	71.27	47.35	49.08		49.30	0.000424	2.10	33.90	22.81	0.55
hilir	6	PF 1	71.27	47.30	49.02		49.26	0.000449	2.14	33.27	22.81	0.57
hilir	4.5000*	PF 1	71.27	47.04	48.86		49.17	0.000558	2.50	28.51	18.12	0.64
hilir	3	PF 1	71.27	47.68	48.58	48.58	49.03	0.001587	2.97	23.98	26.91	1.01
hilir	2	PF 1	71.27	47.48	48.43	48.37	48.83	0.001306	2.80	25.47	26.93	0.92
hilir	1	PF 1	71.27	46.88	48.40	48.18	48.70	0.000800	2.43	29.29	26.32	0.74

Figure 12. Return 25 years

In addition to water level, channel velocity is an essential factor that must be considered in disaster mitigation. Channel velocity that is too high can cause the channel/river to be quickly eroded so that it can cause the dam/river bank to be easily damaged/broken. On the other hand, too low a speed can cause sedimentation/deposition on the side of the river/channel, which can result in reduced channel capacity. From the modeling results, the track prone to erosion is the section 10 channel, which is widening at the same time that the channel is not filled with the CONCRETE channel, so it is effortless to erode. For this reason, it is recommended to repair the walls of the river/channel to avoid scouring, especially if there is a high/extreme discharge.

5. Conclusion

Based on the analysis and discussion, several conclusions can be drawn, planned rainfall for the 2-year return period is 143,808 mm/year, the 5-year return period is 202,538 mm/year, the 10-year return period is 242,330 mm/year, and the 25-year return period is 327,661 mm/year. The planned flood discharge using the Snyder method on a 2-year return period is 55.10 m3/s, a 5-year return period is 64.74 m3/s, and a 10-year return period is 71.27 m3/sec, a 25-year return period is 78, 86 m3/sec.

In the upstream section until 300 meters, the TMA is relatively high with plan 1, which is 3 m deep from the bottom of the channel. However, the track still has a sufficient guard height of about 1.5 m. In other words, no overtopping / river water does not overflow in the upstream area with a return period of 10 years and 25 years. However, due to the narrower channel section, the upstream region is more prone to flooding than the middle downstream area. From the modeling results, the channel prone to eroding is the section 10 channel experiencing widening. At the same time, the track is not filled with concrete channels, so it is very easy to rust. For this reason, it is recommended to repair the walls of the river/channel to avoid scouring, especially if there is a high/extreme discharge.

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