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BANKFULL CAPACITY ANALYSIS ON THE DOWNSTREAM PEKALEN RIVER DUE TO THE LATEST DESIGN FLOOD

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ABSTRACT

Conditions in the upper reaches of the Pekalen River Basin have experienced changes in land cover, causing an increase in flood discharge, overflowing of the river body, and sedimentation. Flash floods in several villages in the Tiris sub-district in 2018 and 2019 made it clear that it was essential to control the cross-section of the river in several sections to anticipate similar events downstream. Then harvesting sengon (*Albizia chinensis*) trees simultaneously on community forest lands impacts the wide opening of the land, resulting in land degradation and lowering environmental quality. The purpose of this study is to determine the cross-sectional capacity of the river based on the latest rain data and to provide alternative solutions to the problem of handling the Pekalen River. Based on the results of hydrology and hydraulics calculations simulated in HEC-RAS, it was found that the existing capacity of the Pekalen River section could not accept the Q_{50} year of 484,090 m^3/s. In the upstream section, 163 stake sections from upstream, middle, and downstream river sections experienced runoff, with a total length of 18,847 km of the river section that experienced runoff. One effective alternative solution to the flooding problem is to install Concrete Sheet Pile (CCSP) embankments at each stake segment that experiences runoff. Besides that, efforts are being made to handle non-structural measures such as erosion control using vegetation, socialization of flood plains, and a flood early warning system.

Keywords: design flood discharge, embankment, inundation, pekalen river

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INTRODUCTION

Flood is a natural phenomenon that occurs in certain places. Natural forces and human activities cause it (Koyari *et al*. 2018, Handini *et al*. 2021). Pekalen River is one of the major rivers originating from Mount Argopuro and Mount Lemongan Springs, passing through Probolinggo Regency and emptying into the Madura Strait. Rivers, including riverbanks, have a massive role in the development of human life in the world by providing fertile areas generally located in river valleys and as the essential source of life for humans. Likewise, the river is a means of transportation to increase mobility and communication between people (Koyari *et al*. 2018). According to Law Number 17 of 2019 concerning Water Resources, a River Basin is a unitary area of the management of water resources in one or more Watersheds and small islands with an area of less than or equal to 2,000 (two thousand) square kilometers.

Meanwhile, according to Government Regulation Number 38 of 2011, a river is a natural and or artificial channel or container in the form of a water drainage network along with the water in it, starting from the upstream to the estuary, bounded on the right and left by a demarcation line (Indonesia, P 2019; Handini *et al*., 2021) Rivers have many positive benefits that help human life, but they can also have negative impacts that can appear at any time which can result in damage to the surroundings (Harisuseno D, 2020; Indonesia, P 2019). Throughout 2017 Badan Nasional Penanggulangan Bencana (BNPB) Probolinggo Regency is informed that there were two flood events in 2018 and 4 flood events during 2017. One was a resident's village hit by flash floods on December 10th, 2018, covering Kedaton Hamlet, Andung Biru Village, Tiris District [2]. The cause of the flooding is likely due to changes in land use in the upstream area of the Kali Pekalen watershed. Besides that, there is also a lot of logging of sengon trees (*Alvizia chinensis*) in community forests upstream of the watershed. The overflow of the Pekalen River is also likely caused by several factors, one of which is the inability of the existing cross-section to accommodate discharge which causes the capacity of the channel section to decrease. Seeing the problems above, it is vital to analyze the cross-section of the Pekalen River from upstream to downstream used to the HEC-RAS to find out how much the existing cross-section of Pekalen Rives is capable of and provide alternative solutions that are effective and doable to overcome the flood problem. The Novelty of this research is the analysis of the threat of flooding in the Pekalen River, which considers the latest morphological cross-sectional conditions, hydrology data, and land use conditions around the barrier.

MATERIALS AND METHODS

Research Area

The Pekalen River basin encompasses an area of 207.92 km^2 with a central river length of 35.1 km and an average width of 5-25 m (A.B Ulum *et al.*, 2015; Harisuseno, 2020). In some river sections, floods often occur due to flash floods in the Andungbiru tributary's upper reaches and the Pekalen River's lower reaches. The study location can be seen in Figure-1 below.

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Figure-1. Pekalen watershed research location.

Required Data

Collecting primary and secondary data is the initial step that must be carried out to carry out a flood discharge analysis. The data requirement used is rain measurement data on 12 rain posts using 20 years of measurement data. Then analyze the cross-sectional capacity of the river based on topographic measurement data consisting of cross-section and long-section measurement data of the river, land use maps, and the area of the Pekalen Watershed.

Research Stages

The stages of the research can be seen in the following Figure-2.

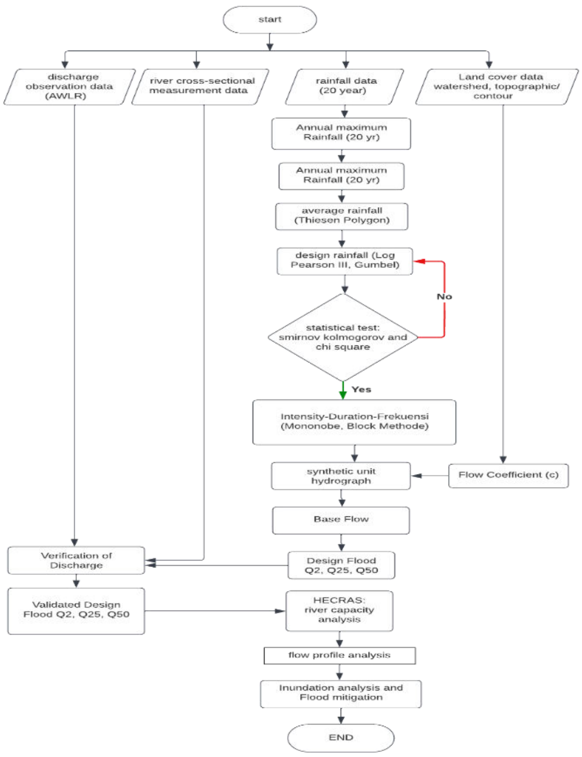

Figure-2. Research stages.

The analysis is carried out in a coherent flow and stages to get the expected results and objectives. The steps taken are data collection, hydrological analysis, river cross-sectional capacity analysis and alternative solutions to problems.

Data Consistency Test

This data consistency test is carried out to see the correctness of the data obtained from field observations with several changing factors that allow recording errors

ARPN Journal of Engineering and Applied Sciences

to occur, which will later affect trends in rain data recording. The multiple mass curve test will be used in the data consistency test to make the rain data feasible. Multiple mass curve tests were carried out at adjacent rain stations. Stream flow changes are generally due to climate variability and human activities. To better analyze the contribution of effective factors towards runoff changes, the double mass curve method was applied (Searcy & Hardison, 1960**;** Abdollah Pirnia *et al.*, 2019; (Gao *et al*., 2013)

Analysis of Annual Maximum Daily Rainfall

The annual maximum daily rainfall is defined as an extreme instance, with critical duration for a river basin, state, or region, with immediate consequences to agriculture, soil conservation, roads, dams, and drainage (Willems *et al*., 2012, de Carvalho J. R. P. 2014)

Calculate annual maximum daily rainfall by sorting data one by one each year from all existing rain stations to determine the highest rainfall data in a rain station area on each station. Then the maximum rain at other stations is taken from rain data that occurred on the same date as the maximum rain for the reference station. The annual maximum regional rainfall is obtained from the sum of the multiplication of rainfall in each rain station with the ratio of the area of the rain station. In this study, the area ratio was obtained by weighting using the Thiessen polygon method (Xue. F, 2019).

The Thiessen method divides a region into subregions centered on each precipitation gauge. The fraction of each Thiessen subregion contributing to each subbasin can be computed, and the weighted averages can be used to estimate the MAP for each subbasin (Xue.F, 2019).

RESULTS AND DISCUSSIONS

Hydrological Analysis

Annual Maximum Rainfall Analysis

Data consistency testing has been carried out, and then the next step is to determine the annual maximum rainfall (Xue. F, 2019). Each rain station has a different coverage area; in this case, the Thiessen polygon method is used to determine the ratio of the area of each rain station. The following results from calculating the area ratio using the Thiessen polygon.

Then after dividing the area and weighting, the Thiessen coefficient can be calculated. The following are the results of calculating the area ratio shown in Table-1 and the calculation of Regional Average Rainfall shown in Table-2.

Table-1. Thiessen coefficient.

Rain Station	Area Code	Area Km^2	Thiessen coefficient (Kr)	Influence Percentage (%)
Kraksan	I	1.081	0.005	0.52
Pajarakan	II	9.321	0.045	4.48
Adibiyo	III	2.507	0.012	1.21
Jati Ampuh	IV	11.420	0.055	5.49
Pekalen	V	4.244	0.020	2.04
Condong	VI	22.987	0.111	11.06
Jurangjero	VII	11.081	0.053	5.33
Segaran	VIII	42.584	0.205	20.48
Tiris	IX	32.261	0.155	15.52
Kertosuko	X	11.743	0.056	5.65
Krucil	XI	3.322	0.016	1.60
Bermi	XII	55.354	0.266	26.62
Sum		207.904	1.000	100.00

ARPN Journal of Engineering and Applied Sciences

Table-2. Calculation of regional average rainfall using the Thiessen Polygon Method.

Year	Rainfall (mm)												Sum
	STA. I	STA. II	STA. III	STA. IV	STA. V	STA. VI	STA. VII	STA. VIII	STA IX	STA. X	STA. XI	STA. XII	
1	0.603	6.187	1.580	7.306	1.715	11.388	6.289	18.434	33.672	6.213	2.237	36.210	131.833
2	0.910	4.394	1.447	4.120	3.001	17.690	8.261	23.555	18.620	13.273	5.641	96.647	197.559
3	0.754	3.587	1.025	3.351	1.307	6.744	3.624	17.410	13.500	8.246	2.541	41.268	103.357
4	0.416	6.815	2.038	8.624	3.062	14.042	6.609	33.796	19.396	5.479	1.742	31.417	133.435
5	0.567	3.811	1.290	4.339	1.960	11.830	5.490	20.278	13.965	6.495	1.806	29.287	101.118
6	0.624	4.259	1.230	4.834	1.654	9.840	5.596	18.434	14.741	7.795	1.933	26.891	97.831
7	0.717	3.587	1.025	4.394	2.103	12.936	5.277	32.772	27.155	5.366	1.438	27.157	123.927
8	0.801	2.780	0.904	5.328	1.633	8.735	6.609	17.410	13.189	7.625	3.356	25.826	94.196
9	1.040	4.304	1.170	5.383	1.470	8.735	8.528	12.085	9.931	6.495	2.157	45.262	106.559
10	0.775	4.304	1.483	5.383	1.592	10.835	12.046	18.434	14.741	5.479	1.534	35.411	112.017
11	0.530	4.035	0.989	3.845	1.531	9.619	10.766	28.675	23.120	7.060	2.892	24.495	117.559
12	0.650	3.138	0.989	5.273	2.205	10.835	9.487	18.844	14.896	7.230	2.780	39.138	115.466
13	0.941	3.362	1.350	4.944	1.797	10.725	7.728	16.591	14.120	8.020	3.100	43.931	116.610
14	0.936	6.277	2.038	7.416	2.756	13.599	12.205	24.579	19.396	9.320	1.566	46.327	146.414
15	0.634	4.035	1.905	5.383	2.001	11.388	5.223	35.230	27.465	10.167	1.933	25.027	130.392
16	1.014	4.035	0.916	4.449	1.878	11.056	5.277	30.519	24.517	9.941	2.029	32.216	127.847
17	0.530	4.035	0.989	7.525	2.429	12.051	10.127	31.133	25.448	7.512	2.221	26.092	130.094
18	0.655	5.739	1.712	6.152	2.287	11.830	7.195	36.868	29.793	7.230	1.486	34.346	145.293
19	0.567	6.277	1.145	6.866	1.654	8.182	4.584	27.037	22.500	6.213	1.278	20.767	107.069
20	0.613	2.286	1.073	5.383	1.429	8.071	13.325	22.531	35.999	7.060	1.182	28.755	127.709

Source: analysis result (2022).

The area ratio results obtained using the Thiessen polygon method can be seen in how large the coverage area of each rain station is. The following is a recapitulation of the annual maximum regional rainfall for 20 years.

Table-3. Recapitulation of annual maximum regional rainfall (mm).

Year	Rainfall (mm)	
	Arithmetic	Thiessen
2001	126.333	131.833
2002	176.333	197.559
2003	99.667	103.357
2004	131.083	133.435
2005	101.083	101.118
2006	102.083	97.831
2007	110.333	123.927
2008	106.917	94.196
2009	112.083	106.559
2010	114.917	112.017
2011	116.250	117.559
2012	116.167	115.466
2013	121.750	116.610
2014	149.417	146.414
2015	125.917	130.392
2016	122.000	127.847
2017	126.250	130.094
2018	132.000	145.293
2019	104.583	107.069
2020	116.500	127.709

Source: Analysis Results (2022)

The results of the two methods can be seen that the maximum yield of the regional average rainfall is the Thiessen polygon method, so for further hydrological analysis the Thiessen polygon method is used.

Design Rainfall Analysis

It is necessary to input design rainfall data based on regional rainfall behavior to determine the design flood discharge in a river. There are many methods for calculating design rainfall, including the Gumbel method, Pearson log type III, Gama I, etc. (Farooq, M., *et al.* 2018, Islam, A., & Sarkar, B. 2020; Bhat, M. S., *et al.* 2019). So that the design rainfall calculation in this study uses the Log Pearson III frequency distribution with return periods of 2, 5, 10, 25, and 50 years. Below are the results of the calculation analysis.

Table-4. Calculation of design rainfall with Log Pearson III.

Return Period (year)	Design of Rainfall (mm)
2	118,093
5	138,180
10	152,679
25	172,279
50	187,743

Source: Analysis Results (2022)

Statistic Test

The methods that can be used in this test are Chi-squared and Smirnov-Kolmogorov (Soewarno, 1995;

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Rojas-Lima *et al*., 2019). These two methods will look at the largest deviation that occurs in a distribution and resolve whether it is still within reasonable limits for the deviation that occurs (Table-5).

Table-5. Distribution suitability test.

Distribution	X^2 calculated	ΔPmax	Chi Square-test		Smirnov Kolmogorov-test	
			α = 1% X^2_{cr} = 9,21	α = 5% X^2_{cr} = 5,991	α = 1% ΔP_{cr} = 0,352	α = 5% ΔP_{cr} = 0,294
Log Pearson	1.000	0,013	accepted	accepted	accepted	accepted

Hourly Precipitation

Several methods of determining hourly Precipitation include Mononobe (Faradiba, F. 2021, Kang, M. S., *et al*. 2013, Kang, H., 2020), and Alternating Block Method/ABM (Wright, D. B., *et al*. 2013). however, in this study, the Mononobe method was used. In this calculation, five return periods will be carried out. Table-6 shows the results of calculations using the Mononobe method for 5 return periods 2th, 5th, 10th, 25th, and 50th.

Table-6. Analysis of hourly Precipitation by the Mononobe method.

hour	Hourly Precipitation (mm/day)				
	2th	**5th**	**10th**	**25th**	**50th**
1	23,96	29,73	32,95	36,49	38,84
2	6,23	7,73	8,56	9,49	10,09
3	4,37	5,42	6,01	6,65	7,08
4	3,48	4,32	4,78	5,30	5,64
5	2,94	3,64	4,04	4,47	4,76
6	2,57	3,19	3,53	3,91	4,16
Effective Rainfall (mm/day)	43,54	54,02	59,87	66,32	70,57

Design Floods Discharge Analysis

The Nakayasu synthetic unit hydrograph (SUH) method is used to analysis of Design Floods Discharge (Sutapa, I. W *et al*. 2018). Although HSS Nakayasu is applied to rivers in Japan, many flood studies in Indonesia use SUH Nakayasu (Yani, D. A, *et al*. 2018). The calculation of flood discharge is divided into 3 sub-basin: upstream, middle, and downstream.

Table-7. Recapitulation of flood discharge hydrograph design by synthetic Unit Nakayasu at Pekalen Watershed.

	Qp (m³/s)				
Tr (year)	**2**	**5**	**10**	**25**	**50**
Upstream Qp (m³/s)	249,81	309,37	342,565	379,217	403,390
Middle Qp (m³/s)	274,41	339,88	376,378	416,672	443,248
Downstream Qp (m³/s)	299,61	371,15	411,025	455,052	484,090

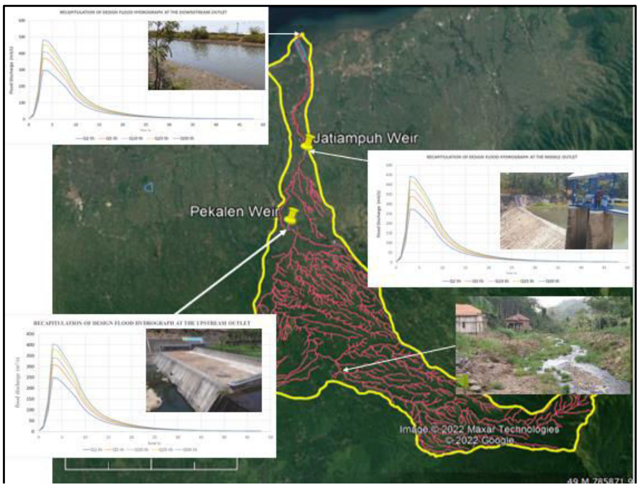

Figure-2. Hydrograph of flood discharge in the upstream, middle, and downstream of the Pekalen watershed.

DISCUSSIONS

Analysis of River Cross-sectional Capacity in Existing Conditions

Bankful capacity analysis is used to determine the river's capacity based on hydrological analysis and the latest cross-sectional measurements of the river. The flood discharge data input used in the analysis is a flood with a return period of 25 years (Q_{25}). In this study, analysis of flood distribution uses HEC-RAS software version 6.2, developed by The Hydrologic Engineering Center (Brunner 2016).

HEC-RAS is used to model steady and unsteady flows in 1 dimension, 2 dimensions, or a combination to conduct simulations of flood inundation, sediment transport, and water quality analysis (Leon & Goodell 2016). HEC-RAS mathematical modeling includes schematization of the existing network system, selection of conditions limits and initial conditions, as well as system design simulations or models with various alternatives (US Army Corps of Engineers, 2022)

River hydraulics analysis was carried out using the HEC-RAS 5 application with steady flow simulation and using a flood discharge design for a Q_{50}-year return period (Munna, G.M, *et al.* 2021, Khalfallah, C.B, 2021, Mohammed, H.S., 2018). In the Government Regulation of the Republic of Indonesia Number 38 of 2011 concerning rivers, article 42, paragraph 1 states that the identification of flood inundation that occurred before and or modeling of inundation with a planned discharge of 50 (fifty) years, so that cross-sectional inspection is used Q_{50} year.

Figure-3 shows that runoff occurs, the average height of runoff that occurs in Pekalen River from the upstream, middle, and downstream river sections is as high as 1.18 m, and there are as many as 163 stake sections that experience flood runoff in the Pekalen River section. Recapitulation of embankments that experienced runoff and which are safe are presented in Table-9.

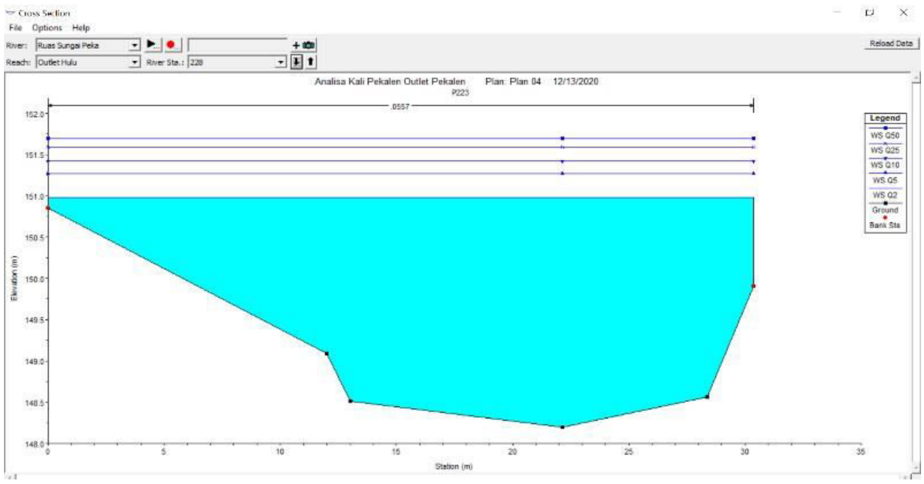

Figure-3. The condition of the cross-section of the river experiencing runoff (Cross section 223).

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Table-8. Recapitulation of HEC-RAS analysis results of downstream river section existing conditions.

River Cross Section (RCS)	CP	El. River Bank		FWL (Q50th)	Freeboard		NOTE	
		LEFT	RIGHT		LEFT	RIGHT	LEFT	RIGHT
		(m)	(m)	(m)	(m)	(m)		
Downstream RCS	104	30,85	28,91	24,75	6,1	4,16	SAFE	SAFE
Downstream RCS	103	30,85	28,91	24,32	6,53	4,59	SAFE	SAFE
Downstream RCS	102	29,43	28,78	22,69	6,74	6,09	SAFE	SAFE
Downstream RCS	101	28,61	26,84	23,05	5,56	3,79	SAFE	SAFE
Downstream RCS	100	24,12	26,46	22,99	1,13	3,47	SAFE	SAFE
Downstream RCS	99	28,15	26,48	22,64	5,51	3,84	SAFE	SAFE
Downstream RCS	98	26,28	24,82	22,29	3,99	2,53	SAFE	SAFE
Downstream RCS	97	25,06	24,51	22,39	2,67	2,12	SAFE	SAFE
Downstream RCS	96	21,81	25,19	22,25	-0,44	2,94	*OVERFLOW*	SAFE
Downstream RCS	95	22,34	27,83	20,52	1,82	7,31	SAFE	SAFE
Downstream RCS	94	20,49	25,61	17,66	2,83	7,95	SAFE	SAFE
Downstream RCS	93	18,55	23,17	18,76	-0,21	4,41	*OVERFLOW*	SAFE
Downstream RCS	92	20,8	21,26	18,63	2,17	2,63	SAFE	SAFE
Downstream RCS	91	23,18	20,77	18,38	4,8	2,39	SAFE	SAFE
Downstream RCS	90	19,31	18,34	18,22	1,09	0,12	SAFE	SAFE
Downstream RCS	89	18,7	20,62	18,14	0,56	2,48	SAFE	SAFE
Downstream RCS	88	20,33	21,47	17,29	3,04	4,18	SAFE	SAFE
Downstream RCS	87	17,69	16,45	17,17	0,52	-0,72	SAFE	*OVERFLOW*
Downstream RCS	86	17,74	16,41	17,12	0,62	-0,71	SAFE	*OVERFLOW*
Downstream RCS	85	17,33	16,23	16,79	0,54	-0,56	SAFE	*OVERFLOW*
Downstream RCS	84	16,39	15,68	16,36	0,03	-0,68	SAFE	*OVERFLOW*
Downstream RCS	83	21,26	16,49	15,95	5,31	0,54	SAFE	SAFE
Downstream RCS	82	20,07	15,72	15,91	4,16	-0,19	SAFE	*OVERFLOW*
Downstream RCS	81	17,01	17,07	15,81	1,2	1,26	SAFE	SAFE
Downstream RCS	80	15,44	14,84	15,53	-0,09	-0,69	*OVERFLOW*	*OVERFLOW*
Downstream RCS	79	17,1	15,07	15,27	1,83	-0,2	SAFE	*OVERFLOW*
Downstream RCS	78	17,14	13,77	15,17	1,97	-1,4	SAFE	*OVERFLOW*
Downstream RCS	77	14,27	12,55	15,14	-0,87	-2,59	*OVERFLOW*	*OVERFLOW*
Downstream RCS	76	14	15,3	14,97	-0,97	0,33	*OVERFLOW*	SAFE
Downstream RCS	75	14,16	13,75	14,95	-0,79	-1,2	*OVERFLOW*	*OVERFLOW*
Downstream RCS	74	15,4	13,44	14,91	0,49	-1,47	SAFE	*OVERFLOW*
Downstream RCS	73	17,84	15,11	14,49	3,35	0,62	SAFE	SAFE
Downstream RCS	72	17,98	15,33	12,92	5,06	2,41	SAFE	SAFE
Downstream RCS	71	15,22	12,94	12,89	2,33	0,05	SAFE	SAFE
Downstream RCS	70	17,56	15,43	12,3	5,26	3,13	SAFE	SAFE
Downstream RCS	69	11,98	14,22	12,31	-0,33	1,91	*OVERFLOW*	SAFE
Downstream RCS	68	11,6	13,66	12,27	-0,67	1,39	*OVERFLOW*	SAFE

ARPN Journal of Engineering and Applied Sciences

Downstream RCS	67	16,32	14,57	12,12	4,2	2,45	SAFE	SAFE
Downstream RCS	66	13,12	13,76	11,73	1,39	2,03	SAFE	SAFE
Downstream RCS	65	12,28	12,13	11,56	0,72	0,57	SAFE	SAFE
Downstream RCS	64	12,68	12,06	10,97	1,71	1,09	SAFE	SAFE
Downstream RCS	63	10,12	11,62	10,67	-0,55	0,95	*OVERFLOW*	SAFE
Downstream RCS	62	9,85	11,86	10,6	-0,75	1,26	*OVERFLOW*	SAFE
Downstream RCS	61	11,51	12,37	10,47	1,04	1,9	SAFE	SAFE
Downstream RCS	60	10,53	12,8	10,17	0,36	2,63	SAFE	SAFE
Downstream RCS	59	10,53	9,43	10,04	0,49	-0,61	SAFE	*OVERFLOW*
Downstream RCS	58	9,78	12,33	10,03	-0,25	2,3	*OVERFLOW*	SAFE
Downstream RCS	57	13,89	11,22	9,71	4,18	1,51	SAFE	SAFE
Downstream RCS	56	13,54	11,62	9,61	3,93	2,01	SAFE	SAFE
Downstream RCS	55	9,88	9,89	9,69	0,19	0,2	SAFE	SAFE
Downstream RCS	54	10,91	11,75	9,65	1,26	2,1	SAFE	SAFE
Downstream RCS	53	10,73	12,98	9,23	1,5	3,75	SAFE	SAFE
Downstream RCS	52	8,24	10,11	9,33	-1,09	0,78	*OVERFLOW*	SAFE
Downstream RCS	51	10,44	10,42	9,3	1,14	1,12	SAFE	SAFE
Downstream RCS	50	8,55	11,75	9,16	-0,61	2,59	*OVERFLOW*	SAFE
Downstream RCS	49	10,33	11,33	8,83	1,5	2,5	SAFE	SAFE
Downstream RCS	48	9,48	8,37	8,92	0,56	-0,55	SAFE	*OVERFLOW*
Downstream RCS	47	15,54	9,02	8,61	6,93	0,41	SAFE	SAFE
Downstream RCS	46	9,41	8,56	8,72	0,69	-0,16	SAFE	*OVERFLOW*
Downstream RCS	45	6,63	7,71	8,65	-2,02	-0,94	*OVERFLOW*	*OVERFLOW*
Downstream RCS	44	7,34	7,28	8,58	-1,24	-1,3	*OVERFLOW*	*OVERFLOW*
Downstream RCS	43	7,17	6,41	8,56	-1,39	-2,15	*OVERFLOW*	*OVERFLOW*
Downstream RCS	42	8,14	6,59	8,32	-0,18	-1,73	*OVERFLOW*	*OVERFLOW*
Downstream RCS	41	8,08	10,64	8,12	-0,04	2,52	*OVERFLOW*	SAFE
Downstream RCS	40	7,7	9,22	7,95	-0,25	1,27	*OVERFLOW*	SAFE
Downstream RCS	39	7,81	9,21	7,99	-0,18	1,22	*OVERFLOW*	SAFE
Downstream RCS	38	5	8,88	7,97	-2,97	0,91	*OVERFLOW*	SAFE
Downstream RCS	37	8,41	9,16	7,67	0,74	1,49	SAFE	SAFE
Downstream RCS	36	6,88	8,92	7,28	-0,4	1,64	*OVERFLOW*	SAFE
Downstream RCS	35	6,87	8,49	7,47	-0,6	1,02	*OVERFLOW*	SAFE
Downstream RCS	34	7,75	8,07	6,87	0,88	1,2	SAFE	SAFE
Downstream RCS	33	5,62	7,13	6,48	-0,86	0,65	*OVERFLOW*	SAFE
Downstream RCS	32	7,57	7,39	6,57	1	0,82	SAFE	SAFE
Downstream RCS	31	5,95	7,93	5,86	0,09	2,07	SAFE	SAFE
Downstream RCS	30	6,74	5,53	5,96	0,78	-0,43	SAFE	*OVERFLOW*
Downstream RCS	29	6,64	3,86	5,9	0,74	-2,04	SAFE	*OVERFLOW*
Downstream RCS	28	6,23	4,26	5,8	0,43	-1,54	SAFE	*OVERFLOW*
Downstream RCS	27	6,26	6,09	5,82	0,44	0,27	SAFE	SAFE
Downstream RCS	26	5,94	5,28	5,52	0,42	-0,24	SAFE	*OVERFLOW*

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Downstream RCS	25	5,83	3,99	5,46	0,37	-1,47	SAFE	*OVERFLOW*
Downstream RCS	24	5,98	5,58	4,95	1,03	0,63	SAFE	SAFE
Downstream RCS	23	5,52	4,96	4,99	0,53	-0,03	SAFE	*OVERFLOW*
Downstream RCS	22	3,22	3,82	4,87	-1,65	-1,05	*OVERFLOW*	*OVERFLOW*
Downstream RCS	21	2,79	2,67	4,7	-1,91	-2,03	*OVERFLOW*	*OVERFLOW*
Downstream RCS	20	4,95	2,75	4,82	0,13	-2,07	SAFE	*OVERFLOW*
Downstream RCS	19	3,99	3,8	4,48	-0,49	-0,68	*OVERFLOW*	*OVERFLOW*
Downstream RCS	18	2,09	2,8	4,54	-2,45	-1,74	*OVERFLOW*	*OVERFLOW*
Downstream RCS	17	1,94	2,66	4,44	-2,5	-1,78	*OVERFLOW*	*OVERFLOW*
Downstream RCS	16	2,82	1,78	4,11	-1,29	-2,33	*OVERFLOW*	*OVERFLOW*
Downstream RCS	15	2,99	1,91	4,09	-1,1	-2,18	*OVERFLOW*	*OVERFLOW*
Downstream RCS	14	2,38	2,22	3,72	-1,34	-1,5	*OVERFLOW*	*OVERFLOW*
Downstream RCS	13	1,89	1,59	3,66	-1,77	-2,07	*OVERFLOW*	*OVERFLOW*
Downstream RCS	12	1,72	2,65	3,45	-1,73	-0,8	*OVERFLOW*	*OVERFLOW*
Downstream RCS	11	1,13	1,73	3,41	-2,28	-1,68	*OVERFLOW*	*OVERFLOW*
Downstream RCS	10	0,64	1,71	3,4	-2,76	-1,69	*OVERFLOW*	*OVERFLOW*
Downstream RCS	9	0,71	1,82	3,32	-2,61	-1,5	*OVERFLOW*	*OVERFLOW*
Downstream RCS	8	0,48	1,14	3,27	-2,79	-2,13	*OVERFLOW*	*OVERFLOW*
Downstream RCS	7	0,5	1,23	3,19	-2,69	-1,96	*OVERFLOW*	*OVERFLOW*
Downstream RCS	6	0,96	1,56	3,04	-2,08	-1,48	*OVERFLOW*	*OVERFLOW*
Downstream RCS	5	0,79	1,92	2,92	-2,13	-1	*OVERFLOW*	*OVERFLOW*
Downstream RCS	4	0,24	1,6	2,14	-1,9	-0,54	*OVERFLOW*	*OVERFLOW*
Downstream RCS	3	1,76	1,04	2,38	-0,62	-1,34	*OVERFLOW*	*OVERFLOW*
Downstream RCS	2	1,9	2,21	1,75	0,15	0,46	SAFE	SAFE
Downstream RCS	1	1,33	1,51	1,89	-0,56	-0,38	*OVERFLOW*	*OVERFLOW*
Downstream RCS	0	1,65	1,54	1,7	-0,05	-0,16	*OVERFLOW*	*OVERFLOW*

Source: Analysis result (2022).

Based on the results of hydraulic analysis on the river cross-section, information was obtained that there were around 163 river cross-sections that could cause flooding in the upstream, middle, and downstream parts.

Alternative Solutions to Flood Control

To overcome the problem of flooding that occurs, there are several alternative solutions, including installing an embankment on the Pekalen River section; in this case, the embankment used as a type of embankment or you can also use a Concrete Sheet Pile (CCSP). The choice of embankment type needs to be adjusted to the geotechnical conditions of the subgrade and land availability. For soil investigations, a cone penetration test can be used on river sections that can potentially cause runoff. However, efforts to handle watersheds in the upstream and middle areas must be handled structurally and non-structurally. Structurally, it is necessary to normalize or widen the river in sections that allow it, but there is a lot of trade in the riverbanks for the downstream conditions. While erosion and sedimentation control can be used by checking dams on tributaries about 10 m wide, for tributaries that are about 3-4 m wide, it is necessary to make gully plug sedimentation controllers. Non-structural efforts, such as lining trees with fruit trees with stilt roots that do not harvest the wood, will be more environmentally friendly, such as durian, avocado, trembesi (Samanea Saman), etc., can be implemented in the upstream Pekalen watershed.

CONCLUSIONS

Based on the results of hydrology and hydraulics calculations simulated in HEC-RAS, it was found that the existing capacity of the Pekalen River section could not accept the Q_{50} year of 484,090 m^3/s. In the upstream section, 163 stake sections from upstream, middle and downstream river sections experienced runoff, with a total length of 18,847 km of river section that experienced runoff. One effective alternative solution to the flooding problem is to install Concrete Sheet Pile (CCSP) embankments at each stake segment that experiences runoff. Besides that, efforts are being made to handle non-structural measures such as erosion control using vegetation, socialization of flood plains and a flood early warning system.

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