STUDY OF FLOOD CONTROL AND MORPHOLOGY OF THE SARIO RIVER IN MANADO CITY

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Abstract. Sario River is one of the rivers that contributes to flooding in Manado City. The floods that occurred caused a lot of loss and damage to facilities and infrastructure, as well as paralyzing the activities of residents. The causes are high rainfall, land conversion in the upstream part, silting occurring due to sedimentation and garbage, as well as river narrowing due to occupation. The condition of the downstream Sario Riverbank is very densely populated, so in this study, the solution for flood control is the construction of a floodway under the road that leads to the sea. The construction of this floodway aims to drain some of the water discharge in the Sario River during the Q25 flood discharge. The methodology used is hydrological analysis, hydraulic analysis, and sedimentation analysis. Hydrological analysis was carried out to calculate the design flood discharge, and hydraulic analysis was carried out using the HEC-RAS 6.1 1D software. This study simulates the water level and discharge after the construction of the floodway under the road, as well as the degradation and degradation that occurs. Based on hydraulic analysis, the presence of a floodway can reduce flood discharge downstream of the river by around 65.35%. From the results of the study, it was also found that the Sario River had sedimentation in several sections, indicating that normalization or dredging of the riverbed was needed.

1. Introduction

Manado City is the capital of North Sulawesi Province, with landscape conditions in the form of land and hills. In the Manado City area, there are several rivers which generally flow from hilly areas and empties into the beach in Manado Bay. The historical floods in Manado City are that in 2014 there was a flash flood, and in 2017, 2019, and 2021 the rivers in Manado City overflowed and caused flooding. One of the contributors to the flood in Manado City is the Sario River. The Sario Subdistrict and Wanea Subdistrict in Manado City are areas that often experience flooding every year due to the overflow of the Sario River. The Sario River itself is no longer able to accommodate the discharge because the capacity of the Sario River has reduced its capacity. This is due to the narrowing of the body and banks of the Sario River due to the impact of increasing population and the development of the Manado City area, as well as silting due to sediment and garbage in the Sario River. As a result of the overflow of the Sario River, flooding occurred in the area. The flooding that occurred paralyzed residents' activities and caused losses and damage to community facilities and infrastructure.

2. Problem Identification

Floods that occur are caused by high rainfall and landslides that occur in the Citraland residential area, where landslide material enters into Sario River so that the capacity of the Sario River becomes small and is unable to accommodate the flowing discharge. Silting of the river occurs due to sedimentation and garbage. The silting that occurs can reduce the capacity of the Sario river. The downstream part of the river often experiences overflow from the Sario river due to the river embankment not being high enough and the river narrowing due to occupation. In some sections of the Sario River, there are buildings jutting into the river. Sedimentation occurred in the mouth of the Sario River. Because land acquisition for the construction of flood control embankments on the Sario River has not been implemented and it still takes a long time, it is necessary to make a proposal for handling flood control, namely by building a floodway under the Bethesda road.

3. Overview of the Study

The Sario watershed is located in the administrative area of Manado City and Minahasa Regency, North Sulawesi Province. The Sario watershed has an area of 26.54 km2 and the length of the main river is 10,906 km. The Sario River has its head at Mount Mahawu at an elevation of about 1170 m and empties into the bay of Manado, which is located at an elevation of around El. +0.0. The Sario River is located in Manado City and Minahasa Regency. Manado City is located at the northern tip of Sulawesi Island and is the largest city in North Sulawesi as well as the capital city of North Sulawesi Province. Geographically, it is located between 10 30' - 10 40' North Latitude and 1240 40' 00" - 1260 50' East Longitude In this study, the study location for construction work on the construction of the Sario River flood control building is downstream of the Sario River.

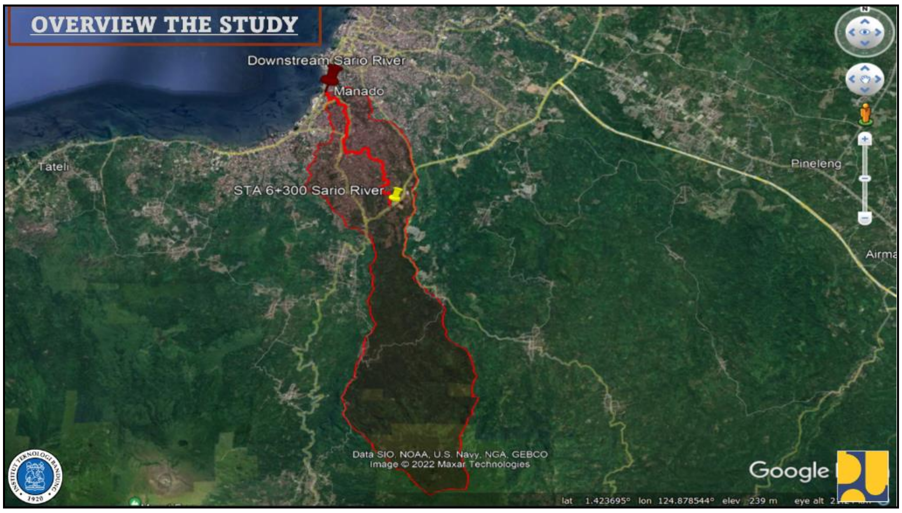

Figure 1. Sario River Basin.

4. Objective and Purpose

The objective of this research is to obtain a study related to flood control in the Sario River with the construction of a floodway and changes in the morphology of the Sario River that occur downstream of the Sario River.

The purpose of this research is to carry out a hydrological analysis to obtain a planned flood discharge to evaluate hydraulic parameters, to perform hydraulics modeling using HEC-RAS software to see changes in flow patterns. changes in sediment rates, as well as river morphology before and after the construction of the floodway, as well as providing recommendations regarding solutions for flood control and river morphology in the section under review, namely the downstream of the Sario River.

5. Research Method

To obtain the information needed for numerical modeling, it is necessary to collect topographic data such as the Digital Elevation Model (DEM), overburden, and Harmonized World Soil Database (HWSD) maps, and then hydrological data such as rainfall data are collected from four rain stations

for 19 (nineteen) years. Topographic and hydrological data were analyzed to obtain a river hydrograph.
A numerical model for hydraulic and sediment transport analysis uses hydrograph as the upper boundary. River geometry data is obtained from shop drawings, and the field data that was collected is used to model the river bed gradation and sediment rating curve.
The general framework of thought used as a methodology in this study is a literature review, data collection, data processing, analysis, conclusions, and suggestions.

6. Result

6.1 Topographic Analysis

Topographic data is obtained in the form of DEM data from DEMNAS and Orthophoto, as well as land cover data. The data is processed to support the hydrological analysis process. By using GIS-based software, topographic data can be analyzed to produce watershed maps, composite CN values, and Thiessen polygon areas for each rain post. It is obtained that the area of the watershed is 26.54. km2, with a curve number of 74.95. Also, the coefficient for the Thiessen rainfall area method is presented in the following table:

Table 1. Thiessen coefficient for Sario watershed.

STATION	THIESSEN POLYGON AREA [KM^2]	THIESSEN COEFFICIENT
TIKALA - SAWANGAN	10.15	0.39
TIKALA RUMNEGKOR	2.19	0.08
MALALAYANG - KAKASKASEN	2.68	0.10
MALALAYANG - TINOOR	11.52	0.43
SUM	**26.54**	**1.00**

6.2 Hydrologic Analysis

6.2.1 Regional Planned Rainfall Analysis

Rainfall data around the location was collected in a span of about 19 years starting from 2002 to 2020 with the source of rain data from the Rain Recording Post owned by BWS Sulawesi I. Based on all the rain recording posts owned by BWS Sulawesi I, which are located around and affect the Sario watershed, there are four rain recording posts. The calculation of regional rainfall in the Sario watershed uses the Thiessen Polygon method with consideration of the rain station points that are less evenly distributed. From the results of the analysis of the area and weight of the Thiessen polygon of each rain recording post, it is then used for regional rainfall analysis. Regional rainfall each year is calculated from the rainfall at the highest rainfall from each post. The highest rainfall for each post does not occur on the same date.

Table 2. Regional Planned Rainfall Analysis in the Sario Watershed.

Year	Annual Maximum Daily Rainfall (mm)				Raverage (mm)
	Tikala - Sawangan	Tikala - Rumengkor	Malalayang Kakaskasen	Malalayang - Tinoor	
2002	100.70	77.90	152.00	43.00	78.97
2003	321.60	105.40	105.00	12.30	147.64
2004	120.40	79.00	80.00	14.00	66.73
2005	75.50	82.00	60.00	36.30	57.46
2006	203.70	57.20	177.00	75.60	133.32
2007	103.00	55.40	63.00	75.00	82.88
2008	130.80	82.10	80.00	74.10	97.04
2009	100.30	118.40	38.00	65.40	80.35
2010	123.00	104.50	65.00	101.70	106.37
2011	120.30	87.80	92.00	102.40	106.99
2012	110.00	111.50	42.00	96.80	97.52
2013	180.40	146.60	157.00	110.50	144.91
2014	170.70	183.00	145.00	184.00	174.89
2015	90.00	108.50	204.00	108.20	110.95
2016	90.70	76.20	95.00	90.30	89.76
2017	180.00	96.00	96.00	156.00	154.16
2018	76.00	78.00	100.00	108.10	92.52
2019	130.00	34.00	104.00	120.30	115.24
2020	121.00	72.00	76.00	134.80	118.39

6.2.2 Rainfall Design

Calculation of planned rainfall is carried out using frequency and probability distribution analysis. The method used in this study is the frequency distribution of Normal, Log Normal, Gumbel, and Log Person III. The results of this frequency analysis will be used as planned rainfall to obtain a planned flood hydrograph.

Table 3. Recapitulation of frequency distribution.

No	Return Period	Normal			Gumbel		Log Normal		Log Pearson III			
		w	KT	XT	KT	XT	KT	XT	z	k	KT	XT
1	2	1.18	0.00	108.22	-0.16	103.07	0.00	103.98	0.00	0.05	-0.05	102.44
2	5	1.79	0.84	134.56	0.72	130.74	0.84	132.99	0.84	0.05	0.82	132.26
3	10	2.15	1.28	148.35	1.30	149.07	1.28	151.27	1.28	0.05	1.31	152.51
4	25	2.54	1.75	163.05	2.04	172.22	1.75	173.52	1.75	0.05	1.85	178.74
5	50	2.80	2.05	172.54	2.59	189.39	2.05	189.61	2.05	0.05	2.22	198.79
6	100	3.03	2.33	181.08	3.14	206.44	2.33	205.34	2.33	0.05	2.55	219.29
7	200	3.26	2.58	188.89	3.68	223.42	2.58	220.88	2.58	0.05	2.87	240.43
8	1000	3.72	3.09	204.99	4.94	262.77	3.09	256.73	3.09	0.05	3.54	292.62

6.2.3 Distribution Conformity Test

The frequency distribution test is to determine whether the distribution can be accepted or rejected. The test was carried out using the chi-square and Smirnov-Kolmogorov methods and statistical parameters. From the test results, it can be seen that the frequency distribution that meets and is accepted is Log Person III.

Table 4. Recapitulation of conformity test.

Distribution Conformity Test	Normal	Gumbel	Log Normal	Log Pearson III
statistical parameters test	rejected	rejected	rejected	accepted
Smirnov Kolmogorov test	0.084 0.300 accepted	0.054 0.300 accepted	0.094 0.300 accepted	0.064 0.300 accepted
Chi Square test	1.263 5.992 accepted	1.789 5.992 accepted	0.737 5.992 accepted	0.737 5.992 accepted

6.2.4 Area Reduction Factor

It is assumed that the rainfall value obtained from the calculation occurs evenly throughout the watershed area. So a regional reduction factor is needed, also called the Area Reduction Factor (ARF). Because the area of the Sario watershed is known, the ARF used is 0.97. So, if the ARF value is multiplied by the planned rainfall value for each return period, the value of the Sario watershed planning rain will be obtained for each return period.

Table 5. Results of Analysis of Rainfall Plans for Return (ARF).

No.	Return Period	planned rainfall (mm) x ARF
1	2	99.36
2	5	128.29
3	10	147.94
4	25	173.38
5	50	192.82
6	100	212.72
7	200	233.22
8	1000	283.84

6.2.5 Hourly Rain Distribution

An analysis of the hourly rainfall distribution was carried out to form a hydrograph. The hourly rain distribution pattern uses the PSA-007 [1]. The distribution chosen is the distribution of 6 (six) hours, considering that rain in the research location rarely occurs for more than 6 (six) hours.

Table 6. Recapitulation of Hourly Rain Distribution

PSA 007	Hour	Rain Distribution							
		99.36	128.29	147.94	173.38	192.82	212.72	233.22	283.84
		2	5	10	25	50	100	200	1000
0	0	0	0	0	0	0	0	0	0
0.05	1	4.97	6.41	7.40	8.67	9.64	10.64	11.66	14.19
0.15	2	9.94	12.83	14.79	17.34	19.28	21.27	23.32	28.38
0.75	3	59.62	76.97	88.76	104.03	115.69	127.63	139.93	170.30
0.91	4	15.90	20.53	23.67	27.74	30.85	34.04	37.32	45.41
0.97	5	5.96	7.70	8.88	10.40	11.57	12.76	13.99	17.03
1	6	2.98	3.85	4.44	5.20	5.78	6.38	7.00	8.52

6.2.6 Infiltration Calculation

The amount of rain loss that seeps into the ground is difficult to estimate precisely, as an approach SCS-CN (Soil Conservation Service Curve Number) was developed by the US Department of Agriculture to determine rainfall infiltration depending on the type of soil in the Harmonized World Soil Database (HWSD). The CN value was analyzed using GIS software to obtain the amount of infiltration in the DAS Sario, which can be calculated using the SCS-Curve Number.

6.2.7 Calculation of the Planned Flood Discharge

Analysis of the calculation of the return flood discharge was carried out using the Nakayasu, SCS, ITB-1b, and ITB-2b methods, with the results as shown in the table below:

Table 7. Recapitulation of Planned Flood Discharge.

Tr	Nakayasu (Alpha=2.0)	SCS	ITB-1b	ITB-2b
2	109.05	66.14	66.42	107.03
5	153.29	96.17	96.76	150.59
10	184.23	117.34	118.17	181.13
25	226.65	146.83	148.03	223.18
50	259.07	169.36	170.85	255.32
100	292.26	192.42	194.21	288.22
200	326.44	216.18	218.27	322.11
1000	410.90	276.72	279.80	405.83

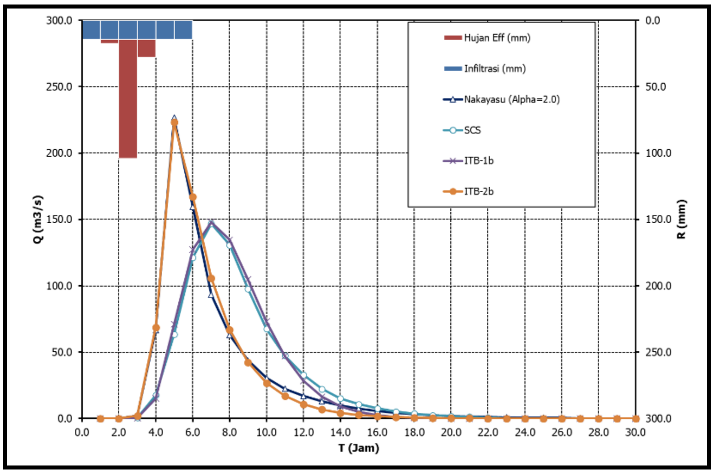

Figure 2. Flood hydrograph TR 25

6.2.8 Flood Discharge Analysis Using Creager

The calculation of flood discharge using the Creager method is used to select the flood hydrograph calculation method that will be used for analysis. The results of the Creager calculation for the Sulawesi region are as follows:

Table 8. The results of the calculation of flood discharge using the Creager method

Return Period	Coef. Creager	Q (m3/det)
2	10	101.93
20	25	254.82
100	35	356.75
200	40	407.71
PMF	90	917.35

Based on the results of the calculation of the return flood discharge, the results that are closest to the calculation of the discharge using the Creager method are ITB-2b for Q2, so the method chosen is ITB-2b.

6.3 Tidal Analysis

In order to be able to obtain the reference elevation value, it is necessary to have at least 15 (fifteen) days of measurement data for the hours. Tidal analysis in this study uses the Admiralty Method. Tidal observation data on Manado Beach was obtained from April 24, 2021, to May 8, 2021. The results of tidal measurements can be seen in the image below:

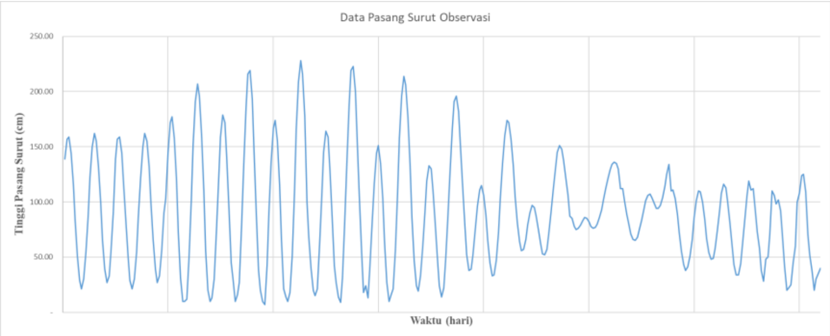

Figure 3. Tidal Observation.

From the results of the analysis :
HHWL : 1.45 m
MHWL : 1.37 m
MSL : 0.77 m
MLWL : 0.16 m
LLWL : 0.09 m
LAT : 0.01 m
and after being calibrated by making MSL = 0, the results is :
HHWL : 0.65 m
MHWL : 0.61 m
MSL : 0.00 m
MLWL : -0.61 m
LLWL : -0.68 m
LAT : -0.76 m
This HHWL will be used in the downstream boundary in hydraulic analysis using HEC-RAS.

6.4 Hydraulic Model Analysis
A hydraulic analysis was carried out to model flood conditions in the study area. Modelling was carried out with the help of HEC-RAS software for the 1D unsteady flow type. Based on the location, Manado City is the capital of the province so that the planned flood discharge of Q25 is used. In this study, the manning value will be used according to the Manning roughness table, which is 0.035.

6.4.1 Flood Modelling with HEC-RAS
For flood modeling using HEC-RAS software, two scenarios were carried out, namely scenario 1 before the floodway was built, and scenario 2 after the floodway was built.
The boundary conditions used in the modeling are adjusted to the conditions in the field. The boundary conditions in the modeling are for the planned flood discharge of the 25-year return period, obtained from the results of the previous hydrological analysis. The slope of the river is obtained from the longitudinal profile of the Sario River in the 2019 measurements. The tidal limit is obtained from the results of the calculated tidal analysis.

Scenario 1
By doing a test run using the planned flood discharge boundary conditions Q25 and tidal, with a manning roughness of 0.035, then for Scenario 1 conditions, the results of the hydraulic model are obtained as follows:

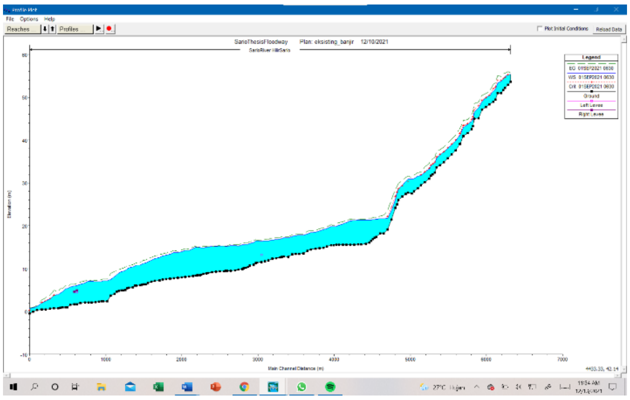

Figure 4. Long Section Scenario 1.

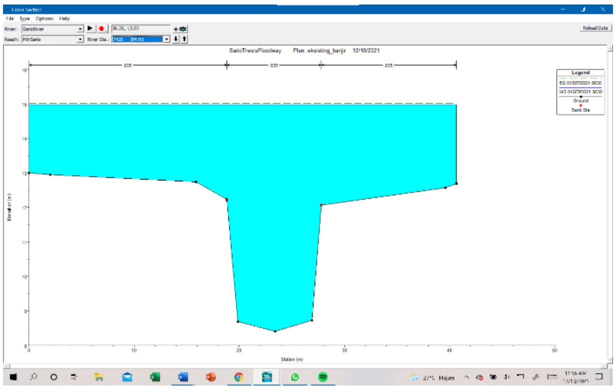

Figure 5. Cross Section 7426 Sario River Scenario 1 .

Scenario 2

The results of the test running for scenario 2 are as follows:

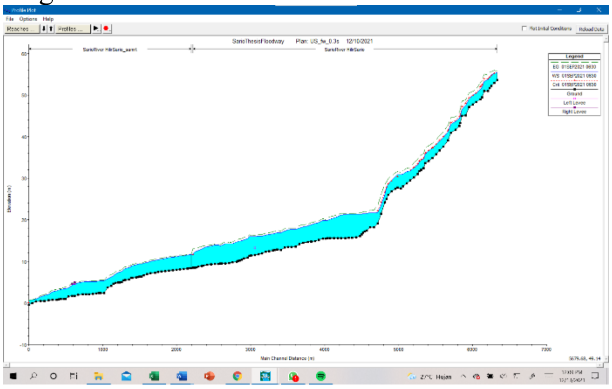

Figure 6. Long Section Sario River Scenario 2.

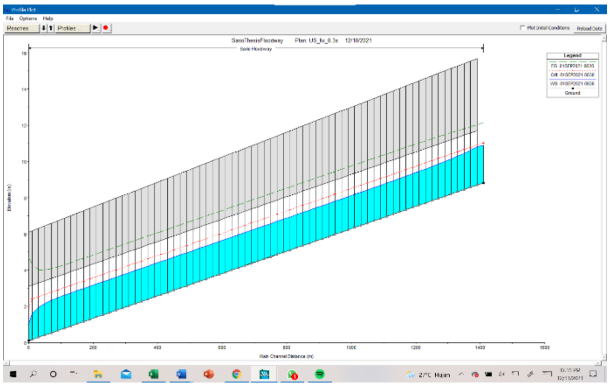

Figure 7. Long Section Floodway.

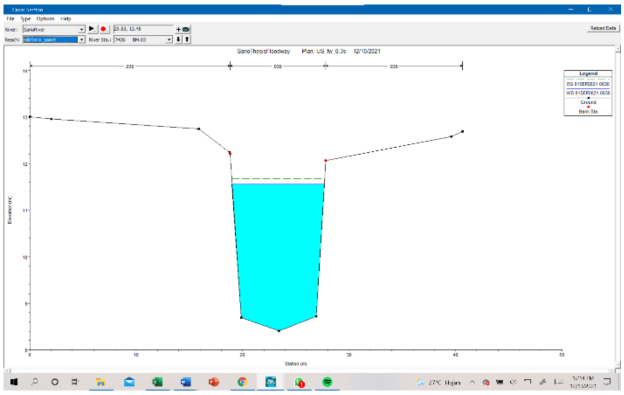

Figure 8. Cross Section 7426 Sario River Scenario 2.

From the results of the hydraulics model analysis for the discharge condition of the 25-year return period on September 1, 2021 at 06.30 at station 7426, which is the location after the floodway, it can be concluded that the construction of the floodway will reduce flooding by 65.35%.

Table *9*. The results of the analysis of the hydraulic model before and after the floodway was built.

	exsiting	After build floodway	Reduce flooding (%)
Q (m3/s)	101.47	35.16	65.35
high water level (m)	14.98	11.56	22.83

6.5 Sediment Transport Analysis

Sedimentation analysis was carried out to determine the sediment transport that occurred in the Sario River. This analysis is also carried out to determine the impact of normalization on changes in the channel bottom. Transport sedimentation analysis was performed using a model of quasi-unsteady flow with the help of HEC-RAS 6.1.0 software with a one-dimensional approach.

6.5.1 Sediment Transport Calibration

In the sediment transport calibration, what is done is the calculation of the rating curve in the field and compare it with the rating curve on existing empirical formulas, such as Engelund-Hansen, Ackers-White, and Yang.

Table ***10***. Comparison between discharge and rating curve in the field and the method used.

No	Q	Ct (ppm by weight)			Ct_obsv
		Engelund-Hansen	Ackers - White	Yang	
1	1.42	956.67	629.90	4,049.77	37.61
2	4.66	2,591.77	2,367.06	7,741.35	140.56
3	8.60	3,840.20	2,637.18	9,630.01	276.93
4	13.37	5,057.68	2,797.35	11,108.47	451.61
5	18.87	6,236.21	2,898.80	12,320.20	661.89
6	25.05	7,373.72	2,964.94	13,343.74	905.82
7	31.85	8,471.09	3,008.56	14,227.57	1,181.95
8	39.24	9,530.18	3,037.04	15,003.64	1,489.19
9	47.18	10,553.09	3,054.96	15,694.03	1,826.68
10	55.66	11,542.66	3,065.46	16,315.15	2,193.83
11	64.66	12,500.83	3,070.49	16,878.76	2,590.08

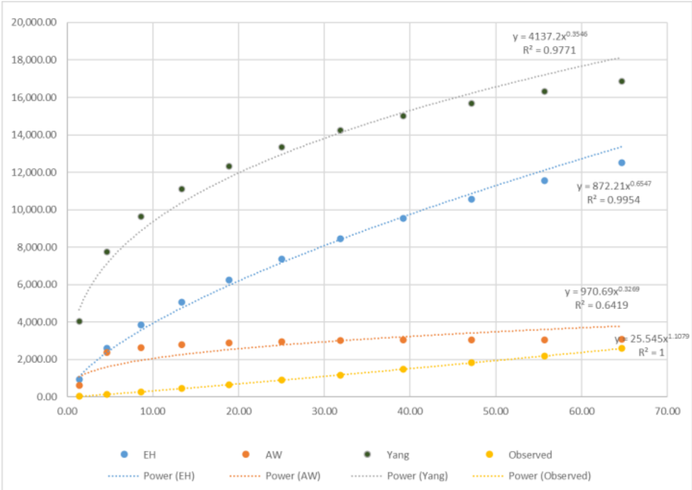

Figure 8. Graph of Relationship Between Q and Ct For Each Method.

From the graph above, it can be seen that the closest approach to the field count (observed) is the rating curve using the Ackers-White method. Then the method that will be used in the HEC-RAS modeling at the sediment boundary is the rating curve of the Ackers-White method.

6.5.2 Sediment Transport Modeling

The modelling that will be carried out for sediment transport is carried out for several simulations to obtain a pattern of river morphology changes to the transport function, river changes to events in the field Simulation 1, namely by input boundary, in the upstream uses daily discharge for 2 (two) years, and in the downstream uses tidal data. After that, it runs for 2 (two) years. Simulation 2 is with an input boundary in the upstream that uses daily discharge for 2 (two) years, and in the downstream it uses tidal data, then the river is normalized 1 (one) time in 2 (two) years. Simulation 3 is with an input boundary in the upstream that uses daily discharge for 2 (two) years, and in the downstream it uses tidal data, then the river is normalized 2 (two) times in 2 (two) years.

Simulation 1

Simulation with input boundary in the upstream uses daily discharge for 2 (two) years, and in the downstream it uses tidal data. After that, it runs for 2 (two) years.

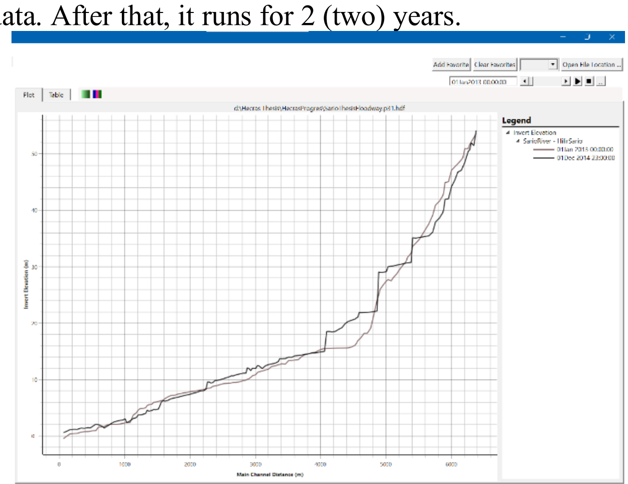

Figure 9. Long section of riverbed elevation changes for 2-year modelling.

In the picture above, it can be seen that with the modelling conditions for simulation 1, in the upstream part there is agradation and degradation, while in the middle part there is mostly agradation, and in the downstream part there is agradation and degradation.

6.5.3 Proposed Sediment Transport Handling
From the modeling results above, it can be suggested that for sediment handling at the Sario River review location, namely normalization, where dredging is carried out for the riverbed where sedimentation occurs.

Simulation 2
The simulation with input boundary in upstream uses daily discharge for 2 (two) years, and the downstream uses tidal data, then normalized 1 (one) time in 2 (two) years. The input for dredging is the elevation of the cross section that undergoes aggradation. And the dredging width is 6 meters, according to the average river width. After the input dredging is carried out and the model runs, the results are as below.

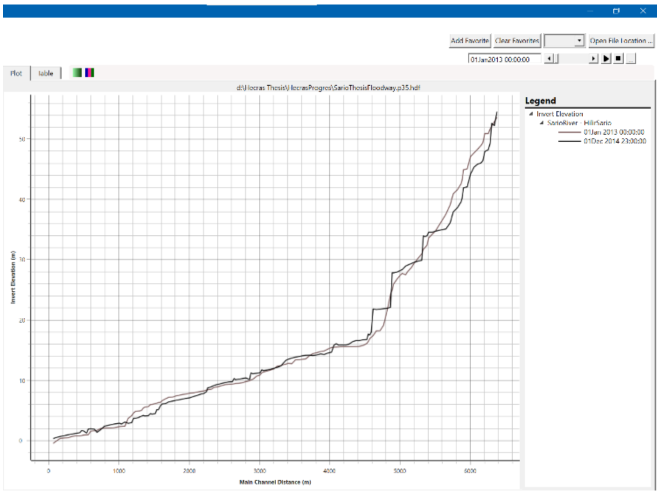

Figure 10. Long section for changes in river bed elevation after normalization once in 2 years.

From the picture above, it can be understood that the normalization was carried out on June 1, 2014, and for the base elevation using the initial geometry. From the modeling results after dredging, it can be seen that the total volume of material along the Sario River is 34,484,148 m^3. From the results of dredging once for a two-year condition, normalization can reduce 37% of the degraded material along the Sario River.

Simulation 3
The simulation with input boundary in upstream uses daily discharge for 2 (two) years, and the downstream uses tidal data, then normalized 2 (two) times in 2 (two) years. The input dredging is still the same as in simulation 1, but for this modeling, dredging is used twice in 2 years, namely dredging on June 01, 2013, and June 01, 2014.

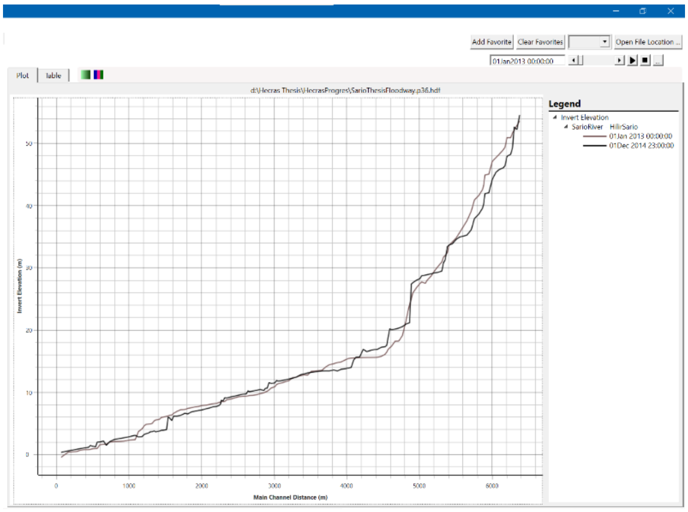

Figure 11. Long section for changes in river bed elevation after normalization twice in 2 years.

From the picture above, it can be seen that the normalization is done twice, for the base elevation and using the initial geometry. From the modeling results, after dringing is done, it can be seen that the total volume of material along the Sario River is 26,770,4297 m^3. From the results of dredging twice for a two-year condition, the normalization carried out can reduce 51.12% of the degraded material along the Sario River.
From the results of sediment transport analysis for daily discharge conditions for 2 years, namely 2013 and 2014, and dredging carried out on June 1, 2013 and June 1, 2014, it can be concluded that after dredging 1 time in 2 years of running, the model will reduce the degraded material by 37.04%. Meanwhile, if dredging is done twice in the 2 years of running the model, it will reduce the degraded material by 51.12%.

7. Conclusion
From the results of the analysis of the study, it can be concluded that:
1. The return flood discharge that passes through the Sario River for the 2, 5, 10, 25, 50, 100, 200, and 1000 year return periods is 107.03 m^3/s, 150.59 m^3/s, 181.13 m^3/s, 223.18 m^3/s, 255.32 m^3 /s, 288.22 m^3/s, 322.11 m^3/s, and 405.83 m/s, respectively.
2. Overall, almost along the downstream section of the Sario River, there is silting due to sedimentation.
3. After the floodway is completed, it can reduce flooding by up to 65.35% in the lower reaches of the Sario River.
4. The morphological condition of the Sario River after normalization was carried out in the upstream, which was considered to be degraded, while in the downstream it tended to occur.
5. After normalization, it is possible to reduce the sedimented material by 51.12% for the condition of two times dredging in the two years examined.

8. References
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