STUDY OF FLOOD EFFECT AS THE IMPACT OF GELIS RIVER MORPHOLOGICAL CHANGES IN KUDUS REGENCIES

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Abstract. Gelis River is located in the middle of Kudus Regencies. In January 2014, there was a flood which caused major losses. The flooding was caused by high rainfall and sedimentation in the downstream of the river, so that the storage capacity of the river is reduced. In addition, backwater occurs from the Wulan River which is the confluence of the Gelis River. During the flood incident in early 2021, 25 m long embankment broke and caused inundation in 4 (four) villages to a height of 1 m. Due to this, the Ministry of Public Works and Housing carried out the Construction of the Gelis River Flood Control in 2020-2021. However, in the planning study, an analysis of sedimentation has not been carried out. Therefore, the study discussed related to it. The purpose of this study was to analyze changes in the bottom of the Gelis River channel on the existing profile and normalization, as well as analyze the rate of sedimentation that occurred and its comparison with the rate of erosion in the Gelis watershed. Hydrological analysis was carried out with the help of software and obtained a calibrated HSS SCS, then continued with an analysis of changes in river morphology using the Toffaletti model and 2 scenarios, namely the existing profile and the normalized profile. The bottom of the river channel resulting from the two simulations is modelled hydraulically with a design flood discharge (equivalent to Q25) to obtain the maximum water level at the time of flooding. The results of the modelling show that the sedimentation rate downstream of the Gelis River is 8,914.59 tons/year. Changes in the bottom of the channel that occur in the form of average degradation is 0.31 m and average aggradation value of 0.2 m for the existing profile, while the normalized profile undergoes the average degradation of 0.39 m and a degradation of 0.15 m. An alternative solution that can be done in maintaining river capacity is to periodically dredge with at least 2,809.25 tons/year along the modelled river.

1. Introduction

The Gelis River was flooding on Januari 2014 which caused major losses at the villages at the downstream of the river. The flooding was caused by heavy rainfall and also sedimentation in the river's downstream, so that the capacity of the river is reduced. On the other hand, there is also backwater from the Wulan River which is the confluence of the Gelis River. In respond of the disaster, the Ministry of

Public Work and Housing through the BBWS Pemali Juana has carried out the work with the aim of increasing river capacity and strengthens the banks of the river through the River Improvement in Gelis River project. The study was carried out in 2014 and constructed in 2020 – 2021. However no analysis about sediment was done in the SID of Flood Control for the Gelis River. Therefore, this paper will discuss about sedimentation in the Gelis River.

2. Overview of The Study

The Gelis River is located in the middle of the Kudus Regency, in the Central Java Province. It is the largest river which cut across the Kudus Regency. The aim of the study is to analyze the erosion and sedimentation of the Gelis Catchment. The Ministry of Public Works and Housing has carried out- river normalization and construction of riverbank reinforcement project to increase the river capacity. The project has been constructed for 5 km long.

The upstream Catchment Area is still in natural shape. The bed materials of upstream river are mostly gravel. There is Muria Mount at the upper of river and in the downstream of the Gelis River, it confluence with the Wulan River. The river's slope at the upper reaches of the Gelis River is steep with a reasonably high flow velocity. While the watershed at the upstream still looks natural, conservation is still not needed in the watershed.

Figure 1. Gelis River's Downstream Condition

The morphology on river downstream has been changed by the human project. The riverbank has been strengthened by the concrete for the straight channel and gabions for the bending river. For the bending section of the river, gabion reinforcement is preferred because the construction method is easier to carry out. At the downstream of the Gelis River, it can be seen that there are existing parapets and embankment. Downstream of the Gelis River is the confluence of the main river, the Wulan River. Its discharge triggered backwater to the Gelis River and causes sedimentation on its river bed at the downstream.

3. Research Methods

In order to obtain the necessary data for numerical modelling, topographical data such as Digital Elevation Model (DEM), land cover and Harmonized World Soil Database (HWSD) maps were collected, furthermore hydrological data such as rainfall data was collected from 4 (four) rain gauge stations for the duration of 30 (thirty) years (1991-2020).

The topographical and hydrological data were analyzed to obtain the characteristics of catchment area.

Numerical model for hydrology inputs the curve number[5] and hydrological data, then the result is Synthetic Unit Hydrograph (SUH). Numerical model for hydraulic and sediment transport analysis uses hydrograph as the upstream boundary, downstream rating curve as the boundary at the downstream, river geometry data is obtained from shop drawing and the field data that was collected was used to model river bed gradation[6] and sediment rating curve. The study uses one dimensional (1D) simulation and unsteady flow analyze[7].

4. Result

4.1. Hydrologic Analysis

The model used rainfall data from 4 (four) stations near the watershed. Thiessen methods were used to get the areal rainfall, then hydrologic analysis was carried out using Synthetic Unit Hydrograph (SUH) due to the lack of discharge data in the river, the bankfull discharge on the downstream Gelis River was then used for calibration.

The return period of bankfull discharge is within the range of 1 – 5 years in the flood frequency analysis[1] or around 2.33 years[2]. The manning's value is 0.029 which used from Ven Te Chow[3] table. The bankfull discharge is 98.7 m^3/s.

HEC-HMS Hydraulic modelling was used to get the flood discharge, then the design discharge was used as boundary in hydraulic simulation and transport sediment simulation.

The hydrograph for various return period is as follows:

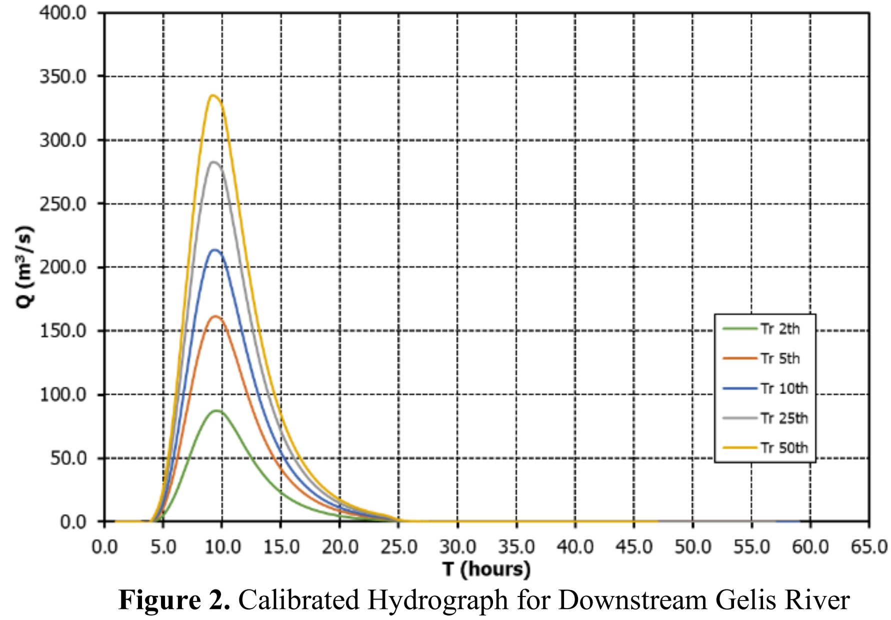

Figure 2. Calibrated Hydrograph for Downstream Gelis River

4.2. Morphological Change Analysis

The study uses normalization geometry to see a pattern of morphological changes, the new geometry will be used for hydraulic model to get the flood effect. The general scheme for sediment transport model is as follows:

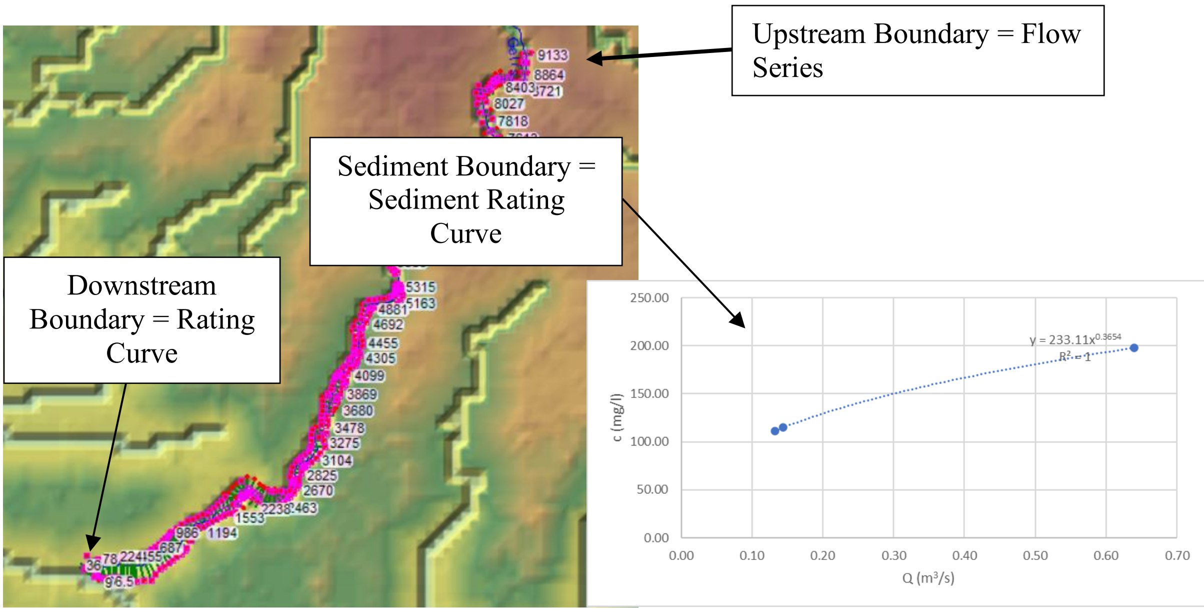

Figure 3. Sediment Transport Analysis Modelling Scheme

The sediment transport model uses Toffaletti by the gradation of riverbed sediment.

1. Existing Geometry

This simulation was carried out using the same existing geometry as hydraulic analysis, with daily discharge for 1 (one) year, using Toffaletti equation.

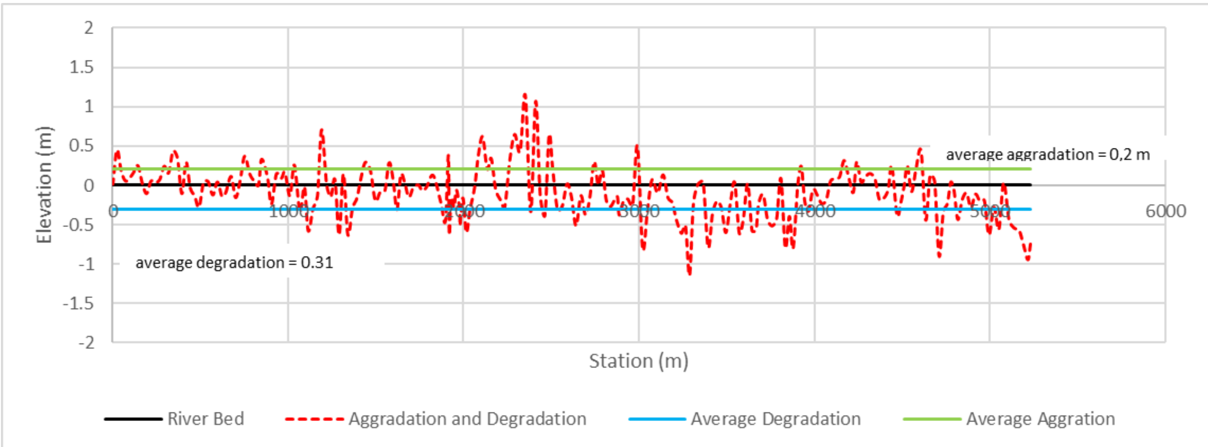

Figure 4. Aggradation and Degradation Pattern (Existing Geometry)

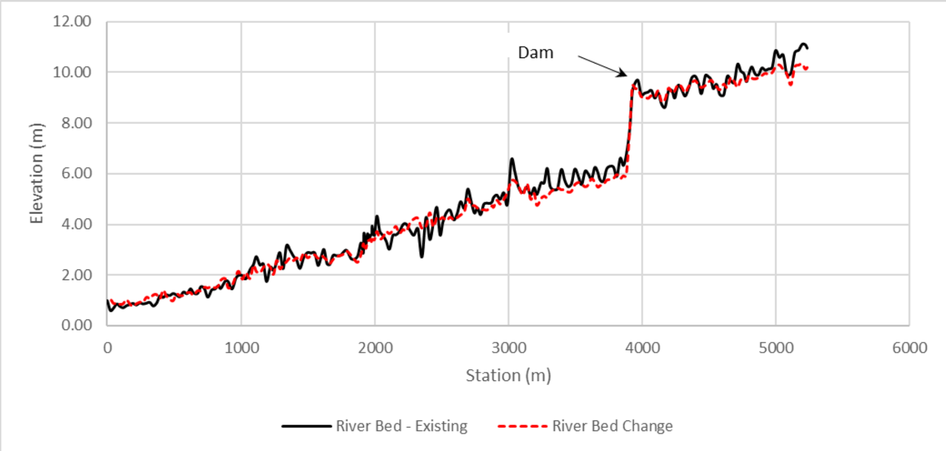

Figure 5. Invert Change Result (Existing Geometry)

Because of the sediment rate, the profile would be eroded and deposited. It was affected by the slope of channel, which caused by various velocity (called unsteady flow). Based on the results above, the slope on downstream dam suddenly changes which could increase the velocity and eroding the river bed. The average aggradation is 0.2 m, then the degradation is 0,31 m. Sediment rate is 8,914 tonnes/year which get in to the river, meanwhile it discharges 8,898.72 tonnes/year. The value of deposited sediment is 13,817.39 tonnes/year along the profile.

2. Normalized Geometry

Based on the river morphology modelling results below, it can be seen that degradation occurs at the downstream of the weir due to a sudden change in slope, which increases the flow velocity and erodes the channel bottom. The maximum degradation that occurs is 1 m at Sta.4712.3 (G21) which is at the upstream of the weir where at that point normalization has not been carried out.

Maximum aggradation occurred at Sta.4346.1 (G36) with a thickness of 0.6 m with 608.6 tons of sediment deposited. Aggradation occurs because the upstream of the station is eroded and results in the deposition of particles carried from the upstream of the river. In addition, the slope of the cross-section is relatively flat so that the flow velocity is slow and sediment particles from the upstream are retained along the cross-section before the weir. The average gradation is 0.15 m and the average degradation is 0.39 m. Based on this value, there was a reduction in the aggradation height of 24.46% from the existing profile.

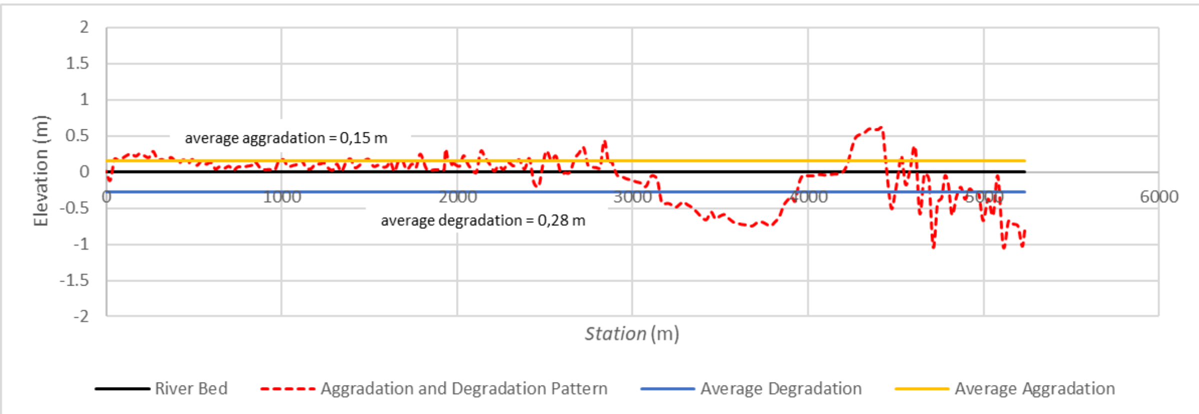

Figure 6. Aggradation and Degradation Pattern (Normalized Geometry)

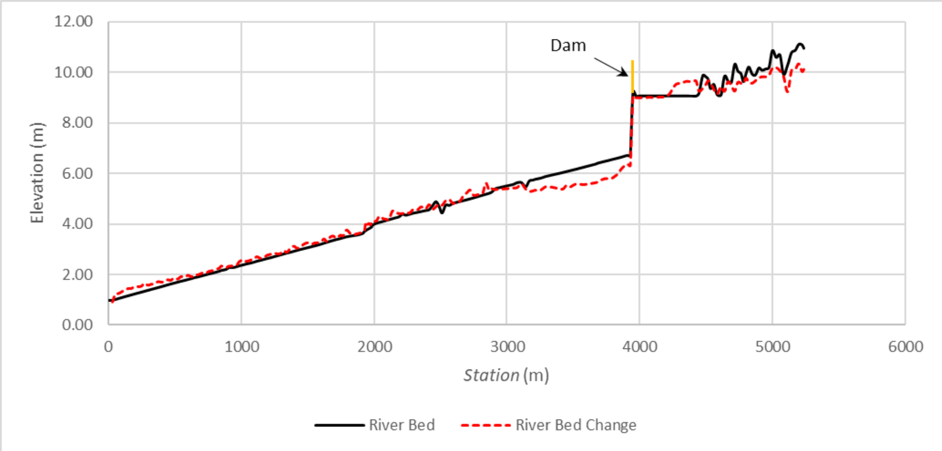

Figure 7. Invert Change Result (Normalized Geometry)

The following figure illustrates the morphological conditions that occur due to the existence of a dam:

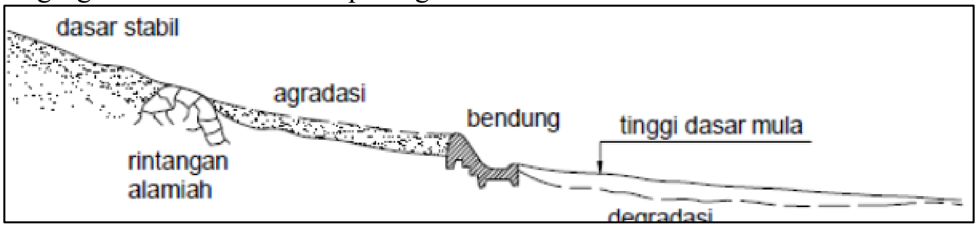

Figure 8. Illustration of Morphological Condition due to Dam
(Source: Irrigation Planning Technical Training) [8]

The incoming sedimentation rate is 8,914 tons/year while the outgoing sediment is 8,898.72 tons/year. In the river profile, there is a section that is eroded and also deposited. Both of these are due to the slope of the cross-section which results in different flow velocities for each cross-section. The average degradation is 261.87 tons/year, while the average sediment is 158.83 tons/year in each cross-section. The total sediment is 20,363.62 tons/year along the modelled river profile. This value is greater than the sediment that occurs in the existing profile. The slope has changed to relatively mild so that the sediment is easily deposited in the new profile.

4.3. Hydraulic Model Analysis

The sediment transport model uses Toffaletti by the gradation of riverbed sediment.

1. Existing Geometry
   Modelling in this condition is used to compare the new cross-sectional capacity that has been carried out by flood control. Based on the modelling results below, it can be seen that the water is still running over at the upstream part of the weir and several points downstream. The maximum runoff occurred at 2 m on the left embankment at Sta.903.9 and 2 m on the right.

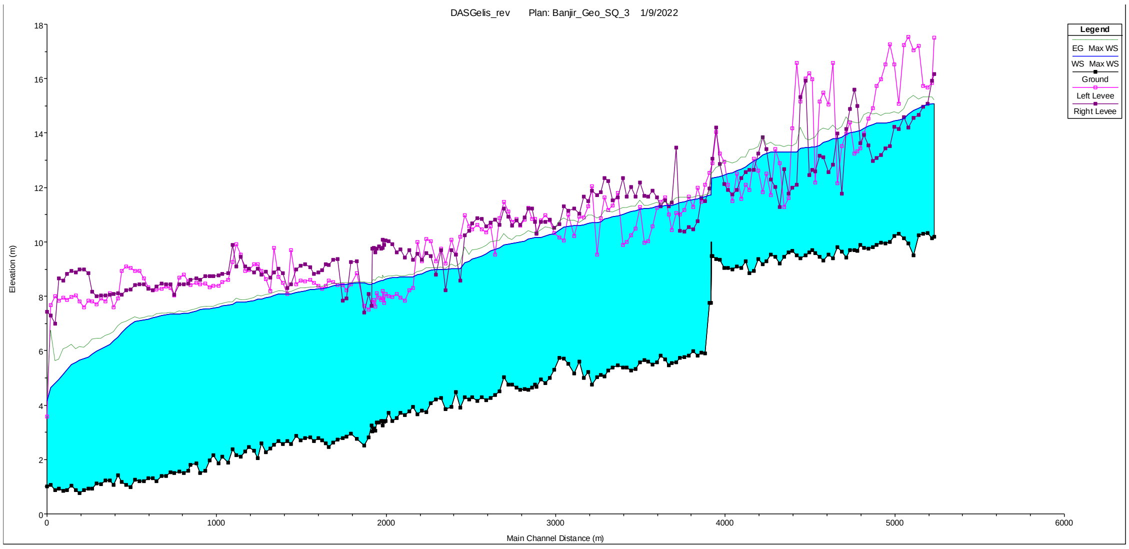

Figure 9. Simulation Result with Q25 (Existing Geometry)

2. Normalized Geometry

Based on the results of the modeling below, it can be seen that the water is still running over the upstream part of the dam, where work has not been done. The maximum runoff occurred at 1.3 m on the left embankment at Sta.4935.6 and 1.9 m on the right embankment at Sta.4661.4.

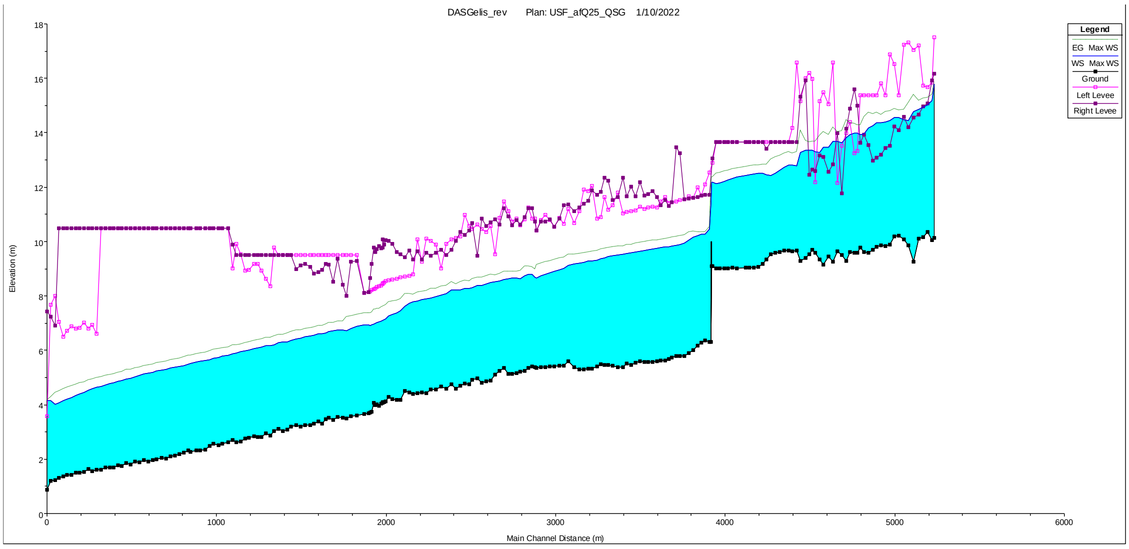

Figure 10. Simulation Result with Q25 (Normalized Geometry)

4.4. Recommendation

Based on the simulation result, it is recommended to conduct maintenance of the river. The results of the unsteady flow simulation using the geometry of the quasi-unsteady flow simulation results of changes in the base channel normalization profile are used as a reference in the needs of the river's maintenance. One of the maintenance activities that can be carried out is dredging in order to maintain the capacity of the river cross section to accommodate the incoming discharge from upstream. From the simulation results, the amount of sediment that is deposited along the modeled profile is 2,809.25 tons/year. The result is the cumulative of the sediment deposited in the cross-sections which if overturned. The following is a recapitulation of the overturned cross section due to morphological changes that occur.

Table 1. Sediment Deposited Quantity in the Overflow Section

Cross Section		Deposited Sediment (tonnes)	Overflow (cm)	
			Left Levee	Right Levee
Sta.0	G0	-	56.6	-
Sta. 4472.3	G184	92.05	-	81.8
Sta. 4494	G185	80.42	-	71.2
Sta. 4512.9	G186	38.44	117	77.1
Sta. 4531.1	G187	104.11	-	18.3
Sta. 4555	G188	66.82	-	17.5
Sta. 4580	G189	100.47	-	71.2
Sta. 4609.3	G190	73.88	-	62.2
Sta. 4661.4	G192	117.02	15.8	190
Sta. 4779.2	G197	108.75	-	35.4
Sta. 4797.6	G198	175.45	-	6.4
Sta. 4819.1	G199	146.83	-	40
Sta. 4843.5	G200	184.94	-	98.2
Sta. 4868.8	G201	216.1	-	107.4
Sta. 4894.1	G202	169.82	-	106.5
Sta. 4919.1	G203	198.03	-	92
Sta. 4945	G204	188.14	-	84.3
Sta. 4970.5	G205	304.49	-	17.2
Sta. 4996.7	G206	218.56	-	36.9
Sta. 5053.3	G208	224.94	-	34.9

Based on the table above, the suggested alternative solution is only concerned with the deposited sediment because it can reduce the river's capacity. At Sta.0 there was no deposition, but there was still runoff on the left embankment, this could still be ignored because the runoff went directly into the main river downstream of the Gelis River. The following illustration is based on this explanation.

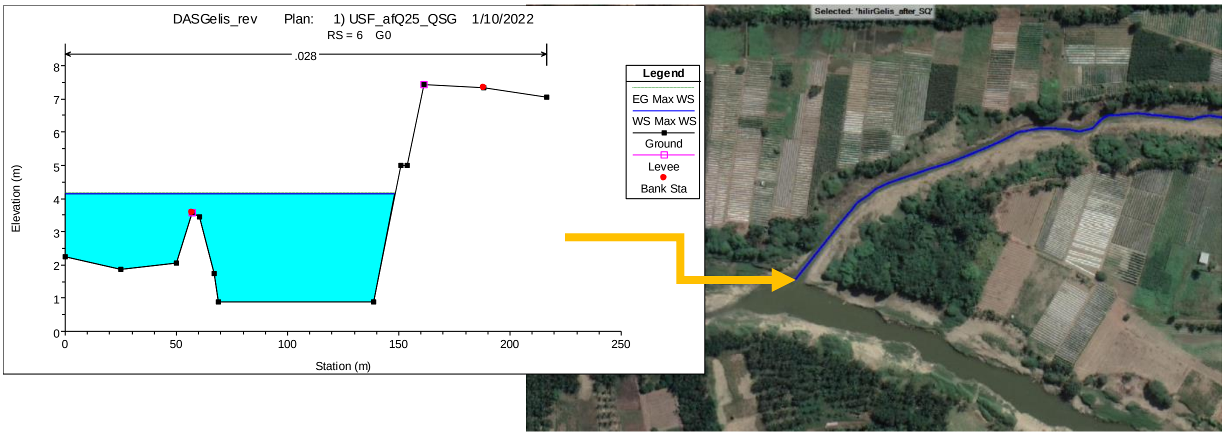

Figure 11. Location of Sta.0 at Lower Gelis River

Based on Figure 11, we can view that lower Gelis River is still overflow. But, the left cross section is still the section of downstream river which is called Wulan River. The right cross section can accommodate the discharge. So, we can conclude that the result of Gelis River Project is effective for controlling the discharge of the river.

5. Conclusion

The conclusions that we can conclude from the study are the average degradation in the existing profile is 0.31 m and the average aggradation is 0.2 m, while the normalized profile, average degradation in the existing profile is 0.39 m and the average aggradation is 0.15 m. The sediment rate that enters the modelled profile of the Gelis River is 8,914.59 tons/year. Based on the simulation, the deposited sediment along the overflow profile are 2,809.25 tonnes. The sediment sampling measurements in this study were carried out during the dry season with a small river discharge, so the value could be much higher than the one calculated above. There are sections that are eroded and deposited by sediment. The amount of sediment that is deposited along the cross-section where runoff occurs is 2,809.25 tons. This value is used as a reference for the amount that needs to be dredged every year to avoid runoff.

6. References

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Acknowledgments

Authors wishing to acknowledge financial support from Ministry of Public Works and Housing, especially BPSDM and BBWS Pemali Juana, special work by staff of Water Resources Engineering and Management Program