

The Influence of Flood Discharge to the Stability of River Morphology

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Abstract. Sedimentation has been an issue for a long periode of time. It affects the river morphology process which is constantly changing from time to time due to its sediment supply system. There are 2 main parameters that strongly affect the morphological process and those are discharge and sediment. When the movement of the sediment occur it will lead to degradation and agradation along the river that will affect the river morphology. Because of those processes, the river dynamic characteristic should be considered in structural design.

In North Sulawesi, Tondano River has been known as one of the main river and it has a discharge all year around. With rapid land coverage change, discharge may increase significantly and hence more sediment could be transported. Moreover, there are increase use of the river resources and more structures built along its sides that appeared to have induced more sediment in transport. This paper presented the corelation between discharge of various flow rates and the amount of sediment being transported at these rates along certain river segments. Slight changes on morphology of the river due to degradation and agradation processes at these segments were also displayed Analysis was carried out to evaluate agradation and degradation processes during various flow rate at the middle section of the Tondano River. Prior to this was the analysis of river discharge. This research has confirmed that indeed the sediment transport occurred at the observed river's segments was due to the varied discharges. The transport therefore instigated the recurrent changes on the river's morphology this may pose threats to the stability of river's structures i.e. by means of scouring progression. Solutions suggested to overcome the problem includes: 1). Non-structural or structural reinforcement on the river bank; and 2). Sediment management to overcome the degradation and agradation processes.

1. Introduction

River morphology is refering to the changes of river planform and cross section shape due to sedimentation and erosion processes. Maintaining equilibrium is very hard to be done because of the river characteristics (Mananoma, 2009). When flow condition reach the critical stage, the loose bed material starts moving (Jansen, 1979) it will lead to aggradation/sedimentation and if the sediment supply is less than its capacity, it will lead to degradation/erosion. The typical of the landscape has a



huge impact on the river with the mountainous terrain and rapid urban sprawl can affect the sediment supply and also the amount of discharge that flows through the river can potentially transport the sediment and affect the sediment capacity in a flow. Hydraulics slope and discharge have a dynamic characteristic since it always vary in time and space. For those reason, the idea to maintain the equilibrium condition of the river morphology is a difficult task. In this paper, Tondano river is carried out as a review study.

Tondano river has a length of 39,9 km. It has span from Tondano lake to Manado bay with total catchment area around 544,13 km² (Rapar, 2014). The river flows through 3 regency Minahasa, North Minahasa and Manado and its catchment has the most rapid urban sprawl in North Sulawesi. There are many activities along the river such as hydro power, farming, fishery, housing, and construction and in 2014 there was a fast flood happened in Manado with discharge from this river which was indicated the decreasing of the water infiltration in the catchment area that can contribute to the increasing discharge of the run off. For the past decade, flood has been frequently occur in its catchment than before and with a lot of construction along the river the sedimentation also appears with increasing in volume. According to a research form JICA (2001) there also a huge scouring process in Tondano river around 1.500-48.000 ton/km²/year with a various discharge between 5 m³/s – 22 m³/s and it is higher than the tolerant number for Tondano river 2.080-3.250 ton/km²/year (Nugroho, 2005). The purpose of this study is to analyze the relation between discharge and sediment transport in Tondano river, especially in a certain area with a lenght of 1 km. This area has been a place for one of the ongoing construction site in North Sulawesi which is the Manado-Bitung highway and because of that, the necessity for having a greater understanding about how the river behave is important.

In order to analyze the discharge-sediment relation we need to identify the actual conditions of the river morphology in the review area and then we analyze the flood discharge at a various time design. By doing this we will have an understanding on how the actual condition of the river accomodate the discharge. Next step we need to analyze the impact of the discharge on the sediment to get a conclusion whether there are concerning impact on the morphology with aggradation and degradation.

2. Method

Various method can be used to analyze discharge and sedimentation. Software such as HEC-HMS and HEC-RAS was used to analyze the data. Some data needs to be acquired as a primary data such as rainfall intensity, digitized map of the catchment area, river geometrics and sediment sample. Sediment sample was took from 3 different area (upstream, middlestream and downstream).

Table 1. Effective size soil particle

d (mm)	Soil particles		
	Location in Section		
	Upstream	Middlestream	Downstream
d ₃₅	0,75	0,26	0,22
d ₅₀	1,20	0,55	0,24
d ₆₅	2,38	0,95	0,26
d ₉₀	4,00	3,60	0,48

After acquiring the primary data then the analysis can be done. We divided the analyzing method into 2 step, hydrology for discharge and sediment transport analysis for the sedimentation process.

2.1. Discharge

Analyzing discharge was done with HSS-SCS (soil conservation service) method. U.S SCS suggested an empirical model for rainfall abstractions which is based on the potential for the soil to absorb a certain amount of moisture. It computes the potential storage S (millimeters) and was related to the curve number CN , as shown in Eq. (1) below :

$$S = \frac{25400}{CN} - 254 \quad (1)$$

The effective rainfall is computed as shown in Eq. (2):

$$Q(t) = \frac{(P(t)-I_a)^2}{(P(t)+S-I_a)} \quad (2)$$

Where $Q(t)$ is the accumulated depth of effective rainfall to time, (t) accumulated depth rainfall to time t , I_a is initial abstraction and S potential storage in the soil. Using the frequency analysis we can compute discharge with a various time design as it shown in Table 2.

Table 2. Discharge by design

No.	Return Period (Years)	Discharge (m^3/sec)
1	2	114,09
2	5	206,44
3	20	379,18
4	50	525,19
5	100	656,65

We assumed that the flow itself is steady then the water level per variation of time design can be calculated as it shown in Figures 1-5.

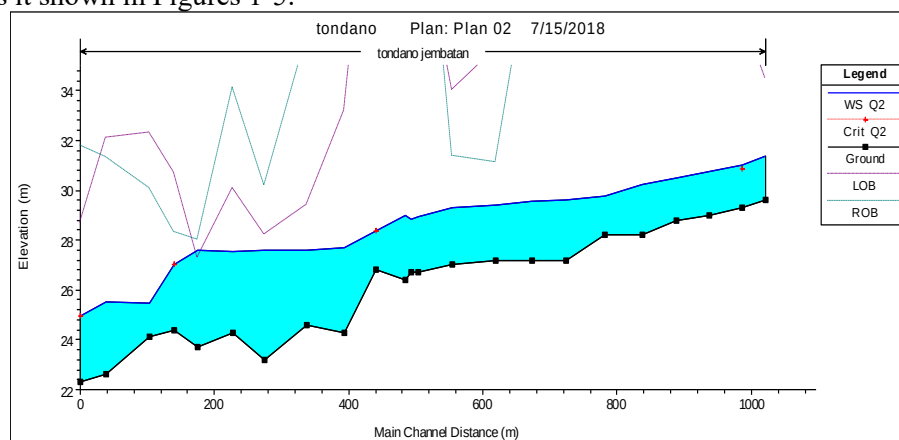


Figure 1. Long section profile of the water level (return period discharge 2 years)

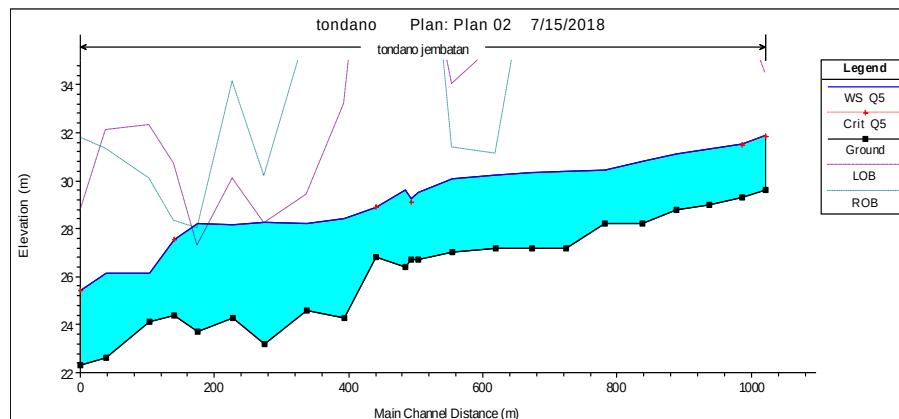


Figure 2. Long section profile of the water level (return period discharge 5 years)

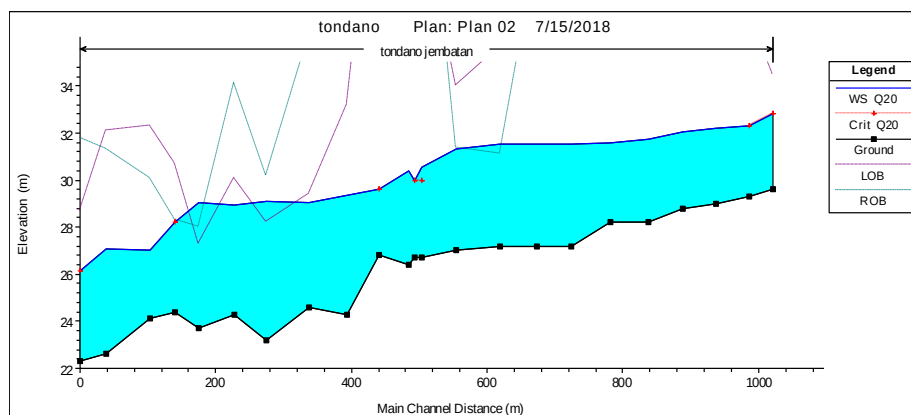


Figure 3. Long section profile of the water level (return period discharge 20 years)

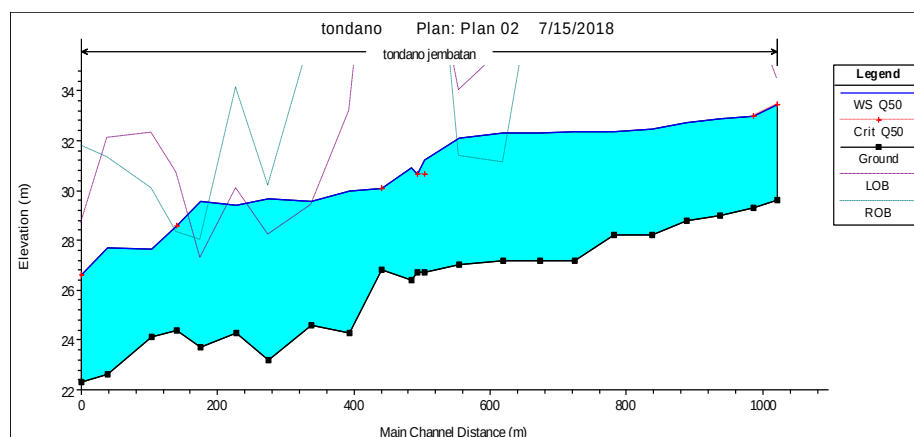


Figure 4. Long section profile of the water level (return period discharge 50 years)

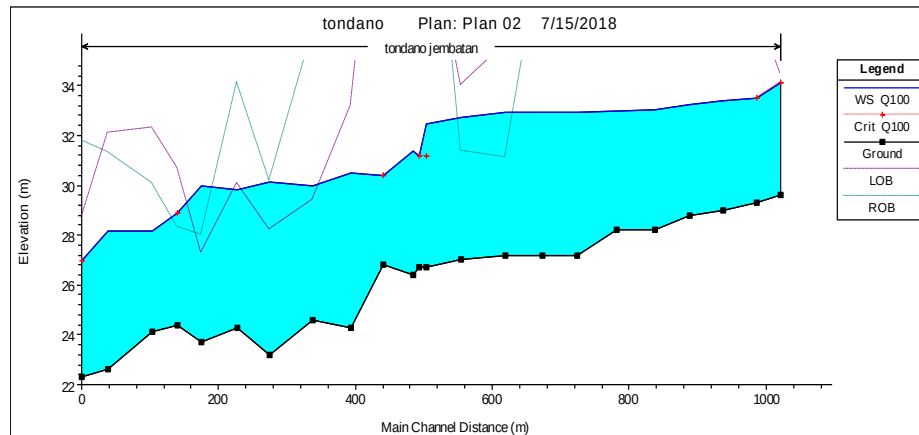


Figure 5. Long section profile of the water level (return period discharge 100 years)

As we can see from figure 1-5, discharge from the river starts to overflow from its watershed even with 2 years return period. At figure 1 the right side of the banks still capable to handle the flow but on the left side of the banks it is getting overflow at a distance of 160 meter from the downstream. At 10 years return period discharge, both riverbanks is getting overflow with water and it's getting wider from it. With vast amount of discharge charging through riverbanks with enough velocity, the scouring process is inevitable and it will bring more sediment to the river.

2.2. Sediment

Analyzing sedimentation was using the *Ackers and White* (1973) for size specific transport is,

$$\frac{q_t}{q} \frac{D}{d_s} \left(\frac{u^*}{V} \right)^n = c \left(\frac{F_{gr}}{A} - 1 \right)^m \quad (3)$$

Where F_{gr} is the square root of the ratio of bed shear stress τ_0 , to the resistance force, q_t is total sediment transport in volumetric rate per unit width of the channel and q is the unit water discharge. A , c and m are coefficients varying with D_{gr} which is the dimensionless grain diameter and D is total flow depth (Habibi, 1994).

As for the fall velocity equation, Rubby (1933) were used to calculate the downward velocity of the particles in a low dense fluid at equilibrium in which the sum of the gravity force, buoyancy force and fluid drag force are equal to zero (Helbar, 2009). The equations are,

$$w = F[d g (s - 1)]^{0.5} \quad (4)$$

with,

$$F = \left[\frac{2}{3} + \frac{36v^2}{gd^3(s-1)} \right]^{0.5} - \left[\frac{36v^2}{gd^3(s-1)} \right]^{0.5} \quad (5)$$

Where d is particles diameter in m, v is kinematic viscosity in m^2/s and s is relative density (ρ_s / ρ). In order to give continuity to the sedimentation process, the porosity of the soil, the width of the bed, the stream of the water and time interval were considered. The equation used for this sedimentation continuity was Thomas Exner 5 (de león, 2018).

$$\frac{(1-\lambda_p)B\delta\eta}{\delta t} = -\delta Q_s / \delta x \quad (6)$$

Where B is the width of the river, λ_p is the porosity of the active layer, η is the flow water elevation of the principal stream bed or river, t is time interval, x is distance and Q_s is the load of sediment soil transported by the flow. The overall analysis of the sediment transport shown in the Figures 6-11.

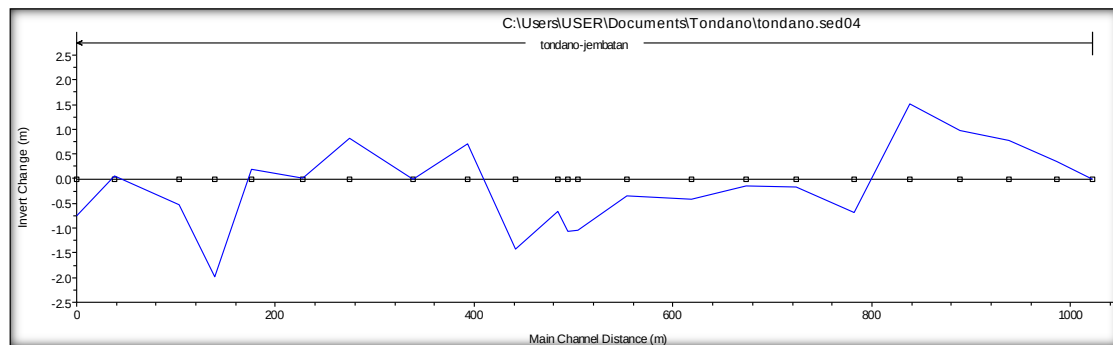


Figure 6. Long section profile of river bed with Q_{2yrs} sediment transport

Figure 6 shows that there is huge amount of aggradation in the upstream (blue line indicates the sedimentation process and the black line indicates the river bed) and a long degradation in the middle stream. Maximum aggradation is 1,51 m high at 160 m from upstream and maximum degradation reach -2 meter at 140 m from downstream.

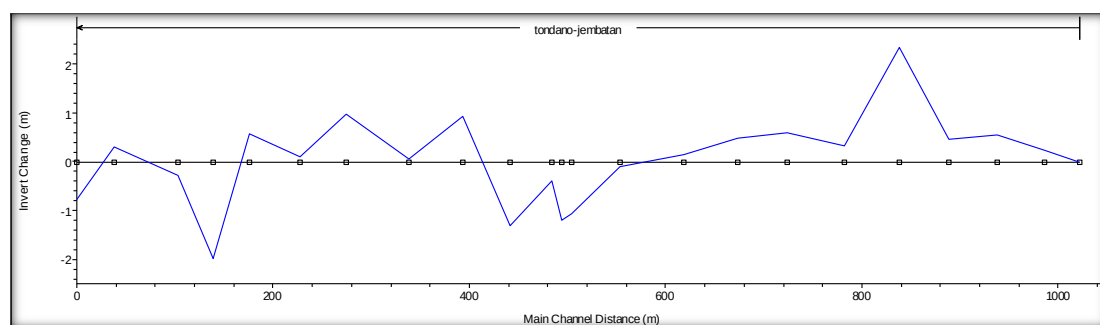


Figure 7. Long section profile of river bed with Q_{5yrs} sediment transport

Figure 7 shows aggradation mostly occur in the upstream with maximum aggradation 2,33 meters and maximum degradation -1,98 meters at 140 m from downstream.

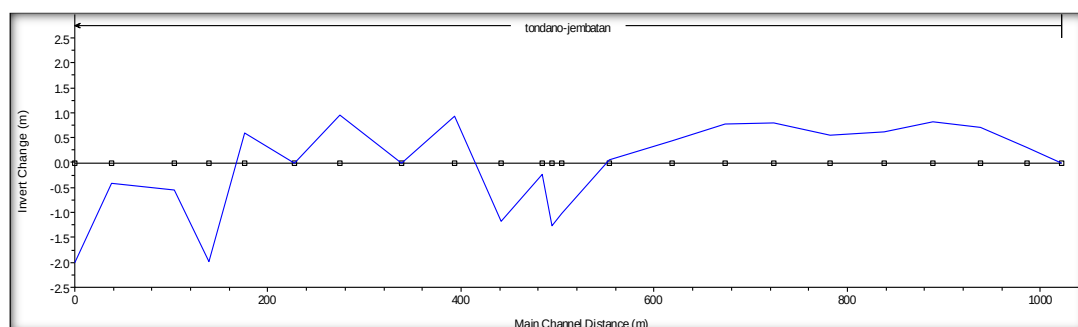


Figure 8. Long section profile of river bed with Q_{20yrs} sediment transport

Figure 8 shows that an even distribution of sediment occur in the upstream and degradation in the middle and downstream. Maximum aggradation is 0,95 m and maximum degradation between -1,98 to -2 meter. It appears that in 20 years return period the degradation of the river bed in the downstream is getting deeper.

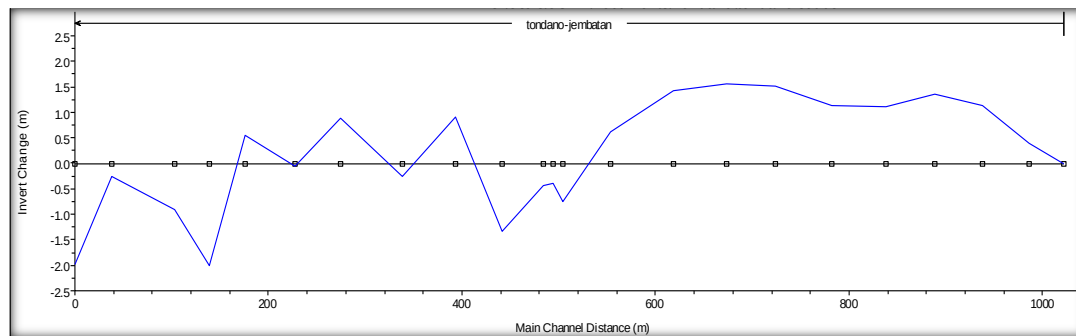


Figure 10. Long section profile of river bed with Q_{50yrs} sediment transport

Figure 10 shows an evenly distribute sediment as a result of aggradation process and with high amount of sediment reached 1,45 meter for 280 meter in length. Scouring process in the middlestream reach 1,4 meter.

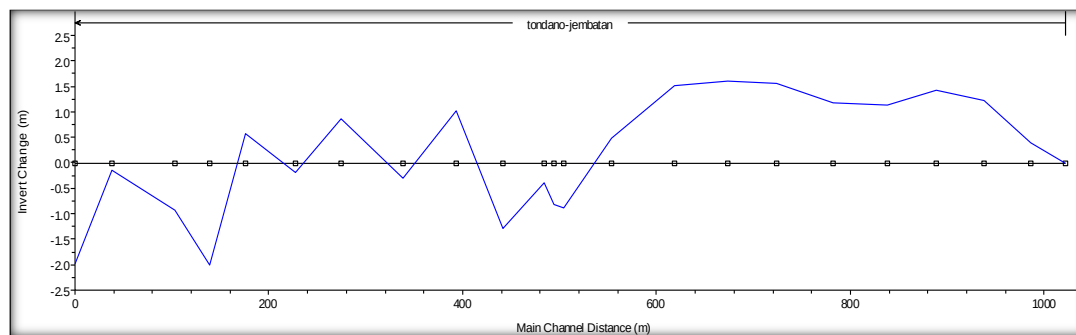


Figure 11. Long section profile of river bed with Q_{100yrs} sediment transport

As for the Q_{100yrs} sediment transport as it shown in the figure 11 aggradation process reach 1,61 m and degradation still at 2 m. However in middlestream, degradation process getting wider.

3. Conclusion

This research shows indeed the flood discharge influences the river morphology especially in the river bed but this research also find that the higher amount of discharge can gives significant changes in the river bed. This research also proves that the sediment transport is occurred in this river with a huge amount of sediment particles. It also gives an understanding that the river bank and the river bed are exposing to the scouring process due to discharge. As a result, the river needs to be reinforced especially in the area where there will be a structural building such as river tondano bridge at 480 m – 490 m from downstream.

As a suggestion in the certain area which are overflow with discharge (fig. 1-5) in the river bank can apply an eco-hydraulics approach to prevent erosion and scouring process because it will give resistance to the discharge (Maryono, 2002). The type of vegetation can be a short or medium vegetation such as short grass or a tall coarse grass. We can also use structural reinforcement such as sheet pile or retaining wall applied to the river bank especially in the bridge area. Scouring also become a thread for its pile because it will be positioned in the degradation area.

Non structural approach such as dredging also will be required in the future because the accumulation of the sediment in the upstream can pose a thread to the bridge and it will heightened the water level to the point where it can cause the flood more spreading to the river bank.

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