The Effect of Sediment Supply to the Damage of Infrastructures

T. Mananoma
Dr., Civil Engineering Department, Sam Ratulangi University, Indonesia
Email: tmananoma@yahoo.com

W.Wardoyo
Civil Engineering Department, Institute of Technology 10 Nopember Surabaya, ,Indonesia
email: dww279@yahoo.com

Abstract

Mountains river has a very dynamics morphological process due to the characteristic of sediment supply system. This system is affected strongly by the dynamic character of rainfall and sediment, two parameters which are varied in time and in space. Therefore it needs a certain management of sediment to minimize the problems caused by the change of river bed due to its sediment supply system . This change, called as degradation and aggradations, may lead to the damage of infrastructure such as intakes, bridges and dams. Some evidence in Progo River shows that lack of sediment supply will create malfunction of infrastructures such as the deformation of Srandakan Bridge structure, the broken of Kamijoro and Sapon Intake. It must be known that the morphology of Progo River, with its 138 km long and of about 2380 km^2 catchments area, is strongly affected by the condition of Mt Merapi.
This paper will presented the effect of sediment supply to the damage of infrastructures. Analysis will be done beforehand by evaluate degradation and aggradations processes at the middle reach of Progo River accompanied by inventory data of infrastructures failure. Further sediment balance approach will be used to calculate the transport sediment and the change of river bed. The result, then, will be used to propose sediment management in the study area.

Through this research, it can be reconfirmed that the sediment management is indeed a complex problem. However, a general guideline on carrying the sediment problems is proposed in this paper. It is consist of system approach and various possible alternatives.

1. INTRODUCTION

Reaching and keeping equilibrium condition is always the main problems on managing a alluvial river. As the sediment supply is greater than sediment capacity, it leads to aggradations/ sedimentation process, in the other hand, if the sediment supply is less than sediment capacity then degradation/erosion process will occur. In case of mountains river, the sediment supply is strongly influenced by the potential deposit of sediment and rainfall intensity at upstream reach. The amount of potential deposit of sediment that can be transported by each unit of rainfall intensity depends on the characters of deposit, such as the slope of deposit, density, value of cohesion and the age of deposit. While rainfall intensity determines the water discharge and hydraulics slope that influences the sediment capacity. These parameters have a dynamic characteristics since it always vary in time and in space. That is the reason that the management design of alluvial river with respect to equilibrium conditions is such a difficult task, then the case of Progo River is carried out in this paper.

The aim of this study is analyzing the relation between water - sediment discharge to damage of infrastructures in Progo River. To reach this goal, first of all, the change of river morphology based on sediment transport pattern should be identified. These can be done by analyzing sediment transport balance. By them than the change of river bed elevation and slope can be known. Furthermore, by understanding the process of aggradations and or degradation of the river then the effect of it in the infrastructures can be known well. Later, this evaluation will be confronted with some field measurement from previous study. The evidence shows that the some structures in Progo River such as Srandakan Bridge, Kamijoro Intake and Sapon Intake were broken due to the problem of sediment supply as shown by Figure 1 and Figure 2.

Fig. 1: Sapon Intake (2004)

Fig. 2: Srandakan Bridge (2002)

2. MORPHOLOGICAL CONDITIONS OF PROGO RIVER

Progo River, one of 12 main rivers that originated from Mount Merapi has ± 138 km of length and ± 2.380 km^2 of catchments area. A study of Progo River has been done since 1920 by measuring the fluctuation of river bed. The result of river bed measurement from year 1920 up to year 2000 shows that the aggradations occurred in front of Kamijoro Intake but the degradation occurred in Sandrakan Bridge. The river degradation rate is about 10 cm up to 30 cm each year [1]. The calculation of recorded river bed change is shown in Table 1.

Table 1: Recorded river bed fluctuation around River Structures

Type of Infrastrutures	Year 2000's Measured Elevation (+ m)		Measured Elevation of River Bed (+ m)		Change of Elevation (+ m)		Average fluctuation per year (cm/year)
	Lowest Elev.	Average Elev.	Year	Average	Duration (year)	Average	
Srandakan Bridge	-0,295	6,00	1929	11,25	71	–5.25	–7,39
Kamijoro Intake	20,570	23,20	1924	22,18	76	+1.02	+1,34
			1930	21,68	70	+1.52	+2,17
					6	–0.50	–8,33
			1970	26,13	30	–2.93	–9,77
					40	+4.45	+11,10
Bantar Bridge	34,650	36,30	1984	40,93	16	–4.63	–28,90
Kebonagung Bridge	51,880	52,00	1982	57,60	18	–5.60	–31,10

Resource: *Review Master Plan Study on Mt Merapi*, 2001

Based on that recorded data, Table 1 also shows that in front of Kamijoro Intake bed elevation is fluctuated : aggradations in the 1920 and degradation in the 1970. This fluctuation is pointed out correlated with the Merapi eruption cycles. The aggradations will be formed just after the Merapi big eruption and later on, as the sediment source is poorer, the degradations will occur by the time. The process of degradation in the river is even become faster by sand mining activity. Consequently, it will influence the stability and the design elevation of infrastructure until it failed.

Some notation can be showed as well in the relation with the effect of degradation/ aggradations to the damage of river infrastructures:

1) Srandakan Bridge

   It was constructed in 1878-1880, and rehabilitated in 1975-1985 to accommodate the increase in traffic volume. The total length of bridge is 531 m with 33 bridge piers. At present, the riverbed has been lowered to about 2 m, especially on the right side. In April 2000, two piers (No. 25 and No. 26) settled down, causing the bridge floor collapse, due to the local scoring around the foot of bridge piers. As a temporary countermeasure, bailey bridge and concrete hexapods were installed and the sand mining within 2 km from the bridge in both upstream and downstream has been strictly prohibited.

2) Sapon Irrigation Intake

   The first intake was constructed in 1914 to irrigate the area of about 1,917 ha of paddy field, but floods destroyed it. In 1982, a new intake (2nd intake) was constructed to irrigate 2,230 ha of land; however, the 2nd intake has no function in the last 5 years due to the serious riverbed degradation. In 1998, a free intake with a channel was constructed at approximately 500 m upstream from the 2nd intake as a temporary measure but the intake volume is not sufficient and stable.

3) Kamijoro Irrigation Intake

   It was constructed in 1924 to irrigate the area of about 2,074 ha through Kebonongan canal. At this time being, the maximum discharge is 2.30m^3/sec in order to irrigate 2,300 ha of land. This intake always has a sedimentation problem in the irrigation tunnel, and during the dry season, it often has no function due to the insufficient water level.

4) Bantar Bridge
Bantar Bridge consists of road bridge, railway and oil pipe line bridge (PERTAMINA). The old bridge was constructed in 1926-1930 with suspension type, and the new one was constructed in 1987-1988 by Austrian steel framework next to the old bridge. Both bridges have 210 m spans. At present, the riverbed degradation is observed more than 2 m, endangering the pier foot.

5) Kebonagung Bridge
It was constructed in 1986 with 153.6 m span and 7m width. Due to the severe riverbed degradation, a groundsill had constructed to protect pier foot; however, the most part of groundsill has been destroyed by tractional load during floods. Therefore, the pier foot foundation is exposed to riverbed.

Further, a study of morphological pattern of Progo River was done by [2]. The result of the study recommended that two (2) main factors which strongly affected the morphological pattern of Progo River are the condition of deposit at upper Progo River followed by its supply mechanism and activity of sand mining. This was supported by research by Barunadri Enginering Consultant [3] which was done in the same period. Barunadri [3] stated that the morphological change of the Progo River is a big disadvantage of sand mining activities since the sand mining created unbalance of sediment at any part of river. There are eight (8) sand mining locations along the Progo River, where most of them are in the sub-catchments area and almost no sand mining activity held in the middle reach of Progo due to the steepness of the river banks in the middle reach. Most of them are located in river branches such as in Pabelan River, Blongkeng, Batang and Krasak Rivers with total explored volume of sediment for 21,238m^3/day or 5,118,720 m^3/year. Figure 3 shows the yearly average sediment volume distribution,whilst the map of sand mining location can be seen at Figure 4.

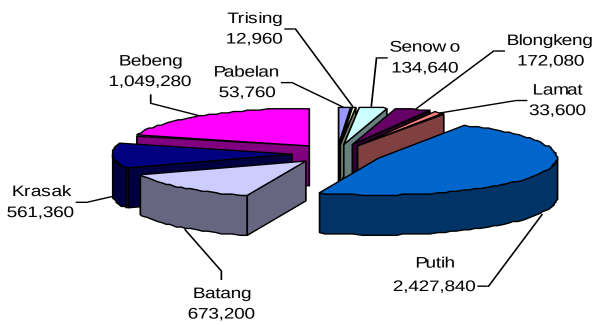

Fig. 3. Distribution of yearly explored sediment volume

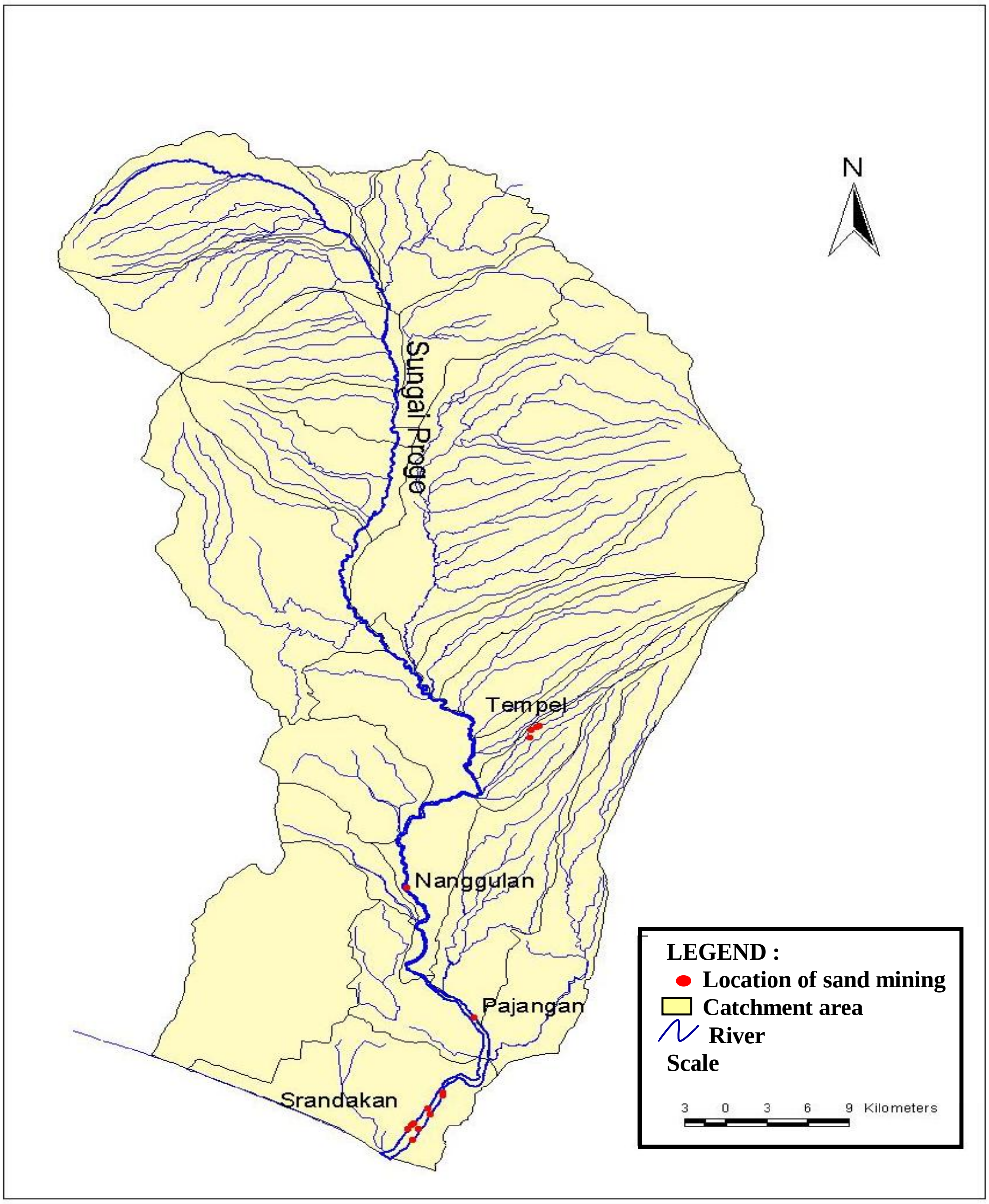

Fig. 4. Map of the locations of sand mining in Progo Catchments Area

Before that, Indra Karya [4] has already reported that human activities can stimulate the process of morphology. It said that degradations is a result of critical conditions of erosion since sediment balance at river is defined as long term of sediment transportation process that is followed by the change of morphology of the river. It is understandable since this process will change the cross sectional area/ control volume resulted the decreased of cross sectional and area. And a consequence, it will decrease conveyance of river especially in flood season. Mananoma et.all [5] even concluded that transport of sediment and the characteristic of sediment is hardly formed the morphology of such river.

Further, the effect of sediment control to the morphological process is discussed. In order to minimize the effect of morphological process of the river, some sediment controls were constructed as well. The main purpose of these is to slow down the sediment transport velocity in order to minimize the sediment effect. These is very useful when the sediment supply were more than sufficient but when the sediment supply was less then another disadvantage will appear such as sediment supply to the lower reach is sluggish and erratic. Therefore, the degradation process can be aggravated by the existence of sediment control.

Some study has already done correlated with the factors that influence sediment supply system in Mountain River, such as Suroso [6], Mulyono [7] and Mananoma [5]. In this case, Suroso found that sedimentation process in mountains area are determined by climate, rainfall characteristic, topography, hydraulics characteristic of the river, bathymetry of the river and Vulcan activity as a sediment sources. In the other hand, Mulyono [7] explained that the amount of sediment will be transported through the water body is influenced by conditions and history of sediment at the sources spot. While Mananoma explained that the rate of sediment transport was strongly influence by characteristics of sediment material, condition of the river bed and characteristic of river flow. Further Suwartha [8] tried to find the relation between Progo trench to sediment transport rate and that was supported by Maulani [9]. Maulani claimed some part of lower Progo has a tendency to degrade. From this above mentioned studies and research can be concluded that the process of erosion and sedimentation occurs naturally with or without human interferences. From above mentioned literature, it can be explained that river morphology is strongly influenced by some factors such as: stream condition, sediment transport process, environment and human interference. The real human interference in Progo is sand mining activity that affects the morphology process [10].

In case of mountains river where its branches originated from an active volcano, the process of morphology is another specific one. Since the sediment source is purely come from pyroclastic deposits, the materials that will be transported are dominated by yield material of land erosion and land slide. In this case, rainfall intensity plays an important role and there fore rather difficult to predict it. Since the number of material will be transported in once event is very huge and move fast, so the effect of this kind of transport can be very strong [11]. Finally, Mananoma [12] wrote that this condition has been more aggravated by non professional sediment management. Therefore, she proposed some models of sediment management in Progo River.

3. BASIC THEORY

Channel of the river as a sediment transport has a very dynamic characteristics. Its form is created by the balanced of water and sediment discharge pattern. An alluvial river is defined as open channel which geometrical value: cross section and long section and slope that vary in time. This condition is formed due to water and sediment discharge, composition of river bed sediment and bed load characteristics.

During the cycles of erosion and sedimentation, the geometry of the river is not stable enough and it depends on the conditions. Therefore the channel try to reach itself equilibrium that follow by temporary stable condition.

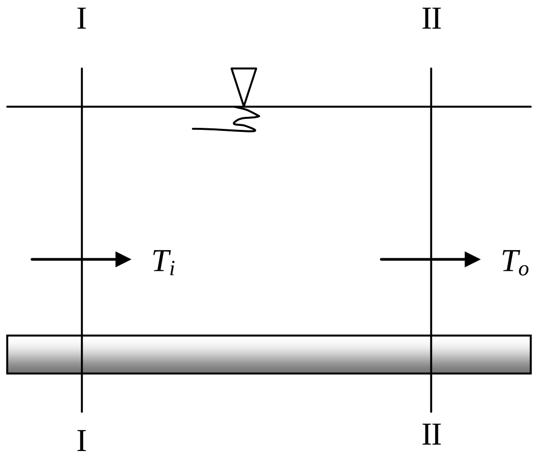

Fig. 5. Sediment balance scheme at such respected control volume.

The basic principal of sediment transport is the effort of a river on reaching equilibrium conditions. That means that inflow of sediment, T_i, is equal with sediment outflow, T_o, in such a respected control volume of water body. Therefore, the elevation and slope of the river bed will remains constant. When inflow of sediment, T_i, less than outflow, T_o, then the degradation will occurs, and vise versa the aggradations occurs (see Figure 5 and Table 2).

Table 2: Classification of river bed condition

Inflow and Outflow of Sediment Transport (*T*)	**The change of river bed**	
	Sediment Balance	**Condition of River Bed**
$T_i = T_o$	Equilibrium	Stable
$T_i < T_o$	Degradations	Decrease
$T_i > T_o$	Aggradations	Increase

Analyzes to the stability of river bed is the most effective one to know the process of degradations/ aggradations. In this case the measurement of bed level in certain period is easiest one. By analyzing this, the process of aggradations/degradation can be detected well.

4. RESULTS AND DISCUSSIONS

From the analysis of recorded measurement of Progo River bed elevation from year 1996 up to 2000 it can withdrew some information:

1. There always a dynamic process in cross section of an alluvial river as shown at Figure 6 and Figure 7.

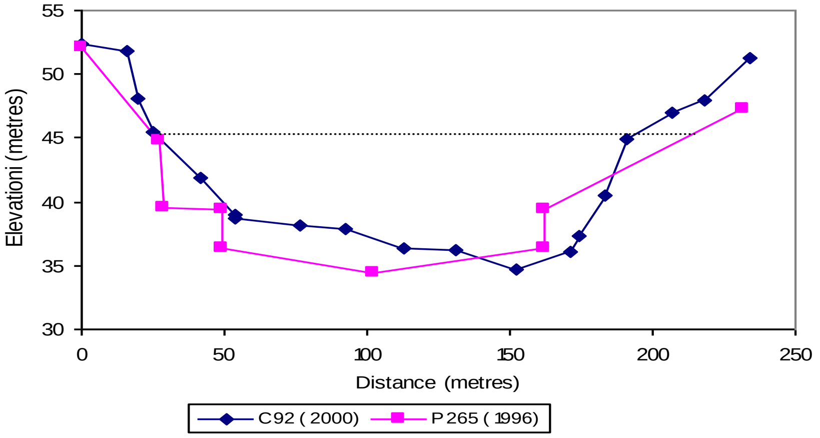

Fig. 6. The change of cross sectional area in Upstream Bantar Bridge

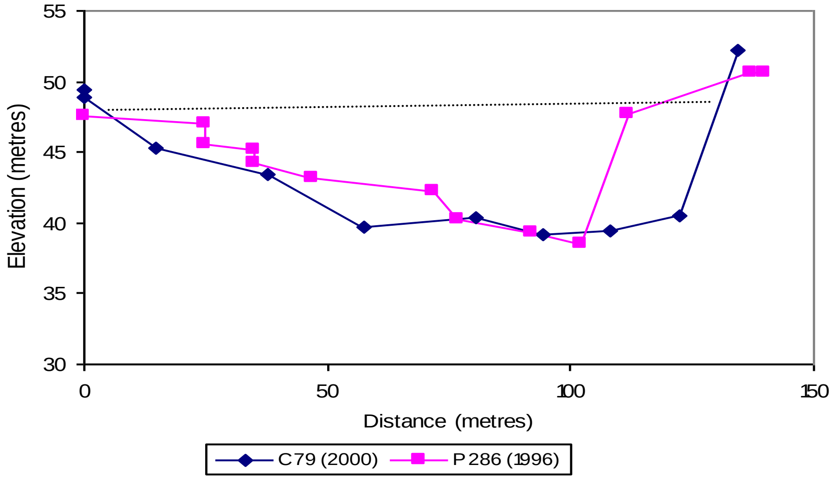

Fig. 7. Change of Cross Sectional area in Downstream Bantar Bridge.

2. Based on this result, then an analysis was developed in order to get general pattern of morphology in Progo River. In can be concluded that in the upper reach of the river with slope of about 1/135 tend to eroded and in lower reach with the slope between 1/200 - 1/550 tend to aggraded as shows in Figure 8.

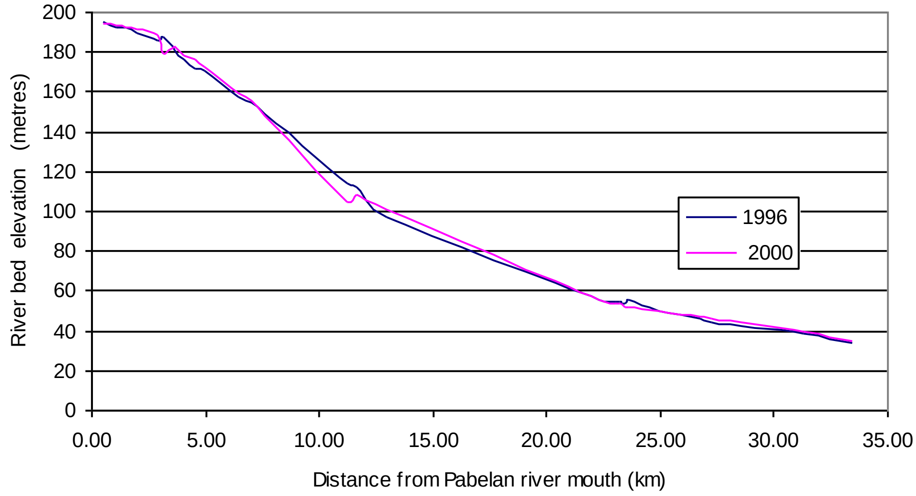

Fig. 8. Longitudinal changes of Progo river bed.

3. Analyzes of sediment balance was done to get the information of aggradations and degradation area along the river. Graphical result of in can be seen in Figure 9.

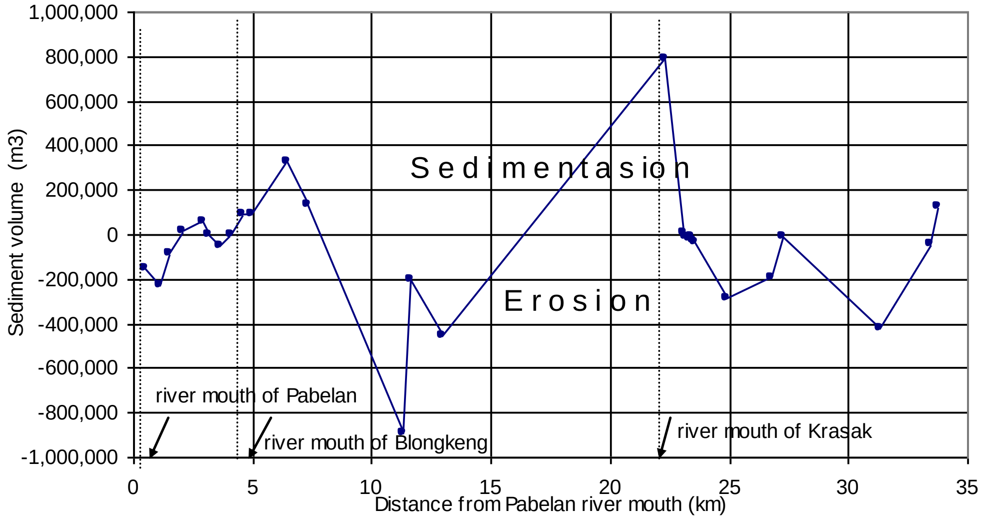

Fig. 9. Sediment transport pattern based on geometry measurement

5. CONCLUSION AND RECOMMENDATION

Based on the study has already done in Progo River, it can be reconfirmed that managing sediment of natural river is such a complicated task. However, through the experience of this study, a general guide line can be proposed on it. It is consist of system approach and various possible alternatives.

1. The process of river morphology is influenced by the specific characteristic of catchments area and characteristic of river itself. There for high understanding of mechanisms and criteria of sediment transport should be used as basic system approach on managing an alluvial river.
2. Some possible alternatives on keeping sediment balance can be arranged by used of some structural and non structural approach. The optimum alternatives of it can be determined by scale of priority modeling.

Lack of data is always a classic problem in such kind of study, therefore, recommendation on collecting a valid and accurate data of sediment transport and its characteristic is a needs.

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