EXPERIMENTAL INVESTIGATION OF SEDIMENT SORTING PROCESSES IN THE VEGETATED CHANNELS

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ABSTRACT

The study investigates the changes of channel and sediment sorting in the bed with vegetation. The sediment channel is irregular, and the amount of the sediment discharge decreases as the vegetation density increases. The bed elevation changes irregularly, and the sediment particle diameter on the river bed surface decreases due to vegetation. With the increase in the vegetation density, the dimensionless median particle diameter on the river bed surface decreases. The sediment is captured by the vegetation zone or deposited due to the boundary layer flow between the vegetation zone and the main flow. The changes of the flow in the vegetation zone result in an irregular distribution of sediment particle diameters on the surface layer. As the dimensionless median particle diameter of the river bed sediment decreases, the shield effect also proportionally decreases. With the increase of the vegetation density, the shield effect on the river bed's surface layer increases, which is consistent with the decrease of the sediment discharge at the downstream end of the experimental channel.

Keywords: *Riparian vegetation, sediment sorting, geomorphic change, mixed sediment*

1. INTRODUCTION

Riparian vegetation plays an important role in the flow, sediment transport, and geomorphic changes in river channels and the formation of biological habitats. In a river channel vegetation zone, the resistance to the flow increases, the flow velocity decreases, and the flow direction is changed. In addition, the sediment is easily captured and the river bed sediment is sorted in a vegetation zone (Tsujimoto, 1999). Moreover, energy exchange between the main waterway and the vegetation zone, increase of the turbulence intensity and flow focusing result in river channel changes in the main waterway and sediment deposition in flood plains and vegetation zones (Nepf and Vivoni, 2000). In addition, deposition of the sediment may also result in the increase of sand bars.

In a river channel consisting of mixed sediment without vegetation, the increase of the flow rate during a flood generally results in the transport of small-sized sediment by flotation, but the decrease of the flow rate results in the capture of the small-sized sediment between large-sized particles and the increase of the river bed sediment particle size. The river bed sediment size is reduced as the river bed height is increased; the inverse is also true. However, when the sediment transport is small due to the low shear stress, the particle size becomes larger in the river bed surface layer than in the base layer, and the river bed sediment particle size is decreased to the downstream. The sediment sorting process due to the changes of the flow and low waterways in the vegetated channels is very complicated. However, studies on river channel vegetation have been limited thus far, and previous studies are insufficient in terms of providing an explanation of the sediment sorting process and the geomorphic changes in river channels in a vegetated river that includes mixed sediment. In this study, an indoor experiment is performed to quantitatively analyze the geomorphic changes in a river channel and the river bed sediment particle sorting characteristics depending on the vegetation density. While artificial vegetation has typically been used for the investigation of the river channel changes by vegetation, actual vegetation (alfalfa) is grown in an experimental channel. This paper describes the changes of the river channel according to vegetation, the sediment discharge characteristics, the size distribution and sorting of river bed sediment particles, and the stabilization of low waterways.

2. LABORATORY EXPEREIMENTS

The indoor experiment was performed using a customized waterway that was 12 m long and 2 m wide. For the experiment using the slope-adjustable waterway, a home-built sand placement apparatus was used to prepare

Table 1. Experimental Conditions

Run	Water discharge (L/s)	Initial Water Depth (m)	Bed Slope (%)	Froude Number (Fr)	Mean Dia. of Bed material (mm)	Std. Dev. of Bed material	Vegetation density (stems/cm^2)	Remarks
1	5.83	0.0156	1/80	1.03	1.48	3.03	0.0	w/o
2	6.30	0.0164	1/80	1.20	1.48	3.03	0.5	w/veg
3	6.30	0.0164	1/80	1.20	1.48	3.03	0.7	w/veg

an initial waterway having an 80 cm long bottom side, a depth of 3 cm, and a riverbank slope of 40°. The channel slope was set to 1/80 (Table 1). To make the eddy flow generated in an elevated tank uniform, a plastic mesh was attached to the screen inside the water tank. Since local scouring occurs at the inlet when water is put from the elevated tank into the mobile bed slope waterway filled with the sand. The mixed sediment used in the experiment had a D50 value of 0.85 mm, wherein the D50 value represents the cumulative passing weight of 50% in the cumulative particle size distribution. The standard deviation of the river bed sediment particle size distribution was 3.03, which is the property of completely mixed sediment. The longitudinal bed profile was measured from 1 m at the upstream to 8 m at every 20 cm in the experimental reach since the upstream 1 m was not considered to avoid the effects of inlet and disturbance of water profile due to the sediment supply. The transverse bed profile was surveyed between 0.05 m and 1.95 m at every 1 cm due to the moving limitation of the profiler.

After a braided channel was fully reproduced, which was 64 minutes, we sprayed alfalfa seed on the channel bed and banks by hand uniformly without the flow. After that, discharge of 0.4 l/s was allowed in the channel for 2 minutes to prevent alfalfa from growing up at the lower channel. The seed was scattered on bars and banks, some were transported on the lower channel bed by the flow and later placed along the banks, border line between bar and water elevation, or washed out the flume. The discharge of 0.15 *l/s* had been allowed to the channel to maintain the saturated bed, leading to keep the channel shapes, and to supply water to alfalfa by two times per day about 1.5 hours.

3. RESULTS AND DISCUSSION

3.1 Geomorphic changes of the channel

The experiment was conducted to analyze the changes of the river channel and the river bed sediment sorting process in the river channel including the mixed sediment. Figure 1 shows the changes of the river channel over time in Run-3. Over time, the width of the low waterway was increased, and the flow was focused on the waterway, scouring the river bed (Figs. 1(a) and (b)). The flow velocity was decreased in the vegetation zone, and a boundary layer flow was formed between the low waterway and the vegetation zone. As the flow velocity was decreased in the vegetation zone where a boundary layer was formed, the sediment having a small particle size was deposited, resulting in the elevation of the river bed height. On the other hand, in the low waterway on which the flow was focused, the river bed height was decreased and the particle size of the river bed sediment was increased. As the flow continued, the riverside was eroded and the low waterway width was increased, the transport of the sediment was enhanced and the river bed height was increased by the sediment supplied from the upstream (Fig. 1(c)). The sediment supplied from the low waterway to the vegetation zone increased the river bed height, destroyed the vegetation zone, and formed a new low waterway.

(a) T= 60min (b) T=120min (c) T=180min

Figure 1. Temporal changes of a vegetated channel for Run-3

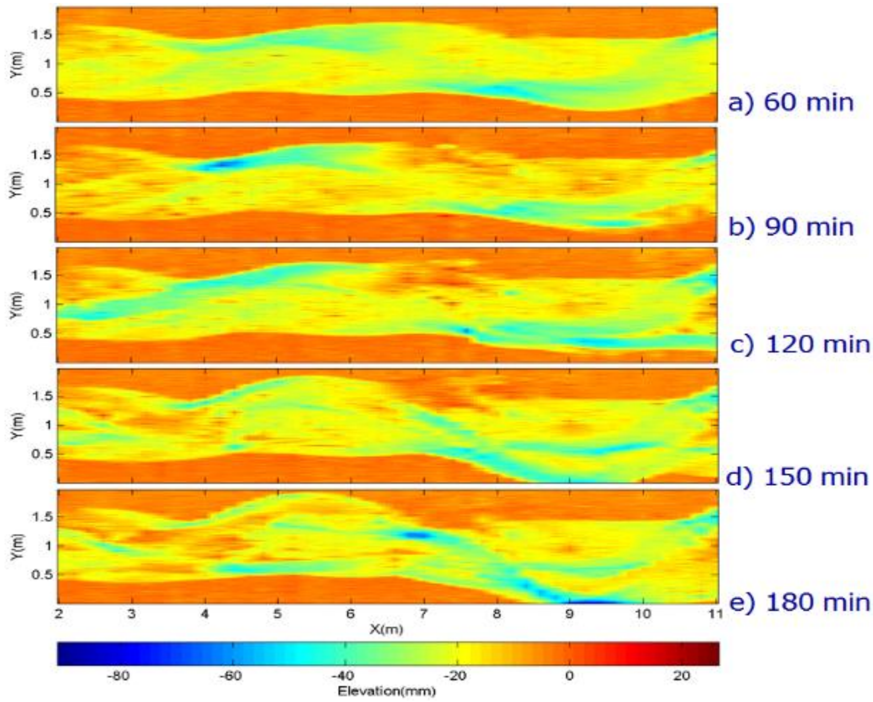


Figure 2. Geomorphic changes for Run-3

Over time, the lower channel was wide, and the curvature of the channel increased at the position 9 m away from the inlet. This was because the vegetation altered the flow direction, focusing the flow on the low waterway (Jang and Shimizu, 2007). The increase in vegetation density caused an increase of the meandering. As the vegetation was destroyed and the low waterway was widened as a result, the sediment transport was enhanced, the sediment was deposited in the downstream vegetation zone, and a new waterway was formed (Figs. 2 (d) and (e)).

3.2 Sediment discharge and sediment particle size distribution of the bed

Figure 3 shows the amount of sediment discharge at the end of the channel over time. The sediment discharge was dependent on the changes of the lower channel and bars. The sediment discharge was measured by sampling once per 15 minutes and drying the samples. In Run-1, where vegetation density was zero, the sediment discharge was high and irregular, indicating that sediment was actively transported through the low waterway. On the contrary, in Run-2 where the vegetation density was low, the sediment discharge was less and regular. In Run-3 where the vegetation density was high, the sediment discharge was less than that in Run-2 and showed a regular pattern. Since the vegetation captured the sediment, the amount of sediment discharged was less in the vegetated channel than in the channel without vegetation.

In a vegetated channel consisting of mixed sediment, the bed sediment particle size distribution is complex. The flow properties in a vegetation zone are critical to the behavior of the sediment and the sorting of the river bed sediment. In the early stage, the flow in the bed was focused on the low waterway, and thus the sediment was actively transported. The vegetation grown in the channel was uprooted and swept to the downstream. The uprooted vegetation was captured in the vegetation zone where the flow was slowed and the flow direction was changed. The particle size of the river bed sediment became large in the low waterway, while it became small in the vegetation zone. In particular, the sediment was deposited around the vegetation zone as a boundary layer flow is formed between the vegetation zone and the low waterway flow, or as the flow was slowed at the front end of sand bars and thus the flow velocity was decreased (Fig. 4). The particle size distribution of the river bed sediment was locally irregular in the vegetated river channel. At point 2) in Figure 4(b), the bed sediment particles became large in the lower channel where the flow was focused. On the other hand, at point 3), the particle size of the river bed sediment was relatively small in the low waterway in the downstream where the sediment was actively transported. These findings are consistent with the sediment sorting process in river channels consisting of mixed sediment without vegetation, wherein the particle size of the surface layer sediment decreases when a large amount of the sediment is transported (Parker et al., 1982, Listle et al., 1993, Jang, 2014).

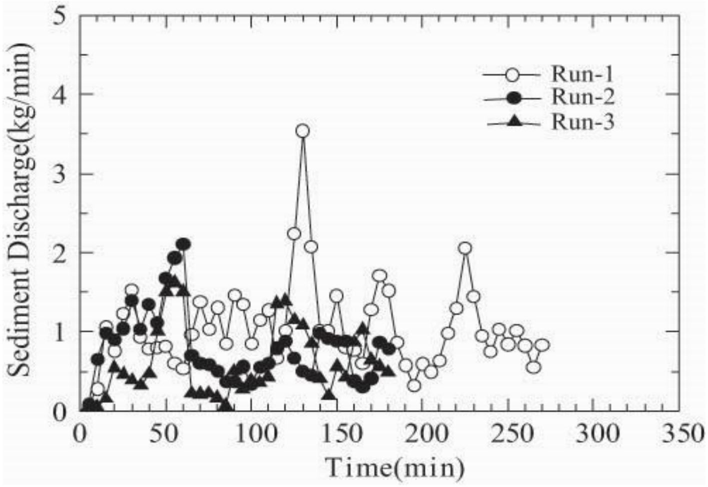
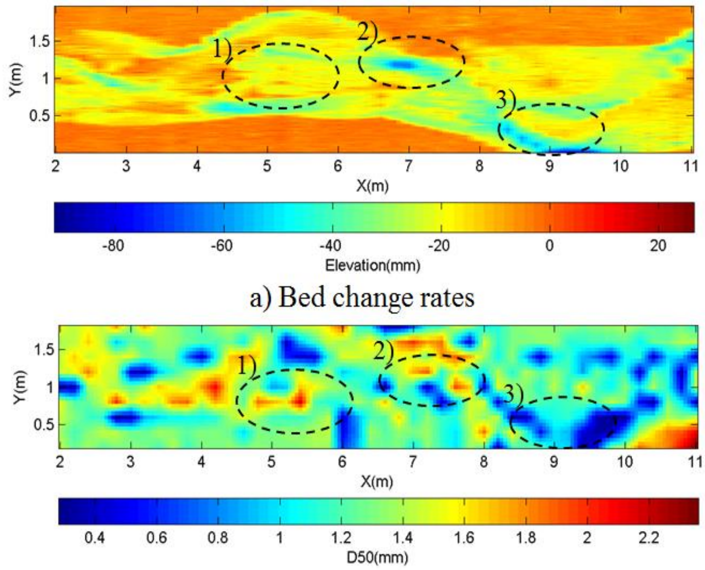


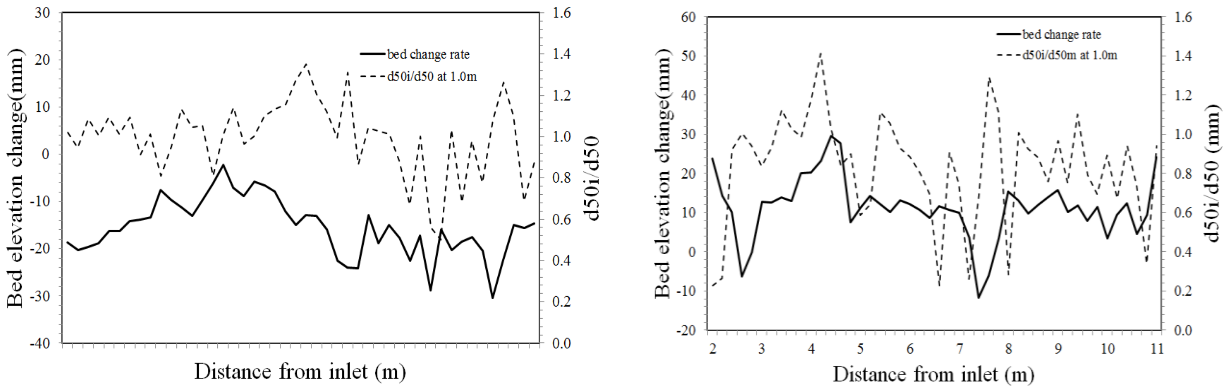
Figure 3. Sediment discharge with time for each run



a) Bed change rates

b) Bed material size distribution

Figure 4. Bed change rates and bed material size distribution for Run-3



(a) Run-1

(b) Run-3

Figure 5. Dimensionless median size distribution of bed materials with vegetation density

Figure 5 shows the change in the dimensionless particle diameter depending on the river bed height. As shown in Run-1, the sediment particle size increased at the points where the bed elevation decreased or in the direct downstream of the points. In particular, the sediment was actively transported at the confluence point due to the strong shear force and secondary flows at the front part of the central bar, resulting in a decrease of the particle size of the river bed sediment in the downstream of the merging points. However, at the points where the bed slope was relatively mild, the dimensionless particle diameter was greatest at the merging points which was found behind the central sand bar. On the other hand, in the vegetated channels (Run-3), there were some intervals where the change of the bed elevation was not consistent with the change of the particle size of the bed sediment. This may likely be because the sediment was captured by the vegetation or a boundary layer flow was formed between the vegetation zone and the mainstream, altering the flow direction in the vegetation zone and thus making the sediment particle size distribution in the surface layer irregular.

To quantitatively investigate the changes of the river bed and the low waterway transport characteristics over time using the individual experimental results, the time-series data for all cross-sections were statistically processed and the correlations with the geomorphic changes were analyzed (Jang and Shimizu, 2007).

$$r = \frac{cov(z_{1,} z_2)}{\sqrt{var(z_1) var(z_2)}} \quad (1)$$

$$cov(z_1, z_2) = \frac{1}{n} \sum (z_{1i} - \overline{z_1})(z_{2i} - \overline{z_2}) \quad (2)$$

$$var(z) = \frac{1}{n-1} \sum_{i=1}^{n} (z_i - \overline{z})^2 \quad (3)$$

In the above equations, r is the correlation coefficient representing the correlation between the time-series data cross-sections, z_1 and z_2, with the change of the river bed height. An r value close to 1 means that the transport through the low waterway is small and stable. An r value close to 0 (zero) means that the transport through the low waterway is active and unstable. z_1 and z_2 are the river bed height at each time step. $\overline{z_1}$ is the mean river bed height at time 1, while $\overline{z_2}$ is the mean river bed height at time 2. cov($z_{1,} z_{2,}$) represents the covariance of, z_1 and z_2, and var(z_1) and var(z_z) represent the variance of z_1 and z_2, respectively.

Figure 6 shows the correlation coefficient depending on the vegetation density. The correlation coefficient was

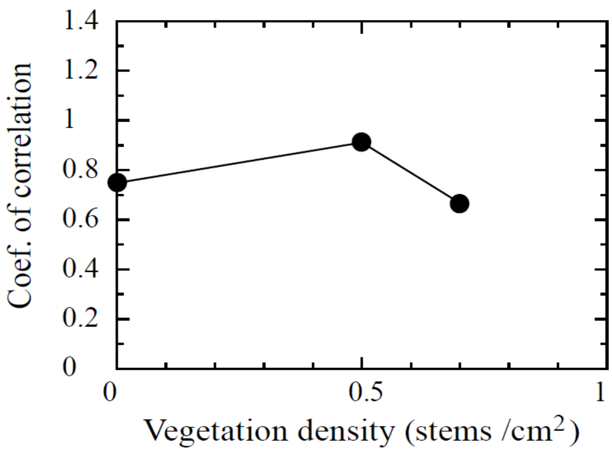


Figure 6. Correlation coefficient of bed topography is plotted against vegetation density

increased as the vegetation density increased to 0.5 stems/cm^2 decreased when the vegetation density was 0.7 stems/cm^2 When the vegetation density was increased to 0.5 stems/cm^2, the transport through the low waterway was decreased and stable. On the contrary, at a vegetation density of 0.7 stems/cm^2, the transport through the low waterway was active. This may be because the serpentine motion of the low waterway was significantly increased by the increase of the vegetation density, and a new low waterway was formed by the deposition of the sediment in the vegetation zone (Tal and Paola, 2000). It is suggested that further studies should be conducted under various experimental conditions in terms of the vegetation density and the low waterway transport limit.

4. SUMMARY AND CONCLUSIONS

The change of the river channel and the sediment sorting by vegetation were investigated. The following conclusions were obtained from the results. The sediment discharge was irregular. With the increase in vegetation density, the sediment discharge was decreased. The change in the bed height was irregular, and the particle diameter of the sediment decreased in the river bed sediment surface layer. With the increase in vegetation density, the ratio of the dimensionless median particle diameter in the river bed surface layer decreased. The sediment particle size distribution was irregular in the surface layer because the flow direction was changed in the vegetation zone. As the dimensionless bed sediment particle diameter decreased, the shield effects on the bed also decreased. With the increase in the vegetation density, the shield effects on the bed surface layer increased, which was consistent with the decrease of the sediment discharge at the end of the experimental channel

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