COARSE SEDIMENT MOVEMENT AROUND U-SHAPED VEGETATION ZONE ON GRAVEL BAR WITH TWO MEANDERING CHANNELS

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ABSTRACT

Vegetation transition was investigated on a large-gravel bar with two meandering channels in Kinugawa River, where the restoration had just been implemented. It is shown that a U-shaped vegetation zone, open to the upstream side, was formed along the main channel and the second channel. This U-shaped zone was mainly composed of Poaceae. The endemic species for gravel bar, such as Aster kantoensis Kitam and Anaphalis margaritacea subsp. yedoensis, and the alien species, such as Eragrostis curvula, seemed to inhabit according to the coarse sediment size deposited in/around the U-shaped zone. Based on the field investigation, Numerical experiments were performed to examin the effect of the U-shaped zone (and its partial clearing) on flow field and coarse sediment movement. The topography of the gravel bar for the numerical analyses was introduced based on a laboratory experiment, and movement of coarse sediment which is smaller than the materials of the gravel bar was investigated. It is suggested that fine sand for Eragrostis curvula can be deposited on the internal or downstream area of the U-shaped zone, and that gravel for the endemic species can appear in the outer edge of the U-shaped zone. It was also shown that the partial removal of the "bottom" part of the U-shape will be most effective for suppression of fine sand deposition, which can be one of the powerful options for effective vegetation management.

Keywords: vegetation, coarse sediment, gravel bar, two meandering channels, numerical analysis

1. INTRODUCTION

In steep rivers, gravel yield and deposition are very active, then, gravel bars and shores are developed in the mid-upper reach of Japanese rivers. Recently, however, artificial impacts, such as gravel-digging, dam construction, and so on, have caused degradation of river bed, reduction of flood frequency and decrease of sediment supply. Therefore, gravel bed environment has been disappearing, which causes not only environmental issues, such as reduction of endemic species for gravel bed and enlargement of alien species, but also flood disaster problems, such as river bank erosion and local scour.

In mid-upper regime of Kinugawa River, for example, the channel morphology was such as braided or two lane meandering more than seventy years ago. In these days, however, channel morphology is changing into single lane meandering, forming water colliding fronts which cause river disasters. Furthermore, habitats of alien species such as Eragrostis curvula is being enlarged and those of endemic species for gravel bed, such as Aster kantoensis Kitam, becomes almost extinct (Muranaka and Washitani, 2001a, 2001b).

As a countermeasure against these issues, from about ten years ago, gravel bar restoration project started in Kinugawa River (Mashiko and Maemura, 2008). This project intends to increase submergence frequency by cut down of the height of gravel bars, and to control flood flow by installing cobble mount at the upstream end of a gravel bar (Suga 2004, Suga, et al. 2008). However, partially because effective maintenance has not been performed after the restoration, gravel bars were covered with fine sand, and grassland of alien species and forest area were enlarged.

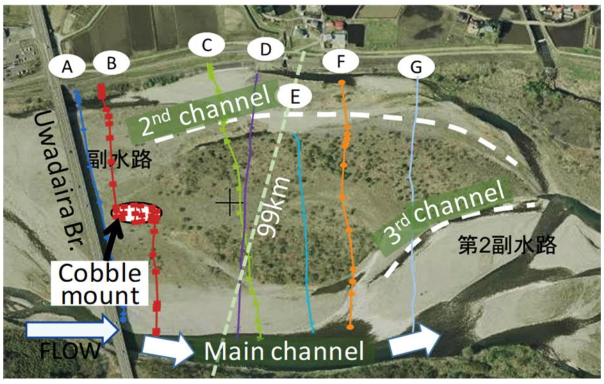


Figure 1. Aerial photograph of the field investigation site and traverse lines for topographic survey (A-G).

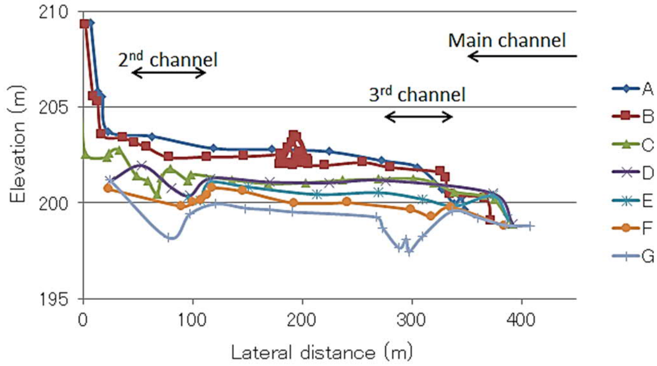


Figure 2. Elevation along the traverse lines (A-G) in Figure 1.

Habitat condition of vegetation on gravel bars has been increasingly clarified (Muranaka and Washitani, 2001a, 2001b; Matsuma, 2005; Akamatsu et al., 2007; Asami et al., 2012; Asaeda et al., 2009, 2010a, 2010b; Gomes and Asaeda, 2009). And the effect of vegetation in rivers on sedimentary environment is also well known (e.g. Gurnell 2013). Meanwhile, some maintenance attempts have been developed to remove the alien species by flushing out during flood or by pulling out in collaboration with regional activities (Tsuzuki et al., 2006; Une et al., 2012). However, on gravel bars with braided or two meandering channels, the vegetation pattern and its influences on flood flow structure and coarse sediment movement are not fully clarified. And, for efficient vegetation management, the effect of partial removal of vegetation is also very important.

In the present study, vegetation transition on a gravel bar with two meandering channels was investigated over three years after implementation of gravel bar restoration. Subsequently, numerical analyses were performed to examine the influences of vegetation distribution pattern and its partial removal on the flow structure and coarse sediment behavior on gravel bars with two meandering channels.

2. FIELD INVESTIGATION

2.1 Investigation site and method

The field investigation site is a gravel bar near the Uwadaira-Bashi Bridge in mid-upper regime of Kinugawa River, located at about 99km point from the confluence to Tonegawa River in Kanto Plain, Japan. Figure 1 shows an aerial photograph of this site in 2011. This gravel bar was about 700m long and 400m wide, and the average bed slope was 1/200. This gravel bar was formed between the two meandering channels (the main channel and the second channel in the figure), and the short third channel was formed locally. The restoration project of this gravel bar was implemented in the year 2011, which cut down the bar height, covered the bar surface with cobble and installed cobble mount at the upstream end of this bar.

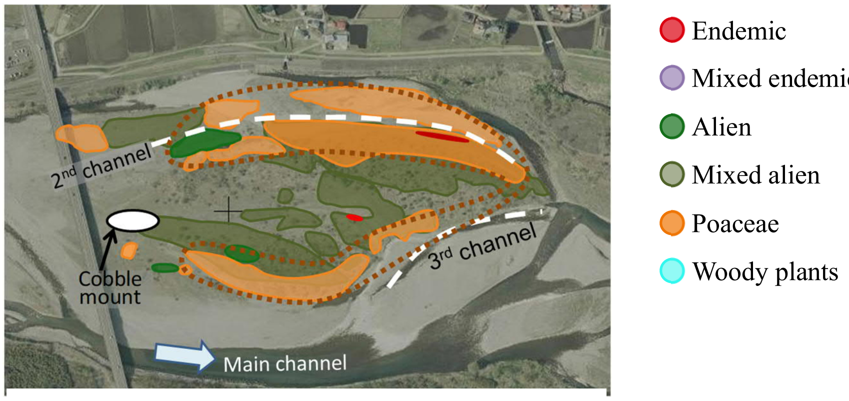
The field investigations were performed from the year 2012 to 2014. Vegetation distribution survey was executed every year, which traced the periphery of each plant community with GPS instruments and created yearly vegetation maps on GIS. Topographical survey was carried out in 2012 along the traverse lines shown in Figure 1. During three years of these field investigations, we had two floods, which made almost no change of gravel bars in mid-upper reach of Kinugawa River.

2.2 Gravel bar topography

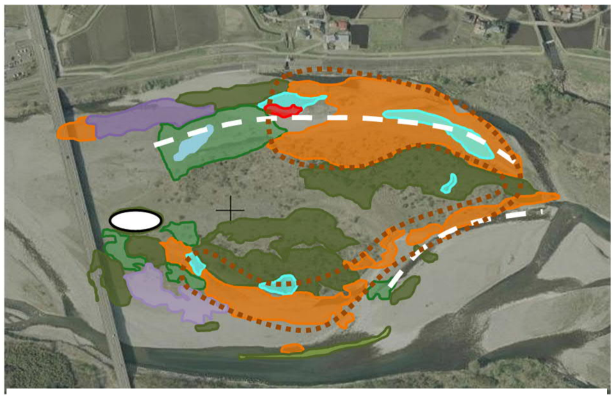
Figure 2 is the result of the topographical survey. It is shown that cross sectional profile of the gravel bar is convex upward with a flat area and the elevation difference between the traverse line A and G was about 3m. The main channel appears in the right bank side and the second channel profile is also clear in the left bank side on lines C to G. The third channel can be seen on lines F and G. The cobble mount installed in the restoration project appears on the line B, which indicate the height is about 2m.

2.3 Vegetation transition after gravel bar restoration

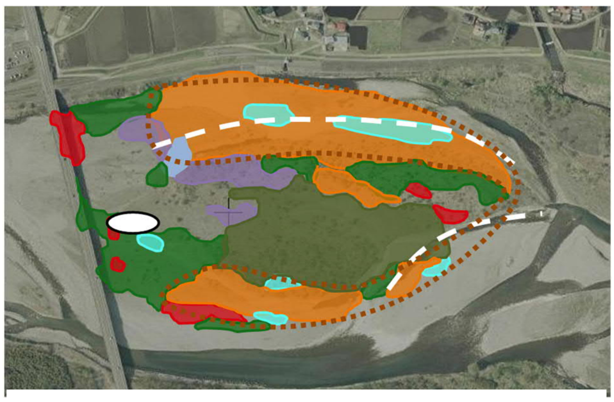
Figure 3 shows vegetation map of the year 2012 to 2014. The correspondence between community name and plant species can be described as follows; “Endemic” community consists of Anaphalis margaritacea subsp. yedoensis, Chamaecrista nomame and Aster kantoensis Kitam. “Mixed endemic” community consists of Anaphalis margaritacea subsp. Yedoensis, Eragrostis curvula and Poaceae. “Alien” community consists of Eragrostis curvula. “Mixed alien” community consists of Eragrostis curvula and Poaceae. “Poaceae” community consists of Miscanthus sacchariflorus, Miscanthus sinensis and Phragmites japonicus Steud. “Woody plants” community consists of Salix gilgiana and Robinia pseudoacacia.



(a) Year 2012



(b) Year 2013



(c) Year 2014

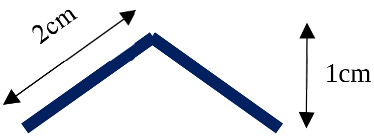
Figure 3. Transition of vegetation distribution from the year 2012 to 2014
(Brown dotted line indicates U-shaped vegetation zone of Poaceae)

As a whole, most of vegetation grew thickly in/around a U-shaped zone, open toward the upstream direction, denoted by brown dotted line. This U-shaped zone is mainly composed of Poaceae, and formed within a certain range of relative height to water surface of the main channel and the second channel. In the third year, 2014, the internal area of the U-shape was almost covered, which made vegetation situation on the gravel bar transfer to another stage.

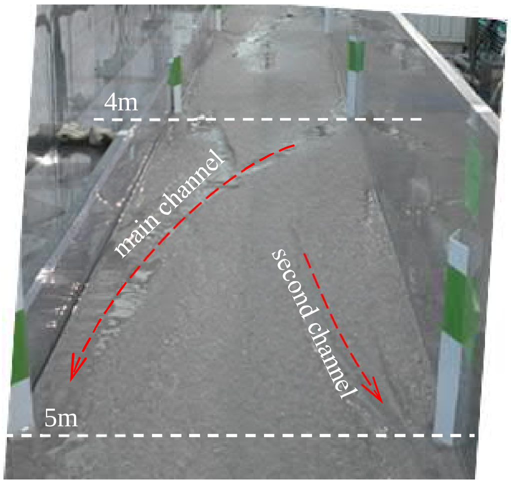
Communities of endemic (and mixed endemic) species for gravel bed, composed of almost Anaphalis margaritacea subsp. yedoensis, were rare but recognized around outer edge of rather upstream part of the U-shaped zone, where gravel was deposited more than the other area. Alien species, composed of almost Eragrostis curvula which adapts to sandy bed (Muranaka and Washitani 2001a, 2001b; Matsuma 2005), were distributed in very large area on the gravel bar, especially in the internal area of the U-shape, where fine sand was deposited. The difference of sediment size between the outer edge and the internal area is supposed to be due to velocity difference in flood flow, affected by the flow resistance of the U-shaped zone. Therefore, the U-shaped vegetation zone, established in initial stage immediately after the restoration, plays a very important role in vegetation transition on gravel bars.

Two kinds of woody plant community were observed, Salix gilgiana and Robinia pseudoacacia. The communities of Salix gilgiana were developed along the second channel, meanwhile those of Robinia pseudoacacia were seen to be scattered on the main channel side of the gravel bar. This difference of habitat

(a) Installation of a groyne



(b) Dimensions of a groyne.



(c) Two meandering channels (red broken lines) with groynes installed in the same phase. White broken lines denote the 4m and 5m line from the upper end of the flume.

Figure 4. Formation of sand bars and two meandering channels in a laboratory flume with groynes.

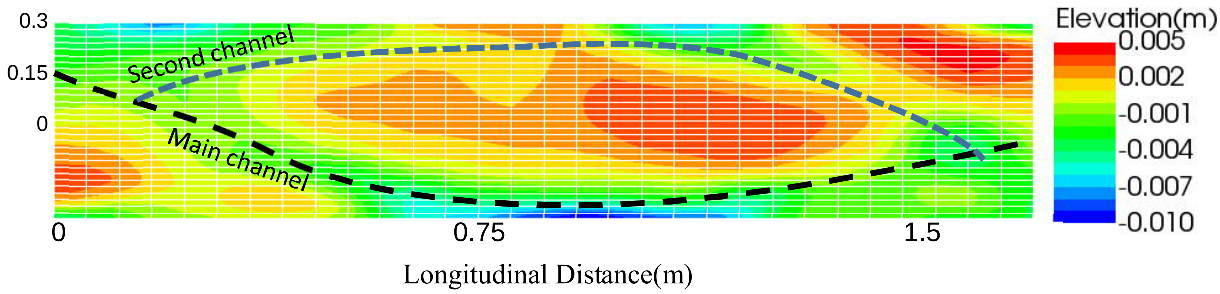


Figure 5. Smoothed topography of a bar with two meandering channels.

condition between the two woody plant communities on a gravel bar with two lane meandering is very interesting, however, because the habitat area of these species is not so large in comparison to herbaceous communities, this is a subject for future analysis.

3. NUMERICAL ANALYSIS

3.1 Laboratory experiment for gravel bar topography

It is well known that stable bar topography with braided or two meandering channel can not be reproduced by simple numerical analyses in straight channels (Watanabe and Kuwamura, 2004). In the present study, therefore, numerical analyses were performed based on gravel bar topography with two meandering channels stably formed in a laboratory experiment.

In the experiment, a straight flume of 8m length, 30cm width and 24cm height (rectangular cross section) was used. In order to obtain stable bar topography, groynes were installed every 1m from the upstream end so that the channel width was narrowed periodically (Takahashi and Yasuda, 2012). Figure 4(a) and (b) shows installation situation and dimensions of the groyne, respectively. The channel slope was set to 1/30, the bed material diameter was 0.9mm, and the flow rate was 430 cm^3/s. Then, 2 hours after supplying water, bar topography was stably formed with two meandering channels where the difference between the main channel and the second channel was clear (see Figure 4(c)).

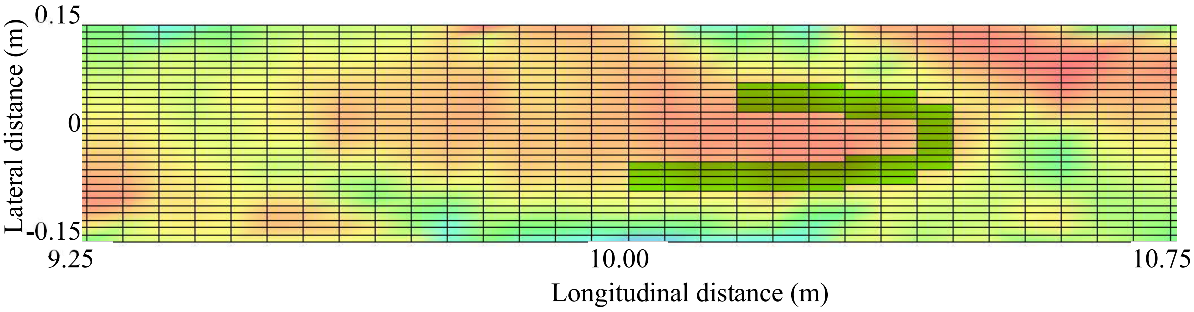
In order to use this experimental topography in numerical analyses, the topography was smoothed with using cubic spline curves after the trend was removed. Figure 5 shows the topographic contour of relative height to an average plain parallel to the experimental channel bed. The length and height of a bar topography were 1.5m and 1.4cm, respectively, and the relative height between the main channel and the second one was 1.1cm.

3.2 Numerical method and conditions

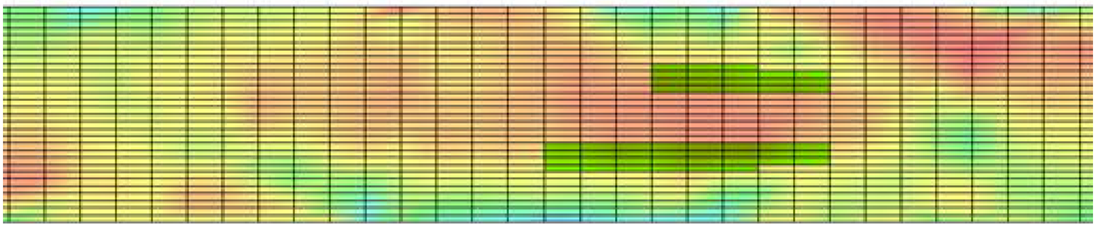
Nays-2DH solver of iRIC system (iRIC-UC, 2020) was used for numerical analyses of the two-dimensional flow and movable bed. In numerical analyses, 10 sets of the gravel bar topography obtained from laboratory experiment was installed periodically in a rectangular straight channel of 30cm width, which was connected to upstream and downstream sections. In the upstream and downstream sections, two sets of the gravel bar

Table 1. Numerical analysis conditions

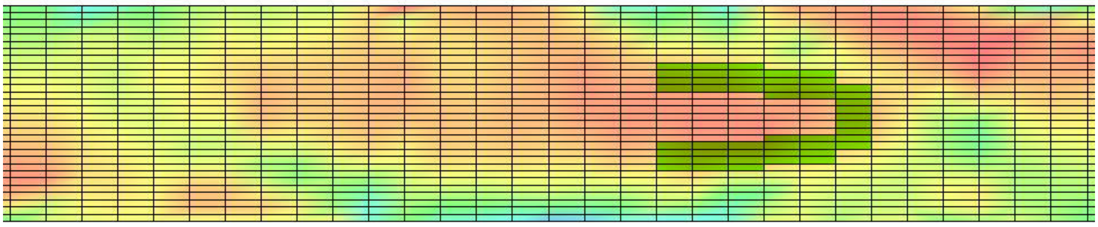
Case	Vegetation pattern	Coarse material	Flow rate (m^3/s)	Bed slope	Bed roughness
Case A1	None	None	$330x10^{-6}$	1/30	0.028
Case A2		Casted (5mmϕ)			
Case B1	Whole U-shape	None			
Case B2		Casted (5mmϕ)			
Case C1	The bottom part removed	None			
Case C2		Casted (5mmϕ)			
Case D1	The main channel side partially removed	None			
Case D2		Casted (5mmϕ)			



(a) Case B1 and B2 : whole U-shape



(b) Case C1 and C2 : removal of the bottom part of the U-shape



(c) Case D1 and D2 : partial removal of the main channel side of the U-shape

Figure 6. Vegetation pattern in numerical analyses

topography were installed respectively, where the height scale of the topographies was changed linearly to zero at both of the upstream and downstream ends. These topographies of gravel bar were fixed in the numerical analyses. The length of a bar topography was 1.5m, then, the total length of the channel was 21m. This numerical channel was divided into rectangular meshes of 5cm length and 1cm width. The numerical results were observed between 9.25m and 10.75m from the upstream end.

Table 1 shows the numerical analysis conditions. The flow rate was less than that in the laboratory experiment for gravel bar topography, which simulates mid-sized flood once a few years (River Foundation, 2009) so that the whole riverbed was below the water surface. The bed material diameter was 0.5mm, less than that of the bar material, which was casted at the upstream end of the channel. Case A1 and A2 were with no vegetation. Case B1 and B2 were with U-shaped vegetation area. The U-shaped area was installed base on the bed topography shown in Figure 6(a), which has longer side arm on the main channel side. The vegetation density and its drag coefficient were $122.5m^{-1}$ and 1.0, respectively (Ikeda, et al., 2018). Case C1 and C2 were cases for removal of the bottom part of the U-shape (Figure 6(b)). Case D1 and D2 were cases for partial removal of the main channel side of the U-shape (Figure 6(c)), where the removed volume was about same as Case C1 and C2.

3.3 Numerical results

Figures 7 and 8 show the numerical results of Case A1 and A2, respectively. In Figure7, meandering flow is observed along the main channel running from the left bank side of the upstream part to the right bank side of

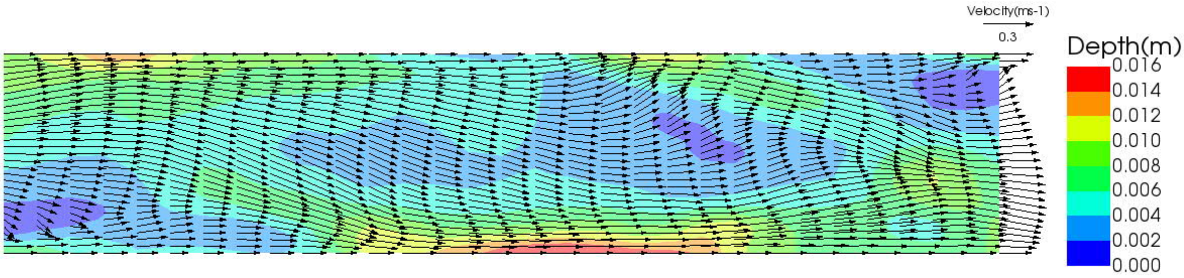


Figure 7. Numerical results of velocity vector and water depth contour of Case A1.

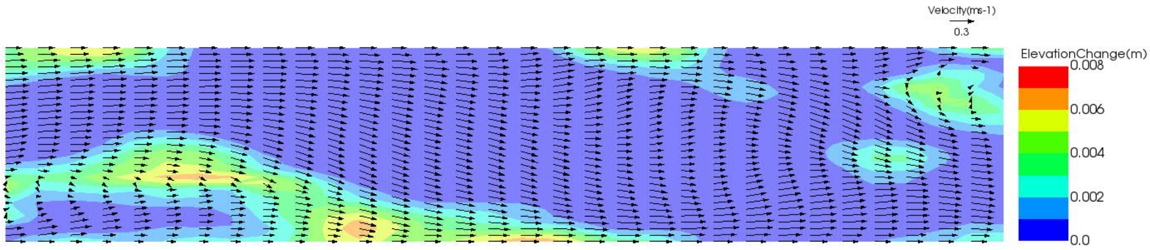


Figure 8. Numerical results of velocity vector and bed elevation change contour of Case A2.

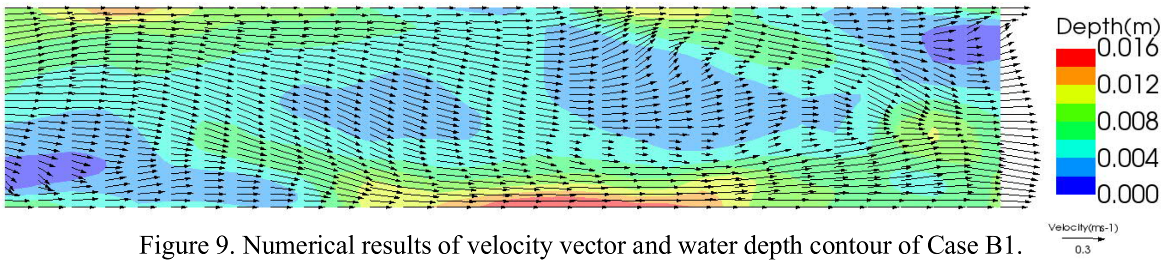


Figure 9. Numerical results of velocity vector and water depth contour of Case B1.

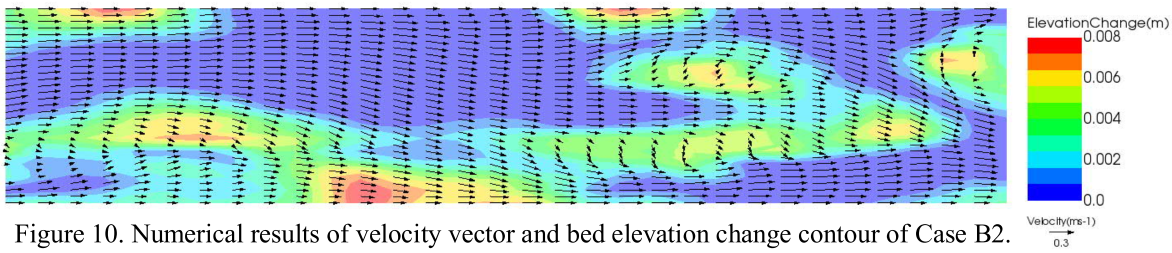


Figure 10. Numerical results of velocity vector and bed elevation change contour of Case B2.

the medium part, and to the center of the downstream part. And a flow along the second channel, divided from the main meandering flow in the medium part, converges into the main flow again. In Figure 8, a large deposition area can be seen along the right edge of the main meandering flow, which highlight the main channel topography. It is also suggested that the other small deposition areas will make the left edge of the second channel distinctive.

Figures 9 and 10 show the numerical results of Case B1 and B2, respectively. Figure9 shows that the flow is decelerated in/around the vegetation area itself and also the behind of the vegetation. Then, low velocity area is extended to the confluence of the main channel and the second channel. In Figure 10, in the deposition areas observed in Figure 8, the river bed was more raised. Moreover, another noticeable deposition area is spread over a wide area in/around the U-shape vegetation, especially to the behind area. This feature agrees well with the field investigation qualitatively. Finer coarse sediment, like fine sand, will accumulate more with a similar tendency, which will encourage the alien species. Then, removal of U-shaped vegetation is very important policy for river management.

Figure11 and 12 show the numerical results of Case C1 and C2, respectively. The effect of removal of the bottom part of the U-shape almost eliminates the low velocity region in the internal and the behind region, therefore, the deposition area around the vegetation is reduced. The influence of the main channel side of the vegetation, however, still remains so that the deposition area distributes continuously along the main channel.

Figure13 and 14 show the numerical results of Case D1 and D2, respectively. The deposition area along the right bank side is a little reduced. However, the most serious deposition areas are not at all reduced because the low velocity areas in the internal and behind region of the U-shaped vegetation still remain. Therefore, if we remove the same volume, removal of the bottom part of the U-shape will be effective. And if possible, additional removal of the main channel side arm, even if partial removal, will be more effective.

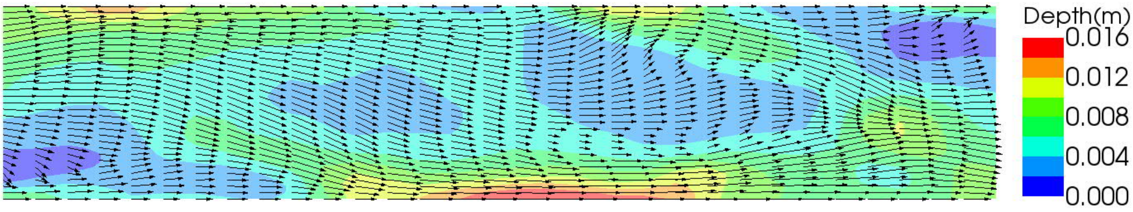


Figure 11. Numerical results of velocity vector and water depth contour of Case C1.

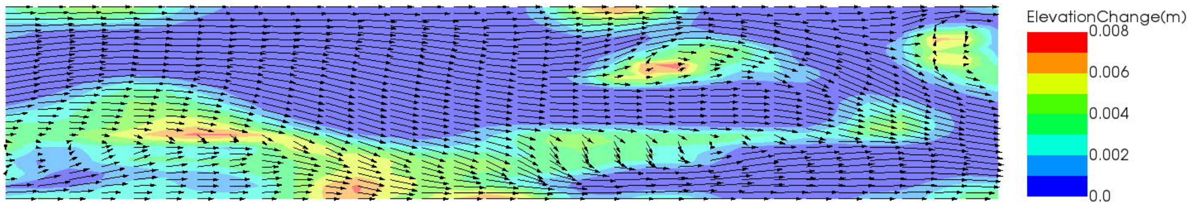


Figure 12. Numerical results of velocity vector and bed elevation change contour of Case C2.

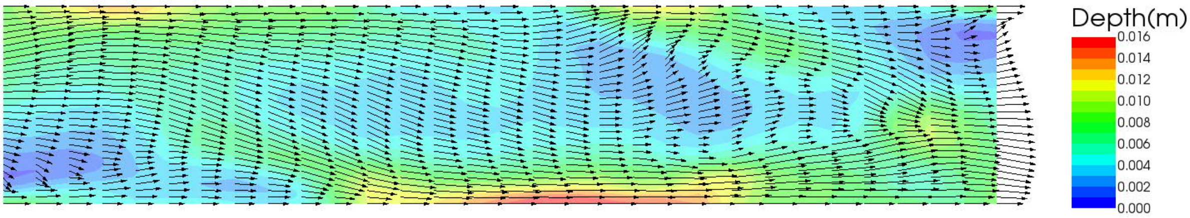


Figure 13. Numerical results of velocity vector and water depth contour of Case D1.

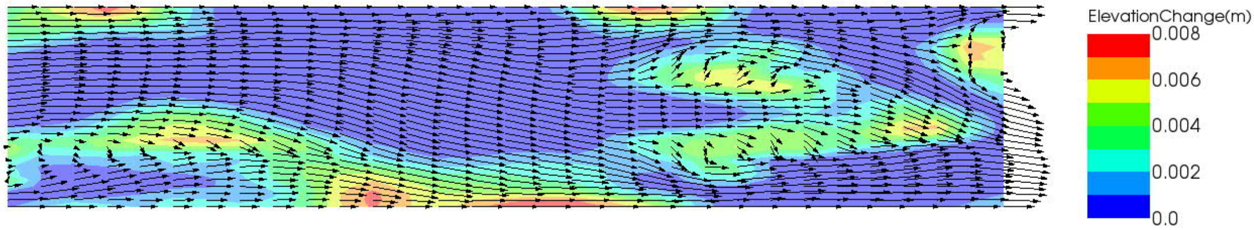


Figure 14. Numerical results of velocity vector and bed elevation change contour of Case D2.

4. CONCLUSION

In the present study, vegetation transition on a gravel bar with two meandering channels in Kinugawa River was investigated, and numerical analyses were performed to examine influences of the vegetation area on flow structure and coarse sediment movement. As a result, following findings were obtained.

On a large-gravel bar with two meandering channels, a U-shaped vegetation zone, open to the upstream side, was formed along the main channel and the second channel immediately after the gravel bar restoration. This U-shaped zone was mainly composed of Poaceae, and formed within a certain range of relative height to water surface of the main channel and the second channel.

Endemic species for gravel bed were mainly recognized around outer edge of the U-shaped zone, and alien species were distributed especially in the internal area of the U-shape where fine sand was deposited. It is suggested that flow resistance of the U-shaped zone affects the flood flow structure and sediment distribution, which influences vegetation segregation on the gravel bar.

Generally, with simple numerical simulation in a straight channel, stable gravel bars with two meandering channels cannot be reproduced. In the present study, stable topography was successfully reproduced in a laboratory experiment with groynes, which was used in the numerical analyses.

Numerical results show that low velocity regions are formed in the internal and behind area of the U-shape vegetation, where coarse sediment is deposited more than the other areas, and the deposition area in the main channel side arm of the U-shape is merged with that along the main channel.

Numerical results also show that removal of the bottom part of U-shape eliminates the low velocity regions, which is most effective on the whole area. And if the main channel ide arm can be removed in addition, significant improvement is expected.

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