The Structure, Function and Management Implications of Fluvial Sedimentary Systems (Proceedings of an international symposium held at Alice Springs, Australia, September 2002). IAHS Publ. no. 276, 2002.

Topographical change and sediment transport after habitat improvement in the Pankenai River, Japan

YOSHIMASA KURASHIGE

School of Environmental Science, The University of Shiga Prefecture, 2500 Hassaka-cho, Hikone 522-8533, Japan

e-mail: kurashig@ses.usp.ac.jp

Abstract At a concrete-lined reach of the Pankenai River, the concrete blocks in the centre of the channel were removed to improve the habitat for aquatic animals. The river-bed topography after the improvement was measured from 1994 to 1998 in four sections. The channel bed was eroded by thawing floods in 1994. In 1995, the eroded channel was filled with gravel at the lower sections, but erosion has continued in the upper sections. In 1996 and 1997, slight erosion was observed at all sections, in contrast to severe deposition at all sections in 1998. Mechanical analysis of the rock showed that shear stress by both water flow and transported sediment was sufficient to erode the bedrock of the river bed. Monitoring with an improved pressure-pillow sensor revealed that, during severe flood events, sudden deposition of river-bed sediment occurred at around the peak water level, and further erosion followed when the flood subsided.

Key words Pankenai River; habitat improvement; river-bed topography; topographical change; rock mechanical analysis; water pillow sensor; thickness of river-bed sediment

INTRODUCTION

Many Japanese rivers have been directed into concrete-lined channels for the purpose of flood control, but the river environment of such channels is known to be most unsuitable for aquatic animals (e.g. Inoue & Nakano, 1994). Recently, in some Japanese rivers, a new construction technique was tested for the conservation of both the ecological environment and the aquatic landscape in addition to flood control (e.g. Mizuyama, 1992). However, such improvement of concrete-lined channels to create a structure more favourable to aquatic habitats has seldom been reported (Toyoshima *et al.*, 1996).

The lowermost reach of the Pankenai River was directed into a concrete-lined channel between 1987 and 1989. Later, in the altered reach, the concrete blocks in the centre of the channel were removed to improve aquatic habitats. Seven months after the channel improvement, pool–riffle sequences developed with an increase in substrate coarseness, and fish-species diversity increased (Toyoshima *et al.*, 1996).

In this study, the topographical change in the reach was precisely measured for five years after the improvement, and the cause of topographical change was mechanically considered. Furthermore, the thickness of river-bed sediment was automatically monitored to understand the features of the changes in river-bed topography to consider the formation of structures favourable for aquatic biota.

STUDY SITE

The Pankenai River, with a basin area of 23.1 km^2 and a channel length of 8.5 km, is a tributary of the Teshio River in Hokkaido, Japan (Fig. 1). It has an average channel slope of 0.01 at the lowermost reach. The flood plain around the lowermost reach is in places used as pasture. Although the geology is mainly composed of serpentine, soft Tertiary mudstone surrounds the lowermost reach. The river has two flood seasons a year: the snowmelt season from April to May; and the summer rainy season from August to October. From November to March is the snowy season, and snow covers

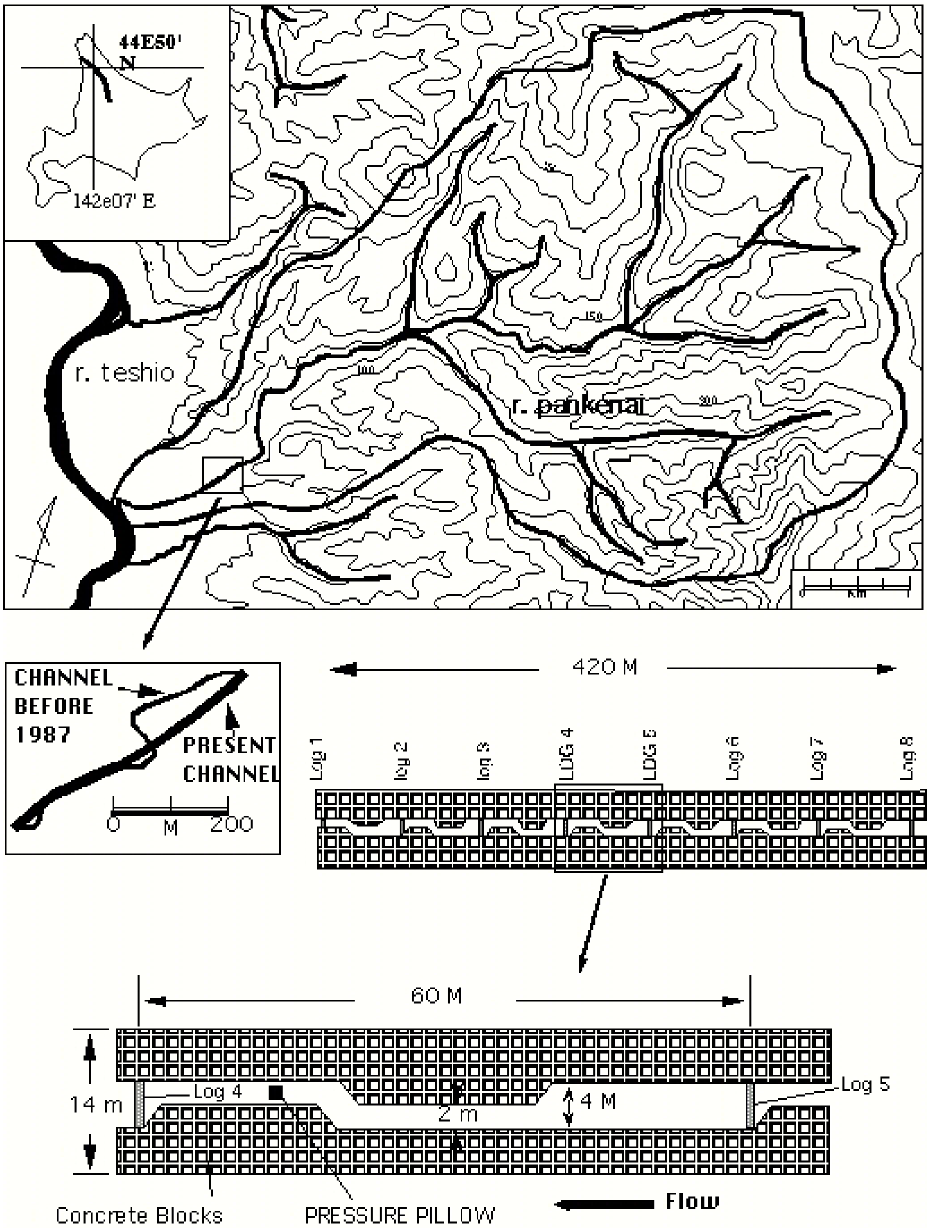

Fig. 1 Map of the Pankenai River basin (*upper*) and the schematics of the improvement reach (*lower*). The actual reach is slightly bent, but here for simplification it is shown to be straight.

the basin for several metres in winter. Thus, the river is usually under baseflow conditions in winter. From June to mid-August, the river is also under baseflow conditions except just after a downpour.

The lowermost reach was directed into a concrete-lined channel between 1987 and 1989. The reach's original channel length of 1080 m was straightened and shortened to 800 m. Moreover, in a 500-m stretch 33 × 49 × 13.5 cm concrete blocks were placed along the bed and the banks.

In the altered reach, an experiment on habitat improvement was carried out from 1993 to 1994. The concrete blocks in the centre of the channel were removed, and some log-drop structures were installed across the channel in December 1993. In addition, an artificial meander was designed by changing the width of the altered channel (Figs 1 and 2). More details of the channel improvement were reported by Toyoshima *et al.* (1996).

Fig. 2 Condition of the improved channel in July 1997. A pressure-pillow sensor set on the bedrock of the river also can be seen (photo by Y. Kurashige).

TOPOGRAPHICAL CHANGE

The topography of the channel bed of the improved reach was measured by a levelling-plane survey every summer (June or July) from 1994 to 1998. Since the top surface of each log structure was set at the same level to the bedrock surface, the relative height from the top surface of the log structure at the upper end was measured at each of the reaches between two adjacent logs. Four sections were the subject of this survey: Section 1 from Log 1 to Log 2, Section 2 from Log 2 to Log 3, Section 3 from Log 3 to

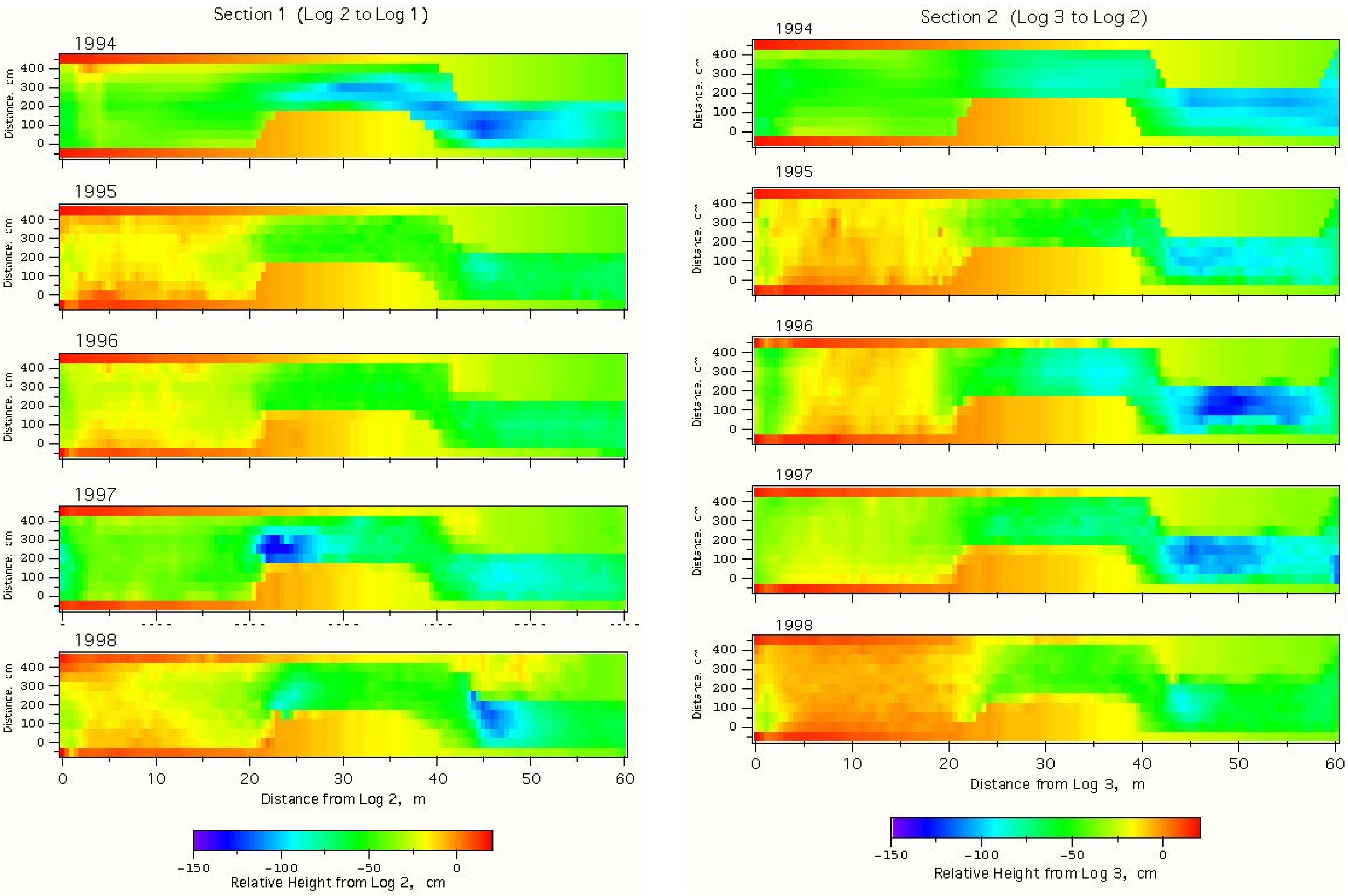

Fig. 3 Topography of the improved reach measured in July 1994–1998. The reference point of relative height was set at the top surface of the upper log of each section.

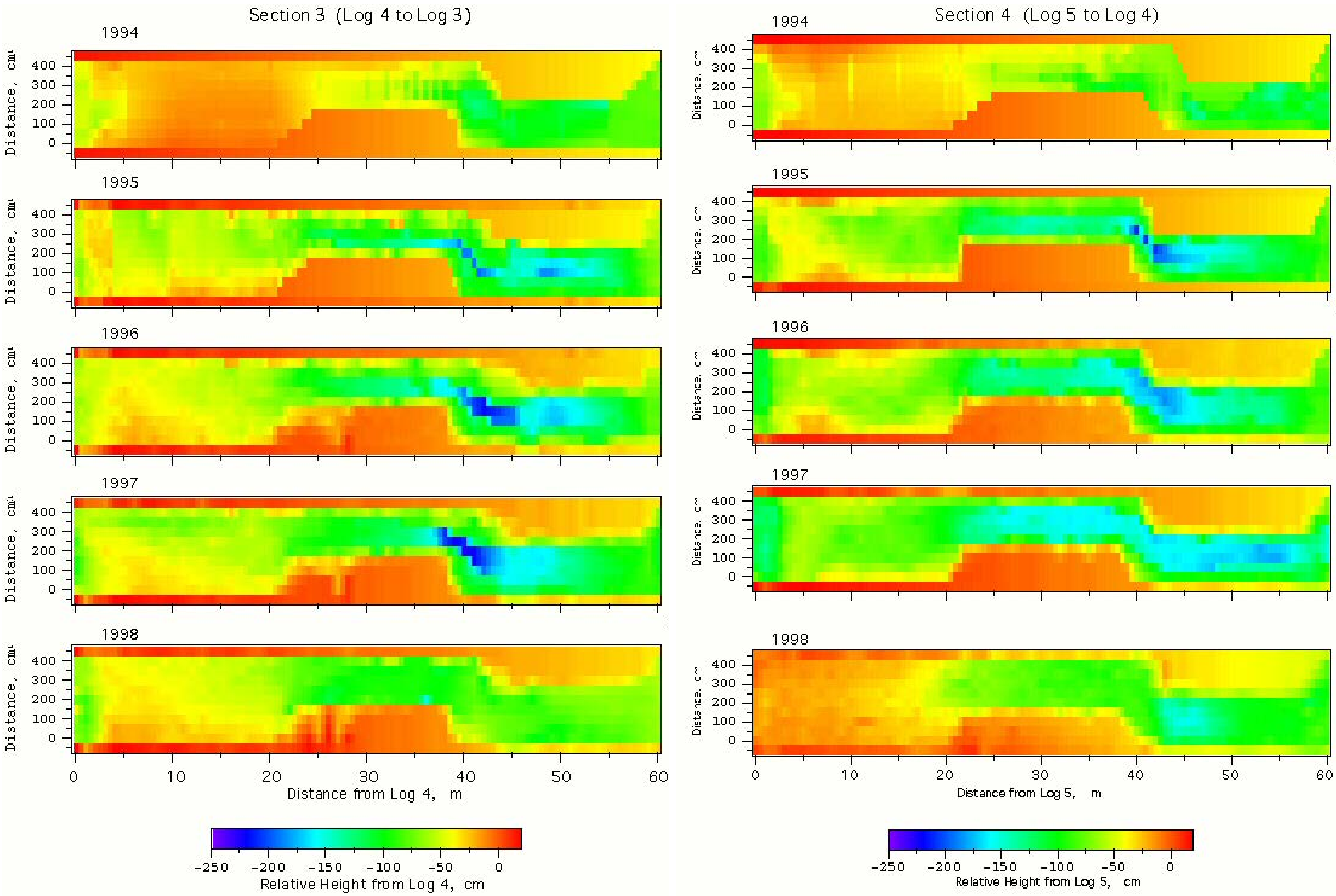

Fig. 3 *Continued.*

Log 4 and Section 4 from Log 4 to Log 5. At each section, the relative height was measured at intervals of 0.5 and 1 m, respectively, for the transverse and longitudinal direction of the channel. Remarkable flood events occurred only in September 1994 and August 1997.

The results are shown in Fig. 3. In summer of 1994, in each section a pool was formed just downstream of the log structure. In addition, a pool 5–30 m in length appeared at the reach from 20 to 50 m from the upper log where the channels were artificially narrowed to create a meander. Pebbles were rarely found in the pools, whereas some areas of each reach were buried in pebbles at the reaches without pools. The flood in September 1994 caused heavy gravel deposits at the reach below Section 1 as well as the gravel fill at the eroded channel in Sections 1 and 2, whereas no gravel fill was observed in Sections 3 and 4. Accordingly, in 1995 the eroded channel was still filled with gravel at Sections 1 and 2. In contrast, the serious erosion continued in Sections 3 and 4, especially around the meandered reaches. In 1996 and 1997, slight erosion was observed in all sections, in contrast to the severe deposition at all sections in 1998. During these changes, however, the pools remained in each section. In addition, the water depth was shallow in the reach from 5 to 20 m from the upper log in each section in each year, indicating that clear pool–riffle sequences had formed.

TEMPORAL VARIATION IN THICKNESS OF RIVER-BED SEDIMENT

An improved pressure-pillow sensor was installed on the river-bedrock surface of Section 4 in July 1997 to monitor the thickness of river-bed sediment. The monitoring results in 1997 are reported in Kurashige (1999). Since a water gauge was lost and the cable of the pressure pillow was damaged during a runoff event on 4 August 1997, a new water gauge was set *c.* 80 cm higher than the original one, and the cable was repaired on 9 September 1997 to continue monitoring (Kurashige, 1999). The monitoring was stopped in July 1999 because the system was seriously damaged by the flood on 29 July.

During normal runoff events, the thickness slightly increased at around the peak water level, and then decreased to a level almost equal to that before the event at the

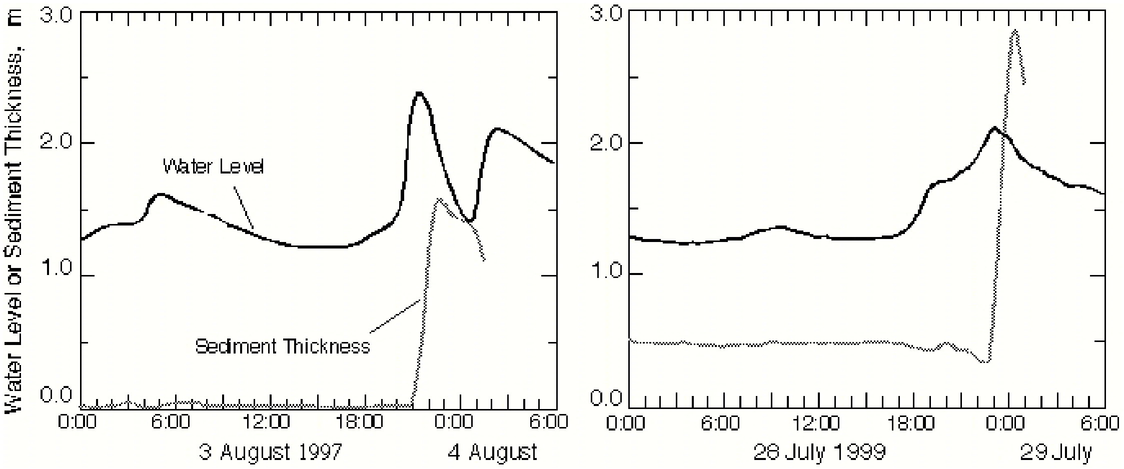

Fig. 4 Time variations in river-water level (solid line) and sediment thickness on the water pillow (hatched line) during two severe flood events.

falling stage of the event (Kurashige, 1999). In contrast, during severe runoff events, an abrupt increase in the sediment thickness was found (Fig. 4).

During the event from 3 to 4 August 1997, the thickness slightly increased at around the first peak of the water level, and decreased to its original level during the subsequent recession. After the second peak of the water level, the thickness abruptly increased to *c.* 1.7 m from 21:00 to 22:30 h. After that, the thickness continuously decreased until 02:00 h when the cable of the pressure pillow was cut (most likely by an increase in the bed-sediment load). The thickness after this event was *c.* 0.8 m. The change in thickness during the event from 28 to 29 July 1999 was similar to that of 3–4 August 1997. The thickness tended to decrease until the peak of water level, and further it abruptly increased to *c.* 2.9 m from 23:00 on 28 July to 0:30 on 29 July. The increase from 23:00 to 00:00 h was especially great (*c.* 2.4 m). The thickness then decreased, and was *c.* 1.2 m after the event.

MECHANICAL ANALYSIS OF BEDROCK EROSION

The erosion in Sections 3 and 4 together with the deposition in Sections 1 and 2 in 1995 shows that severe bedrock erosion occurred in the reach through which a considerable amount of gravel had passed. In other words, the friction process at the river bed from transported gravel caused the bedrock erosion. Thus, the mechanical condition of the friction process was investigated.

The bedrock was soft and cohesive under water-saturated conditions. A vane-shearing test for the bedrock in these conditions showed the cohesion and angle of shearing resistance to be 8.30×10^3 Pa and 32.8°, respectively (Kurashige *et al.*, 1996). These values indicate that for a river bed with the water depth of 1 m, for example, the shear strength becomes 1.5×10^4 Pa. On the other hand, the critical shear stress of a cohesive material is about 1/40 to 1/150 of its shear strength (e.g. Kawamura, 1982; Raudkivi, 1990). This indicates that the critical shear stress of the bedrock ranges between 100 and 400 Pa.

During a flood event when a large amount of gravel was transported, the water depth of the Pankenai River reached about 2 m (Fig. 4). A cross-section of the river channel shows that the hydraulic radius under this condition will be 1.6 m. Since the average river-bed slope of the experimental reach is 0.01, the shear stress from water is around 160 Pa under this condition. This value is about the lowest among the estimated range of the critical shear stresses, indicating that water alone can erode the bedrock—but not much.

In contrast, when bed-load material is transported as a mass with the thickness of 0.1 m, the shear stress induced by this bed-load material will be *c.* 30 Pa (assuming a contact area of 0.5 m^2) or *c.* 160 Pa (contact area 0.1 m^2). This shows that a combination of shear stress by water 2-m deep and bed load with a sediment thickness of 30 or so centimetres will be sufficient to erode the bedrock.

During the severe flood event on 3 to 4 August 1997 when river-bed sediment was deposited on the exposed bedrock, the sediment thickness increased by 1.7 m within 1.5 h. This abrupt increase in thickness was most likely due to the huge mass of bed-load material transported. Thus, the friction from bed-load material transport was judged to be an important cause of the bedrock erosion.

DISCUSSION AND CONCLUDING REMARKS

The fish population in the tested reach was examined before and after the improvement (i.e. in the summers of 1993 and 1994) by Toyoshima *et al.* (1996), as well as habitat variables and characteristics of the fish assemblage. The improvement caused marked changes in habitat variables, not only increasing depth and development of pool–riffle sequences but also decreasing current velocity and increasing substrate coarseness. After the improvement, significant increases were seen in *Oncorhynchus masou* and *Tribolodon ezoe*, and this response resulted in an increase in species diversity.

In general, the amount of good habitat controls fish abundance (Moore & Gregory, 1988; Fausch & Northcote, 1992). The size and number of pools controls the abundance of *Oncorhynchus masou* and other salmonids (Fausch & Northcote, 1992; Nakano, 1995), and *Tribolodon ezoe* prefer to use the bottom of pools where the current velocity is low (Toyoshima *et al.*, 1996). In the improved reach, pool–riffle sequences had already formed in summer 1994, and fish populations rapidly responded to this topographical change. Unfortunately, the fish population was not tested after 1995. However, the complicated structure of the river-bed with pool–riffle sequences continued to be observed every year, suggesting that the environment for fish is much better than before the improvement works.

River-bed shear stress induced by both water flow and bed-load transport caused severe erosion of the soft bedrock of the Pankenai River. Great amounts of river-bed sediment are transported only during severe flood events, and the sediment thickness abruptly increases by 1.5 m or more just after the peak water level. The thickness then decreases when the water recedes, but does not return to the pre-flood level. Such changes have drastically altered the river-bed topography of the Pankenai River, and have consequently improved the habitat environment.

The habitat improvement of a concrete-lined reach is rarely reported in Japan. However, the test case in the Pankenai River indicates that the removal of concrete blocks together with the installation of log-drop structures is an effective means of improving habitat, in particular where sediment below the concrete blocks is movable.

Acknowledgements I wish to thank Akemi Yoda, Keiko Oki, Hiromi Yanagi, Namiko Ueshima and Kyoko Hayashi for their valuable assistance in the field. The research reported here was funded by the Foundation of River and Watershed Environment Management, Tokyo.

REFERENCES

Fausch, K. D. & Northcote, T. G. (1992) Large woody debris and salmonid habitat in a small coastal British Colombia stream. *Can. J. Fish. Aquat. Sci*. **49**, 682–693.

Inoue, M. & Nakano, S. (1994) Physical environment structure of a small stream with special reference to fish microhabitat (in Japanese with English synopsis and illustrations). *Japan. J. Ecol.* **44**, 151–160.

Kawamura, S. (1982) Critical shear stress (in Japanese). In: *Sedimentary Hydraulics*, 44–97. Morikita Shuppan, Tokyo.

Kurashige, Y. (1999) Monitoring of thickness of river-bed sediment in the Pankenai River, Hokkaido, Japan. *Trans. Japan. Geomorph. Un.* **20**, 21–33.

Kurashige, Y., Toyoshima, T. & Nakano, S. (1996) Topographical change in a channel bed after habitat improvement. *Japan. J. Limnol.* **57**, 193–197.

Mizuyama, T. (1992) Movement of environmental oriented Sabo works (in Japanese with English abstract and illustrations). *Trans. Japan. Geomorph. Un.* **13**, 297–300.

Moore, K. M. S. & Gregory, S. V. (1988) Response of young-of-the-year cutthroat trout to manipulation of habitat structure in small stream. *Trans. Am. Fish. Soc.* **117**, 162–170.

Nakano, S. (1995) Individual difference in resource use, growth and emigration under the influence of a dominance hierarchy in fluvial redspotted masu salmon in a natural habitat. *J. Animal Ecol.* **64**, 75–84.

Raudkivi, A. J. (1990) Cohesive sediments. In: *Loose Boundary Hydraulics*, third edn, 300–345. Pergamon Press, Oxford, UK.

Toyoshima, T., Nakano, S., Inoue, M., Ono, Y. & Kurashige, Y. (1996) Fish populations response to stream habitat improvement in a concrete lined channel (in Japanese with English synopsis and illustrations). *Japan. J. Ecol.* **45**, 9–20.