Journal of Hydrology (NZ) 36(2): 173-181, 1997

Field measurements of sediment transport in a piedmont reach of the Laba River

A. B. Shvidchenko[1]

Research Associate, Department of Channel Processes, State Hydrological Institute 23, Second Line, St. Petersburg, 199053, Russia

[1] Present address: Department of Civil Engineering, Rankine Building, 2-7B, University of Glasgow, Glasgow G12 8LT, Scotland, United Kingdom.

Abstract

Results of field measurements of suspended sediment and bedload transport in a piedmont braided gravel-bed reach of the Laba River (North Caucasus, Russia) are presented in this note. Suspended loads were measured with a bottle silt sampler both in the study reach and 10 km upstream at a gauging station. Bedload yields were determined for different time intervals from the surveys of the filling of excavations in the river bed. An equation for bedload discharge in the Laba River in terms of water discharge was derived from the bedload data, which made it possible to calculate annual bedload yields for a 52-year period. Annual mean suspended sediment and bedload yields were determined on the basis of the field measurements.

Introduction

Evaluation of sediment yield is one of the major problems associated with the control and management of large mountain and piedmont fluvial streams. While suspended loads can be measured by existing methods and equipment quite accurately, direct measurements of bedload transport rates are still extremely difficult and complicated. Because of the almost total lack of field data on bedload transport in braided gravel-bed rivers (see, for example, Carson and Griffiths, 1987; Davies, 1987), field measurements of bed loads in such rivers are of particular interest and value. The present note describes a field study of sediment transport in a braided reach of the Laba River, Russia, carried out by the Department of Channel Processes of the State Hydrological Institute (St. Petersburg, Russia) in 1992-1993.

Figure 1 - General view of the Laba River in the reach with excavation at a flow of 217 m^3/s on 6 June 1992 (view against the current).

Laba River - study reach

The Laba River is a left-bank tributary of the Kuban River, the largest river in the North Caucasus, with its source in the glaciers of the Caucasus Mountains. The Laba River is 351 km long, with a drainage area of 12,500 km^2. The study piedmont river reach (Fig. 1) is located near Mostovskoy settlement (40°50' E, 44°23' N), 150 km from the river head and 13 km downstream of the point where the river leaves the mountain terrain. There is a gauging station at Kaladzhinskaya village, 10 km upstream of the study reach, where river flow characteristics (water levels, flow depths

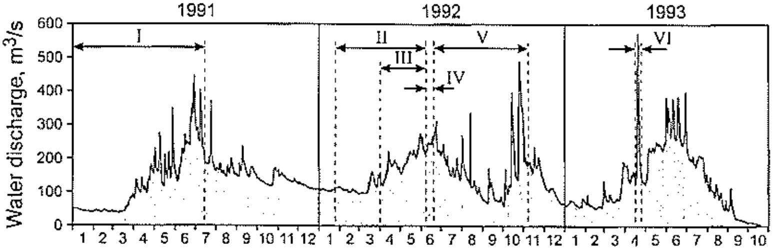

Figure 2 - Hydrograph of the Laba River at Kaladzhinskaya for 1991-1993 (I, II, III, IV, V, VI - time intervals for which bedload yields were measured).

and velocities, water surface slopes, water discharges) have been measured since 1928 (National Committee on Hydrometeorology and Environmental Monitoring, 1986). The hydrological regime of the Laba River is characterised by floods caused by prolonged spring and summer snowmelt and by rainfall at any time of the year, with low water during winter months (Fig. 2). The mean annual flood, measured at the Kaladzhinskaya gauging station, is 411 m^3/s. Mean water level rise during floods is 1.4 m above the winter minimum water level, the maximum being 2.9 m. Mean flow depth during floods is 1-1.5 m, with flow velocities of up to 4.5 m/s; the total stream width is up to 350 m. In general, the maximum flow is observed during a few hours, in rare cases within 2-4 days. The maximum recorded flow of the Laba River is 901 m^3/s, generated by rainfall. The minimum recorded flow is 2.2 m^3/s. Annual mean flow is 87.1 m^3/s.

Comparison of aerial photographs made in 1948, 1965, 1985, 1987 and topographic maps of 1962, 1965, 1968, 1984 shows that the Laba River between Kaladzhinskaya and Mostovskoy is morphologically homogeneous, with no tributaries and a wandering braided channel with poorly defined boundaries. The river flows over a wide (300-500 m) gravel bed that has complicated topography and is mostly dry during low-water periods. Mean slope of the river bed is 0.0048. The study reach of the Laba River has a complex flow pattern, with highly variable channel geometry and behaviour, even under steady flow rates. This results in the absence of any stable relationships between water discharge and flow hydraulic characteristics.

Suspended load

Systematic measurements of suspended load were made at the Kaladzhinskaya gauging station from 1931 till 1979 (National Committee on Hydrometeorology and Environmental Monitoring, 1986). Suspended sediments were sampled at different stages of flow by standard bottle silt point-sampler from a cable carrier, simultaneously with flow velocity and depth measurements. A detailed description of the sampling equipment and methods used at hydrometric stations of the Russian Hydrometeorological Network is given in Central Board of Hydrometeorological Service, 1978. Fractional analysis of the suspended load samples using fractiometer and pipette shows that granulometric composition of the suspended sediments varies over a wide range and does not have a consistent relationship with water discharge. Thus, the finest sediment was observed on 8 June 1957 at a flow of 198 m^3/s, while the coarsest sediment was collected on 9 June 1955 at a flow of 119 m^3/s.

Median size of suspended sediments lies between 0.01 and 0.6 mm (0.1 mm on average), the maximum size being up to 1-2 mm (Fig. 3). Based on data from the Kaladzhinskaya gauging station, the annual mean concentration of suspended load is 220 g/m^3. The maximum suspended load concentration (17,000 g/m^3) was measured on 13 June 1954 at a rather low flow of 190 m^3/s. Annual mean suspended sediment discharge is 20 kg/s (dry weight), the maximum measured being 3,200 kg/s (18 November 1978 at a flow of 511 m^3/s). Annual suspended load yield varies from 150,000 up to 1,800,000 t and is equal to 638,000 t on average.

Suspended sediment loads at different points of the highly turbulent flow were measured by a bottle silt sampler during field work near Mostovskoy in May-June 1992. For the flow from 224 to 284 m^3/s, mean suspended load concentrations varied from 206 to 1,256 g/m^3, suspended load discharge ranged between 47 and 357 kg/s. The data shows that the amount of suspended load in mountain and piedmont rivers depends not only on the flow stage, but also on variable conditions of weathering and slope erosion within the drainage basin.

Bedload

Estimation of bedload yield in the Laba River was the main goal of the field investigations carried out in a reach containing channel excavations mined by the Mostovskoy Crushing and Grading Plant (MCGP). Field observations were made during different flow conditions, including spring-summer snowmelt floods, floods generated by rainfall and winter low flows. During field work, in a river reach about 5 km long, water levels, water surface slopes, flow velocities (by surface floats) and flow depths (by sounding rod and echolocating from a boat or by wading party) were measured, and channel surveys were made of the study reach (Fig. 4). To determine the granulometric composition of bed material, photographs were taken of different parts of the channel during low water periods (26 photos altogether). Analysis of the photographs shows that the surface layer of the river bed is composed of gravel and pebbles with median diameters of between 28 and 107 mm (58 mm on average), with the diameter of the largest particles being 220 mm (Fig. 3). Under an armour layer 10-15 cm thick, a mixture of gravel (75-80 %) and sand (20-25 %) occurs. Throughout the study reach, bed material with a bulk density of 1,950 kg/m^3 extends to a depth of 10-15 m, below which layers of clay occur (report of the All-Union Institute of Building Materials, 1983). Sieving analysis of 131 samples (40 kg each) of the bulk material extracted from channel pits 3-4 m deep by MCGP during 1991-1993 shows that the

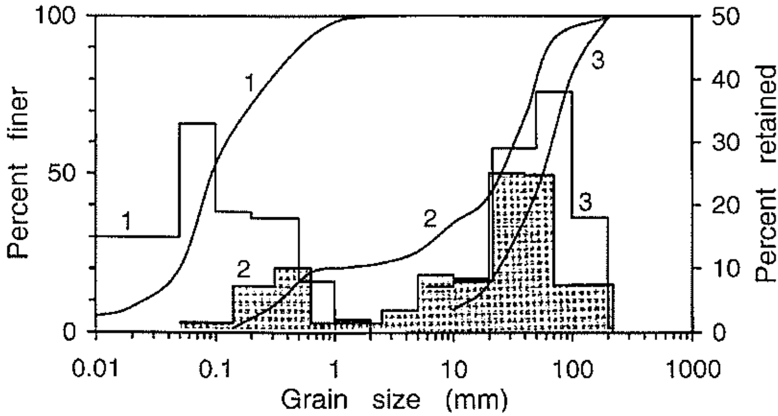

Figure 3 - Size analysis (histograms and cumulative curves) of sediments in the Laba River (1 - suspended sediments, 2 - bulk bed material, 3 - surface layer).

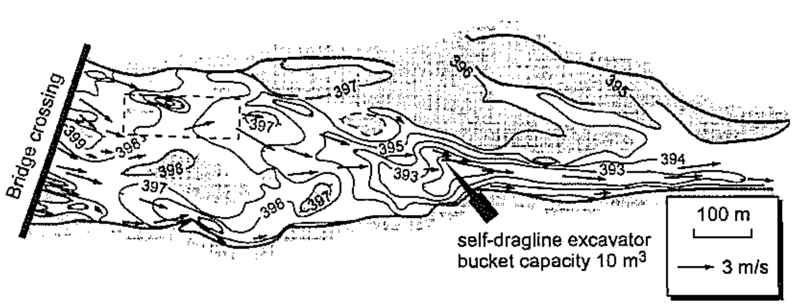

Figure 4 - A Bed topography within the excavation and surface flow velocities at discharge of 256 m^3/s on 19 June 1992. Contour lines are given in metres above the Baltic Sea level. Dashed rectangle shows the position of the experimental pit completed on 15 April 1993.

grain size composition of the subsurface layer is bimodal, with modal diameters of 0.4-0.5 mm and about 40 mm, with the coarse mode being dominant. Median diameter of the channel alluvium varies from 19 to 41 mm and is 26 mm on average (Fig. 3).

Bedload yields for different time intervals were estimated from surveys of the filling of a large pit excavated in the river channel, from 1991 to 1993 (a similar method was successfully applied by Hollingshead, 1971 in the gravel Elbow River). This excavation started at a bridge crossing, and during the field measurements it was 1,100-1,700 m long, from 300 m (at the bridge) to 80 m (downstream end) wide, 3-4 m deep, with an irregular conic shape and complicated bed relief. The pit contained all the river flow (Figs. 1 and 4). In addition, following a program of the State Hydrological Institute, MCGP mined an experimental pit 200 m long, 70 m wide by 3 m deep in the upper drifted part of the long excavation (Fig. 4) and surveyed the pit area before and after a high flood in April 1993. The stream was directed through the experimental pit by a guide embankment of gravel. Comparison of the repeated surveys of the excavations made it possible to determine volumes of sediment deposited during the time intervals between surveys, with the amount of material from banks erosion and bed scour upstream of the excavations being deducted from the measured volumes. Unfortunately, the deposited sediment was not sampled for size analysis. Based on the distinct subdivision of the bed material into suspended load and bedload (Fig. 3), highly turbulent flow in the pits with velocities of up to 3-4 m/s (Fig. 4), and the almost uniform distribution of the suspended sediment concentration along the excavations, it can be assumed that the pits were drifted mainly by gravel transported as bedload. The insignificant amounts of sand deposited in some parts of the large excavation did not enlarge noticeably the total volume of the deposits. Altogether, the volume of bedload retained in the excavations was estimated for six time intervals (Fig. 2, Table 1). Using the determined bedload yields and data on the daily mean flows over the periods of the filling, the following equation of power law form was derived by trial and error (see Table 1):

$$Q_b = 2.3\ 10^{-9}\ Q^{2.9} \qquad (1)$$

where Q_b is daily mean bulk volumetric bedload discharge (m^3/s), and Q is daily mean water discharge (m^3/s). In reality the value of Q_b in braided wandering streams is dependent on the variable channel geometry and flow hydraulics and may be different for the same value of Q. Therefore, Eq. 1 may be considered as an averaged bedload rating curve and can be applied only for long-term assessments.

Table 1 - Results of bedload transport measurements

No.	Period	Flow (m^3/s) min	mean	max	Bedload yield (thou m^3) measured	calculated by Eq.1
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	1 Jan - 14 Jul 1991	37.8	128	448	130-170	142
II	24 Jan - 7 Jun 1992	96.0	153	274	70-80	76
III	1 Apr - 7 Jun 1992	120	194	274	60-70	63
IV	8 Jun - 19 Jun 1992	224	246	270	20.5	21
V	20 Jun - 7 Nov 1992	59.8	165	493	130-140	142
VI	15 Apr - 24 Apr 1993	138	263	574	45	44

From experiments in a hydraulic non-distorted mobile bed model of the study river reach (Shvidchenko and Kopaliani, 1994), critical flow Q_0 for bedload motion was assumed to be about 30 m^3/s, with stream widths from 20 to 140 m, a mean depth 0.5-1 m, and flow velocities of up to 2-3 m/s. Similar values for bedload threshold were obtained during special field measurements in some similar braided gravel rivers by Belova *et al.*, 1975; Jaoshvili, 1986; and Romashin *et al.*, 1982. In fact, the value of Q_0 must be variable and determined by the local channel geometry and flow characteristics, which for the same water discharge may differ significantly. The composition of the surface layer formed during preceding flood periods has also a great effect on the threshold for bedload motion. However, computations showed that the total contribution of flows less than 100 m^3/s to annual bedload yield in the Laba River was negligible.

Bedload yield of the Laba River at Mostovskoy was calculated from daily mean flows (Central Board of Hydrometeorological Service, 1936-1987) exceeding Q_0 for the period of 52 years using Eq. 1. According to the calculations, annual bedload yield varied from 31,000 m^3 (60,000 t) to 319,000 m^3 (622,000 t) with an average of 132,000 m^3 (257,000 t).

Conclusions

The following principal conclusions on the sediment regime of the Laba River at Mostovskoy can be drawn from this study:

1. The Laba River in the study reach is a typical piedmont braided fluvial stream with a wandering channel composed of a bimodal mixture of gravel (75-80 %) and sand (20-25 %).
2. The most active sediment transport in the Laba River takes place during flood periods (about three months a year), especially

increasing during extreme flow rises of short duration. Critical flow for gravel motion is about 30 m^3/s.

3. Mean annual suspended load yield in the river is 638,000 t, with the maximum observed being 1,800,000 t, and the minimum being 150,000 t.
4. According to computations based on the field data, annual bedload yield depends on the character of the hydrograph and varies from 60,000 t to 622,000 t with the average being 257,000 t. Bedload yield represents 15-49 % (27 % on average) of the total sediment yield.

Acknowledgements

The field study described was conducted under the scientific supervision of Dr Z. Kopaliani with the technical assistance of A. Bashkov, A. Kondrat'ev, R. Lomunov, V. Nikitin, S. Pershin and O. Shvarev.

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Manuscript received: 20 January 1996; accepted for publication: 5 September 1997.