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THE RIVER KATUN, ITS CHANNEL MORPHOLOGY AND CHANGES DUE TO RIVER ENGINEERING AND ALLUVIUM EXTRACTION

Abstract: The paper discusses the main features of the transformation of the semi-mountainous channel of the River Katun (Altai region) on the basis of long-term studies. A mobile braided channel in its lowermost reaches was trained to improve navigation conditions and large scale sand and gravel excavation operated over a long period of time. The resulting incision of the channel has caused a significant change to its morphological pattern.

Key words: river channels, river engineering, alluvia, Altai Mts.

1. Introduction

Historically, the River Katun had not been extensively used for navigation purposes despite its sufficient capacity and large channel section. The obstacles were inherent in the channel processes characteristic of its semi-mountainous nature, high gradient and highly mobile, braided, pebble-gravel channel. Navigation conditions do not even materially improve in the reach immediately before the confluence where the channel develops a flatland character.

A large gravel pit was opened in the River Katun floodplain in the early 1970s to satisfy the demand for construction materials in the Altai region, but it was hampered by the difficulty of delivery of its products to consumers. To address this situation a 30 km long waterway was constructed between the confluence with the River Ob and the quarry. The waterway was designed to be 1.3 m deep, 40 m wide and to have curvature radii of 250 m.

The first detailed investigation of the lower Katun channel was carried out in 1974 before the start of the engineering project. The waterway took into consideration the patterns and trends in channel evolution established during that investigation. Dikes and groins were constructed and the digging of the cuts was completed in the mid-1970s. After the opening of the waterway for navigation, new gravel pits were opened within the channel proper. Alluvium extraction reached 500 thousand m^3 per year and more than 5 million m^3

of gravel had been extracted by the mid-1990s. Two subsequent studies carried out after the completion of the river training revealed significant changes in the channel due to the river engineering and alluvium extraction.

2. Study area

The River Katun forms the headwaters of one of the largest Russian rivers, the River Ob, after it merges with the River Biya. The source of the river is situated at 2600 m a.s.l. in the Altai Mountains and almost all of its drainage basin is mountainous. The river is 688 km long, the catchment area covers 60 900 km^2 and the mean gradient is about 4‰. The river emerges from the Altai Mountains at a distance 100 km from its confluence (Figure 1), the longest stretch of the river, in total over 500 km, flowing within mountains where the river valley is as narrow as 1 km. The gorge has steep rocky slopes.

The Katun has a mean long-term water discharge of 620 m^3·s^{-1}, and a total annual discharge of 20 km^3. The mean maximum discharge stands at 3025 m^3·s^{-1}, while its peak was recorded at 5520 m^3·s^{-1}. The channel forming discharge was estimated at about 1900 m^3·s^{-1} with a 6% recurrence. The average low water discharge stands at 300 m^3·s^{-1}. The flood discharge accounts for about 75% of the total annual discharge. The river receives most of its water from snow melt (44%) followed by rainfall (20%) and glacier melt (8%).

The mean annual water level amplitude is 2.8 m and the maximum amplitude is 3.9 m. Along the semi-mountain section the flow speed ranges between 1.6 and 2.4 m·s^{-1}, peaking at 5.5 m·s^{-1}.

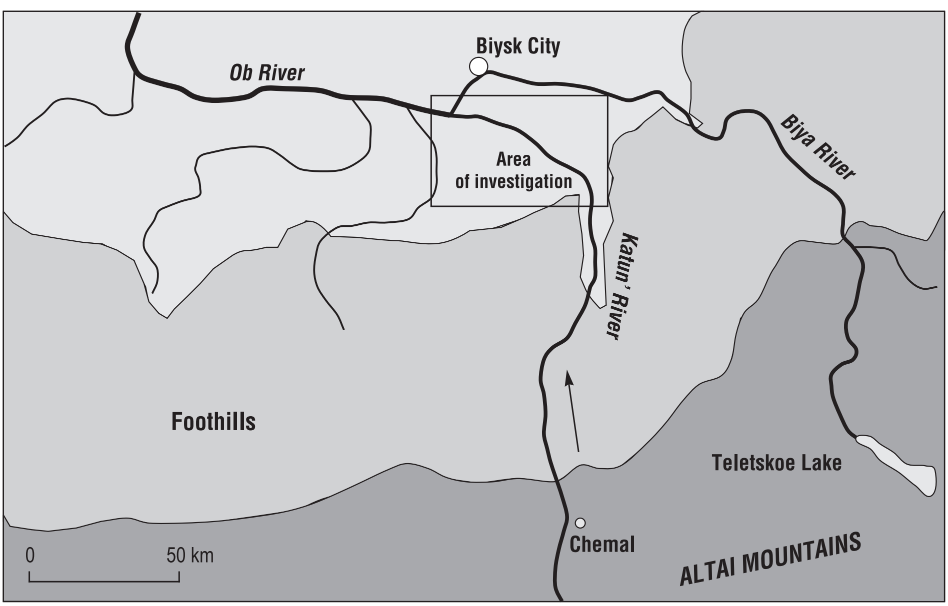

Figure 1. Scheme of the Altai foothill terrain

3. Channel characteristics

Until the early 1970s, the River Katun had not been studied from the point of view of fluvial processes, but its use as a reliable waterway for navigation required a detailed analysis and forecasting of its channel evolution. The first studies were carried out in 1974, involving channel and floodplain surveys, echo sounding, water surface levelling and sediment sampling.

The river channel remains semi-mountainous even after leaving the mountains and entering the foothills. The mean water surface gradient can be as high as 0.70-1.20‰, its mean bed sediment size is 30-60 mm and the river is 1200-2000 m wide including islands within the river. The mean channel depth at the channel forming discharge is 2.0-3.6 m, and the maximum discharge is 6.5 m. The amplitude of depth in pool-bar systems can be as high as 3.5 m. The width-to-depth ratio at the forming discharge ranges from 35-60 to 100-150. The river channel is heavily braided, with the braiding sections occupying almost 70% of the length of the semi-mountainous reach. Bar drift rates reach 200-300 m per year.

The terraced river banks are built of sand and rounded gravel and are severely eroded. During the last 50 years, the mean bank failure rate has been 4-5 m per year. Along certain reaches up to 50-70 m per year collapsed every year. The braided reaches usually consist of two or three main channels connected by a few transverse branches. The islands are small, at 100-150 metres in length, and have an uneven shape. The largest channel, 300-400 metres wide, accounts for 30-35% of the total discharge. Some branches bend sharply and are often cut off by little arms. Most of the islands drift downstream at the rate of 2.5-10 m per year and run-off redistribution between the arms and branches takes place during every flood event. The riverbed is not as stable as might be expected taking into consideration the sediment grain size. At the mean maximum discharge, the Makkaveyev's stability coefficient ($K_s = 10^2 d/BI$; d – grain size, B – channel width, I – water surface gradient) only equals 5.1, which is comparable to flatland riverbeds. Certain long-term trends were observed in the movement of the entire channel with a duration of 20-40 years.

The intense riverbed transformation is due to high rates of flow. The bedload is mobilised by discharges exceeding 1500-1700 $m^3 \cdot s^{-1}$. During floods the bedload moves within 70% of the channel width. Bars are eroded during floods, whereas channel bed elevation rises during flood water recession and at low water. The average sediment composition (25-30 mm) occurs at flow rates equal to or higher than 1.1 $m \cdot s^{-1}$, the critical rate being 1.5-1.6 $m \cdot s^{-1}$. At discharges lower than 1000 $m^3 \cdot s^{-1}$ the flow rate drops down to 0.9-1 $m \cdot s^{-1}$, and the bedload becomes stable, just as it does during low-water periods. The annual bar elevation amplitude can reach 1.5 m.

4. Riverbed characteristics of the navigable reach

Two sections can be distinguished within the navigable reach; i.e. the upper (30--14 km from the confluence) and the lower. The semi-mountain riverbed of the former has a gradient of up to 0.5‰ and a bedload granularity of 30 mm; the latter section is typically of the flatland type having a more gradual gradient, at 0.2‰, and bedload size of 2-5 mm. The upper section channel is heavily braided and can reach up to 1.5 km in width. The channel characteristics change slightly as compared with the upstream reach (30-60 km).There are significant differences between the main and the secondary channels. The main channel, which has only a slight degree of sinuosity, is 300-400 m in width and accounts for up to 80% of total discharge during low water periods. The secondary branches are usually narrow and heavily sinuous.

Researchers observed a long-term trend to concentrate the flow into one channel. The river tended to abandon secondary arms and branches and individual bends were eventually cut off. This tendency was taken advantage of when creating the waterway. Some of the secondary arms were blocked with low earth dams in order to increase the flow in the main channel during low water periods. This was accompanied by the dredging of selected connections. In this way the channel training took into consideration the natural evolutionary tendencies. Levees and groin systems contributed to concentrating the flow during the low water periods while during floods the channel remained unchanged. By 1984, 12 structures were erected along 10 km.

This engineering project helped to increase significantly the guaranteed depth of the waterway and the river bed was lowered by 0.5 m on average, the mean depth increasing by 0.7 m (Figure 2).

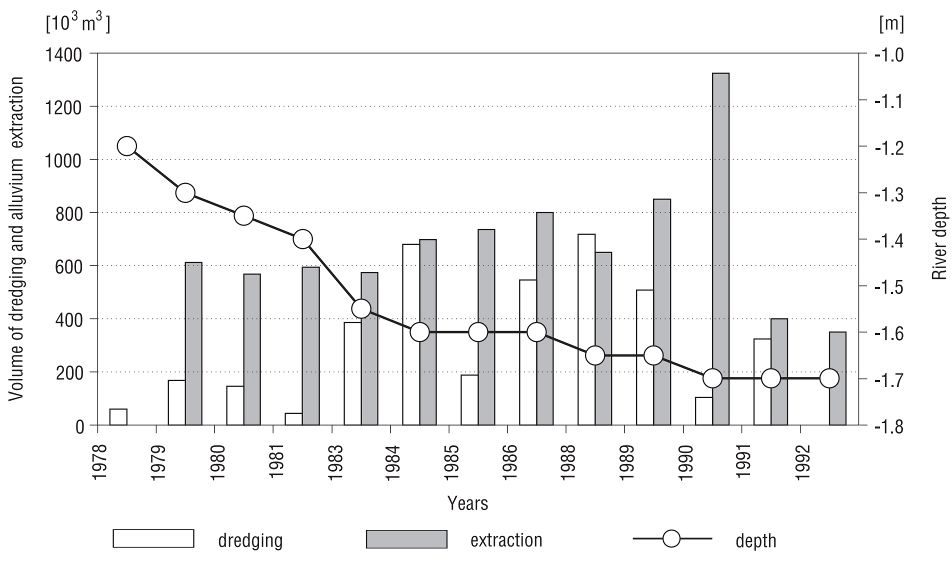

Figure 2. Correlation between the volumes of dredging and alluvium extraction and river depth

At present, the main channel is meandering and carries up to 95% of the overall discharge. Even in braided sections there is always one branch concentrating most of the water discharge (56-73% at low water). Many of the arms and branches blocked by engineering structures have silted up and become parts of the flood plain. Thus, the contemporary river channel between 30 and 14 kilometres from the mouth has been transformed from a braided into a meandering type. River bends develop very quickly with the bank retreat rate varying between 15 and 45 m per year. Only a few cut-offs developed during 1990s, one of which is currently used as the waterway (Figure 3).

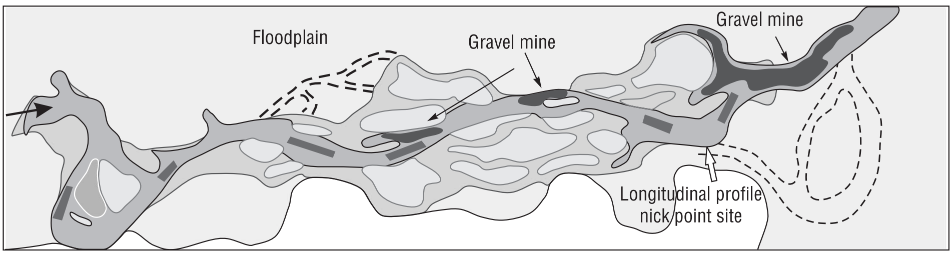

Figure 3. Scheme of the Katun' River navigable reach

The lower section (14-0 km) of the Katun river channel is of the lowland type; the riverbed being 500-800 metres wide with a reduced channel gradient and bedload size. Sand prevails in the bedload composition with small quantities of gravel and pebbles. This portion of the river coincides with the common flood plain of the Biya and the Katun rivers, containing the route of the former confluence of the Biya and the Katun named the Old Katun. The lower section in question ends with a delta consisting of an island system. Its formation is related to a backwater which stretches 10 km up the Katun river from the Biya confluence during floods. The present delta is four kilometres long and has been growing since the 1930s due to intensive sedimentation. This accounts for the vast shallows that make navigation difficult and require extensive dredging. Natural tendencies of channel evolution were utilised to enhance the navigation conditions, in particular the gradual delta expansion and the main branch shifting within the delta. A short confluence was used as the waterway until 1978, but since it was located within a strong deposition zone it made navigation difficult. At a later stage, a drainage channel was made along the left bank and the central branch of the delta, and in addition a long left-bank levee was erected. This improved the navigation conditions and increased the channel stability with coarser sediment due to dredging.

5. Influence of river engineering and gravel excavation on channel morphology

The natural channel evolution was, however, disturbed by sediment extraction along a stretch 14-4 km from the confluence. This resulted in a reduction in the gradient and an increased mean and maximum depth. As a result, low water level dropped by 80 cm and more (Figure 4) adversely affecting the waterway conditions and requiring extensive dredging. A sharp nick point evolved just upstream from the three-kilometre-long sediment output sec-

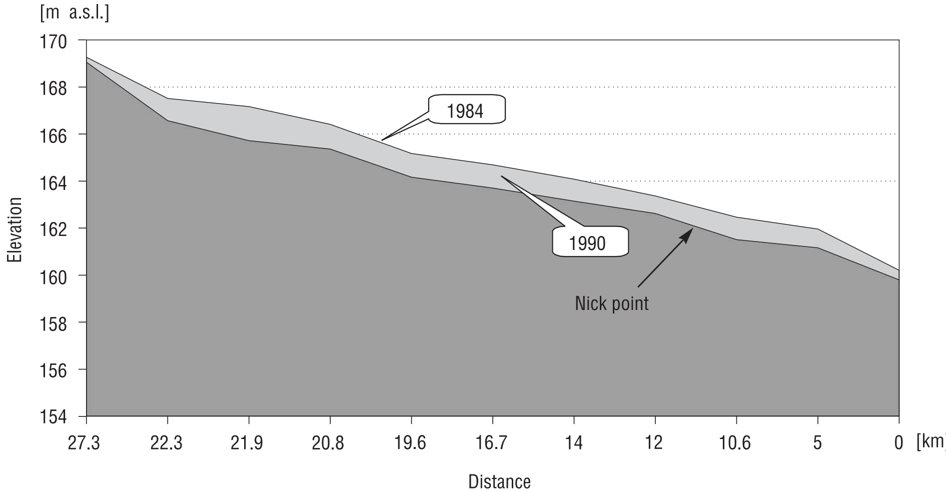

Figure 4. The Katun' River longitudinal profile in navigable reach by low water

tion, and travelled upstream at a rate of up to one kilometre per year, an effect stemming from both channel bed erosion and dredging that removed layer after layer in order to maintain the waterway depth.

It seems interesting to look at the changing channel morphology due to the training measures. A reach without engineering was chosen for comparison purposes. Various relationships were used, to identify the river morphology patterns. These included the relationship between discharge and channel gradient (Leopold, Wolman 1957), gradient/Froude number ratio against relative depth (Parker 1976) etc. Three main patterns were identified along the alluvial channel: straight, meandering and braided. They differed in the actual morphology and the transformation regime. The channels cutting into cohesive and/or rock formations are distinguished as incised channels. This corresponds to the principal classification scheme proposed by N. Makkaveyev (Table 1).

Table 1. Main principles of the riverbed classification

Formations in riverbed	Flood plain characteristics	Channel pattern	Riverbed forms and their mobility
1. Rock and cohesive layers	1. Narrow (less than channel width)	1. Single thread:	Thresholds and ridges
2. Alluvial:	2. Wide	a) meandering	Stable mobile
a) pebbles and boulders	a) one side	b) straight	
b) gravel	b) two side	2. Braided	
c) sand	c) enclosed by levee		

Source: Makkaveyev 1955.

The previous pattern of the Katun river channel corresponded to the braided type according to Leopold/Wolman's discharge/gradient ratio, as well as to Parker's *I/Fr* against *h/B* ratio (*I* – channel gradient, *Fr* – Froude Number, $Fr = v^2/gh$, *v* – flow velocity, *h* – depth, *B* – channel width). It is worth noticing that many other flatland rivers in Russia with widespread braiding correspond to either the meandering or braiding patterns. Incidentally, the lower course of the River Vistula followed the Leopold/Wolman's curve before training. After the engineering was completed, however, the Katun river channel became meandering or even incised according to the ratios mentioned above, just like the River Vistula downstream of the Włocławek Dam.

Also the relationship (Figure 5) of the flow velocity/critical velocity ratio (v/v_0) vs. N. Makkaveyev's stability coefficient K_s permits a classification of the river channel pattern to reveal its changes (Makkaveyev 1955). The relationship was created on the basis of hydraulic and morphological surveys of a number of Russian rivers. After the engineering measures and the sediment extraction, the character of the Katun river channel has changed to that of a meandering river (the shift is shown by an arrow). A similar shift occurred in the River Vistula downstream of the Włocławek Dam (as calculated from data of Z. Babiński (1992) and also shown with a dotted arrow). Thus morphological and hydraulic relationships confirm the river channel pattern change resulting from channel training.

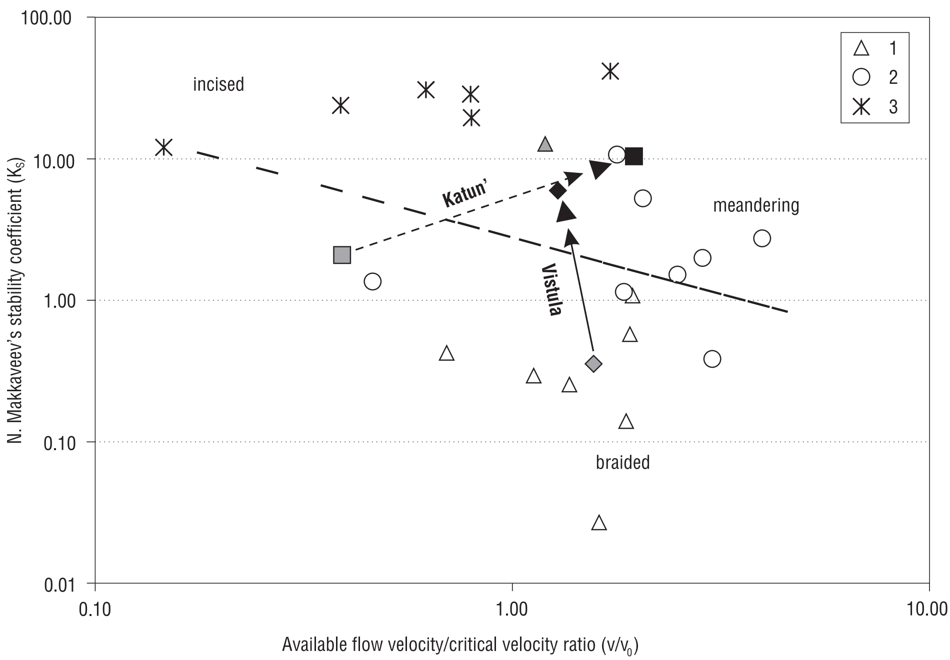

Figure 5. Relationship of N. Makkaveyev's stability coefficient K_s and available/critical velocity ratio with channel patterns picking out

Explanations: 1 – braided channel, 2 – meandering channel, 3 – incised channel.

6. Conclusions

The River Katun's semi-mountainous braided channel is a mobile one and undergoes intense transverse transformation. Researchers observed a long-term trend to concentrate the flow into one channel. The river tended to abandon secondary arms and branches and individual bends were eventually cut off. Natural tendencies of channel evolution were utilised to enhance the navigation conditions. A levee and groin system helped to concentrate the flow, especially during low water periods. The river training helped to significantly increase the guaranteed waterway depth.

The natural channel evolution was disturbed by sediment extraction operations located within the channel, reducing the gradient decrease and increasing the depth and leading to a consequent reduction of the low-water levels. The sediment extraction resulted in the degraded channel progressing upstream and the formation of nick points. As a result of the river training and sediment extraction, the river pattern has changed radically.

Acknowledgements

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