THE PECULIARITIES OF FORMATION OF THE LOWER ZEYA SEDIMENT DISCHARGE

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Abstract

The present research has been carried out within the frame work of the target program "Integrated research in the Amur River Basin" of the Far East Branch, Russian Academy of Sciences.

The paper features the results of geomorphological studies in the lower reaches of the Zeya River, which is one of the largest left tributaries of the Amur River. The studies of the erosion and fluvial processes in the Zeya valley as well as the current channel processes of the Zeya River have revealed the peculiarities of the channel formation in its lover reaches. Basing on the analysis of the bed-load we established a character of the changes in its composition in the Zeya River channel and its main supply sources i.e. fluvial processes developed within the basin.

The sediments brought in the channel in great volumes due to the fluvial processes cause the replacement of the channel meandering (290-137 km) by its subsequent braiding (137-0 km).

The regulation of the river flow and the related rearrangement of the hydrologic characteristics (first of all, it is a reduction in maximum water discharge) resulted in the additional decrease in a transportation capacity of the stream, active sediment accumulation and intense channel reformation within the lower section of the Zeya River. Due to the above factors the braiding process has grow sharper and has become more complex. There are also features of the sediment accumulation in the lower Zeya channel. A preservation of that tendency can cause the activation of the landslide processes on the right bank of the Zeya River.

Keywords: The Zeya River, channel processes, channel-forming alluvium, bed-load, water level changes, sediment accumulation, erosion, grain-size distribution of alluvium.

INTRODUCTION

The Zeya River is one of the largest streams in the Russian Far East. The area drained by the river (233 000 km^2) is entirely located within the Amur Region (Amurskaya oblast') and covers more than 60% of its territory (fig. 1). The river head is at the height of 1680 m above the sea level and at the confluence with the Amur River the elevations of the earth's surface decrease to 230 m above the sea level. The Zeya drainage network includes almost 7000 streams of various orders. They constitute a single basin comprising different natural landscapes: mountainous tundra of the Stanovoy Range and mountainous taiga of the Tukuringra Range in the north, taiga forest tracts of the central part of the Amur-Zeya plain. They are replaced by the far-eastern mixed forests southward. In the south the river drains the vast areas of the Zeya-Bureya plain, which are actively used in agriculture, mainly as arable lands.

The Zeya River plays one of the leading parts in the development of the Amur Region nature, having a great impact on the social and economical situation there. It connects the poorly developed but rich in commercial minerals northern territories with the developed southern district. For more than a century the Zeya River has been used as a convenient transport waterway. The river has a great potential of hydro resources. In 1974 the first in the Russian Far East large Zeya hydroelectric power station (HEPS) was constructed at the place of crossing the Tukuringra Range. By the present time the projects on the construction of the three more hydroelectric power stations in its channel have been developed. Meanwhile,, the changes in the channel dynamics caused by the discharge regulation urgently require the systematic and comprehensive investigation of the channel processes. Some papers [Gusev, 1990, 2002; Gusev, Pomiguev, 2005] suggest that the discharge regulation of the Zeya River resulted in essential structural changes in the level dynamics the within its middle and lower reaches and that has caused the significant reformations within the channel, as well as the changes in the dynamics of the river bank slopes and in the floodplain development. It is universally recognized that one of the main factors in the channel development and in the formation of the river basin is the sediment discharge [Makkaveiev, 2003; Chalov, Liu Shugong, Alekseyevskiy, 2000]. Under the conditions of the river discharge regulation the character, regime and the volumes of sediments transported by the river change which is reflected in reformation of the various channel forms and in the entire peculiar morphologic its of the channel and the whole valley bottom. With the aim of establishing the morphodynamic state of the Lower Zeya channel as well as the character of the changes which occurred in the dynamics of the channel processes during HEPS's operation the investigations of the modern channel-forming [according to the concept of N.I. Makkaveyev and R.S.Chalov, 1986] alluvium ink the Zeya river have been carried out. The main attention has been paid to the study of the changes in the grain-size distribution of alluvium along the river. We used the data from the field works[1] and laboratory analysis. The traditional research methods were applied: the following field observation, morphometric, instrumental etc.

CONDITIONS OF THE CHANNEL FORMATION

According to the conditions of the valley formation and hydrological regime the Zeya River is presented by three sections corresponding to the upper (from the headwaters to the Tukuringra Range), middle (from the Range to the mouth of the Selemdzha River) and lower (downstrem to the confluence with the Amur River) reaches (fig. 1).

In regard of water resources the Zeya River is the largest in the Upper Amur Basin. Its average annual discharge is 1910 m^3/s exceeding that of the Amur River (1360 m^3/s) almost by 20% (before the Amur confluence with the Zeya River). The annual water yield of the river is 60,2 km^3. The pluvial recharge is 80%. The main precipitation (up to 70% of the annual norm) occurs in July – September.

Among the Zeya tributaries the Selemdzha River is the most abounding in water, its annual discharge being 70% of the total Zeya River's yield (32 km^3). In the lower reaches of the Zeya River the largest tributary is the Tom' River with water discharge over 16% in the total water volume of the former. All the other tributaries' account for only 2% of the yield.

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[1] The field works have been conducted by the Geoecological Laboratory, Institute of Geology and Nature Management FEB RAS, in the framework of the program "Integrated Research in the Amur River basin" of the Far Eastern Branch, Russian Academy of Sciences.

In the middle and lower reaches the Zeya River drains the Amur – Zeya intramountane depression which is the largest in Russia. During the entire neotectonic stage this territory has been developing as an integral formation [Geomorphology..., 1973]. And this reflects the general features of its geomorphology. In general the depression surface is typical for a plain and shows inclination to the south. The absolute elevations of the surface vary from 400 – 450 m (in the north) to 200 – 250 m (in the south).

Within the depression there are two regions steadily dipping during the entire neotectonic stage: the Amur – Zeya Trough in the north and the Lower Zeya Trough in the south [Sorokin,Glotov, 1997]. During the formation of the Amur – Zeya Trough there accumulated a thick series (up to 1 km) of sedimentary (mainly sandstones, conglomerates and siltstones) and effusive rocks. The Lower Zeya Trough is entirely filled (down to 3 – 3,5 km) with primarily loose sandy-argillaceous rocks with the layers of volcanic rocks. A relatively elevated block separating the above structures is presented in the topography as the Amur-Mamyn Uplift [Sorokin, Glotov, 1997].

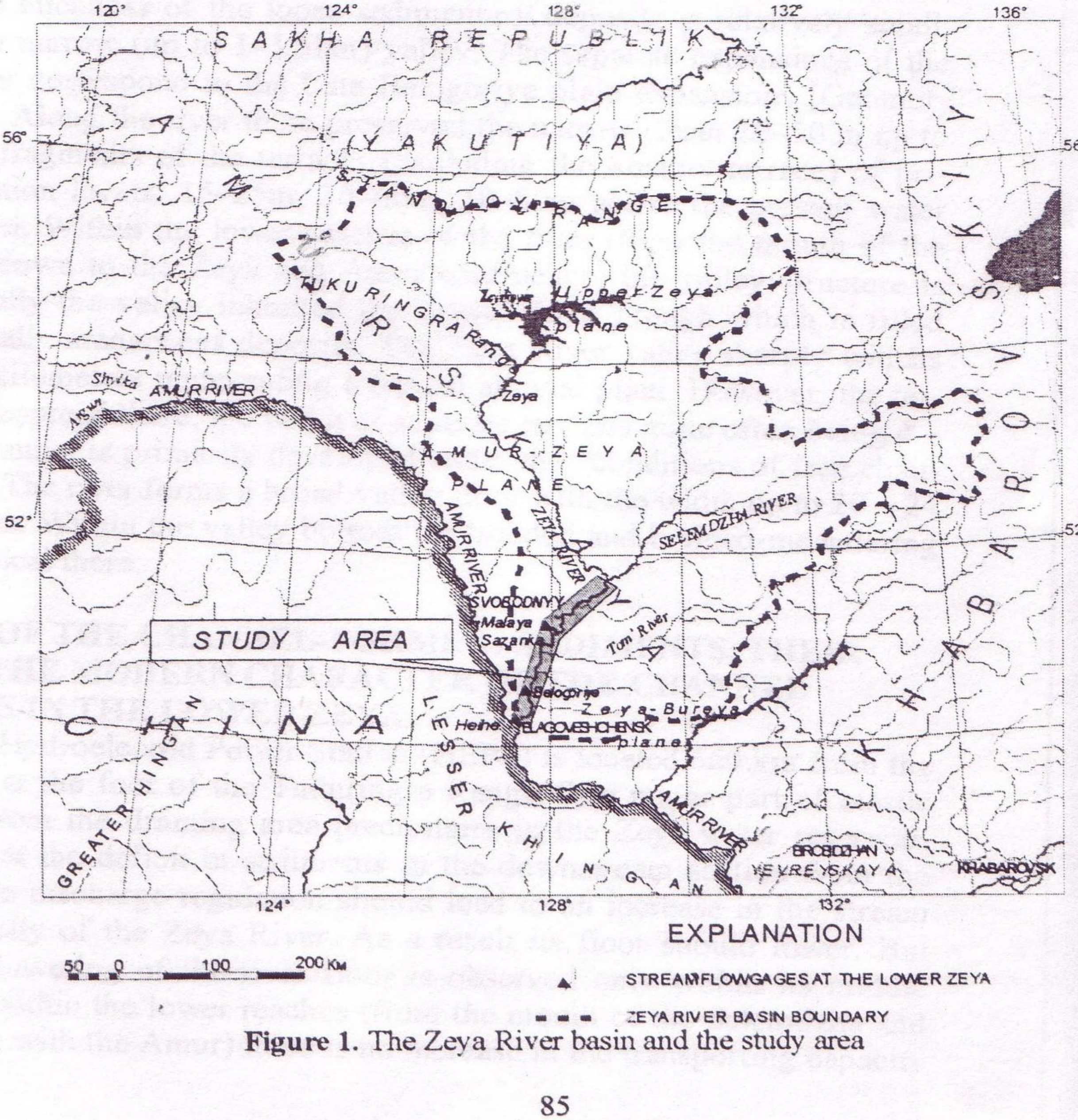

Figure 1. The Zeya River basin and the study area

Mainly effusive rocks and also metamorphic and intrusive rocks of the Precambrian, Paleozoic and Mesozoic age composing its basement quite often outcrop to the earth surface. In the end of Tertiary and in the beginning of Quarternary time (Late Belogorskoye – N^3_2 –Q_{1blg}) the territory within the structures under consideration has been developing as an integral formation. It experienced a common dipping within its central and the most subsided part which comprises the Lower Zeya Trough, the Amur-Mamyn Uplift and the southern portion of the Amur-Zeya trough, there accumulated loose, arenaceous-alluvial deposits. They formed vast accumulative deltaic-terrace plain [Geomorphlogy…, 1973]. The stage of formation of the modern river network began with the dissection of that plain. During the Quarternary time the large streams have deeply dissected the plain. The magnitude of the Zeya incision into an initial surface is in the range of 100 – 140 m.

The peculiar lithologic structure and the character of the neotectonic development of the main structural elements in the Amur–Zeya Depression set the most important parameters of the river valley and the morphodynamic pattern of the channel. In the middle reaches (within the Amur–Zeya Trough and Amur–Mamyn Uplift), where the thickness of the loose sedimentary deposits is relatively small, the river formed a narrow (up to 1–1.5km) valley. The separate expansions of the valley and its floor correspond to the Late Belogoriye plain expansions [Geomorphology…, 1973]. Along the river there preserved the narrow (from 20–50 m up to hundreds meters) fragments of the terraces (excluding the «main» terrace) of primarily three elevation levels: 15–25m, 30–60m, 50–80m above the present water level in the channel. Within the lower reaches of the river (from the mouth of the Selemdzha River down to the Zeya and Amur confluence) the valley structure is different. Structurally the valley inherited the Lower Zeya Trough which is filled with loose, essentially arenaceous deposits. The Zeya River valley sharply widens up to several tens kilometers representing a typical alluvial plain. However, the terraces are more widespread there, the width of separate terraces quite often being 4 – 8 km. The river channel is primarily developed under the "conditions of free channel deformations". The river forms a broad valley floor with the width up to 20 – 24 km at some sections. Within the valley bottom the braided and braided-meandering channel is most typical there.

COMPOSITION OF THE CHANNEL-FORMING SEDIMENTS, THEIR SOURCES AND THE MODERN CHARACTER OF THE CHANNEL DEFORMATIONS IN THE LOWER ZEYA

The dam of the Hydroelectric Power Station (HEPS) is located 660 km from the Zeya River mouth at the foot of the Tukuringra Range. The major part of clastic material supplied from the draining area precipitates in the Zeya water reservoir. We may assume that the deficit in sediments in the downstream section from the HEPS caused by the discharge regulation should lead to an increase in the stream transportation capacity of the Zeya River. As a result its floor should lower. But actually a relative lowering of the river floor is observed only within its middle reaches. However, within the lower reaches (from the mouth of the Selemdzha and up to the confluence with the Amur) there is no increase in the transporting capacity of the Zeya reflected in the channel dynamics. On the contrary, the active accumulation of sediment is presently recorded.

To establish the cause of changes in the channel of the Lower Zeya the study of the channel-forming alluvium and the character of its distribution along the river has been carried out. Choosing the particular methods of research we have taken into considerations that the channel-forming alluvium is a reliable indicator of the river's work reflecting a specific character of the channel processes and the orientation of transformations in the channel.

It was earlier established [Gusev, 1990; 2002], that the deficit of the bed-load downstream from the HEPS led to the rewashing of the channel-forming alluvium in the benthic part of the river bed within the middle reaches before the mouth of the Selemdzha. There occurred an efflux of the relatively small alluvial grains. The channel became wider in the benthic part average depths increased and the water level lowered slightly. On the whole there were no significant morphodynamic changes with reformation of fluvial processes in the middle reaches due to the high stability of the channel.

Much greater dynamism is characteristic of the Lower Zeya (from the mouth of the Selemdzha up to the Zeya mouth) (fig. 2). Unlike the middle reaches the channel develops there under the conditions of the broad (up to 20–24 km) valley bottom ($W_{CH} \backslash W_{FP} < 0,25$, where W_{CH} and W_{FP} are the widths of the channel and flood plain, respectively) (fig. 2). Within the valley bottom there are three main channel types: braided-meandering (192–290km), meandering (112–192 km), braided (0–112 km). The certain fluvial forms correspond to the above channel types: flushed meanders, free and forced meanders, braided channels.

A mean diameter of sedimentary grains along the lower reaches (290 km) of the Zeya River corresponds to fine pebble-size (10,6mm). However, the grain size is extremely variable along the channel (fig. 2). At the section of the Lower Zeya (from the mouth of the Selemdzha to the mouth of the Bolshaya Pyora River) the mean diameter of the channel-forming sediments gradually decreases from 22–24 to 16–18 mm. Downstream the mouth of the Tom' the diameter of the alluvium decreases being 12–16 mm in the average. From the mouth of the Tom' to the Zeya influx into the Amur River a sharp change in the mean diameter of the channel-forming alluvium to 2,1 mm is observed (fig. 2).

We have established that this peculiarity in the grain-size distribution is related to a specific character of the sediment supply to in the Zeya channel. At the river section from 290 to 192 km the channel is developed within the flood plain banks and there are no large tributaries. The main sedimentary source is the material from the Zeya upstream and also the alluvium brought in by the Selemdzha.

Within the middle section of the river (from 192 to 112 km) a slight decrease in the mean diameter of the channel-forming sediments is caused by the additional supply of fine clastic material into the Zeya River due to the bank erosion in the meandering channel.

Further downstream (from 140 km to the Zeya mouth) the channel is pressed to the right high (up to 100–120 m) and steep (up to 20° and more) valley slope which is mainly composed of the easily erodible arenaceous deposits (the prevailing grain-size being 1–0,25 mm) of the Zeya series (N_1-Q_1). Along the whole length of this section within the left–bank drainage basin the fluvial processes, primarily erosion-accumulative and landslide, are widespread and active (Gusev, 2004). They supply huge volumes mainly arenaceous material directly into the Zeya channel. The average annual supply along the 140 km section under consideration is 3–3.5·10^8 kg owing to the erosion processes only.

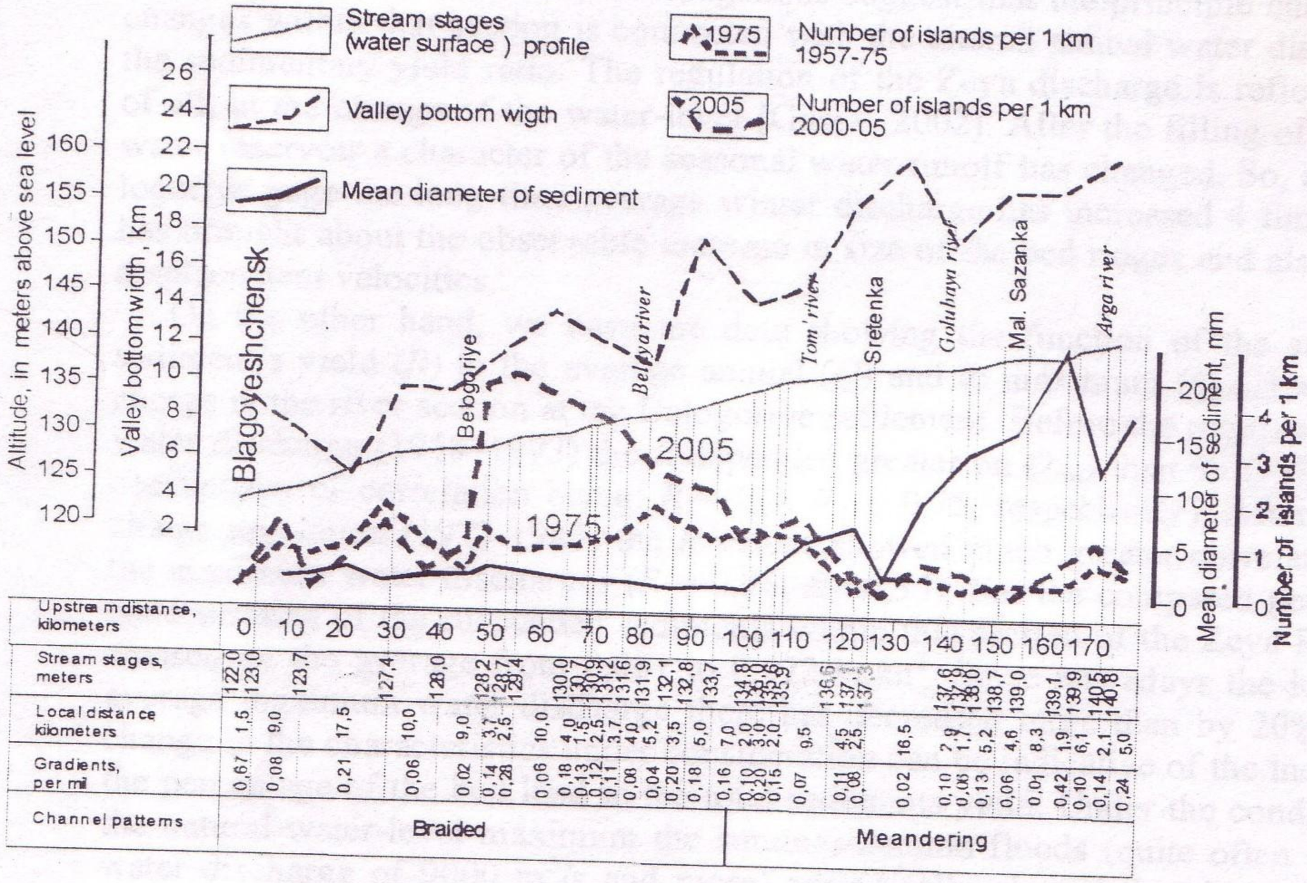

Figure 2. Variations in valley bottom width, water surface gradient, mean diameter of sediment and number of islands per 1 km along the Lower Zeya channel.

According the discharge data at the Belogoriye gage (35 km upstream from the Zeya River mouth) the annual yield of the suspended sediments for the period of 1973-1980 is equal to 4·10^9 kg [Long-time annual data…, 1986]. The other large sedimentary source is the Tom′ River – the left tributary flowing in to the Zeya in 107 km from its mouth. In its lower reaches the Tom′ forms a valley also composed of the loose deposits belonging to the Zeya series (N_1-Q_1). Its channel is highly dynamic. During the floods the Tom′ intensely reforms its valley bottom discharging a considerable volume of mainly sandy material into the Zeya.

The volumes of sediments supplied to the Zeya channel due to the fluvial processes reach transportation capacity and this leads to the reduction of its channel stability. Thus, the river deposits a part of the clastic material (releasing it from transportation). As a result the stream gradients increase downstream (fig. 2). The morphological results of the retardation of the sediment transport at that section are the formation of islands and the development of numerous branches. Therefore, the replacement of the channel meandering in the section (192–112 km) by its braiding (112–0 km) is naturally caused by the local characteristics of the sediment discharge.

At present the braiding along the (112–0 km) section has grown sharper and the braiding of the channel has become more complex: the number of islands, aits and sand bars has increased. So, in comparison with the period of 1957–1973 the number of islands per 1 km stretch in the channel along 50–100 km the section from the mouth has increased from 1,3 to 3 in 2000–2005, their total having grown from 48 to 116 km^2. Diachronically such a character of the channel's braiding should indicate a decrease of the transporting capacity of the river along the section under consideration. The results of our investigations suggest that the principle cause of the changes within that section is connected with the altered annual water discharge to the sedimentary yield ratio. The regulation of the Zeya discharge is reflected, first of all, in the change of the water-level [Gusev, 2002]. After the filling of the Zeya water reservoir a character of the seasonal water runoff has changed. So, at the Belogoriye gage the long-time average winter discharge has increased 4 times which has brought about the observable increase in size of the bed ridges and also in their displacement velocities.

On the other hand, we have the data showing the function of the suspended sediment's yield (R) to the average annual (Q) and to maximum (Q_{max}) water discharge in the river section at the Belogoriye settlement. Before the regulation of the water discharge (1958–1973) the R depended greater on Q_{max} than on Q (Pearson's coefficients of correlation being: R_1= 0,8; R_2 = 0,75, respectively). After the discharge regulation (1973-1983) the R values showed much greater correlation with the maximum water discharges (R_1= 0,96; R_2=0,55). For the compared periods the concentration of the suspended sediments within this section of the Zeya River decreased on the average from 0,081 to 0,072 kg/m^3. Since nowadays the long-time average maximum water discharge there has decreased more than by 20% such a change in the characteristics under consideration can be indicative of the increase in the percentage of the bed load in the total sediments yield. Under the conditions of the natural water-level maximum the summer-autumn floods (quite often with the water discharge of 9000 m^3/s and more) periodically cleared the channel from a surplus of the sandy material converting it to suspended sediments.

At present under the conditions of the water discharge regulation the volume of sediments brought in the Zeya channel appears to be relatively excessive. At the section under consideration the surplus of sediments forms the river valley bottom which leads to the accretion of the river bed and to the formation of new aits, sand bars, islands and other bed forms. The curve diagrams showing the water stage – discharge relation at the Belogoriye gage before and after the water discharge regulation are also indicative of that sediment accumulation (fig. 3). In comparison with the period of the natural water-level the correlation curves are plotted slightly higher on the diagram.

CONCLUSIONS

In the course of our investigations of the Lower Zeya stream we came to the following conclusions:

1) The replacement of the channel meandering (112-192 km) by its braiding (0-112 km) is the regular natural process caused by the local characteristics of the sediment discharge.

2) The effect of the intense river incision downstream from the large HEPS as a result of the stream power is not distinct under the conditions of the Russian Far East. More over, within the lower reaches of the Zeya River along rather extended section of its channel the bed accretion is observed. This is caused by a decrease in the stream power as a result of the regular character of the water discharge. Such an effect of the water discharge regulation requires an additional research.

3) The planned development of the hydropower engineering in the Amur Region urgently dictates the necessity of the regular systematic research of the water and sediment discharge in the Zeya and Bureya regulated streams.

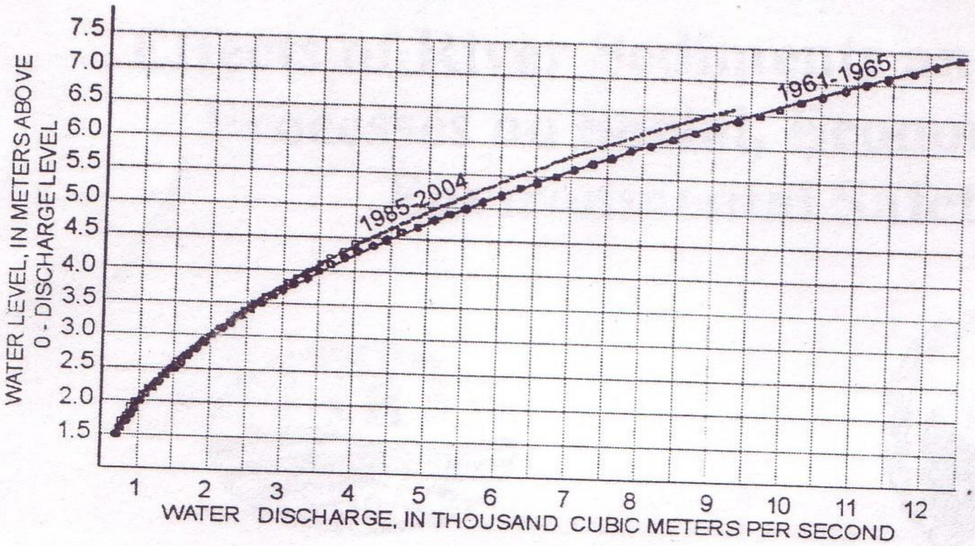

Figure 3. The water level – discharge relation at the Belogoriye gage before and after the water discharge regulation

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