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The influence of water level fluctuations in the Ust-Ilimsk water reservoir in Russia on the action of some geological processes

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ABSTRACT

The Ust-Ilimsk water reservoir is located in the taiga zone in the Central-Siberian Upland. It was created between 1975-1977 as a result of storage of flood waters and water from the higher located Bratsk Reservoir. With an area of 1873 km^2 and a water capacity amounting to 59.4 km^3 it belongs to the group of largest water reservoirs in the world. It is the third level of the Angara cascade, projected as a multifunctional object – for the efficient functioning of the Ust-Ilimsk Hydroelectric Power Station, to streamline navigation on the lower Angara, to fulfil municipal and industrial water needs and also for floating timber. On the basis of the author's own investigations and source materials obtained from the Irkutskgidromet and the Institute of the Earth's Crust in Irkutsk, the fluctuations of the water level and the volumes of water outflow in the period 1975–2007 and the volume of processed material at the selected water shores in the period 1977-1990 were analysed. In addition, the data of seismic events in the region of the Ust-Ilimsk water reservoir were compiled. During this period the functioning changes of the reservoir in terms of the capacity of the water mass occurred under the influence of both natural and anthropogenic factors. It was determined that the creation of this natural-technical water object activated two geological processes in its shore zone – abrasion and induced seismicity. It was stated that the especially large transformations of the reservoir shore zone by these dangerous processes occurred in the first years of its intensive exploitation, in the period of small water resources in the drainage basin of Yenisei – Angara, which forced specific conditions of reservoir functioning. At rocky shores the predominating process is abrasion of their waterside parts, whereas at shores built of loose deposits the complete transformation of underwater parts of shallows takes place.

KEY WORDS: large water reservoir, hydroelectric power station, abrasion, induced seismicity, Central Siberian Upland

1. Introduction

The building of anthropogenic water reservoirs, especially the largest ones, causes a significant interference in their environment (VICULINA & SELJUK, 1966; BARDACH & DUSSART, 1973; DIXON ET AL., 1989; MCCARTNEY ET AL., 2001; DEGU ET AL., 2011; TASHLYKOVA, 2007a, 2013a). Man-made water reservoirs are natural-technical water objects, which despite being controlled by man, develop as natural water reservoirs. Their appearance causes changes in almost every element of the geosphere and connections between them (TASHLYKOVA, 2012a), an example can be the Angara-Yenisei Cascade of Hydroelectric Power Stations and the Ust-Ilimsk water reservoir functions within it. It is the third level on the Angara and simultaneously the following transit reservoir and one of the largest and deepest reservoirs in the world. In this study the influence of water level fluctuations in this reservoir (in connection with its fulfilled functions) on the activation of some geological processes was presented.

2. Materials

This work originated as part of author's own investigations and also uses source materials obtained from the Irkutskgidromet and the Institute of the Earth's Crust in Irkutsk. The following data concerning the functioning of the Ust-Ilimsk reservoir were compiled: 1) average annual water levels and average annual volumes of water outflows in the period 1975–2007, 2) average monthly values of side water inflows and size of water outflows from the hydroelectric power station between 1992 and 1993, and 3) the volume of processed material at selected reservoir shores during the period 1977-1990. Data of seismic events in the region of the Ust-Ilimsk reservoir were also compiled.

3. Study area

The Ust-Ilimsk reservoir is located within the borders of the Central Siberian Upland, in the north-western part of Irkutsk Oblast (Fig. 1). It was built in a relatively short time (3.10.1974–25.05.1977) and the reservoir of water mass results from storing flood waters and water from the higher-located Bratsk Reservoir. The total area of the reservoir up to the height of its normal damming level (296 m a.s.l. in the Baltic system) amounts to 1873 km^2, the water capacity is equal to 59.4 km^3 (TASHLYKOVA, 2013a). The maximum depth of the reservoir at the dam in Ust-Ilimsk exceeds 90 m; water damming is observed on the Angara river up to the dam of hydroelectric power station in Bratsk and reaches up to 304 km, whereas on the Ilim river – 302 km (UST-ILIMSKOYE VODOKHRANILISHCHE, 1975; SAVEL'YEV, 2000). The Ust-Ilimsk reservoir is located in the taiga zone and because of this its accessibility for research is poor. In the majority of cases it is possible to reach particular sections of the shore only from the water body itself. Its shores are often steep and precipitous, up to 200–250 m high above the water level and occur in narrow valleys, with rocky outcrops of the *Trappean formation*. For this reason these sections of the river are similar to rocky canyons (Figs. 2 and 3). The river Angara dams of the hydroelectric power stations were built in such narrow valleys at Bratsk and Ust-Ilimsk.

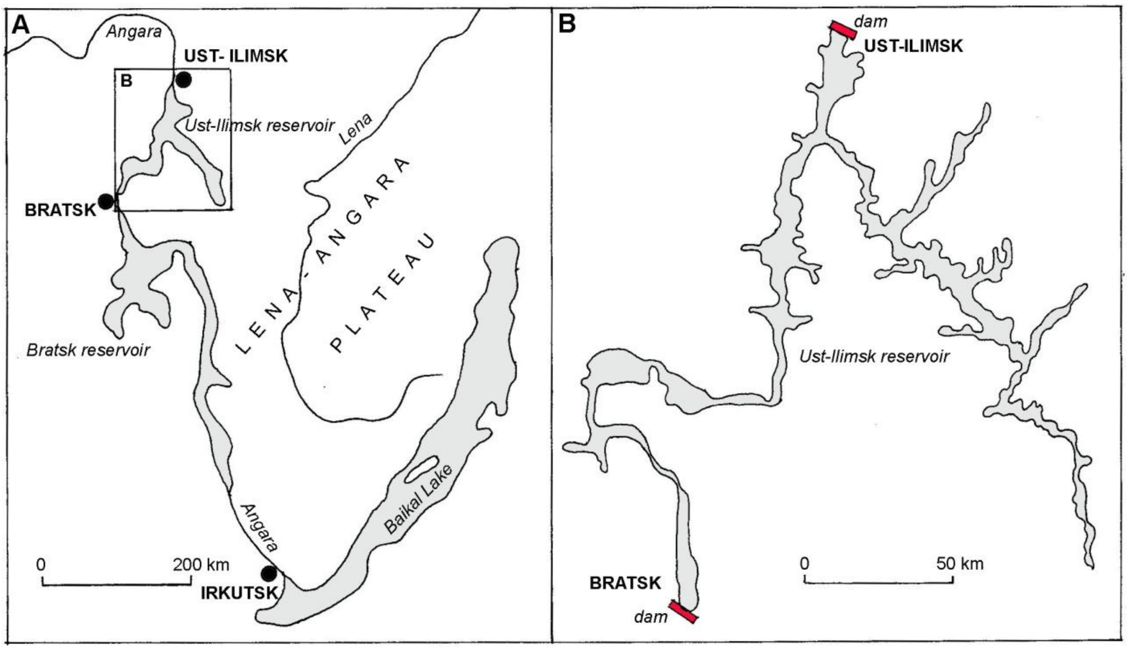

Fig. 1. Location of the Ust-Ilim reservoir (after Tashlykova, 2013a)

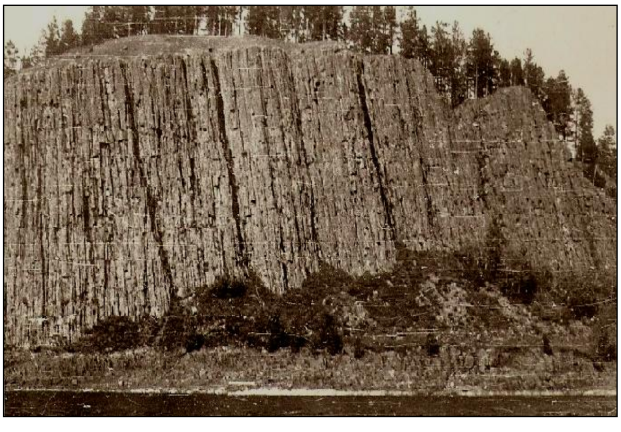

Fig. 2. The front side of the Trappean landslide block in the area of Badarma narrowing (*V. F. Osadcheva*)

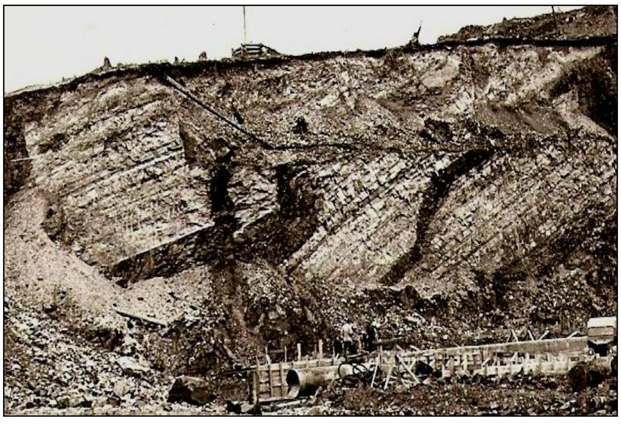

Fig. 3. The character of interaction between the diabase rocks and enclosing rocks of the Kat suite of Carboniferous in the area of Ust-Ilim power plant (*F. N. Leshchikov*)

4. Functions of the reservoir

Water reservoirs are subject to the rules of development typical of natural objects (VODOKHRANILISHCHA, 1986), but all processes, occurring in both the reservoir and at the shore, are influenced by human activity, which consists of a regime of exploitation for every hydro-technical system. This influences numerous hydrological phenomena connected with properties of water mass shaping and their hydrodynamic influence on the shore zone.

The water mass of the Ust-Ilimsk reservoir is created from discharge of the Angara waters through the dam of the power station in Bratsk, side inflows and the activity of the Ust-Ilimsk hydrotechnical system. This reservoir is characterised by seasonal regulation of the runoff of the Angara waters. The purpose of this type of regulation is to store water from the humid seasons of the year and to use it in the drier seasons (OVCHINNIKOV, 2003). There is a connection between the seasonal variance of maximum runoff and water demand for hydro-energy for industrial and municipal purposes and with the necessity to streamline the navigation in the lower part of the river Angara and also for floating timber.

The basic function of the described reservoir is to produce energy. The existence of the dam favours the origin of a definite hydraulic thrust. A difference in depth of about 100 m allows the proper thrust to obtain the maximum water flow through the Ust-Ilimsk hydrotechnical system and to produce the proper amount of electric energy. Due to its location at the third level of the Angara cascade of hydroelectric power stations and the work regime of the Ust-Ilimsk hydrotechnical system, the reservoir is regulated by humans on the basis of a calculated regulation of the use of the water resources in the reservoirs of the Angara cascade of hydroelectric power stations (OSNOVNYJE PRAVILA, 1983). The Ust-Ilimsk reservoir also fulfils a flood control function.

5. Fluctuation of the water levels

The Ust-Ilimsk water reservoir is characterised by the seasonal regulation of runoff. The permissible amount of water level lowering is small: under normal conditions of exploitation it amounts to 1.5–2 m, and under extreme ones – up to 4 m. The change of water level in the Ust-Ilimsk reservoir forms the integral characteristics of its water regime. Fig. 4 presents fluctuations of water level in the reservoir during its existence, and also the size of the water outflows in the Ust-Ilimsk hydrotechnical system. The water level in the reservoir is completely shaped and controlled by the Federal Agency for Water Resources of the Ministry of Natural Resources and Environment Protection of the Russian Federation. During the life of the reservoir functional changes occurred in the water mass capacity under the influence of both natural and anthropogenic factors (TASHLYKOVA & LUK'YANOVA, 2011). During this investigation the general character of changes in the discussed parameters was stated, and proves the existence of defined water cycles of reservoir and regimes of exploitation of the hydrotechnical system (TASHLYKOVA, 2013b).

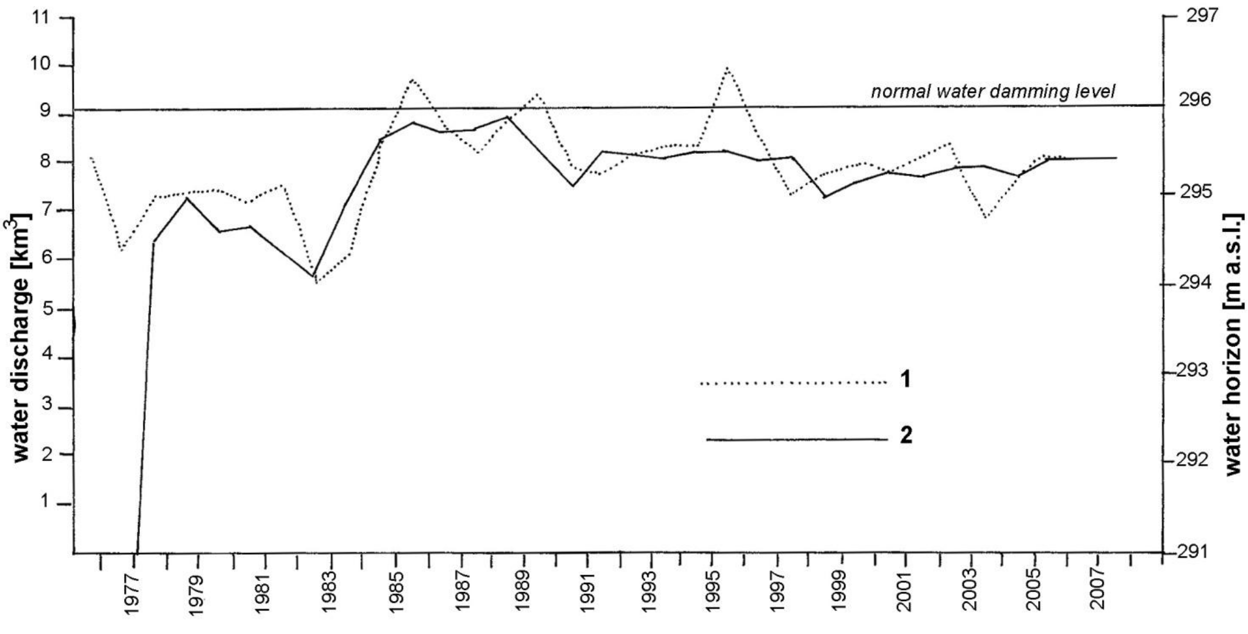

Fig. 4. The average annual water discharge (1) of the Ust-Ilim power plant and the average water horizon (2) of the Ust-Ilim reservoir (Data of Irkutskgidromet; after Tashlykova, 2010, changed)

The lowering of the water volume outflows from the hydroelectric power station correspond to periods with lower amounts of water in the Angara – Yenisei drainage basin. This situation took place in the first years of the existence of the Ust-Ilimsk reservoir (1975–1982), which was determined as a „hydrological catastrophy", when at the end of 1981 all the reservoirs on the Angara and Yenisei had already functioned and only the annual regulation of the Angara runoff took place (SAVEL'YEV, 2000) (Fig. 4). In that period the production of indis pensable amounts of electric energy by power stations in Ust-Ilimsk was kept up owing to a lowering of the water level in reservoir at an „intensive" exploitation regime, but within the borders determined by OSNOVNYJE PRAVILA (1983). In that period nine cases of increased lowering of the water level– below the dead level capacity (up to 292.65 m a.s.l.) occurred, which gives the maximum value for lowering in the whole period of functioning of the reservoir. Among these cases, the extreme lowering level – up to 4 m, was stated four times (TASHLYKOVA, 2007a,b; TASHLYKOVA & LUK'YANOVA, 2011). Therefore, the maximum lowering of the water level in the reservoir was the value forced by the determined situation, in which natural factors (period with small amount of water) overlapped with anthropogenic ones (TASHLYKOVA, 2013b). The results of such situations caused problems in the water-economy system, when the needs of water users were disturbed; then there were also sanitary limitations, limitations in the regular sailing of water craft and in floating timber (SAVEL'YEV, 2000).

In more favourable natural conditions the reservoir functions in a different way. The maximum volumes of water discharged by the Electric Power Stations in Ust-Ilimsk are connected with periods with large amounts of delivered water (1985, 1988, 1995), when overfilling of Irkutsk and later Bratsk and Ust-Ilimsk reservoirs took place. The water level in these reservoirs in the whole period without ice reached the forced values: on average 0.5 – 0.7 m above the normal water damming level. In such a crisis situation of water excess the forced decisions, concerning empty water discharges from all Angara-Yenisei reservoirs were made. So such water discharges from the Irkutsk reservoir in September of 1985 amounted to 600 m^3/s, and from Bratsk and Ust-Ilimsk reservoirs–1800 and 4400 m^3/s respectively (SAVEL'YEV, 2000). The size of water outflows from the Ust-Ilimsk reservoir indicated that in that period of high water level this reservoir fulfilled only transit functions of discharges of Baikal water. In spite of the fact that the capacity of Bratsk reservoir is three times larger than that of Ust-Ilimsk, the amount of discharge from the latter was three times larger in comparison to the former, which shows that the Ust-Ilimsk reservoir has a transit position. In this described period of the cascade management the Inter-Department Operations Group worked permanently on the regulation of the regime of Angara and Baikal reservoirs. It controlled the water level in all Angara reservoirs and determined the decisions, which result in the current situation (TASHLYKOVA & LUK'YANOVA, 2011; TASHLYKOVA, 2013b).

The second function of the Ust-Ilimsk reservoir is that of flood control. The phenomenon of spring-summer floods exists on rivers in this region, which often lead to special situations, in connection with violent rising of the water levels and periodic flooding of the area. The building of the reservoir helped to solve this problem. Increased amounts of surface flow, as the result of spring thaws and summer rains, falling in spring and the early half of the summer, are stored in the reservoir, increasing the capacity of its waters. Fig. 5 presents a comparison of side water inflows into the Ust-Ilimsk reservoir in contrasting years: 1992 – with full water and 1993 – with a small amount of water and the lowest precipitation levels in the last 30 year functioning period of the reservoir. It is notable that in 1992 the volume of these inflows was almost 4 times higher than in 1993 (TASHLYKOVA & LUK'YANOVA, 2011). Thus, it is very important to store the excess of flood waters to use them in the period of low water flow. In addition, the regulation of runoff allows an increase in the intended and guaranteed power of the hydroelectric power station, the amount of energy produced and the degree of energy use flow. The second important filling of reservoir occurs in the autumn to secure the winter usage of the hydrotechnical system.

On the other hand, at the Ust-Ilimsk reservoir, similar to those of Irkutsk and Krasnoyarsk, it was necessary to drain large amounts of water (so-called sanitary or ecological discharges) below the dam to retain the level necessary for the functioning points of water intake. The main reason for the distinct drops in water level is the uncontrolled exploitation of sand and gravel in the river channel, which leads to their widening and deepening. During the work of the reservoir it is often necessary from time to time to increase the water volume to streamline navigation – regular sailing of water craft (barges, fishing vessels, ships) by the defined sections. For example, in 1996 it was necessary to increase the amount of water discharged to the Angara below the dam in Ust-Ilimsk from 2600 up to 3200 m^3/s (SAVEL'YEV, 2000).

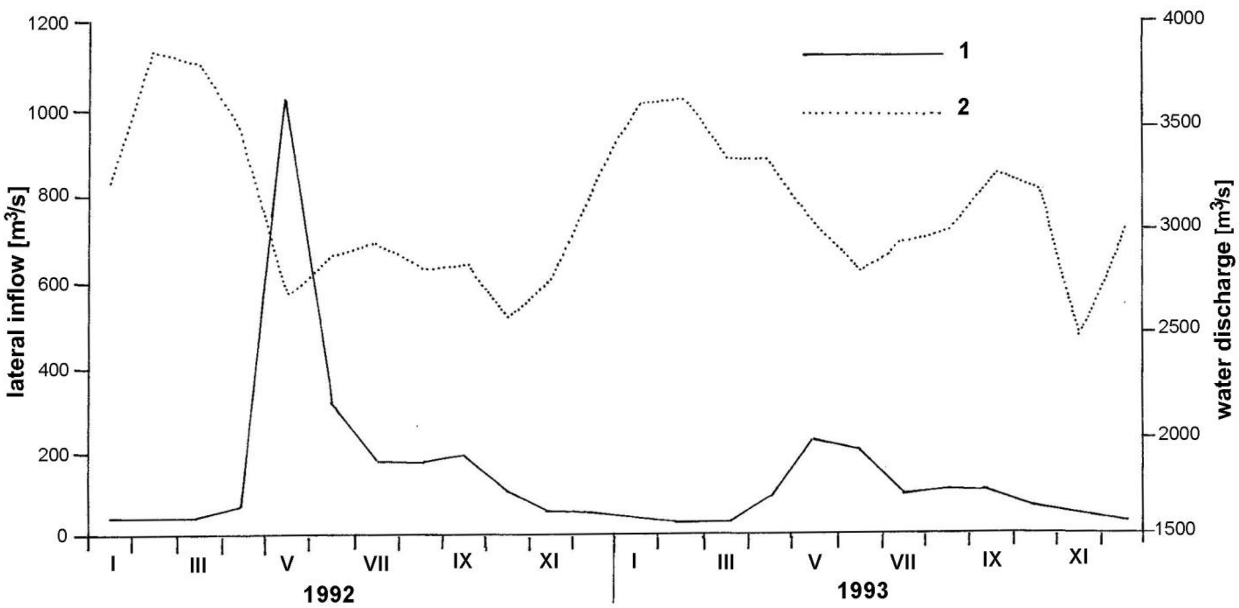

Fig. 5. Integrated plots of the monthly average of lateral inflow (1) in the Ust-Ilim reservoir against the water discharge of the Ust-Ilim power plant (2) in contrasting years (after Tashlykova, 2010, changed)

6. Abrasion-accumulation processes

The Ust-Ilimsk water reservoir is an anthropogenic object with comprehensive functions, but its formation disturbed the balance in the nature, which has resulted in the modification of the microclimatic and geological-engineering conditions, and also the underground water regime of flooding and soil swamping occurring in the zone of its influence (TASHLYKOVA, 2007c, 2013a). The formation of the reservoir caused the development of new relief-shaping processes. One of them is the abrasion of the shores that belongs to the group of the most dangerous – from a point of view of human being – natural phenomena (TASHLYKOVA, 2012a,b,d, 2013b). The analysis of data on the abrasion-accumulation processes within the Angara part of the Ust-Ilimsk reservoir indicates that the predominating process in the rocky deposits is the abrasion of the waterside parts, which to a lesser degree is accompanied by the accumulation of material under the water (Fig. 6). The loose deposits cause a complete remodelling of the underwater parts of the shallows, which leads to the abrasion and accumulation processes occurring.

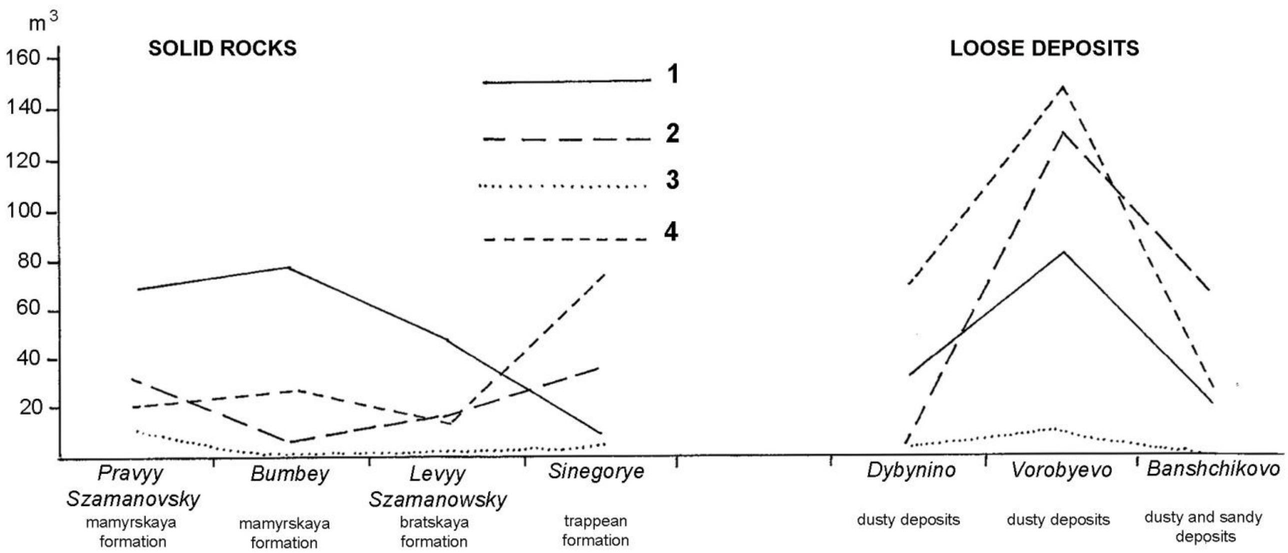

Fig. 6. Total amount of reworked material in the observation sites (period 1977–1990) accumulation (after Tashlykova, 2010, changed)
1 – water side degradation; 2 – subaqueous degradation; 3 – water side accumulation; 4 – subaqueous accumulation

7. Induced seismicity

Compiling the data concerning the water regime of the reservoirs – Ust-Ilimsk and Bratsk, has also provided data on the occurrence of seismic events in the Middle Angara region and shows the existence of another dangerous process – induced seismicity. The analysis of the location of epicentres of earthquakes recorded in the area around the Ust-Ilimsk reservoir has distinguished three groups of seismic events occurring: 1) in the neighbourhood of the shores of the reservoir, 2) at night (eight in nine registered seismic events), 3) only in the deep part of the reservoir (i.e. not connected with industrial explosions) (TASHLYKOVA, 2012c). On the basis of her own research the author draws the conclusion that the induced origin of seismic activity in the region of the Middle Angara is caused by the influence of the deep water reservoirs – Ust-Ilimsk and Bratsk (TASHLYKOVA, 2012a-e).

8. Conclusions

From the investigations conducted during the 36 years of the functioning of the Ust-Ilimsk reservoir changes in the capacity of the water mass under conditions of both natural and anthropogenic factors have occurred. Lowering the volume of water outflow in the hydroelectric power station corresponds to periods with lower amounts of water in the Angara-Yenisei drainage basin. Such a situation took place in the first years of the existence of the Ust-Ilimsk reservoir (1975–1982). The maximum volumes of water discharged by the power stations in Ust-Ilimsk were connected with periods of high water delivery (1985, 1988, 1995), when the overfilling of the Irkutsk and later Bratsk and Ust-Ilimsk reservoirs happened. Fluctuations in water level in the reservoir are also connected with the storage of excess flood waters in order to use them in periods of low water flow. There are also so-called sanitary or ecological discharges below the dam to keep up the level necessary for functioning of points of water intake. From time to time there is the necessity to increase the amount of water to streamline navigation – regular sailing of water craft (barges, fishing vessels, ships) through defined sections of the reservoir.

It has also been determined that creating the Ust-Ilimsk reservoir has activated two dangerous geological processes – abrasion and induced seismicity in its shore zone. Especially large transformations of the reservoir shore zone by these processes occurred in the first years of its intensive exploitation, in the period of small water resources in the Yenisei – Angara drainage basin, which forced specific conditions of reservoir use. At rocky shores the predominant process is the abrasion of their waterside parts, whereas at shores built of loose deposits the complete transformation of the underwater parts of the shallows takes place.

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