FLOODS IN SIBERIAN RIVER BASINS

DMITRY A. BURAKOV*, YULIYA V. AVDEEVA,
AND VERA F. KOSMAKOVA
Sredhesibirian SUGMS, Department of development and application of hydrometeorological forecast, 28 Surikova st.,Krasnoyarsk 660049, Russia

Abstract- In the article the causes of floods in the basins of three major rivers – the Ob (with the tributary Irtish), the Yenisei (with the tributary Angara) and the Lena are given. The floods can be territorial which covere up to 50-60% of the total area or the floods can be local which are formed on separate reaches of rivers or in limited areas of the region. According to the frequency of maximum water level the following subdivisions are made to distinguish the characteristics of floods: extreme flooding — with a frequency to 1%; severe flooding — with a frequency from 1% to 10%; heavy flooding — with a frequency from 10 to 25%. The examples of territorial and local flooding, the spatial and temporal variation of floods, ambiguity of cause-effect connections and laws governing the formations of maximum runoff, and experience of the operational forecasting of floods in West and Middle Siberia are presented in this paper.

Keywords: flood; ice jam; rainfall; releases of hydro power station; hydrological forecast; hydro-mathematical modelling

1. Factors Responsible for Flooding and the Geography of Flooding

The territory of Siberia occupies the greatest portion of the North Asia landmass. Within this territory are situated the basins of major rivers — the Ob (with the Irtish), the Yenisei (with the Angara) and the Lena. The total area of these basins covers eight million sixty thousand km^2.

The flooding that occurs on the rivers of Siberia has, historically, caused extensive damage and has led to the loss of human life. These events have occurred mainly during the spring season**.** There are only two specific areas where floods outside this season present a significant hazard. These are the

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Upper parts of the Angara and Lena river basins, where rain floods constitute a threat.

Analysis shows that extremely high levels of spring floodwater are caused by a combination of the following prior conditions: heavy autumn rainfall, severe winter conditions, extensive snow-accumulation, cold temperatures persisting into late spring with a heavy amount of precipitation, or an early very benign spring (characterized by a steady, gradual increase in temperature, leading to a consistent simultaneous snowmelt across the whole territory) with a heavy amount of precipitation, and the sudden, rapid onset of warm weather. In these conditions, floods can be formed by the intensive influx of snowmelt and rainwater. In addition, there is an increased probability of the formation of ice-jams, which are a feature of the Siberian rivers, whose courses flow from south to north. As a result of an earlier onset of spring in the south, the wave of seasonal flooding being moved northwards, breaks open the stable ice cover (Busin, 2005, Lisser, 1981). Frequently the ice jams are formed on one and the same stretch of rivers. This is connected with the geomorphologically special features of the structure of the river bed: by the presence of steep river bends, islands, channel contractions, rapids.

The degree of the influence exerted by each of the factors listed above varies across the territory and at different points of time. For example, in some cases floods in essence are connected with the accumulation of the extremely high water equivalent of snow cover during the long Siberian winter (with a relatively smaller influence of other factors). In other cases the determining influence is exerted by precipitation of heavy rain during the period of snow-melt, or extraordinarily high autumn moistening of the river basins, which can be aggravated by conditions of deep soil freezing, that increase the soil's permeability.

Finally, if factors favorable to high water content and to the formation of ice jams are combined, floods on catastrophic scale occur.

According to the frequency of maximum water level the following subdivisions are made to distinguish the characteristics of floods: extreme flooding — with a frequency to 1%; severe flooding — with a frequency from 1% to 10%; heavy flooding — with a frequency from 10 to 25%.

E.V. Blizniak referred to the extreme and severe floods on the river Yenisei in the town of Yeniseisk in the following years of the nineteenth century: 1824, 1837, 1839, 1841, 1845, 1848, 1853, 1857, 1888. I.Ya. Lisser (Lisser, 1981) gave information about 14 reaches on the river Yenisei from the city of Kyzyl to the town of Igarka, which was at risk from ice jams. However, since the construction of Krasnoyarsk hydro power station (1967) spring ice jams are no longer formed on the reach of river Yenisei stretching from the dam of Krasnoyarsk hydro power station as far as the Angara river mouth. However on the stretches further downstream the probability of their formation has increased substantially.

Since the establishment of the Bratskaya and the Ust'-Ilimskaya hydro power stations, ice jams on the river Angara now occur downriver at points along a 350 kilometer stretch. Here the most dangerous situations occur, when flooding from snowmelt with ice break-up and intervention of ice jams, raises water level to the maximum 9.0–11.0 m (gauges Boguchany, Kamenka, Ribnoe, Tatarka). Along the reaches of the mouth of the rivers Ilim, Yuda, Burisa, Taseeva, Ia, Oka, Kova (the tributaries of river Angara), inflow caused by ice-jams characteristically raises water levels by 2.00 to 10.00 meters.

In the Lena river basin, where the winters are at their most severe and where the risk of a critical rise in water level, with outbreaks of flooding is the most intense, there are found conditions even more favorable to the formation of floods than on the river Yenisei, and the river Ob — the latter being the least severely affected.

In the Ob river basins, floods caused by the snowmelt and ice jams are noted in the river systems of the Irtish, the Tom and the Chulim. On the river Ob, ice jams are formed along the upper course of the river as far as the town of Kamen-na-Obi. On the middle and lower course, the river has frequently reached maximum water levels as early as the end of the period of floating ice.

Total damage from the floods increases if they are repeated in frequent succession and secondly if they cover an extensive area at the same period of time. Records are available which detail, over the last century, the particular cases of extremely high floods, covering simultaneously, to a greater or lesser extent, the Ob, Yenisei and Lena river basins (Table 1). In these cases, all or the majority of the flood-causing factors, identified above, were involved.

Such widespread floods can be named "territorial", to differentiate from "local", which describes flooding occurring along individual reaches of rivers and over a limited area of territory. Siberia experiences' flooding that is territorial - observed simultaneously over the whole territory of the Ob and Yenisei river basins, or of Yenisei and Lena river basins-, and local, manifested in the individual reaches of its rivers.

2. Characteristics of Territorial Flooding

During the seventy year period that observations have been recorded, territorial floods have recurred only at relatively long intervals — on average once in 20-25 years.

Territorial flooding can occur in the period of the spring flood when the effects of the factors of high water volume prevail across the whole region. Ice jams, which occur during this same period lead to a disparity in the rise of water levels recorded, raising individual levels above the high general background level. For this reason, on different rivers and reaches of rivers, floods in all three categories, heavy, severe and extreme can be recorded. The probability of the occurrence of territorial floods caused by rain runoff is exceptionally small because precipitation is not experienced uniformly across the whole region.

2.1. FLOODS IN 1941

The floods of 1941 can serve as an example of the extreme and severe floods, simultaneously enveloping territory over the two largest river basins – the Ob and the Yenisei. A rainy autumn and a mild winter with heavy snow, accompanied by intensive cyclonic activity preceded it. Water equivalents of snow cover before the beginning of snow melt reached 150-200% above normal. Spring 1941, in contrast with the relatively warm winter, was cold, and it was characterized by large amount of precipitation. A rise in air temperature above 0^0C occurred in the latter part and warming up was intensive. Perceptible snowmelt began in the mountains of South Siberia in the middle of May, and an intensive snowmelt occurred across the region at the end of May and in the first week of June.

TABLE 1. The territorial extent and severity of floods - extreme, severe and heavy - on the Siberian rivers during the period of instrumental observations.

Year	Characteristic of floods and territory affected
1941	Extreme and severe in the Ob and Yenisei river basin; severe and heavy in the Lena river basin
1948, 1947	Extreme and severe in the territory of the South Taiga and the swampy forest steppe of the Western-Siberian plain; In 1947 a catastrophic ice jam on the river Tom' near the city of Tomsk with the water level rising up to 10 meters. Ice jams on reaches of the river Yenisei and its tributaries
1958	Severe and heavy in the Upper Ob and Lena river basins. Moderate in the Yenisei river basin. Moderate and low in the central and lower regions of the Ob river basin
1966	Severe in the river basin of the Upper Ob and the Yenisei river basin, moderate in the central and lower areas of the Ob river basin and in the Lena river basin

1969	Extreme, severe and heavy in the basin of Upper Ob and Yenisei river basin, moderate in the central and lower regions of the Ob river basin and of the Lena river basin
1999, 1998	Extreme and severe in the river basins of South Taiga and the swampy forest steppe of the Western Siberian plain. Moderate and low for the rest of the territory; A catastrophic ice jam on the river Yenisei near the village of Vorogovo in 1999
2001	Severe and heavy over the whole territory of the river basins of the Upper Ob, the Yenisei river and the Lena river excluding the Western Siberian plain; extreme ice jams on the Lena river near the city of Lensk

Extremely high maximum water discharge and water levels were experienced in 1941 with the arrival of the spring floods on the rivers of the Ob river basin. During these floods the highest water levels were observed since records began on the river Bia (city of Biisk), river Ob (towns Kolpashevo, Molchanovo, etc.). Water levels approaching an all-time high were also recorded on the rivers of Southern Taiga and across the swampy woodland of the Western Siberian plain: (rivers Chaya, Iksa, Vasyugan and others). Water levels with a frequency from 1% to 15 % were recorded in the Chulym and Tom river basins.

In 1941 extreme and severe floods were formed on many rivers of the Upper and Midlle Yenisei river basin, including the Angara river basin. The water level on the river Yenisei (cities of Kyzyl, Minusinsk, Krasnoyarsk, village Kazachinskoe, city of Yeniseisk) and on the Angara river (village Boguchany, etc.) rose to a level deemed “extreme” or close to this level. During the period from 7th to 19th of June many populated areas were flooded, including the cities of Kyzyl, Minusinsk, Krasnoyarsk, and Yeniseisk.

2.2. FLOODS IN 2001

The disastrous situation in Siberia during the spring of 2001 provides a more recent example of extreme and severe floods. The flooding was formed simultaneously over a vast area of territory (river basins of the Upper Yenisei and the Lena, and -less severe- in the river basin of the Upper Ob). On the river Katun near the town of Srostky (the largest tributary of the river Ob) the highest water level was observed since records began in 1932. On the many rivers of Altay and on the river Ob near the city of Barnaul the frequency of maximum water level was 10-20%.

In the Yenisei river basin the flood was caused by large snow accumulation (at least 130%-150% above normal), and by the low air temperature in April 2001 which shot up to a record high during May, both factors contributing to a massive concentration of floodwater. These features notably affected the ice-break, with ice jams on the river Yenisei and the river Angara. The consequence was extreme floods on many rivers in the river basin of the Upper and Middle Yenisei. Particularly grave was the hydrological situation in the river basin of the Tuba (a major tributary of the river Yenisei) where the maximum water level near the village Bugurtak was 1079 cm (the danger limit is 950 cm) and was the highest water level since records began. On the tributaries of the River Tuba (the Kazyr, Kizir, Amyl) water levels were also at their highest point and exceeded the danger limit by 1.0-1.4 meters.

The ice break-up along the downstream reaches of the river Angara was accompanied by the massive ice jams. On the 17^{th} of May the water level near the village Ribnoe reached the mark of 536 cm, that exceeds the alarm level by 0.8 m. On the river Yenisei the first wave of flooding hit on the 11^{th}-14^{th} May, as a result of the artificial destruction of an ice jam on the Lower Angara river, which produced a rise in water levels of 3m - 5m along a stretch of river from Strelka as far as Yeniseisk. The second wave on the Yenisei also arrived after the destruction of an ice jam on the river Lower Angara. The consequent additional rise in water levels amounted to 2.0m-2.5m on the river reach Strelka - Yartsevo, where the maximum flood levels exceeded the normal water level by 0.8m-2.9m. On the 18^{th} of May, the river Yenisei recorded a maximum water level of 952 cm (alarm level 800 cm) near the mouth of the river Angara, the highest water level since observations began. On the river Yenisei near the city of Yeniseisk the maximum was reached on the 19^{th} of May, peaking at 1158 cm (alarm level is 910 cm). This was also the most extreme value since observations began. Houses, and industrial enterprises in the region were flooded and roads were washed away.

The character of the ice-break on the major tributary of the river basin of Middle Yenisei - Podkamennaya Tunguska also led to the formation of ice-jams. The rise in water levels reached 2m-7m and 11.0m-19.0m on the stretch of river Podkamennaya Tunguska which is downriver from trading station Kuz'movka. The ice-jam that blocked the mouth of this river was of massive proportions. In the village of Sulomay maximum water levels rose to their highest since records began at 7.2 meters above alarm level and reached 2368 cm on the 18^{th} of May. The village was completely flooded.

During May of 2001 the water inflow into the reservoir of the Yenisei hydro power station swelled to extreme levels, far surpassing all previous records. The water inflow into the Sayano-Shushenskoe reservoir totalled 4800 m^3/s, and lateral inflow into the Krasnoyarsk reservoir was 7000 m^3/s. It is calculated that the probability of reaching and exceeding such discharges stands at about 1 %.

In the Lena river basin the winter of 2000-2001 was exceptionally cold and the thickness of ice exceeded mean values. The water equivalent of the snow cover in the Upper Lena river basin was 100-140 % above normal. Water levels in the period of freezing were extremely high, which indicated the presence of large accumulations of frazil and ice. These conditions, listed above, and the sharp increase in temperature in the first half of May caused the almost simultaneous formation of discharges and took water levels up close to an historic high on 13th-14th May along the 800 kilometer stretch of the Upper Lena. The most dangerous incident of the 2001 spring floods involved the extreme flooding near the city of Lensk. This disaster was caused by the combination of the two factors of excessive water volume and the presence of ice-jams. As a result, the maximum water level exceeded the mean value by 9.5 meters (representing a calculated frequency of 0.1 %). The city of Lensk with a population of 30000 was completely flooded. In the city more than 3000 buildings were destroyed and 18000 inhabitants were forced to leave their homes (Kilmianinov, 2001).

3. Characteristics of Local Flooding

Local floods occur with considerably greater frequency than territorial floods. The term "local floods" is given to flooding formed on separate reaches of rivers or in limited areas of the region and this can occur against a general background of average or low rises of water levels. Such floods are caused by ice jams or connected with localised heavy rain (storm rain) both in the period of snow melting and in the summer-autumn period. The pattern of localised flooding caused by ice jams reflects the non-uniformity of the manifestation of ice conditions along a length of river, as well as the effect of permanent geomorphological factors. Ice-jams are determined, to a considerable extent, by the special features of freezing and the form of the development of the process of ice break up. These questions are sufficiently illuminated in available literature. In our view, the focus of attention should be upon ice jams caused by heavy rains in the period of the snow melting, when the ice cover has not yet had time to lose its strength. At this juncture, a sharp rise of water levels sets in action the mechanical factor of break up and the subsequent formation of the ice jam. Cases of such floods are described below.

3.1. FLOODS CAUSED BY SNOWMELT AND RAIN AND ICE JAMS

In a general background of average or lower than average water level raises, the distribution of floods across the territory is seen to assume a mosaic pattern. Localized floods are generally caused by isolated ice-jams or by precipitation in particular localities during the period of snow melting.

As an example of this we can take the floods of the year 2004 in the river basins of the Upper Tom and the Abakan. In this region, during the period from 13[th] to 16[th] April an extremely heavy amount of precipitation (82-182 mm) fell in the form of rain and snow. At this period of time, 50%-80% of the forest area was covered by snow. The mean daily air temperature during the rainfall and throughout the next 10 days varied from -3^0 C to $+7^0$ C and so the snow fell with sleet and rain. Floods caused by the extreme snowmelt and rain were formed with the ice jams on the upper and downstream reaches of the river Tom and its tributaries, where the water levels rose to dangerously high levels. The flooding that ensued caused much destruction.

Another case of local flooding illustrates how precipitations during the period of snow melt, even when the water equivalent of the snow cover is average or low, can initiate an ice jam flood. In the river basin of Birusa, a rise in temperature during the weeks of April 2005 passed unobserved; the breakup of ice cover on the river took place gradually and safely until the third quarter of the month and then the rains fell. On the upper reaches of the river, where the ice was forecast to remain stable, ice floes began to break away. Slabs of ice, five meters in size covered the village of Patrikha in the deep of the night, catching the people totally unaware. Inhabitants of the village were urgently evacuated. A large part of the housing in Patrikha was completely destroyed by this elemental force.

A local extreme flood occurred in 1999 on the river Yenisei near the village of Vorogovo, which is situated 394 km downstream from the city of Yeniseisk. This was caused by an exceptional rise in air temperature during the spring season. At the onset of the sharp rise in temperature the ice had not been weakened by solar radiation. The ice break-up on this stretch of the Yenisei then took place in accordance to the most unfavorable ice jam scenario. The durable ice cover on the river broke up rapidly but was blocked by some islands 18 km downstream from the village of Vorogovo. Water levels on the river above the ice jam rose 4.6 meters higher than the critical level. 80% of the village was flooded. 773 people were evacuated. 25 houses were seriously damaged and 9 houses were completely destroyed.

3.2. LOCAL RAIN FLOODS

In some years water levels in the Ob, Yenisei and Lena river basins, during the summer and autumn low-water level period are disrupted by the influx of water from localized rain floods. Such floods occur on the small and average rivers and can present a variable patchwork effect of territorial distribution. In the Yenisei river basin and, especially, in the southern part of the Angara river basins, rain floods have caused significant flooding in past years. On the river Kan at the town of Kansk the maximum water level reached during the rain floods of 1960 proved disastrous. The river rose to a level approximately one meter higher than the level of the spring flood and reached the highest level since records began. An even larger territory was enveloped by the rain floods of 1988. Rain floods create the greatest problem in the southern part of the Angara river basin (the basins of the rivers Irkut, Kitoy, Belaiya, Oka, Ia, etc.), where the rain floods are consistently heavier than the spring floods. In 1980 on the Ia river basins 181 mm of precipitation fell in several days, leading to a water level rise of 967 cm near the town of Tulun. The depth of runoff of this rain flood was 95.9 mm. During July of 1984 a rain flood on this river was formed near the town of Tulun the highest maximum water level reached during this protracted flood was 1132 cm. The rise in the water level above the low-water level mark totaled about 10 meters. This high water mark can be accurately described as historic. The result was flooding of extreme severity.

4. Floods Caused by a Combination of Natural Factors and Human Intervention

Floods can be caused by a combination of natural factors and human intervention. A typical example of such combined actions is floods caused by the discharge of water into the reaches of rivers below power stations. This discharge is performed to relieve the threat of flooding in neighboring reservoirs. Since the construction of Krasnoyarsk hydro power station, serious floods on the river Yenisei near the city of Krasnoyarsk have been experienced in three years: 1972, 1988, 2004. This flooding was caused by heavy rains in the summer season after the passage of the wave of spring floods during its decrease. The overloading of Yenisei reservoirs necessitated heavy emergency water release. The most significant seasonal flood, which caused flooding within the reach of current research, was observed in the summer of 1988. In 1988, persistent, intensive rainfall (100-150 millimeters) across the whole of a vast territory caused an extremely high water inflow into the Krasnoyarsk reservoir. As a result, the total water inflow into reservoir rose from 4700 to 12500 m^3/s. A decision was made to make discharges into the lower reaches of the Yenisei, south of Krasnoyarsk, increasing the water discharge from 3800 to 12000 m^3/s. The high water discharges continued until the 20th of August. This human intervention led to heavy damage downriver: structures were flooded, tracts of forest were swept away, harvesters ready for dispatch were damaged, and the water intakes, which provide Krasnoyarsk with water were put out of action.

5. The Development and the Implementation of the Forecasting System of Floods in Ob and Yenisei River Basins

The basic difficulties of predicting the floods on the Siberian rivers arises from the inadequacy of the extremely limited hydrometeorological information that is available. Realistically, however it has to be accepted that, in view of the infinite variety of data required, the actual conditions for the formation of runoff cannot possibly be described without the use of various assumptions. For these reasons, in Siberia, a model has been developed, that operates with combined indices, averaged across the whole region.

This forecasting model, researched and developed in the Siberia, has been published in various papers (Burakov, 1966, Burakov, 1978a, Burakov, 1978b, Burakov, 1978c, Burakov and Avdeeva, 1996). This model takes into consideration both the meteorological parameters (snow-accumulation, air temperature, rainfall) and the hydrological parameters (levels or discharge of water in the drainage network of the basin). In the generalized form the structure of model is represented on Figure 1:

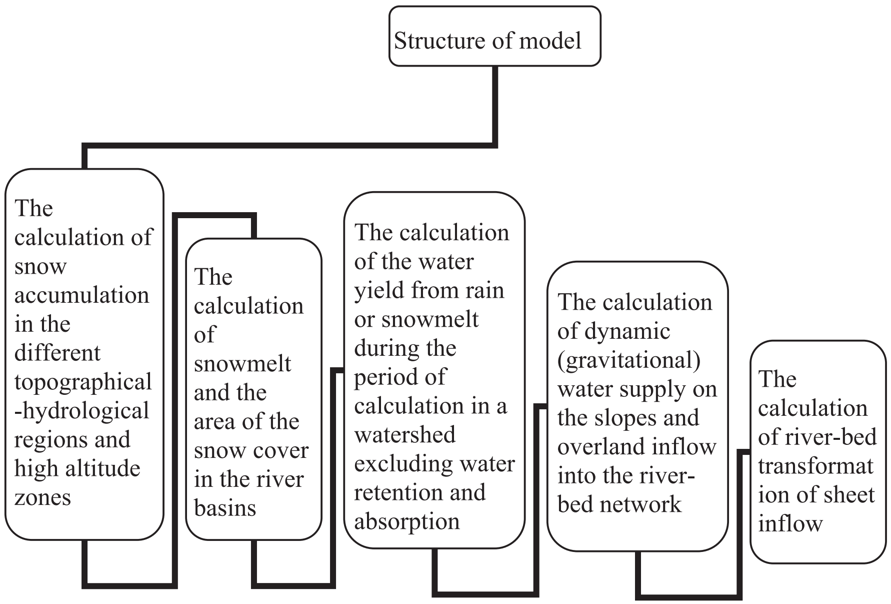

Figure 1. Structure of the model

In the model, the territorial variety of the processes of runoff is considered by identification of the different topographical-hydrological regions in the basins. For assessment of mountain conditions, each region would have its high-altitude zones distinguished. As a result of the uneven availability of information on the outlying parts of the region and in the high-altitude zones, it is necessary to consider certain factors with the use of the probabilistic distributions (Popov, 1963, Burakov, 1978c, Burakov and Avdeeva, 1996).

The more detailed model of sheet inflow is based on its idea in the form of the sum of three components ("three-volumetric transformation"): 1) "dynamic", i.e., surface, and also rapid soil-ground inflow (q); 2) the "slow" (qm) surface and soil-ground inflow, which forms the lower part of the hydrograph of flood (seasonal flood); 3) "basic", steady inflow, with constant water discharge Qmin., to which leaves the depletion curve (decrease).

The river-bed transformation of sheet inflow is achieved with the use of the Duhamel integral:

$$Q(t+\Delta t)=[\sum_{i=1}^{n}\int_{0}^{\Delta t} q_i(t+\Delta t-\tau)f_{q_i}(\tau)d\tau]+Q_w(t+\Delta t)+Q_{\min} \quad (1)$$

where Q(t+Δt) — water discharge in outlet gauge, t — date of forecast, Δt - term of forecast, n — number of landscape-hydrological regions in a basin, qi(t) — total inflow to river-bed network from the i-region, fqi(τ) — routing curve of tributaries inflow from i -region (zone) (function of influence) (Burakov, 1978a, Burakov, 1978b, Burakov, 1978c, Burakov and Avdeeva, 1996), Qw(t+Δt) - the component of the water discharge, caused by the exhaustion of the initial (at moment t) water supply in the river-bed network, Qmin – constant base feeding of river.

The travel time curve treats as the density of the distribution of the travel time of the elementary water volume. This curve is apprixímated by the density function of distribution probabilities (density function of gamma distribution, of Brovkovich and of Kritsky-Menkel) (Burakov, 1978a, Burakov 1978b, Burakov, 1978c). The moments of these distributions are estimated according to the theoretical dependences. The simple formulae of moments for the determination of the travel time curve are obtained for the case of the stretch of river without tributaries (Burakov, 1966, Burakov, 1978a). Let τ_L =L / v - mean travel time of the stretch of river with a length “L”, v - average velocity of travel (lag). In this case (stretch of river without tributaries) the mean-square deviation of the lag-time of the elementary water volume (σ_τ) is proportional to $\sqrt{\overline{\tau}_L}$, the variation index of lag-time

C_v is proportional to ($1/\sqrt{\bar{\tau}_L}$), and third central moment (M3) is proportional to τ_L, i.e.

$$\bar{\tau}_L = L/v; \sigma_\tau = a\sqrt{\bar{\tau}_L}; C_v = a/\sqrt{\bar{\tau}_L}; M_3 = ka^2\bar{\tau}_L \tag{2}$$

In the given formulae: a — the parameter of longitudinal dispersion; k — ratio of the asymmetry index to the variation index of the lag-time of the elementary water volume of stretch of river without tributaries (k could be equal 3).

The total of the moments of the travel time curve for tributaries is arrived at the stretch of river, river or river basin are amounted by the integral (Burakov, 1966, Burakov, 1978a):

$$m_r = \int_0^{\tau_L} m_r(\bar{\tau}) p(\bar{\tau}) d\bar{\tau}, \tag{3}$$

where m_r — initial moment "r" — order (r=1,2,3) of distribution of travel time of tributary, $m_r(\tau)$ — the same for the tributary flow into the river on the length x= τ v from outlet (τ = x / v), p(τ) — density function of distribution of tributary water volume alone the length of river or river system (moment $m_r(\tau)$ could be found by the formulae of moments of stretch of river without tributaries using the relation between initial and central moments). Works (Burakov, 1978a, Burakov 1978b, Burakov 1978c, Burakov and Avdeeva, 1996) are given the calculation formulas of the moments of the curves of the attainment, obtained on the basis of the given above integral for different particular tasks.

After expressing the water inflow in the river-bed network depending on the water levels Hi(t) in the observation points of river system, we will obtain the following equation (conclusion it is given to (Burakov and Avdeeva, 1996)):

$$H(t+\Delta t) = [c_0 \sum \int_0^{\Delta t} q_i(t+\Delta t-\tau) f_{qi}(\tau) d\tau + \sum c_i (H_i(t) - H_{i\min})^{y1} + \sum C_{i+1}(H_i(t) - H_i(t-1))\ ]^{1/y2} + H_{\min} \tag{4}$$

where H — forecasted water level in outlet gauge; c_i, $y1$, $y2$ - coefficients; $H_{i\,min}$ — minimal water level in i-gauge of river system accepted as the conditional zero references; H_{min} — the same in outlet gauge.

The parameters of the formulas of separate model units, are determined by the combination of the methods of optimization and linear regression.Satellite information on the dynamics of the snow cover of the basin is used in order to optimize assessments of snow-accumulation and snowmelt and for a daily correction of forecasts (Burakov et. al., 1996). The object of forecast is the daily water levels for the rivers of the Yenisei and Ob river basins and water inflow into reservoirs of the Sayno-Shushenskay, Krasnoyrsk and Novosibirsk hydro power stations.

Let us describe the methods of the forecast of the maximum water level on river Yenisei at village Podkamennaya Tunguska (HPTmax), which is situated 2 km downstream of river mouth of Podkamennaya Tunguska. In this gauge the maximum water levels occur both ice jam and non ice jam origin. The middle date of HPTmax — 21th of May; latest dates —30th of April and 7th of June. The periods of maximum water levels occur at the onset of the spring floods, which coincides in 70% of cases with the beginning of the period of floating of ice. The resultant equation takes the form (the dates of forecast is the end of the second quarter of March):

$$H_{PT}max = 3.914 \cdot S_{PT} — 2.33 \cdot \Delta H_1 — 1.668 \cdot L_1 — 5.245 \cdot D_2 + 2021. \quad (5)$$

The accuracy of the forecasts are: R = 0.898, the criterion of the quality of the forecast S/σ = 0.475. The description of variables are given in Table 4.

TABLE 4. The description of variables and complex indeces of equation

Characteristic	Description	T-value in equations (9)
S_{PT}	$S_{PT} = (0.65\ S_3 + 0.35\ S_5)$ - the index of water equivalent of snow cover, where S_3 - water equivalent of snow cover on 20th of March, Chuna; S_5 - water equivalent of snow cover on 20th of March, Vanavara	4.1
ΔH_1	The difference of water levels in gauges river Yenisei at village Bahta and river Yenisei at village Vorogovo at the start of ice formation in the previous autumn	-6.5
L_1	The minimum distance to the line of ice cover during the winter from the city Krasnoyarsk	-4.1
D_2	The date of the ice break on river Yenisei at village Kazachinskoe	-5.0

The complex parametr ΔH1 characterizes the inbank capacity of the river. L1 indicates severe winter and consequently the icethickness and strenght of ice cover. D2 characterizes the spring conditions.

The analogous equations are obtained for the Middle Yenisei (Yeniseisk, Nazimo, Yartsevo, Vorogovo, Bor), of Lower Angara (Boguchany, Kamenka, Ribnoe, Tatarka), river Taseeva (Mashukovka), some rivers of Tom river basin.

It is to be emphasized that in connection with the inclusion of the characteristics taking into account the ice jam, it is a possible to predict the levels in both eventualities: with ice jams and without ice jams by means of one single equation with a term of forecast of one month or even longer. The results obtained in past years are used for the daily forecasting operation.

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