On Ice Jam Formation in the Middle Lena

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Abstract. Ice jams are an integral part of the ice regime of the rivers of the Lena basin, and reach the greatest scales here [1]. Huge masses of ice moving downstream form hummock accumulations, clog the river bed and form ice dams. The nature of ice jams is determined by the conditions of flood formation. The height of the ice-jam water levels varies from year to year, significantly changing both the length of the rivers, and on the territory. Prolonged ice jams embracing large areas of the river during the spring breakup of ice in the Lena cause such natural hazards as flooding. Inhabited localities along the banks of the river are flooded. Catastrophic floods on northern rivers are one of the types of natural emergencies that pose a threat to the life of the population, as well as they cause great environmental and economic damage. Observation data at hydrometeorological stations and posts do not fully reflect the processes of jamming on rivers [2]. An analysis of the ice and the level regime of the middle reaches of the Lena River in the area of Lensk in this paper is conducted according to the perennial observations of Yakut management on hydrometeorology and monitoring of environment of Rosgidromet of Russia. The work was carried out in order to determine the values of a number of factors that lead to the critical levels at the sites of ice jams.

Study area is the average flow of the river Lena.

1. Introduction

Ice jam formation on the Lena River in majority of cases is one of the characteristic features of the breakup of ice in the northern rivers. Huge masses of ice, moving downstream, form hummock accumulations, clog the river bed and form ice dams. Prolonged jams covering large sections of the river at spring breakup cause flooding. Inhabited localities located along the banks of the river are flooded. Catastrophic floods on northern rivers are one of the types of natural emergencies that pose a threat to the life of the population, as well as cause great environmental and economic damage. The peculiarities of the water regime during ice jam are considered in the works of Buzin V.A., Nigmetov G.M., Ilkhov A.V. [3, 4, 5]. Exact same jamming issues were discussed in the works of Yakovlev V.B., Kuleshov S.L., Pchelkin V.I. [6, 7, 8].

Critical levels formed during ice blocking are its most important characteristic. By catastrophic flooding during the spring flood of 1915, 1998, 2001 concerned to form ice jams in the middle flow of the Lena River. In 1915, when the ice was jammed, the village Muhtuya (the Lensk) was heavily flooded. The city of Lensk also underwent significant flooding in 1966, when 2/3 of the city's territory was under water, and in 2001 the city of Lensk was almost completely flooded from a powerful ice block [2].
The aim of this work is to analyze data from stationary observations of the hydrological regime in the middle reaches of the Lena River to prevent catastrophic floods.

Methods for the study. Technique of determination the location of the ice jam was applied in the work [9].

2. Ice jams on the river Lena in the area of the Lensk
The Lena River is a waterway that flows through the permafrost in Eastern Siberia. Its length is 4400 km. The area of the basin is 2488 thousand km².

The headstream of the Lena relates to Irkutsk region, and then the Lena flows through the territory of Yakutia. The upper section of the Lena River is characterized as a shaped channel with a rapid fall of water surface and riffles. Wide calm stretches appear only after the confluence with the Kirenga. The middle course is counted from the confluence with the Vitim tributary to the confluence of the Aldan River, administratively this is the territory of the Sakha (Yakutia) Republic. Here the river becomes more water-abundant with a wide river valley. The lower course is the section from the Aldan to the delta. River width reaches 10 km within the lower section, after the confluence with the tributary of the river Vilyui. The width increases to 25 - 30 km, where river channels are formed. The channel narrows from 5 km to 2.0-2.5 km at Zhigansk.

Study of the level and ice regime of the River Lena had been received significant development since 1911. Study area (Krestovsky - Lensk – Nyuya) belongs to the middle section of the Lena River. In this study, data for the period of observation 67 years for stream gauges operating in settlements: Krestovsky (2655 km), Lensk (2508 km), Nyuya (2424 km) were used. Long-term data on the water level in the settlements: Krestovsky, Lensk, Nyuya from 1936 to 2005 were used. Information about the gauging stations is given in table 1.

### Table 1. Information about gauging stations.

| Location   | Distance from the mouth, km | Catchment area, km² | Zero of gauge: height, height system, m | Gauge action period | Affiliation of gauge |
|------------|-----------------------------|---------------------|----------------------------------------|---------------------|---------------------|
| Krestovsky | 2655                        | 440 000             | 166.20 BS                              | Sept. 01, 1932      | Operating            |
| Lensk      | 2508                        | 450 000             | 152.47 BS                              | Jan. 10, 1932       | "                   |
| Nyuya      | 2424                        | 453 000             | 147.21 BS                              | Aug. 05, 1927       | "                   |

Spring flood in the study area begins in late April - early May. Water level rise occurs as the result of snow melting. The highest levels of spring flooding on the river Lena were observed both during the free state of the channel, and drift ice and ice jams. Typical levels of the spring period of the Lena River in the area under consideration: Krestovsky - Lensk - Nyuya are given in table 2.

### Table 2. Characteristics of the water levels of the river Lena.

| Feature          | The highest level above zero of gauge | Note   |
|------------------|--------------------------------------|--------|
| Spring period    | cm, date                             | cm, date |
| Spring ice drift | cm, date                             | cm, date |

Krestovsky. 1933-2005. Zero of gauge – 166.20 m BS

Level
- middle 987 - 871 -
The highest water levels in the spring period of various exceedance probability in centimeters and in absolute altitude for water gauges are given in tables 3, 4.

**Lensk. 1932-35, 1937-2005. Zero of gauge – 152.47 m BS**

| Level       | Date       | Average Date |
|-------------|------------|--------------|
| - middle    | 1112       | 1083         |
| - the highest | 2012 *     | 2012 *       |
| - lower     | 752 *      | 668          |

**Date**

- average
- early
- late

**Nyuya. 1927-2005. Zero of gauge – 147.21 m BS**

| Level       | Date       | Average Date |
|-------------|------------|--------------|
| - middle    | 970        | 943          |
| - the highest | 1669 *     | 1669 *       |
| - lower     | 649        | 486          |

**Date**

- average
- early
- late

Note: * - levels of jam origin
Table 3. The highest levels of water of various supplies of the river Lena, see above zero of gauge.

| Gauge      | Highest water levels | Exceedance probability, % | Catastrophic | Zero of gauge, m BS |
|------------|----------------------|----------------------------|--------------|---------------------|
|            | Years of observations| Observed                   | 1   | 5   | 10  | 25  | 50  | 75  | 80  | 90  |         | |
| Krestovsky | 67                   | 179.3                      | 179.1 | 178. | 177. | 176. | 175. | 174. | 174. | 174. | 166.2   |
| Lensk      | 63                   | 172.5                      | 170.3 | 167. | 166. | 164. | 162. | 161. | 161. | 161. | 152.4   |
| Nyuya      | 67                   | 163.9                      | 163.6 | 160. | 159. | 157. | 156. | 155. | 155. | 154.7| 147.2   |

Table 4. The highest levels of water of various exceedance probability of the river Lena, m BS.

| Gauge      | Highest water levels | Exceedance probability, % | Catastrophic | Zero of gauge, m BS |
|------------|----------------------|----------------------------|--------------|---------------------|
|            | Years of observations| Observed                   | 1   | 5   | 10  | 25  | 50  | 75  | 80  | 90  |         | |
| Krestovsky | 67                   | 316                        | 1370 | 1220 | 1160 | 1050 | 950 | 880 | 840 | 795 | -       | 166.20  |
| Lensk      | 63                   | 2012                       | 1830 | 1530 | 1390 | 1200 | 1040| 930 | 910 | 860 | 2012 (May 18, 2001) | 152.47  |
| Nyuya      | 67                   | 1669                       | 1620 | 1340 | 1220 | 1070 | 940 | 825 | 800 | 750 | -       | 147.21  |

Highest intensity of the rise and fall of the water level (cm/d.) during spring flood was fixed at the Lena in the study area along the gauges, respectively:

Middle section:
1. Krestovsky – 513 / year 1945; 286 / year 1961.
2. Lensk - 627 / year 1937; 402 / year 1939.
3. Macha - 526 / year 1967; 331 / year 1974.

The average duration of the spring flood is 75 days. On average, in the upper reaches of the river Lena spring tide ends up in the first ten days of July, in the middle course of the second decade of July and in the lower reaches of the end of July.

Ice regime of the river Lena. Destruction of ice in a large non-frozen rivers begins with the appearance of water on the ice. As the water level rises, the ice rises and breaks away from the banks, then its movement begins. The first movements of ice occur in places where the river channel expands, in particular, on island sections, as well as in channels (about a week earlier than in the main channel). In this case, the ice cover breaks open and the ice is piled up on the coast, shallows and midges. Until the full development of the ice drift, ice movements can be renewed several times. The beginning and development of ice drift in any section of the river is determined by the strength of the ice, the intensity of water rise and the state of the ice cover downstream. The breakup of the river Lena is
greatly influenced by the regime of its tributaries, since the opening of the main river and its tributaries do not coincide in time. For example, the Vitim and Aldan rivers open earlier or later than the Lena river at the site of their confluence, while the opening of the Olekma river begins, as a rule, earlier. If the tributaries of the main river break open earlier, ice is carried out of them into the river bed, where freeze-up is still preserved. In this case, the ice cover on the main river breaks open, the channel becomes clogged with ice and the ice jam forms. The capacity of the ice jam depends on the amount and strength of the ice and the nature of the flood.

Characteristics of ice phenomena on the river Lena in the study area at the gauges is given in table five.

According to table 5, the average date of the beginning of the spring ice drift at Krestovsky was on May 12 with an average ice drift duration of 10 days, while the early ice drift start date was noted on April 28 with the longest ice drift duration of 20 days, and the late one - on May 20 and with the shortest ice drift duration of 3 days. Near the city of Lensk, the average date of the beginning of the spring ice drift is May 13 with an average duration of 9 days, the early date is April 30 with the longest ice drift of 19 days, and the late date is May 27 with the shortest duration of 2 days. The average date of the beginning of the spring ice drift at the Nyuya is May 16 with an average duration of 8 days, the early date is May 1 with the longest duration of 16 days, and the late date is May 27 with the shortest duration of 2 days (Table 5).

**Table 5. Ice phenomena on the river Lena.**

| Feature         | Freeze-up date | Ice thickness, cm | Spring period | Spring period |
|-----------------|----------------|-------------------|---------------|---------------|
|                 |                |                   | Start date of ice drift | End date of ice drift | Duration, day |
| Krestovsky 1933-1980 | Nov. 13       | 95                | May 12        | May 22        | 10            |
| Average         | Nov. 2         | 128               | Apr. 28       | May 8         | 20            |
| Late            | Nov. 27        | 72                | May 20        | May 31        | 3             |
| Lensk 1932-1935; 1937-1980 | Nov. 9       | 155               | May 13        | May 23        | 9             |
| Average         | Oct. 31        | 160               | Apr. 30       | May 7         | 19            |
| Early           | Nov. 24        | 95                | May 27        | Jun. 3        | 2             |
| Nyuya 1927-1980 | Nov. 9         | 155               | May 16        | May 24        | 8             |
| Average         | Oct. 30        | 191               | May 01        | May 10        | 16            |
| Early           | Nov. 22        | 84                | May 27        | Jun. 1        | 2             |

Ice jamming is one of the characteristic features of breakup of ice in the river Lena. The nature of the ice jam is determined by the conditions of flood formation. A protracted spring leads to intermittent flood formation and relatively low water content during the period of breakup of ice in the river with small ice jams. During a stormy spring, high water forms rapidly, there are few jams, but the floods caused by them reach a critical rise.

Ice jams on the river Lena are usually formed in the same places:
- on sections with decreasing slopes,
- with a sharp change in the direction of the channel,
- with the expansion of the channel due to its branching into binnacles,
- with a narrowing of the main channel,
- in areas with the presence of shoals, islands.

Ice jams on the Lena River cover large areas and are observed for a long time. Their length ranges from several to 100 km or more, and their duration reaches 10 days (Nogovitsyn, Kilmyaninov). Longer-term jams are most likely to form in sections of the river with a drastically reduced channel capacity.

Power ice jam is usually characterized by the highest water level in the period of ice jam formation or an excess over some initial level (e.g., above the minimum winter). However, for a complete assessment of the power of ice jams, it is also necessary to take into account the degree of influence of the ice jam on the maximum value.

A preliminary qualitative assessment of the thickness of ice jams at the beginning of their development could be made using the developed classification of jams, which is based on the morphological features identified during aerial reconnaissance of the ice state of the Lena River during the period of its opening. Therefore, the morphological features of the river section on which ice jam is formed and the ice situation on it are taken into account, when organizing work to eliminate the ice jam.

Critical water levels of the Lena River and floods. When certain levels (critical) are reached, floods often occur. The marks of the critical values of water levels above the zero of the water station schedule, according to the data of the Hydrometeorological Service is shown in table 6.

| Gauge       | Distance from the mouth, km | Observation period | Years | Height of zero of gauge, m BS | The water level mark at which water comes up to floodplain or flood of individual buildings and land begins | The highest water level for the observation period, cm/year | Catastrophic level, cm/year |
|-------------|-----------------------------|--------------------|-------|-----------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------|-----------------------------|
| Krestovsky  | 2662                        | 1936-2005          | 67    | 166.20                      | -                                                                                               | 1316 (1966)                                                | 1702 (1998)                 |
| Lensk       | 2508                        | 1937, 1939-1945; 1949-2005 | 63    | 152.47                      | -                                                                                               | 1350/4                                                    | 2012 (2001)                 |
| Nyuya       | 2424                        | 1936-1939; 1941-2005 | 67    | 147.21                      | 1050/5                                                                                         | 1300/4                                                    | 1486 (1949)                 |
|             |                             |                    |       |                             |                                                                                                 |                                                            |                             |

Note: * - level of jam origin.

Critical floods on the Lena River are repeated quite often, but have a local distribution. A number of settlements, located along the banks of the Lena River, were flooded during the formation of powerful ice jams of rare recurrence. So, the most outstanding flood in the region of Yakutsk took place in 1933, which was second only to the 1864 flood. After 1933 significant floods in the area of Yakutsk didn’t occur. In 1958, 1966, 2001 only parts of the city were flooded and the size of flooding was much less than during the floods of 1864 and 1933.
In 1915, when the ice was jammed, the village Mukhtuya (Lensk) was flooded. The city of Lensk also underwent significant flooding in 1966, when 2/3 of the city's territory was under water, and in 2001 the city was completely flooded from a powerful ice jam. The ice jam formed near the city of Lensk in 2001 also affected the settlements located downstream - the villages of Nyuya and Macha.

There are no regularities in the thickness and frequency of ice jams. In the studied area of gauges Krestovsky - Lensk - Nyuya an analysis of ice phenomena 67-year series of observations (1936-2005) had been conducted. As a result of ice phenomena nature analysis on each gauge, it is found the incidence of ice jams: Krestovsky - 26 (58%); at the city of Lensk - 34 (77%); at Nyuya - 40 (60%). Table 7 shows the number of cases of exceeding the highest observed level over the critical one, which amounted to 67 years of observation: in the city of Lensk - 9 cases; at Nyuya - 4. These high levels were observed only with jam. Abnormal water levels according to these observation points for a period of 67 years were observed 1-2 times and only with ice jams as well (tables 2 and 6).

| Gauge        | The mark at which the flooding of individual buildings and land begins, cm | Ice jams formed during observation period 1938-2005 | Observation period 1937-2005 | Exceeding the highest annual level over the critical | Historical and catastrophic levels (cm) |
|--------------|---------------------------------------------------------------------------|------------------------------------------------------|-----------------------------|-----------------------------------------------------|---------------------------------------|
| Krestovsky   | -                                                                         | 26                                                   | 58                          | -                                                   | 1316 (May 14, 1966)                  |
|              |                                                                          |                                                      |                              |                                                     | Thick ice drift                      |
| Lensk        | 1350                                                                     | 34                                                   | 77                          | 9                                                   | 1702 (May 18, 1998), 2012 (May 18, 2001) |
|              |                                                                          |                                                      |                              |                                                     | Ice jam                              |
| Nyuya        | 1300                                                                     | 40                                                   | 60                          | 4                                                   | 1669 (May 18, 2001)                 |
|              |                                                                          |                                                      |                              |                                                     | Ice jam                              |

Great length ice jams in the river Lena (more than 120) form annually in the same locations and formed along its entire length [10]. The most jam-hazardous sections of the river are in the area of settlements. There are no regularities in the thickness and frequency of ice jams, as the nature of jams is determined by the conditions of flood formation and the morphology of the channel.
3. Conclusion

As a result of ice phenomena nature analysis in the Middle Lena, it is found the incidence of ice jams for 67 years of observations: Krestovsky - 26; at the city of Lensk - 34; at Nyuya - 40. Highest observed level excess over critical elevation mark for the reporting period was in the middle section: at Lensk - 9; at Nyuya - 4. These high levels were observed with ice jams only. Abnormal water levels at these points over a period of 67 years were observed 1-2 times and also only with ice jams.

Consideration of the data series on the ice breakup timing separately on the Lena and Vitim rivers did not reveal any regularities in their long-term fluctuations. It also allowed to detect the presence of a 30-year period from its highest and lowest values, as well as the presence of a mirror opposite mode vibrations jam highs in the city of Lensk. They were recorded in 1878, 1915, 1937, 1966 and 2001, what also indicates their certain periodicity, which is about 30 years. In these years, the values of the difference in the ice breakup timing of the main river and the tributary are close to its average long-term values. An explanation of the detected variations and conclusions about their possible influence on the formation of jam levels in the future is yet to be obtained. It can only be assumed that in the period from 1995 to 2025 the level regime during ice jams will be similar to their regime in the period from 1935 to 1965, when positive anomalies of ice jam maxima were observed relatively often.

4. References

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