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LONG-TERM CHANGES OF DAUGAVA RIVER ICE PHENOLOGY UNDER THE IMPACT OF THE CASCADE OF HYDRO POWER PLANTS

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This paper presents the results of the study of long-term changes of Daugava River ice phenology, i.e. the freeze-up date, the break-up date, and the duration of ice cover from 1919/1920 to 2011/2012, under the impact of the cascade of hydro power plants. The long-term changes of ice phenology were determined by global climate warming at the turn of the 20th and the 21st centuries and anthropogenic activities after the year 1939. The Mann-Kendall test showed that the ice freeze-up date has a positive trend, while the ice break-up date and the duration of ice cover had negative trends. The changes were statistically significant. Data series covering twenty years before and after construction of the hydro power plants were used for assessing the impact of each hydro power plant on changes of Daugava River ice phenology parameters. The study results showed that the duration of ice cover was significantly longer in water reservoirs, i.e. the freeze-up date was earlier and the break-up date was later. Downstream of dams duration of ice cover was shorter with later freeze-up dates and earlier break-up dates. The impact of hydro power plants on ice phenology parameters gradually decreased with distance down from the dams.

Key words: *river ice, trends, hydro power plant, Daugava River.*

INTRODUCTION

The ice regime of a river depends on climate (air temperature), hydrodynamic (flow rate), and anthropogenic (e.g., temperature of effluents input to the river, hydro-technical facilities) factors and the type of river feeding (e.g., temperature of ground water) (Šarauskienė and Jurgelėnaitė, 2008). However, air temperature is the main factor that regulates ice formation on rivers and lakes (Magnuson *et al.*, 2000; Kļaviņš *et al.*, 2009). Studies of changes in air temperature in the Northern hemisphere during the 20th century indicate that warming of the climate occurred in the period 1920–1940 followed by a period of worsening of the climate conditions. During the last few decades before the turn of the 21st century, however, a more rapid increase in air temperature and warming of the global climate was observed (Anonymous, 2007). Many studies have shown increased duration of the ice-free period, an increasing trend in ice freeze-up dates and a decreasing trend in ice break-up dates of rivers and lakes (e.g., Magnuson *et al.*, 2000; Šarauskienė and Jurgelėnaitė, 2008; Kļaviņš *et al.*, 2009; Solomon and Knut, 2011). Hydro-technical facilities, e.g., construction of a hydro power plant (HPP) on a river, also can affect long-term changes of ice phenology. There are very few such studies that have been carried out on the Daugava River (Glazacheva, 1963; 1965) and on the Nemunas River (Šarauskienė and Jurgelėnaitė, 2008).

The Daugava River is the largest river in Latvia and one of the largest rivers in the Baltic Sea catchment. Along its length ice freezing and breaking-up processes differ among sections, in relation to the hydrodynamic conditions of the river-bed, climate conditions, and anthropogenic activities. The ice regime of the Daugava River in the beginning of the 1930s was studied by Stakle (Stakle, 1933) and in the beginning of the 1940s by Kanaviņš (1942; 1943a; 1943b). Kanaviņš not only described the ice conditions in the Daugava River in winters of 1941/1942 and 1942/1943, but he also performed experimental research on formation of ice cover in fast-flowing reaches of rivers and on ways to release ice in the Daugava River where ice congestions and ice jams have formed (in particular, at Jēkabpils–Ķegums river section). Glazacheva (Glazacheva, 1963; 1965) studied ice formation and break-up in rivers of Latvia, as well as the impact of the Ķegums HPP on ice freeze-up and break-up dates. Pastors (Pastor, 1987), studied ice congestions and ice jams of the Daugava River in the Jēkabpils–Pļaviņas section during the period from 1968 to 1982. The Daugava River has the longest data series on ice conditions in Europe, with the first records in 1530 (Kļaviņš *et al.*, 2009). A pronounced downward trend of the break-up date was observed over the last 150 years, which was more clearly evident during the recent 30 years. No downward trend was observed for the initial period, which includes the Little Ice Age. The historical records show recurring periods of mild and severe winters.

The objective of this study was to describe long-term changes (1919/1920 to 2011/2012) of ice phenology of the Daugava River in winter season, in relation to the impact of hydro power plants (in Ķegums, Pļaviņas, and Rīga).

Table 1

DESCRIPTION OF THE CASCADE OF THE DAUGAVA RIVER HPPs

Name of HPP	Distance from river mouth, km	Mean annual discharge, m^3/s	Head, m	Reservoir storage, mill. m^3	Year of construction
Pļaviņas	111	619	40	509	1968
Ķegums	67	620	16	157	1939
Rīga	36	640	18	339	1974

HPP, hydro power plant

MATERIALS AND METHODS

Description of the Daugava River and its hydro power plants. The length of the Daugava River is 1005 km (325 km in Russia, 328 km in Belarus, and 352 km in Latvia). The total catchment area of the Daugava River is 87 900 km^2 of which 24 700 km^2 are located in the territory of Latvia. The total slope of river is 221 m (99 m of the slope in the territory of Latvia). Mean annual discharge in the Daugava River is 650 m^3/s. Discharges above 8000 m^3/s are observed during spring high water periods and discharges below 100 m^3/s are observed during summer or winter low water periods (Ziverts *et al*., 2000). The scheme of the Daugava River in the territory of Latvia is shown in Figure 1.

The cascade of hydro power plants was constructed on the Daugava River in the 20th century — Pļaviņas HPP, Ķegums HPP, and Rīga HPP (Table 1). The Ķegums HPP is the oldest large HPP in Latvia, which was constructed in 1939. The Pļaviņas HPP was built later, and is the largest HPP in the Baltic countries. The Rīga HPP, constructed in 1974, is the second largest HPP in Latvia. The cascade of HPPs controls the discharge regime, thermal conditions, and the ice processes downstream of the Daugava River.

Data and methods. Ice phenology parameters (freeze-up date, break-up date, and duration of ice cover) were investigated in the Daugava River using records of the Latvian Environment, Geology and Meteorology Centre and the publication of the Marine Board by Stakle and Kanaviņš (1941). The used hydrological stations (HS) and observation data series are presented in Table 2.

The ice freeze-up date was assumed to be the first day of ice occurrence. The date of disintegration of the ice cover during a period with regular ice cover was assumed to be the ice break-up date. The duration of ice cover was calculated as the actual number of days during which ice occurred. Data series covering a period of twenty years before and after construction of the HPP were used to determine the effect of each HPP on ice phenology parameters. For statistical analysis, the freeze-up and break-up dates were expressed as the number of days since October 1. For trend analysis and the assessment of the HPP effect for years without ice cover, the freeze-up date was assumed to be March 10 (160 days after October 1) and the break-up date was assumed to be December 10 (70 days). These values are slightly higher/lower than the actual extreme values observed for each station.

The Mann-Kendall test (Hirsh *et al*., 1982; Hirsh and Slach, 1984) was used to identify trends in the annual river ice phenology parameters. The test was applied separately to each variable at each site, at a significance level of $p < 0.05$.

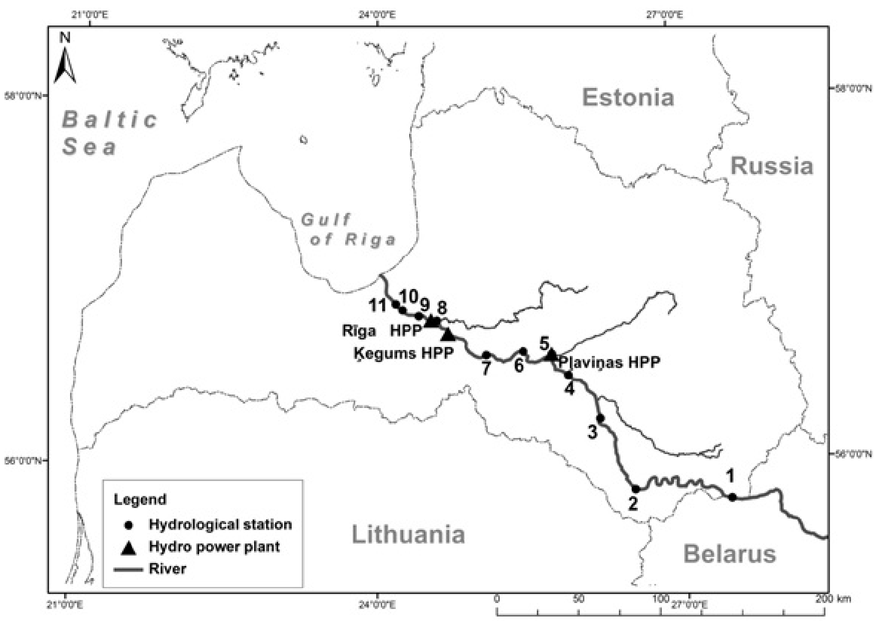

Fig. 1. The Daugava River in the territory of Latvia, location of hydrological stations (HS) and hydro power plants (HPP). Numbers designated ice observation stations according to Table 2.

Table 2

DESCRIPTION OF ICE OBSERVATION STATIONS USED IN THE STUDY

No.[1]	Name of hydrological station	Distance from river mouth, km	Observation period, year	Description of impact of HPP
1	Piedruja	354	1944/45 – 2011/12	Not impacted
2	Daugavpils	256	1921/22 – 2011/12	Not impacted
3	Jersika	214	1931/32 – 2011/12	Not impacted
4	Jēkabpils	172	1919/20 – 2011/12	Not directly impacted
5	Pļaviņas	152	1930/31 – 2011/12	Impacted since 1968
6	Dzelzlejas	124	1931/32 – 1965/66	Not directly impacted
7	Jaunjelgava	98	1919/20 – 1994/95	Impacted since 1939
8	Ogre	55	1926/27 – 1956/57	Impacted since 1939
9	Lipši	39	1928/29 – 1971/72	Impacted since 1939
10	Maruška	30	1922/23 – 1985/86	Impacted since 1974
11	Sarkanais Kvadrāts	22	1941/42 – 1986/87	Impacted since 1974

[1] the number used in Figure 1

A trend was considered significant at the 5% level, if the test statistic was above 1.96 or below –1.96.

Statistical analyses were performed using software R 3.0.2. (Anonymous, 2013). The t-test at the significance level of $p < 0.05$ (Sokal and Rohfl, 1995) was used to compare the mean freeze-up date, break-up date, and duration of ice cover before and after construction of the HPP for twenty-year periods.

RESULTS

Long-term changes of Daugava River ice phenological parameters. Table 3 summarises the data on the ice freeze-up and break-up dates and the duration of ice cover. Due to climatic conditions, the river usually freezes up earlier and breaks up later in upper reaches of the Daugava. The data series from the HSs at Piedruja, Daugavpils, Jersika, and Jēkabpils are long (till 2012) and cover the time period when global climate warming was observed at the turn of the 20th to 21st centuries. The observation periods are shorter at the other HSs, and the values of the ice phenology parameters were more or less determined by the construction of the cascade of the HPPs on the Daugava. In upper reaches of the Daugava River (HSs of Piedruja, Daugavpils, and Jersika) there were no years without the formation of ice cover on the river. The highest number of years without formation of ice cover was observed at the Pļaviņas HS, which was located at a rapid reach prior to the construction of the Pļaviņas HPP, explaining why the river did not freeze up often in that period of time.

The long-term changes of ice phenology parameters were statistically significant (Mann-Kendall test) for observation data series more than 60 years and extending up to 2012 (Table 4). At the Daugavpils HS (Fig. 2), for example, the ice freeze-up date had a positive trend, while the ice break-up date and duration of ice cover had negative trends. At these HSs, during the last decades, the ice formed later, broke up earlier, and the duration of ice cover was shorter.

Impact of the cascade of hydro power plants upon the Daugava River ice phenology. To assess changes of the phenological parameters of the Daugava River due to the

Table 3

SUMMARY OF ICE FREEZE-UP AND BREAK-UP DATES AND DURATION OF ICE COVER WITH MINIMUM (min), MAXIMUM (max), MEAN AND STANDARD DEVIATION (SD)[1]

Hydrological station	Ice freeze-up date				Ice break-up date				Duration of ice cover, in days				Number of years without ice cover
	min	max	mean	SD	min	max	mean	SD	min	max	mean	SD	
Piedruja	11-Nov	01-Mar	21-Dec	28.8	21-Dec	20-Apr	24-Mar	20.2	3	146	92	37.0	0
Daugavpils	10-Nov	14-Feb	17-Dec	22.6	15-Dec	21-Apr	22-Mar	23.5	14	150	94	32.6	0
Jersika	09-Nov	11-Feb	14-Dec	20.2	26-Dec	18-Apr	24-Mar	19.2	21	149	100	29.1	0
Jēkabpils	30-Oct	10-Mar	25-Dec	30.1	10-Dec	19-Apr	16-Mar	30.8	0	144	78	42.5	9
Pļaviņas	05-Nov	03-Feb	13-Dec	22.6	02-Feb	18-Apr	24-Mar	17.3	0	159	78	48.7	18
Dzelzlejas	17-Nov	25-Feb	25-Dec	22.5	31-Dec	17-Apr	22-Mar	24.0	0	145	79	41.4	4
Jaunjelgava	08-Nov	24-Feb	23-Dec	28.6	03-Jan	20-Apr	23-Mar	18.9	0	153	88	39.0	1
Ogre	02-Dec	06-Mar	06-Jan	25.1	10-Feb	21-Apr	22-Mar	16.6	0	126	68	39.5	4
Lipši	24-Nov	02-Feb	27-Dec	18.8	10-Feb	21-Apr	28-Mar	15.5	0	129	80	37.4	4
Maruška	31-Oct	06-Mar	12-Dec	23.5	26-Dec	21-Apr	27-Mar	18.5	0	159	98	40.4	3
Sarkanais Kvadrāts	09-Nov	05-Feb	15-Dec	19.0	03-Jan	20-Apr	27-Mar	17.6	0	142	102	27.8	3

[1] The observation periods differ for each hydrological station (see Table 2).

Table 4

RESULTS OF MANN-KENDALL TEST FOR ICE FREEZE-UP AND BREAK-UP DATES AND DURATION OF ICE COVER

Name of hydrological station	Number of samples	Ice freeze date		Ice break-up date		Duration of ice cover	
		tau	*p*-value	tau	*p*-value	tau	*p*-value
Piedruja	67	0.208	0.0136	–0.322	0.0001	–0.332	0.0001
Daugavpils	90	0.144	0.0457	–0.275	0.0001	–0.284	0.0001
Jersika	77	0.167	0.0339	–0.199	0.0112	–0.219	0.0051
Jēkabpils	81	0.242	0.0008	–0.178	0.0142	–0.251	0.0005
Pļaviņas	64	-0.364	.0001	0.216	0.0051	0.333	.0001
Dzelzlejas	30	-0.184	0.1280	0.255	0.0311	0.311	0.0107
Jaunjelgava	70	0.048	0.5598	–0.103	0.2103	–0.087	0.2916
Ogre	25	0.365	0.0061	–0.030	0.8301	–0.318	0.0170
Lipši	37	0.150	0.1682	0.071	0.5158	–0.087	0.4313
Maruška	56	0.038	0.6801	0.037	0.6897	0.000	1.0000
Sarkanais Kvadrāts	45	0.269	0.0100	–0.074	0.4809	–0.247	0.0194

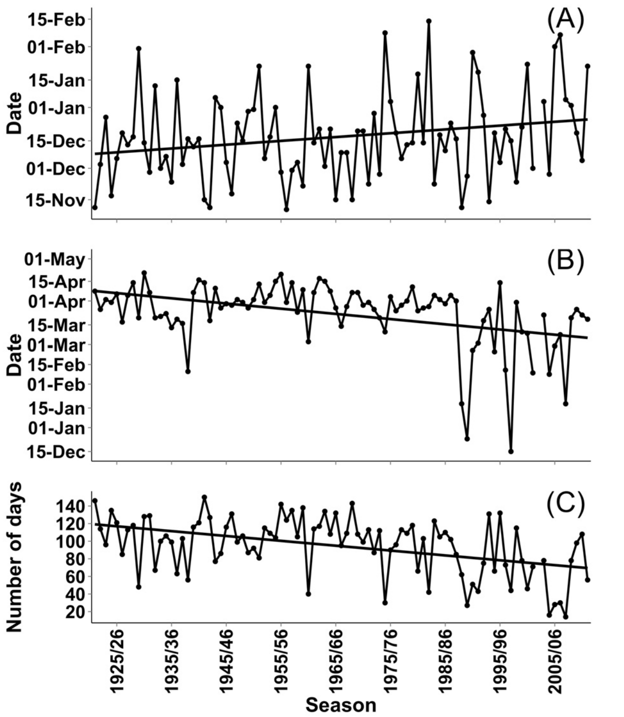

Fig. 2. Long-term changes in the ice freeze-up (A) and break-up (B) dates and the duration of ice cover in days (C) for the Daugavpils Hydrological Station during the period 1921/22 – 2011/12.

construction of the Ķegums HPP, two periods were compared: the period 1920/1921–1938/1939, before the HPP construction, and the period 1939/1940–1957/1958, after construction. Significant changes in phenological parameters (Table 5) occurred at the Jaunjelgavas HS, which is located at the Ķegums water reservoir 31 km upstream from the dam. Observations at this station showed that during the period 1939/1940–1957/1958, ice formed earlier (33 days earlier) and broke up later (15 days later), also the duration of ice cover was longer (by 46 days), compared to the period before construction of the dam. Similar changes in ice phenological parameters were observed at the Dzelzlejas HS, which is located above the Ķegums water reservoir (57 km up the dam). At the Ogre and Lipši HSs, which are located 12 km and 28 km below the dam, respectively, after construction of the dam the river froze up later and broke up earlier, and the duration of ice cover was shorter. The impact caused by the HPP on ice formation gradually decreases with distance from the dams.

To assess the impact of the Pļaviņas HPP, two periods were compared: the period 1947/1948–1967/1968, before the HPP construction, and the period 1968/1969–1987/1988, after construction (Table 6). The impact caused by the Pļaviņas HPP can only be assessed based on observations at the Pļaviņas HS (41 km upstream from the dam). There are no HSs located downstream from the dam within the area subject to direct impact of the HPP. The study showed that, following the construction of the HPP, the ice formed 68 days earlier and broke up 69 days later, and the duration of ice cover was 80 days longer at the Pļaviņas HS. All these changes are statistically significant at the level of $p < 0.05$. These dramatic changes can be explained by the fact that the Pļaviņas HS was located at a rapid reach of the river, which did not often freeze up before construction of the dam. After the construction of the water reservoir in 1968, this river reach freezes up every year.

In 1974, the third HPP on the Daugava River, the Rīga HPP, was commissioned, which was built 36 km from the river mouth. Two study periods were compared: the period 1953/1954–1973/1974, before the HPP construction, and the period 1974/1975–1992/1993, after construction (Table 7). In this case, the impact caused by the Rīga HPP can be assessed using data from the Maruška and Sarkanais Kvadrāts HSs located 6 km and 12 km from the dam, respectively. Significant changes in ice phenological parameters were observed at the Maruška HS: ice formed 58 days later, it broke up 41 days earlier, and the duration of ice cover decreased by 91 days. During this period of time, the ice regime was affected both by the HPP and also by global climate warming, particularly at the end of the 1980s. This is confirmed also by observations at the hydrological stations located in upper reaches of the Daugava River (Piedruja, Daugavpils, Jersika HSs).

Table 5

IMPACT OF THE ĶEGUMS HPP ON DAUGAVA RIVER ICE PHENOLOGICAL PARAMETERS[1]

Name of hydrological station	Ice freeze-up date			Ice break-up date			Duration of ice cover, in days		
	before	after	difference	before	after	difference	before	after	difference
Daugavpils[2]	13-Dec	12-Dec	1	26-Mar	04-Apr	10	102	111	10
Jersika[3]	13-Dec	07-Dec	6	23-Mar	02-Apr	9	101	114	13
Jēkabpils	12-Dec	19-Dec	–7	24-Mar	10-Mar	–14	94	86	–9
Pļaviņas[4]	16-Jan	12-Feb	–26	15-Feb	24-Jan	–21	50	34	–16
Dzelzlejas[3]	16-Jan	01-Jan	15	26-Feb	16-Mar	18	54	85	31*
Jaunjelgava	02-Jan	30-Nov	33*	20-Mar	04-Apr	15*	78	124	46*
Ogre[5]	28-Dec	28-Jan	–32*	20-Mar	04-Mar	–17	82	56	–27
Lipši[6]	22-Dec	09-Jan	–18	21-Mar	19-Mar	–2	88	72	–16
Maruška[7]	12-Dec	13-Dec	–2	23-Mar	27-Mar	4	100	107	7

[1] The period 1920/21–1938/39 is before HPP construction, the period 1939/40–1957/58 is after HPP construction, and difference is between the two study periods; [2] 1921/22–1938/39; [3] 1931/32–1938/39; [4] 1930/31–1938/39; [5] 1926/27–1938/39 and 1939/40–1956/57; [6] 1928/29–1938/39; [7] 1922/23–1938/39; * statistically significant at $p < 0.05$;

Table 6

IMPACT OF THE PĻAVIŅAS HPP ON DAUGAVA RIVER ICE PHENOLOGICAL PARAMETERS[1]

Name of hydrological station	Ice freeze-up date			Ice break-up date			Duration of ice cover, in days		
	before	after	difference	before	after	difference	before	after	difference
Piedruja	12-Dec	26-Dec	–14	04-Apr	30-Mar	–4	113	95	–17
Daugavpils	14-Dec	20-Dec	–6	03-Apr	30-Mar	–4	109	98	–11
Jersika	10-Dec	16-Dec	–5	31-Mar	31-Mar	0	110	106	–4
Jēkabpils	31-Dec	30-Dec	1	04-Mar	30-Mar	26*	76	90	14
Pļaviņas	11-Feb	05-Dec	68*	21-Jan	01-Apr	69*	35	115	80*
Lipši[2]	12-Jan	04-Jan	8	16-Mar	31-Mar	15	73	77	4
Maruška[3]	11-Dec	02-Jan	–22	29-Mar	11-Mar	–18	109	74	–35
Sarkanais Kvadrāts[4]	09-Dec	24-Dec	–16[1)]	01.Apr	23-Mar	–9	113	88	–26*

[1] The period 1947/48–1967/68 is before HPP construction, the period 1968/69–1987/88 is after HPP construction and difference is between two study periods; [2] 1968/69–1971/72; [3] 1985/86–1938/39; [4] 1968/69–1986/87; * statistically significant at $p < 0.05$;

Table 7

IMPACT OF THE RĪGA HPP ON DAUGAVA RIVER ICE PHENOLOGICAL PARAMETERS[1]

Name of hydrological station	Ice freeze-up date			Ice break-up date			Duration of ice cover, in days		
	before	after	difference	before	after	difference	before	after	difference
Piedruja	07-Dec	30-Dec	–23	03-Apr	17-Mar	–18	117	77	–40
Daugavpils	08-Dec	24-Dec	–16	02-Apr	17-Mar	–16	113	82	–31
Jersika	07-Dec	22-Dec	–15	31.mar	20-Mar	–11	113	89	–24
Jēkabpils	27-Dec	04-Jan	–8	13-Mar	15-Mar	2	84	80	–4
Pļaviņas	17-Jan	04-Dec	44	18-Feb	24-Mar	34	67	108	41
Maruška[2]	05-Dec	01-Feb	–58*	30-Mar	17-Feb	–41*	118	26	–91*
Sarkanais Kvadrāts[3]	08-Dec	28-Dec	–20	28-Mar	25-Mar	–3	110	85	–25

[1] The period 1953/54–1973/74 is before HPP construction, the period 1974/75–1992/93 is after HPP construction and difference is between two study periods.; [2] 1974/75–1985/86; [3] 1974/75–1986/87; * statistically significant at $p < 0.05$

DISCUSSION

The processes of freeze-up and break-up of ice differ along the Daugava River among reaches of the stream, due to hydrodynamic conditions of the river-bed where rapid flows interchanges with slower flows, as well as due to climate conditions and the construction of the HPP cascade after the year 1939.

The long-term changes in ice phenological parameters of the Daugava River at the HSs of the studied upper reaches are similar to results of other studies in the Baltic countries and in Belarus by Kļaviņš *et al*. (2009), in Lithuania by Stonevicius *et al*. (2008) and Šarauskienė and Jurgelėnaitė (2008), and in the Northern hemisphere by Magnuson *et al*. (2000). During recent decades, rivers have frozen up later and ice broke up earlier, and the duration of ice cover decreased. Changes in the ambient air temperature and the distance from the Baltic Sea are among the major factors determining the formation and the break-up of ice (Šarauskienė and Jurgelėnaitė, 2008; Kļaviņš *et al*., 2009). Lizuma *et al*. (2007) found that the annual mean air temperature in Latvia increased by 1.4 °C during the last 50 years. In the study period from 1950 to 2003, the highest increase in the mean air temperature was recorded in spring (March–May) and early winter (November and December).

Anthropogenic activities, in particular, construction of the HPPs cascade, also affected ice phenological parameters on the Daugava River in the middle and lower reaches. Large water reservoirs are created by construction of a dam. In the reservoirs, ice forms earlier, breaks up later there and the duration of ice cover is longer. Construction of a water reservoir results in less water exchange and more rapid cooling of the upper layers of water. During the cold period of a year, inverse thermal stratification is observed, i.e. water temperature at the bottom is higher than at the surface. In the warm period, water coming from deeper layers of the water reservoir cools the Daugava River. Downstream of the HPP, in the cold period, the process is reversed, i.e. water warms up, freezing is delayed, and early break-up occurs.

The results of our study are similar to those of Glazacheva (Glazacheva, 1963; 1965) on the impact of the Ķegums HHP on the freeze-up and break-up dates of the Daugava River during the period from 1928 to 1960. After construction of the dam, at the Jaunjelgavas HS the river froze up one month earlier and ice broke up four days later, and at the Ogres HS, the Daugava froze up 27 days later and broke up seven days earlier. Until now, no studies have been performed on the impact of the Pļavinas HPP and the Rīga HPP on changes of Daugava ice phenological parameters. In a study by Šarauskienė and Jurgelėnaitė (2008), on impact of the Kaunas HPP in Lithuania on ice forming processes in the Nemunas River, the greatest impact of construction of the dam was observed at Kaunas and Lampėdžiai HSs, where ice cover during the study periods (1931–1960 and 1961–1990) decreased on an average by 15 and 5 times, respectively. After construction of the dam, in 1960, the average ice freeze-up date at Druskininkai and Nemajūnai HSs was slightly earlier, whereas at the other HSs the river froze later than in period of 1930/61.

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HIDROELEKTROSTACIJU KASKĀDES IETEKME UZ DAUGAVAS LEDUS FENOLOĢIJAS ILGTERMIŅA IZMAIŅĀM

Šajā publikācijā ir apkopoti pētījuma rezultāti par Daugavas ledus fenoloģijas parametru (ledus veidošanās datums, ledus uzlūšanas datums un ledstāves ilgums dienās) ilgtermiņa izmaiņām un triju hidroelektrostaciju (Rīgas, Ķeguma un Pļaviņu) ietekmi laika posmā no 1919./1920. līdz 2011./2012. gadam, izmantojot matemātiskās statistikas metodes. Pētījums parādīja, ka ledus fenoloģijas parametru ilgtermiņa izmaiņas ir statistiski ticamas četrās hidroloģiskajās novērojumu stacijās (Piedruja, Daugavpils, Jersika, Jēkabpils), ja novērojumu periods ir garāks par 60 gadiem un novērojumi veikti līdz 2012. gadam. 20. un 21. gadsimta mijā globālā klimata pasiltināšanās rezultātā ir novērojamas šādas tendences: ledus izveidošanās datumam ir pozitīvs trends (t.i., ledus veidojas vēlāk) un ledus uzlūšanas datumam un ledstāves ilgumam ir negatīvs trends (t.i., ledus uzlūst ātrāk un ledstāves ilgums ir īsāku laika periodu). Lai pētītu hidroelektrostacijas ietekmi uz ledus fenoloģijas parametru izmaiņām, tika salīdzināti 20 gadu ilgi laika periodi pirms un pēc hidroelektrostacijas uzbūvēšanas. Pētījums parādīja, ka hidroloģiskajās stacijās, kas atrodas augšpus aizsprosta ūdenskrātuvē, pēc hidroelektrostacijas uzbūvēšanas ledus izveidošanās notiek ātrāk, uzlūšana iestājas vēlāk un ledstāves ilgums palielinās. Savukārt hidroloģiskajās stacijās, kas atrodas lejpus aizsprosta, ir novērojams pretējs ledus režīma process – ledus izveidojas vēlāk, uzlūst ātrāk un ledstāves ilgums samazinās. Ledus fenoloģisko parametru izmaiņu ilgums atkarīgs no hidroloģiskās stacijas atrašanās attāluma no aizsprosta. Jo tā atrodas tālāk no aizsprosta, jo mazāku ietekmi uz ledus fenoloģiskajiem novērojumiem atstāj hidroelektrostacijas darbība – tas ir saistīts ar ūdens termiskā režīma izmaiņām.