551.311.18
551.506.8

On River Level Rising in Springtime as caused by Ice Jams.

By

HEIKKI SIMOJOKI

The present investigation was undertaken to shed light on the effect of river level rising at ice break-up time and to examine water level rising caused usually by ice jams.

The investigation embraced some rivers flowing into the Gulf of Bothnia. The observation places with data concerning drainage areas and lake percentage are given in Table 1 and Figur 1. The observations were

Table 1. The rivers.

Nr.	Name	Lat.	Long.	Drainage area in sq km	Lake percentage
1	Kemijoki, Rantaniemi	65° 49′	24° 34′	50 885	2.9
2	» Taivalkoski	65° 55′	24° 42′	50 815	2.9
3	Iijoki, Ii	65° 19′	25° 26′	14 315	5.5
4	Kiiminginjoki, Haukipudas	65° 12′	25° 24′	3 845	3.4
5	Lestijoki, Kannus	63° 54′	23° 55′	1 195	9.8
6	Kyrönjoki, Skatila	63° 06′	21° 52′	4 780	1.0
7	» Pappilankoski	63° 00′	22° 20′	4 240	1.0
8	Loimijoki, Loimaa	60° 51′	23° 04′	1 250	7.1
9	Kokemäenjoki, Harjavalta	61° 18′	22° 11′	26 025	11.7
10	» Pahakoski	61° 16′	22° 25′	25 790	11.8
11	Putaanjoki, Koski	60° 37′	21° 45′	94	1
12	» Putta	60° 39′	21° 43′	79	2
13	» Vihtjärvenoja	60° 41′	21° 43′	29	3

made during the years 1920—36 on the tide-poles of the Hydrographical Bureau and have been published for the main part in the yearbooks of the said bureau. For purposes of comparison also Putaanjoki, a river representing the so-called poor drainage areas was included. The material concerning this river came from the technical office of the Agricultural Department and contains observations made during the years 1931—48.

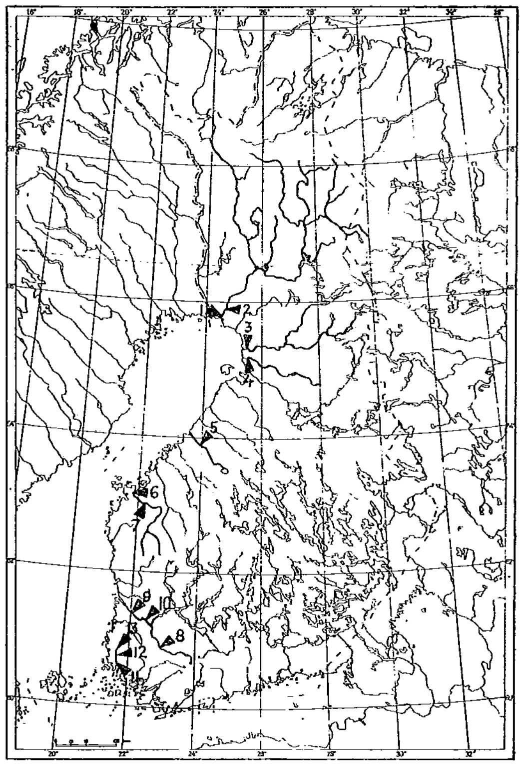

Figure 1. The map of the observation stations.

The water course in all the investigated rivers was natural. Later on, however, the power stations built on the Kemijoki- and the Kokemäenjoki-rivers changed the natural course of these rivers.

In rivers, ice break-up time will depend considerably on the rapidity which water level rises in consequence of melting of snow in springtime. Of course, the direct effect of insolation must also be into consideration alongside the turbulence of flowing water with consequent melting of the lower surface of ice. Due to the rising of water level ice will loosen from river banks, break and begin to move.

Table 2 gives the average data respecting the beginning and ending of ice break-up, A_1 and A_3 respectively. (The symbols used are same as those in the author's previous investigation into ice conditions of lakes.) Table 2 also gives the average differences $A_1—T_0$ between the spring 0°-isoterm and A_1, the said values varying from 8 to 16 days. This difference will naturally depend on the location of the place for taking temperature observations. The corresponding difference for large lakes is about 25 days.

Table 2. The average data (April) for beginning and ending of ice break-up respectively A_1 and A_3 as also the average time from the 0°-epoch T_0 to the phase A_1.

Observation place		A_1	A_3	$A_1—T_0$	Place for temperature observations
Kemijoki	(1)	39	45	15	Sodankylä
»	(2)	36	44	13	»
Iijoki	(3)	31	42	16	Oulu
Kiiminginjoki	(4)	26	36	11	»
Lestijoki	(5)	23	26	13	Vaasa
Kyrönjoki	(6)	24		13	»
»	(7)	22	24	11	»
Loimijoki	(8)	17	21	8	Tampere
Kokemäenjoki	(9)	12	21	10	»
»	(10)	14		10	»
Putaanjoki	(11)	11			
»	(12)	9		11	Turku
»	(13)	7			

For instance, for Oulujärvi $A_1—T_0$ is equal to 26 days. The fact that ice breaks up considerably earlier in rivers than in lakes must be the principal consequence of the above mentioned mechanical effect caused by rising of water level. The same fact will appear also from examination of the water level data.

The variations in water level during ice break-up were studied as follows. First, the daily water level readings for different years were grouped according to time of beginning of ice break-up A_1, and then the averages for water level in the neighbourhood of A_1 were computed for different days. The obtained values represent the average course of water level, thus relating to the one and same phenomenon and not to the mean value computed for the calendar year.

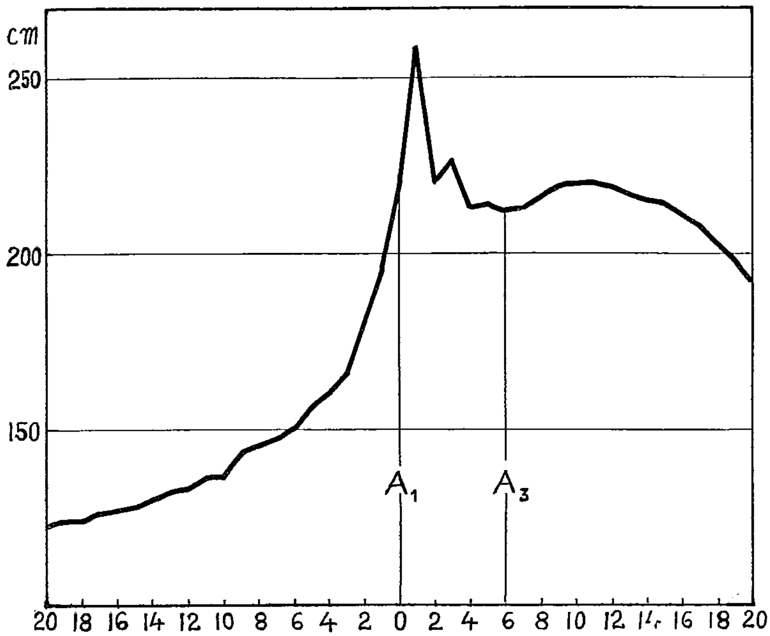

Figure 2. Mean water level course during ice break-up at Kemijoki, Rantaniemi. A_1 the beginning, A_3 the ending of ice break-up.

Diagram 2 which gives the average course of the water level as observed on the tide-pole at Rantaniemi on the Kemijoki shows an abrupt rising of water level before the beginning of ice break-up. During ice break-up irregularities mainly caused by ice jams appear. After the elapse of time A_3 for disappearance of ice, the variation water level course is regular. The same facts are revealed in Table 3, where the average differencies $h_n—h_{n-1}$ of water level for consecutive days are given instead of the water level values. The table shows also the total rising of water level during springtime as computed from the water level h_{-20} twenty days before A_1 to the maximal spring water level h_{max}. The lower limit h_{-20} is, of course, arbitrary, but may be used in this introductory investigation because the variation in water level on the whole is slight during this time.

In general the difference $h_n—h_{n-1}$ increases until the beginning of ice break-up, subsequently reaching its maximal value; later on it becomes negative. The considered observation period is too short to allow detailed comparisons. The irregularities may originate to some extent, from uncertainty in determining the phase A_1, which fact in part influences the grouping of water level values. In Putaanjoki $h_n—h_{n-1}$ reaches its maximum before the phase A_1.

A study of the separate years shows, that during some springs ice break-up may occur in connection with decreasing water level. Such a typical ice break-up was noted in the year 1930 when, with the exception of some northern rivers, the maximal value of water level was generally

Table 3. The average differencies $h_n—h_{n-1}$ in cm during ice break-up.

River		Before A_1										A_1	After A_1										$h_{max}-h_{-20}$	
		10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	Average	Max
		$h_n - h_{n-1}$																						
Kemij.	(1)	0	7	2	2	3	6	4	6	14	16	24	39	—39	6	—13	1	—2	1	3	3	1	186	312
Iij.	(3)	2	3	—1	1	1	4	6	14	2	—2	73	12	7	8	10	2	1	4	1	6	5	149	252
Kiiminginj.	(4)	0	0	0	1	1	2	4	9	11	12	27	2	6	9	5	1	—1	—2	—2	0	—1	137	210
Lestij.	(5)	1	3	1	5	7	10	13	14	18	21	23	33	10	—31	—11	—6	—15	—13	—11	—6	—6	195	319
Kyrönj.	(6)	10	9	10	10	5	9	12	75	75	9	12	0	—5	—1	—4	—24	—4	—5	—6	—8	4	172	362
Loimij.	(8)	1	3	4	0	1	2	4	8	11	72	11	0	—3	—3	—1	0	—10	—4	—9	6	—1	93	202
Kokemäenj.	(9)	0	2	1	6	4	1	1	4	7	5	8	19	—5	9	—3	—5	—7	—4	—3	—5	—1	97	306
Putaanj.	(11)							2	77	9	3	6	3	5	—1	0	—8	—9	—4					
»	(12)				8	5	6	—3	5	70	4	7	—5	—9	—8	—10	—7	—9	—7					
»	(13)		3	3	2	4	2	4	4	3	0	—4	—4	—4	—2	—3	—5	—4	—1					

reached already in January or February, while temperature of air was exceptionally high. During mild winters several ice break-ups and freezings may occur and can be seen from the course of the water level curve.

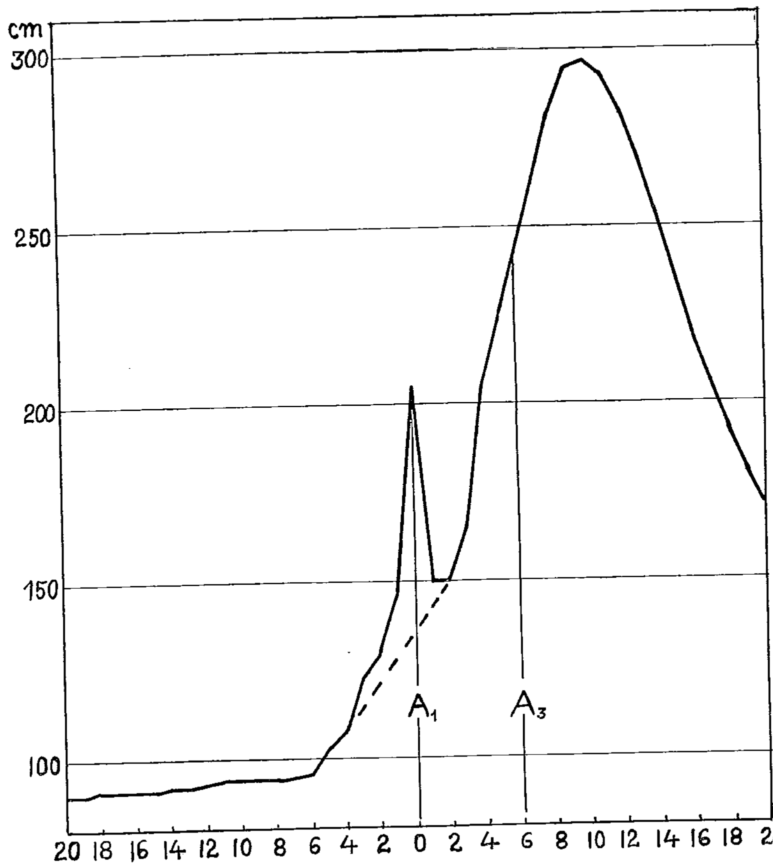

Figure 3. The water level fluctuations at Kemijoki, Rantaniemi in the spring 1923.

Table 3 shows that in many rivers there is, in the beginning of ice break-up, an abrupt increase of the difference $h_n - h_{n-1}$, which mainly depends upon the jamming effect of ice. In the following an attempt is made to estimate the rising of water level caused by ice jamming by using the water level observations for this purpose.

To determine the jamming caused by ice a graphic analytical method was used. The water level curves for each spring were drawn separately and the abrupt water level risings occuring during the time of ice break-up were explained as having been caused by ice jamming. The determination of jamming of ice in the spring of 1923 for the tide-pole at Kemijoki, Rantaniemi is illustrative in showing this method (Figure 3). On the solid curve obtained for water level an area separated by using a broken line is assumed to be dependent upon ice jamming. Should jamming last a short time and the rising of water level be abrupt, this method may be used for the approximate determination of jamming. If, on the contrary, the rising of the water level is slow, the determination of jamming may be rather uncertain. The result of the method will therefore depend considerably upon subjective circumstances.

The analysis results of the water level curves are tabulated in Table 4, which presents the average distribution of jamming about the period of time for ice break-up. In the rivers of large drainage areas the maximum was generally reached during the first or second day of ice break-up. In Putaanjoki, which represents a small drainage area, the maximum was reached earlier. Jamming was rather great on the tide-pole of Kemijoki—Rantaniemi, where water level rose 70 cm on average during the day after beginning of ice break-up. In other cases jamming was considerably less. When at its minimum it was on the top tide-pole of Putaanjoki. The table shows moreover, that jamming occured before the beginning of ice break-up, for instance, in Kyrönjoki and in Kokemäenjoki. The discussion of jamming during the winter does not fall within the scope of this examination.

Table 4. Average jamming in cm during ice break-up.

River		Before A_1																		A_1	After A_1					
		18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6
Kemij.	(1)					1	2	3	3	3	4	4	4	3	5	3	5	11	28	38	*70*	33	35	13	9	5
Kiiminginj.	(4)																1	7	13	*32*	13	1	2	3	2	
Lestij.	(5)			4	10	11	10	6	4	2	2	2	4	5	5	4	4	4	8	20	32	*42*	8	4	2	1
Kyrönj.	(6)	7	8	8	9	6	7	8	7	7	6	6	10	9	10	10	11	10	11	*14*	10	8	4	4	4	3
Kokemäenj.	(9)	4	4	5	6	6	6	7	7	6	5	4	7	7	5	4	5	7	9	15	*25*	16	17	13	10	5
Putaanj.	(11)	4	3	6	9	14	18	17	19	*22*	*22*	20	12	5	5	14	5	7	1							
»	(12)	4	11	10	9	7	6	6	7	5	5	7	11	*12*	*12*	7	6	6	3	6	4	3	1			
»	(13)	3	5	3	3	2	1	1	4	3	1	2	2	4	*6*	3	4	*6*	*6*	3	1					

Table 5, which contains the average and extreme values for maximum jamming, gives a clear picture of the order of jamming.

Table 5. The average maximum values of the jamming during ice break-up and its extreme values in cm. K on using curve analysis, D on using difference method.

River		Maximum jamming			
		Average values		Extreme values	
		K	D	K	D
Kemij.	(1)	110	127	212	322
Kiiminginj.	(4)	39		121	
Lestij.	(5)	63		125	
Kyrönj.	(6)	38	50	125	132
Kokemäenj.	(9)	39	43	165	159
Putaanj.	(11)	38		86	
»	(12)	33		57	
»	(13)	15		22	

To verify the results obtained, jamming was determined according to another method not dependent upon subjective circumtances and based upon observations made simultaneously on two water level tide-poles in the one and same river.

Suppose that the difference between water level readings on tide-pole h' observed during two consecutive days is represented by $h'_n - h'_{n-1} = \Delta'$ and that the difference between water level readings on another tide-pole h'' in the one and same river is correspondingly $h''_n - h''_{n-1} = \Delta''$. The difference $\Delta' - \Delta''$ will then express the order of jamming on the assumption that a variation in river water quantity causes the same deviation on both tide-poles. If jamming occurs at the lower situated tide-pole while the runoff higher up is undisturbed, the difference $\Delta' - \Delta''$ will denote jamming at the lower tide-pole. If, on the contrary, jamming occurs at the higher up situated tide-pole with no disturbance at the lower tide-pole the difference $\Delta' - \Delta''$ will represent jamming at the higher tide-pole in comparison to the lower one. However, the value obtained will be too large because the water level at the lower tide-pole has decreased in consequence of the influence of jamming higher up.

Generally, as the tide-pole profiles in reality differ from each other, the correction caused by this fact was determined as follows: A comparison curve for the water levels of the tide-poles h' and h'' was drawn for the time of high water. h'' and h' were selected respectively as abscissa and ordinate for the comparison curve. The comparison curve may approximately be substituted by a line whose angle coefficient $tg\,\alpha$ is the correction factor caused by the shape of river bed. Jamming may then be computed upon application of the formula

$$\Delta_i = \Delta' - tg\,\alpha \cdot \Delta''.$$

When $\Sigma \Delta_i$ is computed the jamming during a definite period of time will be obtained.

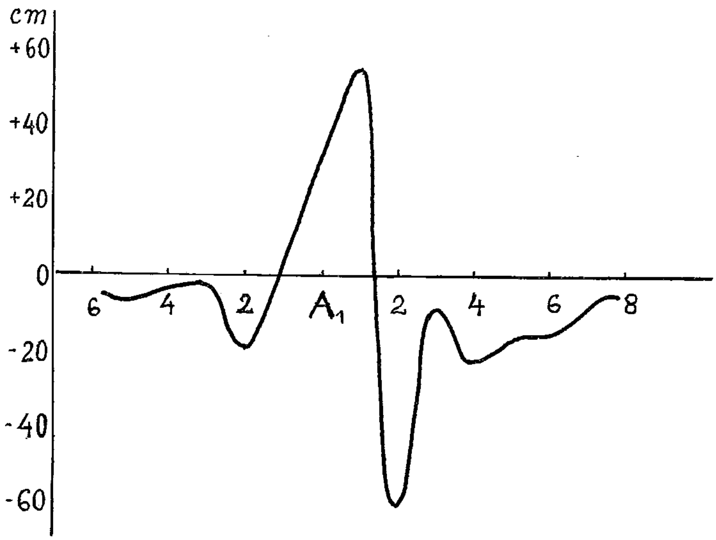

Figure 4. Average course Δ_i at Kemijoki, Rantaniemi during the ice break-up.

The latter method is illustrated in Figure 4, which presents the average course of Δ_i at the Rantaniemi tide-pole in Kemijoki during the time of ice break-up as computed by application the formula $\Delta_i = \Delta_R - 0.7 \cdot \Delta_T$. In this connection Δ_R and Δ_T denote the average changes in water during consecutive days for the tide-poles respectively at Rantaniemi and at Taivalkoski. Before the phase A_1 jamming was noted at the Taivalkoski tide-pole $\Delta_i < 0$. On the first and second day of ice break-up $\Delta_i > 0$, which denotes jamming at the Rantaniemi tide-pole. Later on Δ_i decreased abruptly and becomes negative. A similar result was obtained from the other rivers examined. Figure 4 gives 31 cm as the average order of jamming at the Rantaniemi tide-pole on the first day of ice break-up and 87 cm on the following day which last mentioned value is 17 cm higher than the result obtained from the curve analysis.

The above mentioned difference method was applied to the observations made in Kemijoki, Kyrönjoki and Kokemäenjoki. The average maximum values and the extreme values obtained are given in Table 5. The $\Sigma \Delta_i$ which of the different jamming-covering periods gives the maximum value of the sum was considered as maximum jamming. Maximum jamming occured during or around the phase Δ_1. If jamming is of long duration and the Δ_i values are small, difficulties may arise in determining the lenght of the period. In such cases the method may give too high values.

Intercomparison of the results of the two methods shows, that the average values differ from each other within the range of from 4 to 17 cm. Use of the difference method implies, as mentioned, that at the higher situated tide-poles no considerable jamming has occured. If the latter distinctly established cases are not taken into account the results for different methods differ less.

The maximum value of the jamming constitutes from 20 to 60 % of the maximal rising of water level during springtime. The results vary considerably for different tide-poles in the same river, depending mainly upon local circumstances.

REFERENCES

KAITERA, PENTTI, Lumen kevätsulamisesta ja sen vaikutuksesta vesiväylien purkautumissuhteisiin Suomessa. Maataloushallituksen kulttuuriteknillisiä tutkimuksia. N:o 2. Helsinki 1939.

—»— On the Melting of Snow in Springtime and its Influence on the Discharge Maximum in Streams and Rivers in Finland. Teknillisen Korkeakoulun tutkimuksia N:o 1. Helsinki 1949.

SAUKKO, PENTTI, Suppotulvista Vuoksen suvannoissa. Über die Breieisüberschwemmungen an den seeartigen Wasserstrecken des Wuoksi. Maanviljelysinsinööriyhdistyksen vuosikirja 1938. Helsinki 1938.

SIMOJOKI, HEIKKI, Über die Eisverhältnisse der Binnenseen Finlands. Annales Academiae Scientiarum Fennicae. Ser. A. Tom LII, N:o 6. Helsinki 1940.

Tulvakomitean mietintö. Helsinki 1939.