POAC '99
Espoo, Finland

Proceedings of the 15th
International Conference on
Port and Ocean Engineering
under Arctic Conditions

THE IMPACT OF THE PROPOSED WINTER NAVIGATION ON KYMIJOKI HYDROPOWER PLANTS

J.Laasonen[1] and O.Holm[2]
[1]VTT Manufacturing Technology, P.O.Box 1705, 02044 VTT, FINLAND
[2]Finnish Maritime Administration, P.O.Box 171, 00181 Helsinki, FINLAND

ABSTRACT

This paper presents information on the operation of power stations in the winter and the related problems. As for the gate structures of the regulating dam, no changes are necessitated with respect to winter trafficability in the River Kymijoki. Ice quantities formed in the river section have been estimated with the formula, with the effect of flow velocity included. From the point of view of ice management, the quantity of ice drifting per day in an average winter is not very high. What causes problems is the total quantity of ice which cannot be deposited controllably in the river channel. More detailed numerical modeling is required for the estimation of the drifting of ice and the formation of potential ice jams.

1. INTRODUCTION

In 1996 VTT Manufacturing Technology started to investigate the possibility of extending the navigation period in Lake Saimaa and Saimaa Canal. The studies were extended to the planned Kymijoki and Mäntyharju Canals. The locations of the canals are presented in Figure 1. Some results of those studies are presented in the paper by Rytkönen et al; 1999. The research studies on the proposed Kymijoki Navigation Channel comprised: ice reconnaisence flights, ADCP flow measurements, 1-D ice modelling and 2-D flow modelling [VTT Manufacturing Technology, 1998a and 1998b]. This paper presents an estimation of the impacts of the wintertime navigation on the hydropower plants at the River Kymijoki.

Several examinations and technical plans have been made of Kymijoki Navigation Channel during the last few decades. None of them has led to the construction of the canal since the effects on transportation economy have not been significant enough. The construction of the Keitele Canal during the years 1989-93 increased the interest in investigating the possibilities of a sea connection to the Päijänne lake area. The channel would connect Lake Päijänne area to the Gulf of Finland and create an extensive transportation route for the industry in Central Finland and along the Kymijoki river valley. The channel would also open new routes for recreation and tourism.

The canal is planned for vessels with a length of 120 m and breadth of 15 m. The draught of the vessels is either 3,4 m or 4,5 m and the air draft accordingly either 8,0 m or 10,0 m. The canal is designed for year-round navigation.

The fall of 76 m between Lake Konnivesi at the upper reaches of the River Kymijoki and the Gulf of Finland is divided into eight locks, whose fall varies from 6,25 m to 12,7 m. The locks are 142,7 m long, 16 m wide and have a waterdepth of 4,0 m or 5,2 m. The total canal length from Lake Konnivesi to the sea is over 90 km, of which about 25 km would be excavated canal, the rest being natural, although in places a dredged waterway along the lakes and the River Kymijoki.

The canal plan has alternative routes between Anjala and the Gulf of Finland. The Korkeakoski route follows the most eastern river bed to Kotka. The Tavastila route separates the river below Anjala and runs to Salminlahti bay at the east side of Kotka.

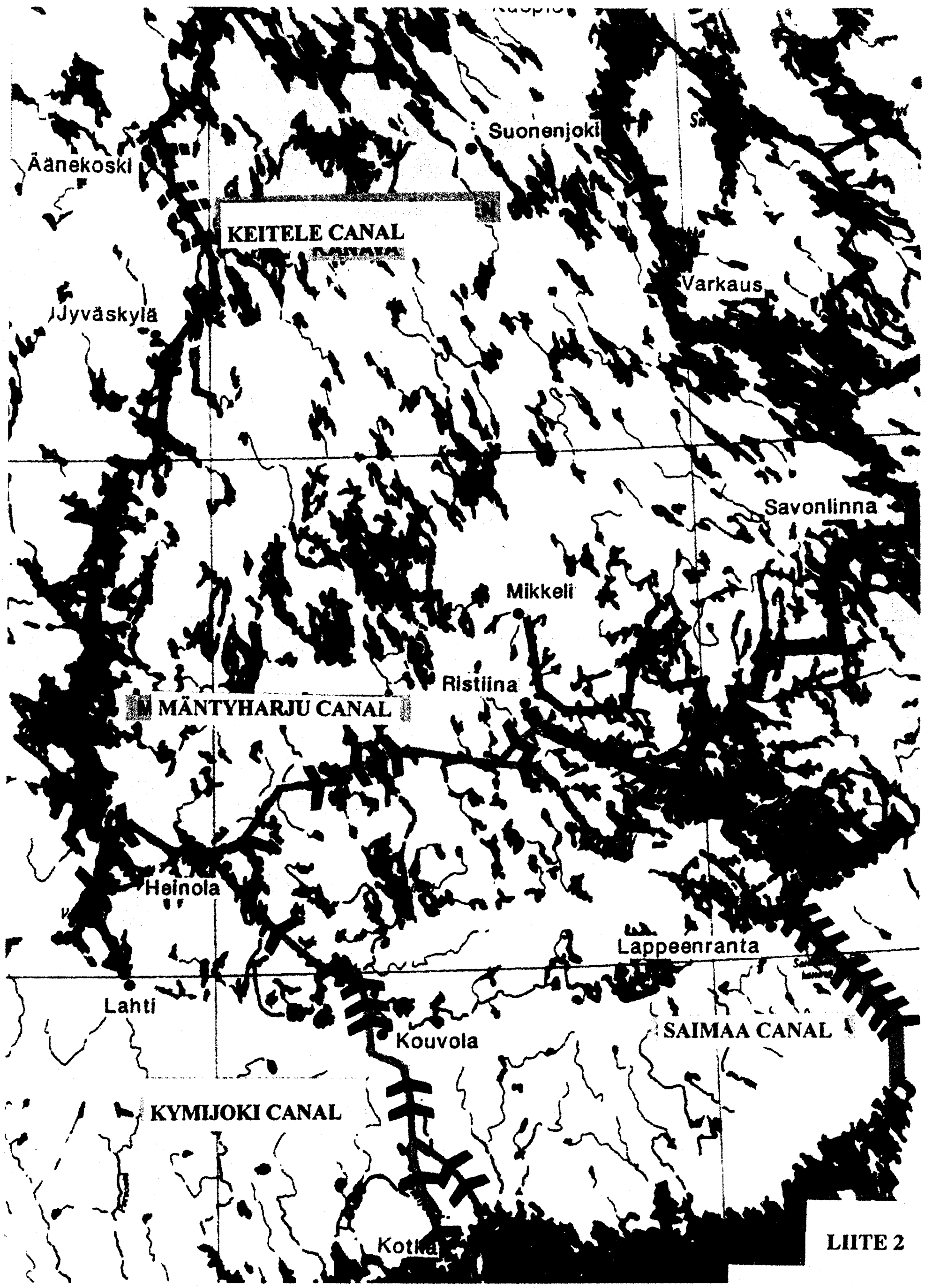

Figure 1. *The location of the Kymijoki Canal.*

2. SOME HYDROLOGICAL AND METEOROLOGICAL DATA

River Kymijoki is located in the south-eastern part of the Finland. The catchment area of the river is c. 37 160 km^2. Kymijoki Navigation Channel is situated in the lower part of the water course. The lower part of the canal will go along the river and the upper part will mainly go through lake areas. The construction of the canal will have an influence on the use of twelve hydropower plants.

The mean discharge (MQ) of the River Kymijoki at Kuusankoski hydropower plant has been 308 m^3/s during the period 1961-1990. The highest value (HQ) was 677 m^3/s and the lowest was 114 m^3/s. The mean discharge during the winter months (December - March) varied from 305 to 324 m^3/s.

The mean value of the sum of freezing days at Anjalankoski has varied from 343 to 1370 degree-days in period 1986-1997, where the average value has been 695 degree-days.

Flowing water decreases the amount of ice developing in the natural state. The calculated estimates of natural ice found in reference literature are often fairly conservative. In normal winters, the thickness of ice in the River Kymijoki varies between 20 and 50cm. In a winter of heavy ice conditions, ice thickness in some places may be as high as 80–90cm.

3. HYDROPOWER PLANTS IN THE KYMIJOKI CANAL AREA

Several paper mills have been established in the River Kymijoki. The first hydro-electric power stations were constructed in that region at the beginning of this century. Some of the older stations were reconstructed in the 1980's and 1990's. The construction of the canal will have an influence on the use of twelve hydropower plants. The installed capacity of those power plants is 210 MW. Technical data for the hydropower plants are presented in Table 1.

Table 1. Technical data of the hydropower plants in the Kymijoki Canal area.

Name	Installed capacity [MW]	Rated discharge [m^3/s]	Head [m]	Location
Vuolenkoski	9,0	370	3,7	Lake region
Mankala	25,0	370	8,1	"
Voikkaa	30,0	405	9,0	Main channel
Kuusankoski	30,0	400	9,2	"
Keltti	16,5	340	6,1	"
Myllykoski	25,0	470	7,0	"
Anjalankoski	36,0	435	9,7	"
Koivukoski	1,9	47		Pernoo branch
Korkeakoski	8,7	95		"
Klåsarö	3,6	180	3,2	Hirvikoski branch
Ediskoski	0,4	5,3	9,0	"
Ahvenkoski	24,0	250	9,7	"
Total	210,1			

3.1 Hydropower plants in the lake region

In the lake region the navigation channel will not follow the river channel. From Lake Konnivesi to Lake Pyhäjärvi the canal will go through Kimola canal, which was built for log floating. Therefore *Mankala* and *Vuolenkoski* hydropower plants, which are located in the main channel, will only lose water due to the sluicing.

3.2 Hydropower plants in the main channel

The hydropower plants in the river reach are run-of-the-river powerplants, which means that the power plants do not have any storage capacity. All the river discharge should go through the turbines or the gate openings.

At Pernoo, River Kymijoki splits into two branches. The eastern river branch, which flows towards the City of Kotka is called Pernoo branch and the western one is called Hirvikoski branch. In the river reach between Lake Pyhäjärvi and the splitting point the fall of the river is almost fully utilized and there are five hydropower plants.

The first power plant downstream of Lake Pyhäjärvi is *Voikkaa.* The site has a long history which had already began at the end of the last century. The power plant has been expanded and the old units have been replaced by new ones. The last replacement of the units was carried out in 1991. The tainter gates of the regulating dam have electrical heating units. The power station has ice jamming problems during a freeze-up of Lake Pyhäjärvi. These problems will end when the lake has ice cover. Anchor ice can be formed during the winter floods. Severe anchor ice accumalations must be blasted, but this happens quite seldom (approx. every 25 years).

Kuusankoski and *Keltti* hydropower plants were constructed in the 1940's. The gates of both regulating dams can operate during the winter-time. Electrical heating equipments and air bubble curtains have been installed. Ice booms (Figure 2) are placed in the river reaches in order to facilitate the ice cover formation. There are no ice problems in Kuusankoski. In Keltti the water level fluctuations due to the discharge variations causes the ice-cover to break-up and the drifting ice can form a blockage at the intake of the power station.

The utilization of hydropower in *Myllykoski* began in the 1920's. The operation of the new power station started in November 1997. The steam is used in ice removal from the gates of the regulating dam. An ice boom has been installed a few hundred meters upstream of the power station. Earlier, there were problems with the drifting ice. Because of these problems the new intake channel has been excavated to a depth of eight meters. No ice problems occured during the first winter of operation.

The hydropower plant on the east bank of the river in *Anjalankoski* was completed in 1922. Three of its turbines were replaced by new ones in 1994. The power station on the west bank was constructed in 1983. The operating gates of the regulating dam have heating equiment and when necessary the steam can be supplied. In Anjalankoski there are seldom ice problems. The intakes of the power station can become clogged due to the super-cooled water.

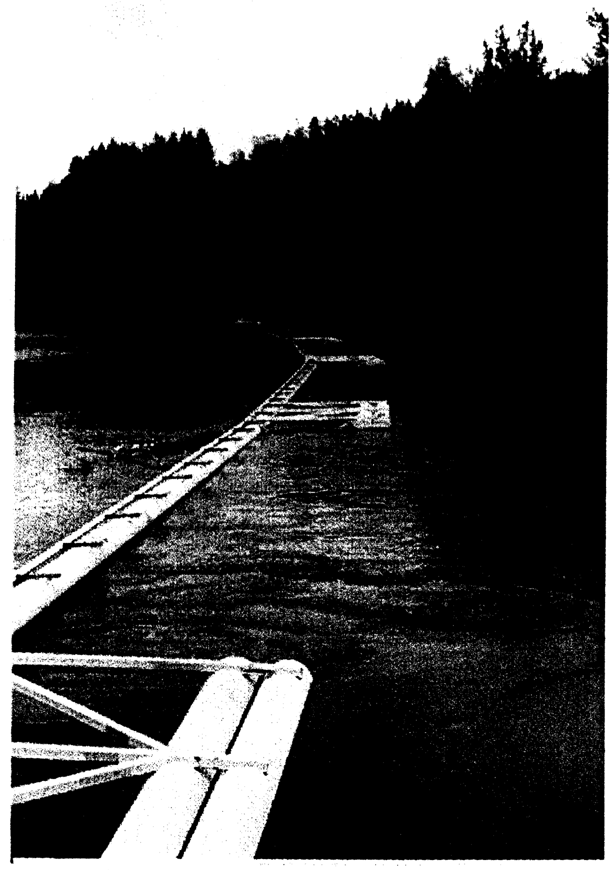

Figure 2. Ice boom at the Keltti hydropower station. Earlier the boom was used for log floating in River Kemijoki.

3.3 Hydropower plants in Hirvikoski and Pernoo branches

Downstream of Anjalankoski hydropower plant begins a river reach where there are several freely flowing rapids. The flow of the river branches are regulated by the dam which is located at the Hirvikoski branch. At Pernoo branch there are some rapids before the hydropower stations in Kotka. The total fall of the rapids is about 12 meters. In the planned Korkeakoski route, the excavated channel and a lock will be constructed to bypass this cascade of rapids. The excavated channel will start downstream of Anjala and will join the river below the rapids.

There are three hydropower plants at Hirvikoski branch: *Klåsarö, Ediskoski* and *Ahvenkoski.* The construction of the Kymijoki Canal will only influence their operation if the discharge of the river branches is changed.

The Pernoo branch is further divided into two branches at Parikka (Figure 3). *Korkeakoski* hydropower plant is located at the eastern branch and *Koivukoski* at the western branch. The power plants have the same upstream water level. The flow is regulated so that Koivukoski will always receive 20 m^3/s and the rest of the flow will be discharged through the turbines of Korkeakoski until it reaches the rated discharge. The flood flows will be diverted through the Koivukoski regulating dam.

Korkeakoski hydropower plant was constructed during the years 1925-27 and Koivukoski was completed in 1933. The operating gates of the regulating dam in Koivukoski have heating equipment. Ice booms are placed in the intake channel of Koivukoski and in the river reaches.

Due to the freely flowing rapids on the river reach between Anjalankoski and Korkeakoski ice problems occur nearly every year, probably the hardest ice condition in Finland. In the rapids the water is supercooled and anchor ice is formed. Ice jams must be blasted several times during the winter.

In Korkeakoski the intakes of the turbines are blocked by frazil ice formed in supercooled water. This usually occurs, when the temperature drops rapidly after mild weather. If, during that time, the winds are blowing along the river reach, the heat exchange in the surface of the open water is accelerated. The discharge of Korkeakoski power plant is decreased when the water temperature is lowering and it is near freezing point. Ice jams have also been formed in the downstream river reach of Korkeakoski. The water level fluctations due the discharge variations in Koivukoski have caused the break-up of the ice cover. The intakes of the Koivukoski power station are then blocked by the drifting ice. The ice blocks are discharged through the ice gate of the power station. The opening of the blocked intake channel will last app. 6 hours, when the ice thickness is 5 cm.

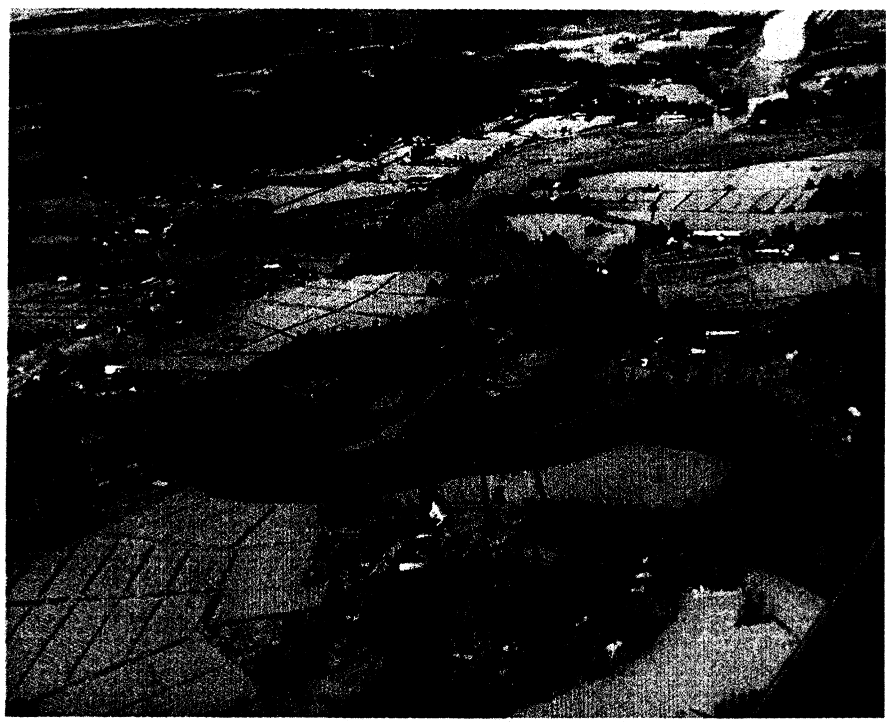

Figure 3. The River Kymijoki split at Parikka.

4. ESTIMATION OF THE IMPACT OF WINTER-TIME NAVIGATION

4.1 Increasing the discharge in the excavated channel

The canal plan has two alternative routes between Anjala and the Gulf of Finland. In both cases an excavated channel and a lock will bypass the river. The excavated channel in Tavastila route alternative will start at Anjala and run to Salminlahti bay. The excavated channel in Korkeakoski route alternative will also start at Anjala and join the river below the rapid section. The cost of discharging water in order to facilitate the ice conditions in the excavated channel is studied.

If a stream in the section of the excavated channel consists of lockage water, the freeze-over may resemble the conditions in the lakes. It is assumed that the decrease of the ice thickness correlates linearly with the increase of the water velocity. The upper velocity limit is 0,6 m/s then the ice cover is not expected to form. Although the frazil ice production is then increased and may cause other problems downstream.

An increase of 10 cm/s in the flow velocity in the channel increases the discharge to approx. 23 m^3/s. Theoretically the increased discharge in the channel in the Korkeakoski route will not cause any energy losses to the hydropower production. The discharge of the branches is divided by the regulating dam in Hirvikoski branch and the present discharge division can be maintained. On the other hand, this would reduce the discharge in the freely running rapids, possibly leading to changes in the living conditions of aquatic fauna.

The results of the energy loss calculations in the Tavastila route alternative during an average winter is presented in Table 2. In the calculation the funneled water is assumed to reduce equally the discharge of the river branches. This reduction of the discharge will have an influence on the hydropower production of Klåsarö and Ahvenkoski in Hirvikoski branch and the hydropower production of Koivukoski and Korkeakoski in Pernoo branch. The value of the produced energy is assumed to be 0,2 FIM/kWh.

Table 2. The cost of discharging water in order to decrease the ice thickness in the excavated channel in Tavastila route alternative. The value of the energy is assumed to be 0,2 FIM/kWh.

Velocity in the excavated channel [m/s]	Annual energy loss [GWh]	Cost of energy loss [milj. FIM]	Ice thickness [m]	Cost of reduced ice thickness [FIM/cm]
0,0	0,00	0,0	0,82	
0,1	5,31	1,1	0,68	75857
0,2	10,63	2,1	0,54	76000
0,3	15,94	3,2	0,41	81692
0,4	23,00	4,6	0,27	100857
0,5	30,05	6,0	0,14	108462
0,6	37,10	7,4	0	100714

Even a small increase in the discharge in the excavated channel in Tavastila route will cause quite considerable energy production loss to the hydropower plants in Kymijoki. The cost of the melting of the ice is about 75 000...110 000 FIM per reduced 1 cm ice thickness.

The influence of the vessel traffic on the formation of the ice was not taken into account. Another possibility is to make the cross profile of an excavated canal large enough for a vessel to run among ice floes. If ice is allowed to form in the land canal and there is no additional discharge, ice thickness in the canal may grow up to 2,0–2,5m.

4.2 Drifting ice broken by the vessels

The regulating dams of the power plants in the main channel of the River Kymijoki have heating equipment, or steam can be conducted to them in order to remove ice. The gates of the regulating dams can be used in winter conditions. As for the gate structures, no changes are necessitated with respect to winter trafficability in the River Kymijoki.

Some ice booms in the river are located in the fairway. Near the hydropower plants, where the lock is planned in the dam structures, the ice booms have to relocate. The vessels will break the ice cover daily. Therefore it is important that the ice booms prevent the drifting ice from blocking the intake of the power station.

Ice quantities formed in the river section have been estimated with the formula presented by Hausser et al; 1986 (Equation 1)

$$h = 0,1*(-1+\sqrt{(1+0,125*s)} \qquad (1)$$

where h is the ice thickness and s is the sum of freezing degree-days of the air temperature (in Celsius) from the beginning of the formation of the initial ice cover.

In these preliminary studies it was found out that the ice thicknesses calculated with this equation were bigger than the measured ones. Therefore the effect of flow velocity was linearly included in the equation. The upper flow velocity limit was 0,6 m/s (no ice cover) and the lower limit was 0 m/s (ice thickness according to equation 1). The other values were interpolated. The average velocity of the river reach was used. The ice thickness of 20...40 cm during the average winter was calculated.

Three different types of winter were calculated (hard - 1370 degree-days, mean 695 - degree-days and mild - 314 degree-days). It was assumed that the ice cover of the width of 20 meters would be broken twice a day by the vessels. It was assumed that all that broken ice will drift downstream. The formation of the ice jams or other limiting factors such as the friction of the border ice were not taken into account.

The drifting ice in Korkeakoski in an average winter would be about 2300 m^3/day (1200...4400 m^3/day) and the total amount would be about 350 000 m^3 (180000...670 000 m^3). Impact of the supercooled water and frazil ice from the rapids were not taken into account in the calculations. Similar amouts of ice were calculated in the other reaches. If all the drifting ice between Susikoski (first rapid below Anjalankoski) and Lake Pyhäjärvi has to pass downstream, the total amount in an average winter would be about 1 300 000 m^3 (700 000...2 500 000 m^3).

From the point of view of ice management, the quantity of ice drifting per day in an average winter is not very high. What causes problems is the total quantity of ice which cannot be deposited controllably in the river channel. For example, the total amount of the drifting ice in the Korkeakoski route would be about 350 000 m^3 and the surface area of the river in Koivukoski, Parikka and Korkeakoski is only 1700 m^2. It is difficult to pass the ice blocks through the gate openings without tug assistance. The flow through the regulating dam will also limit the hydroppower production. Similar problems are expected in Susikoski.

Large ice masses may form ice jams. These may be formed at the junction of the excavated channel and a river, for example upstream of Susikoski, in the river branch in Parikka and in the upper basin of the Korkeakoski hydropower station. If the decision to build the Kymijoki Canal is made, the drifting and formation of ice jams should be studied using numerical 1-D and 2-D river ice modeling.

5. CONCLUSIONS

In this paper, information on the operation of power stations in the winter and the related problems has been presented. At present, accumalation of ice in the trashracks in Voikkaa and Korkeakoski is a problem in the winter. In Keltti, as a result of fluctuation of water levels, the ice cover has been broken and ice has drifted to the power plant. The regulating dams of the power plants in the main channel of the River Kymijoki have heating equipment, or steam can be conducted to them in order to remove ice. The gates of the regulating dams can be used in winter conditions. As for the gate structures, no changes are necessitated with respect to winter trafficability in the River Kymijoki.

Ice quantities formed in the river section have been estimated with the formula, with the effect of flow velocity included. From the point of view of ice management, the quantity of ice drifting per day in an average winter is not very high. What causes problems is the total quantity of ice which cannot be deposited controllably in the river channel. More detailed numerical modeling is required for the estimation of the drifting of ice and the formation of potential ice jams.

On the basis of the study, it is difficult to estimate which canal routing (Tavastila/Korkeakoski) would be the better alternative in the lower section of the River Kymijoki. From the point of view of releases in the land canal, the routing via Korkeakoski would be better, as losses suffered by power plants can be compensated for by discharge arrangements. On the other hand, this would reduce the discharge in the freely running rapids of the River Kymijoki, possibly leading to changes in the living conditions of aquatic fauna. In the Tavastila canal routing, it is unprofitable to melt the ice cover by releasing water into the land canal on the basis of losses in energy production of the power plants. The ice problems in the free sections of the River Kymijoki will linger also after the canal is finished. In routing via Korkeakoski, ice jams may form in the river branch at Parikka, posing a risk to property. Both alternatives include a land canal route, in which hard winters may cause traffic interruptions. On account of this, the Tavastila routing would be better, as the problems related to ice drifting in the Korkeakoski route would be excluded. On the other hand, the Tavastila alternative would result in bigger ice problems in the section near the sea in the excavated canal, because the melting effect the flow in the River Kymijoki has on ice would be excluded. In order to obtain a better overall view of ice formation and modification, ice measurements and ice reconnaisance flights should be conducted in the River Kymijoki. The flow of water and thermal radiation from the sun influence the thickness of ice. Especially the melting effect of the late spring should be surveyed in more detail.

Few ice thickness observations in the river section have been made, and no far-reaching conclusions can be made based on them. Ice thickness and temperatures in the river should be measured systematically in the coming years in order to increase basic knowledge on ice formation in flowing waters in the climatic conditions in Finland.

6. ACKNOWLEDGEMENTS

The wintertime operation experiences of the hydropower plants in River Kymijoki is based on the visits to the site and the interviews. The authors wishes to thank Mr. Jorma Lehtinen from Kymi Paper Ltd, Director Heikki Pyykkönen from Myllykoski Paper Ltd, Manager Hannu Tähtinen from Enso Ltd and Director Matti Laukkanen, Manager Mauri Savolainen and Mr. Heikki Oksanen from Ahlstrom Energy for their help.

7. REFERENCES

Hausser, R., Drouin, M. and Parkinson, F.E. 1986. Thin Ice Sheet Formation on Warm Water. Proceedings of IAHR Ice Symposium, Iowa City, Iowa, Vol I, pp. 521-532.

Rytkönen, J. and Kostiainen, K. 1999. The Improvement Plans of the Finnish Inland Winter Navigation. To be presented in 15th International Conference on Port and Ocean Engineering under Arctic Conditions, POAC'99.

VTT Manufacturing Technology. 1998a. Prerequisites for the Management of Winter Traffic in the Proposed Kymijoki Canal. Research Report VAL34-8046 (confidental), 57 p. + 12 app.

VTT Manufacturing Technology. 1998b. Study on the effects of the canalization of the River Kymijoki. Measurements of the River Kymijoki, Hydrological Observation Materials and the Definition of the Disadvantages to Power Plants. Research Report VAL34-980240 (confidental), 99 p.+ 12 app.