THE FINNISH RIVER ICE MODEL IN USE

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ABSTRACT

The Finnish River Ice Research Project was carried out in 1985-1989. The Results of the project have already been presented in quite many papers (Huokuna 1988a, Huokuna 1988b, Maunula and Huokuna 1988a, Maunula and Huokuna 1988b, Huokuna 1990). The main purpose of the River Ice Research Project was to develop a numerical one-dimensional river flow model for winter conditions to be used as an engineering tool. During the project the River Ice Model was developed to simulate ice conditions at four river reaches with lengths of 40-70 km. The development of the computer program was made by Consulting Engineers Reiter Ltd. The total costs of the project was about 700 000 US$, of which 300 000 US$ was used for observations.

The model is a combination of an one-dimensional flow model and the modeling of water temperature, ice cover formation, growth and decay. It includes the components for solution of the one-dimensional dynamic flow equations, flow simulation around islands, calculation of heat exchange, solution of the longitudinal water temperature distribution, formation of frazil and skim ice (moving surface ice), border ice formation, dynamic ice cover formation, deposition and erosion of frazil under the ice cover, thermal growth and decay of the ice cover and simulation of ice cover friction factor. In this paper a brief description of the model and some of the calculation results are given.

1. GENERAL

In Finland, the ice cover in watercourses persists for several months annually, and problems associated with the formation of frazil ice and ice jams occur practically every year. These problems are encountered in both unconstructed and partially constructed watercourses.

The hanging dams caused by supercooling of water in conjunction with ice formation on the rivers often cause considerable flood damage in Finland and hamper the utilization of the whole watercourse. During the midwinter period cracking of the ice surface due to vertical and horizontal movements of river ice covers, rising of water above the ice surface and increase in the thickness of the ice layer result in practical difficulties, which short - term regulation has been claimed to exaggerate. Ice jams in spring are also a regular annual problem in many Finnish rivers.

The aim of the river ice research project was to develop a calibratable mathematical model with which it would be possible to investigate the effect of flow characteristics on the formation of ice and frazil ice on the development of the surface layer of ice and on breakup of ice in spring. Such a model has become possible as a result of the rapid development in computer technology and watercourse modeling in recent years.

2. THE FIELD OBSERVATIONS

The field observations needed for development and calibration of the numerical model were carried out in four river reaches with lengths of 40-70 km mainly during three winters (1985-1986, 1986-1987 and 1987-1988). The location of the research reaches are presented in figure 1. During every winter about 800 hours of work was needed for observations at every study reach.

Most of the numerical data collected during the project is digitized and stored in a data bank. The data from the data bank is available from the National Board of Waters and the Environment. The original data including observation forms, maps, drawings and photographs are stored by the organisations that carried out the observations: the Kymi district office of The National Board of Waters and The Environment (Kymijoki), the Kokkola district office of the National Board of Waters and The Environment (Kalajoki), Oulujoki Ltd (Oulujoki) and Kemijoki Ltd (Kitinen) (see fig 1).

The most important parameters gathered were discharge, stage, water temperature, ice cover appearance, growth and melting of ice cover, ice break up conditions and weather conditions (air temperature, wind velocity and direction, relative humidity and cloudiness). Also observations about the strentgh of ice cover and about anchor ice were made.

The reaches investigated differ strongly from each other. Climate conditions, mean discharges and the type of regulation are quite different in each river. Therefore, special observation programs were made for each reach. The attention was pointed at the events and the problems caused by ice that are typical for each reach. There is a separate report on the observations of the Finnish River Ice Research Project (Huokuna 1991).

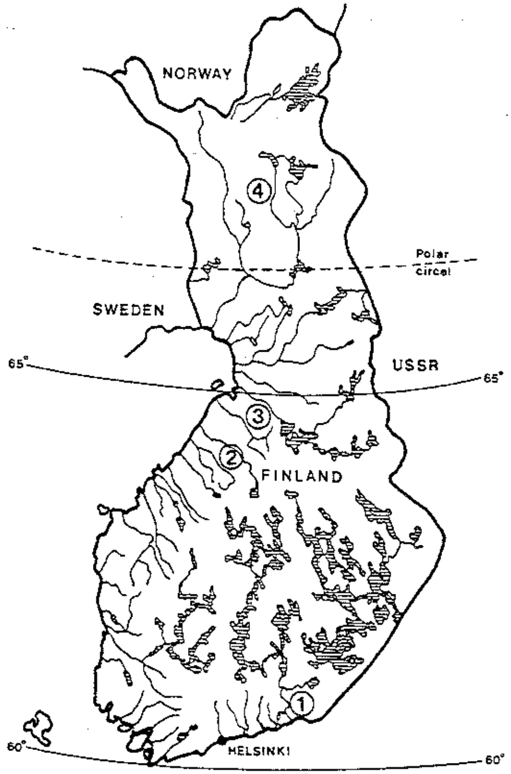

Fig. 1. The locations of the research reaches.
1) Kymijoki 2) Kalajoki 3) Oulujoki 4) Kitinen

3. THE RIVER ICE MODEL

The JJT-model is a combination of a one-dimensional flow model and modelling of water temperature, ice cover formation, growth and decay. The solution of the unsteady flow equations in the model is based on the weighted four-point implicit scheme and the resulting equations are solved by the Newton-Raphson iteration algorithm. The decrease of cross-sectional area and increased frictional resistance due to the effect of the ice cover have been taken into account. The components of the numerical model can be seen in figure 2. The model has the following features:

- solution of the one-dimensional dynamic flow equations;
- calculation of initial conditions for the flow model using backwater equations;
- calculation of heat exchange (solar radiation, long wave radiation, convection and evaporation);
- solution of the longitudinal water temperature distribution;
- formation of frazil ice and skim ice (moving surface ice);
- border ice formation;
- dynamic ice cover formation;
- deposition and erosion of frazil under the ice cover;
- thermal growth and decay of the ice cover including formation of snow ice;
- simulation of ice cover friction factor.

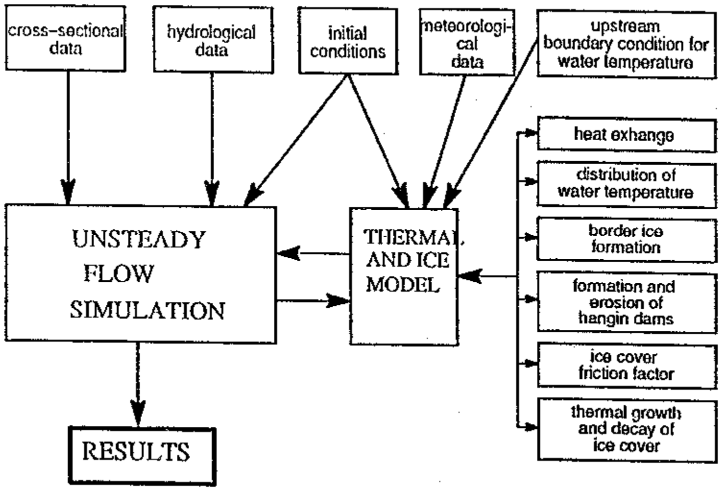

Figure 2. Components of the JJT-model

The flow equations are solved using the weighted four point difference scheme and an iterative solution. The advection equation for water temperature and for concentration of frazil is solved using the method of characteristics.

For every time step the model first calculates heat flux values along the river. Then the longitudinal distribution of water temperature or ice concentration, dynamical formation of ice cover or deposition of frazil under the ice cover are calculated. After that the model calculates the formation of border ice and thermal growth and decay of the ice cover. After these thermal and ice processes are calculated the model solves the flow equations to find out the new values for discharge and stage at every cross-section.

Describtion of the model is given by Huokuna (1990).

4. SOME APPLICATIONS OF THE RIVER ICE MODEL

4.1 Kalajoki

The Kalajoki watercourse with its small number of lakes is typical for the watercourse area near the coast, when the annual flow fluctuations are great. The spring floods are often sudden and ice jams cause considerable damage.

The model has been used to calculate ice cover formation and growth in the 75 km long river reach for three winters. The observed and calculated ice coverage for the study reach for December 15. 1985 are presented in figure 3.

4.2 Oulujoki

The simulation of the dynamic ice cover formation and growth has been made for a 38-km long river reach in the Oulujoki river between Montta and Merikoski power plants for four winters. Figure 4 presents the observed, calculated and simulated open channel stages 25 km down stream of power plant Montta for the time between December 1. and December 25. 1986.

4.3 Perhonjoki

The Perhonjoki watercourse with its small numer of lakes is as well typical for the watercourse area near the coast, where the annual flow fluctuations are great. The regulation capacity of the Perhonjoki watercourse was increased by increasing the water level of the low grass-grown lakes and by forming a connected group of lakes.

Using the river ice model it was calculated how the melting of ice could be speeded up in the spring by utilizing the heat storage of the lake.

The study reach, which is 4,5 km long is controlled by the upstream power plant. The calculated ice cover thickness and observed mean thickness of the ice cover for cross-sections located 3,6 km and 2,7 km downstream of power plant are plotted in figure 5.

The utilization of the lake heat storage was simulated for years 1977 and 1985. In addition to that, a sensitivity analysis was done, in which the assumed temperatures for the water flowing out of the lake was 0,25°C, 0,30°C and 0,35°C (figure 6). The best results, in regard to the melting of the river ice, were achieved by emptying the reservoir (6 million m^3) of the lake group during two weeks in the beginning of April.

4.4 Kyrönjoki

The Kyrönjoki watercourse lies as well near the west coast. The spring floods are often sudden and ice jams cause considerable damage. The largest uniform flood area (80 km^2) in Finland is situated in the Kyrönjoki area.

The River Seinäjoki is tributary river of the River Kyrönjoki. Three artificial lakes called Kyrkösjärvi (6,5 km^2), Kalajärvi (11,3 km^2) and Liikapuro (3,1 km^2) lie on the River Seinäjoki Basin. The main problem on this River Seinäjoki reach is, that water level fluctuations, partly because of short time regulation, during winter time are too large and water rises over the ice cover increasing the ice thickness. Flood damages for fields and summerhouses have occured and bank erosion has been remarkable.

The River Ice Model has been used in planning water construction works and wintertime operation of the watercourse. One of the main targets was that the formation of frazil ice and hanging dams would be as it minimum. In figure 7 there is presented the solution where the water level has been rised by several submerged weirs.

4.5 The Jing-Mi Canal, China

The Jing-Mi Canal, from the Miyun reservoir to the Beijing city, is the major water conveyance channel in the Beijing municipality. The 110-km long canal with a total of 440 structures was constructed between 1960 and 1965. The main purpose of the project during its construction was irrigation, but at present the Jing-Mi water conveyance canal is becoming increasingly important for domestic and industrial water supply all through the year with strong needs for relaiable winter operation. The mean temperature in winter months ranges between -2.8°C and -5.1°C and the recorded extreme low temperature is -27.4°C.

The project to enable water transport during winter time was started in 1987 as a Chinese-Finnish cooperative project within the governmental technical-scientific cooperation agreement. During the winter period of 1988/1989 the upper part of the Jing-Mi Canal was, based on numerical model investigations, successfully used to divert water. Extensive observation of the winter regime has been undertaken.

The water temperature at the canal intake varied with date. The maximum water temperature was 3.99°C and the lowest temperature was 1.54°C. The observed distribution of water temperature in the longitudinal direction of the canal showed the strong effects of sun radiation and transport velocity of temperature on the distribution. This observation data has been used for accurate model verification. The calculated and observed water temperature values for syphon 13 km down stream of the reservoir has been presented in figure 8.

5. CONCLUSIONS

The River Ice Research Project has been a big step in the field of river ice hydraulics in Finland. The applications of the model have given good results and the model is used by experts working on river ice problems.

The river ice model can be used e.g. in the planning of watercourse projects, in the estimation of the ecological effects of the projects, in flood protection, as well as in the planning of hydropower production and in the operational use of regulation.

The river ice model is also suited for studying the effects of changes in the climate. The greenhouse effect is estimated to cause changes in Finland, i.e., the wintertime discharges will increase and the temperatures will rise. By using the forecast weather conditions and changes in discharge as basic data, the effects of the greenhouse effect on the ice condition of rivers can be studied using the river ice model.

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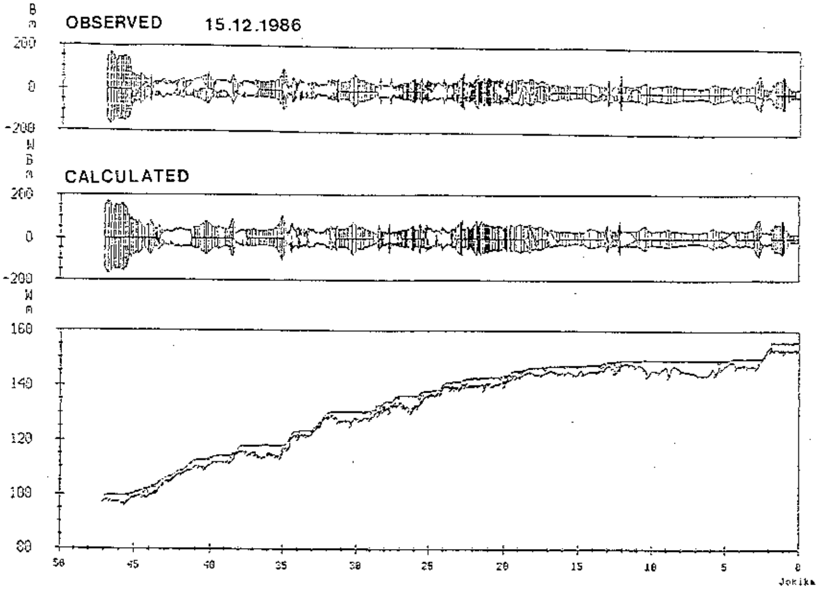

Figure 3. Observed and calculated ice coverage for Kalajoki along the 45 km long river reach.

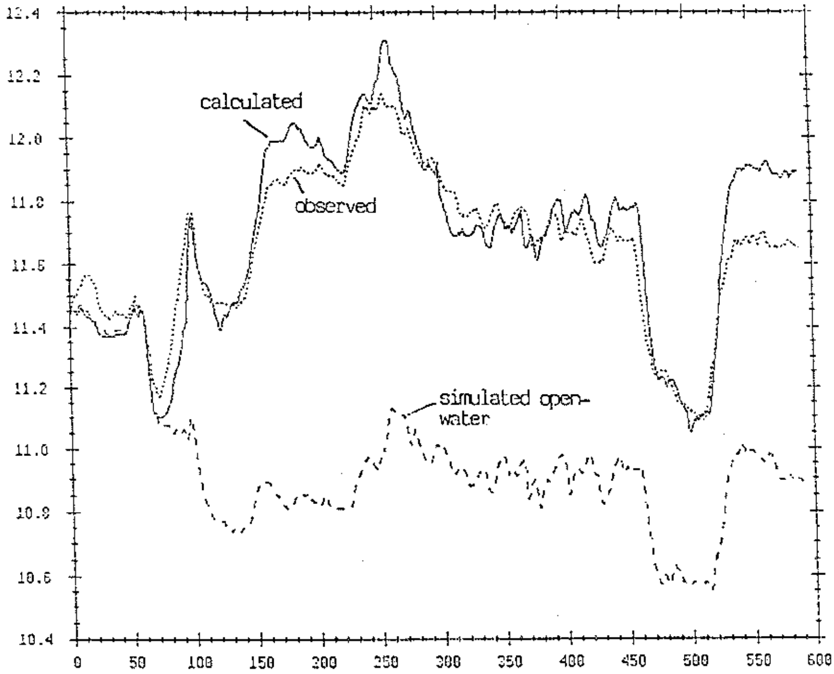

Figure 4. Observed and computed stages 25 km down stream at power plant Montta December 1 - 25, 1986.

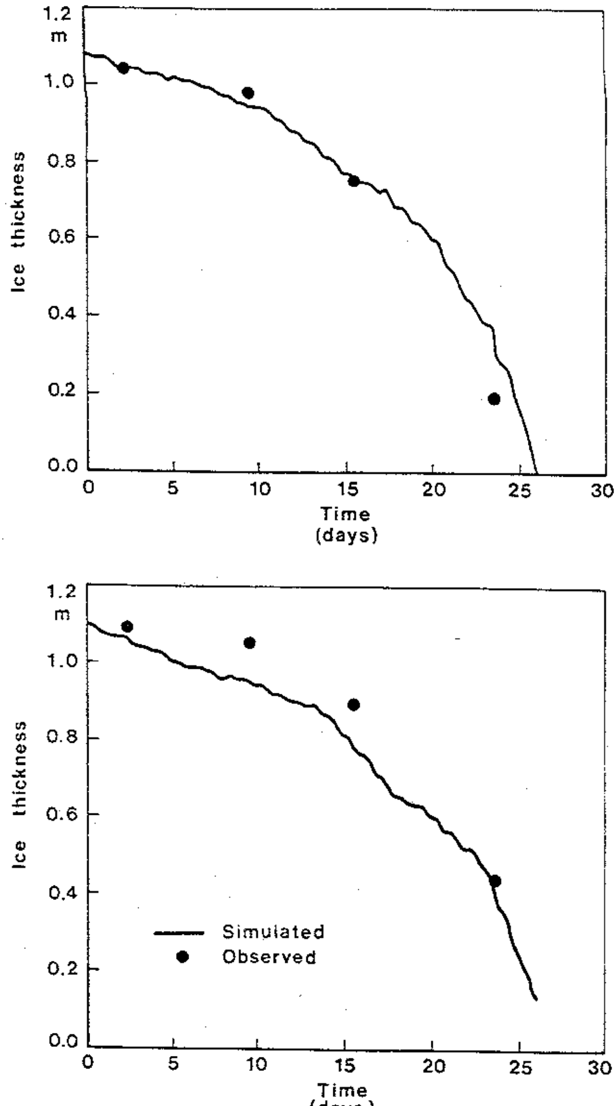

Figure 5. Calculated and observed decay of the ice cover Perhonjoki river April 1987 2,7 and 3,6 km downstream of power plant.

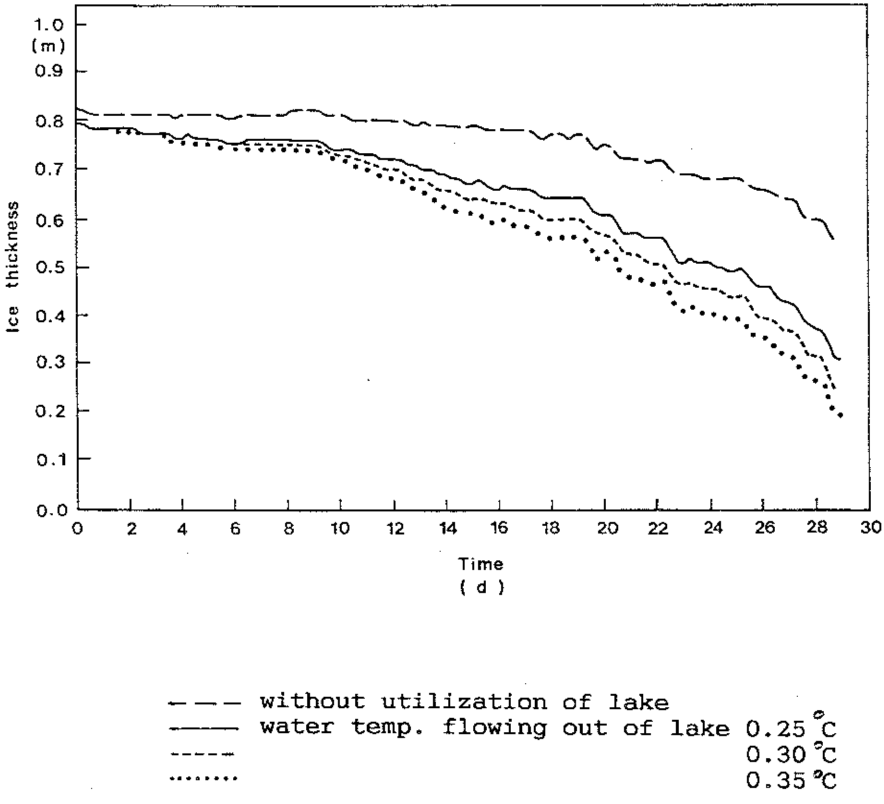

Figure 6. Calculated ice thicnesses in April 1977 2,7 km downstream of the power plant.

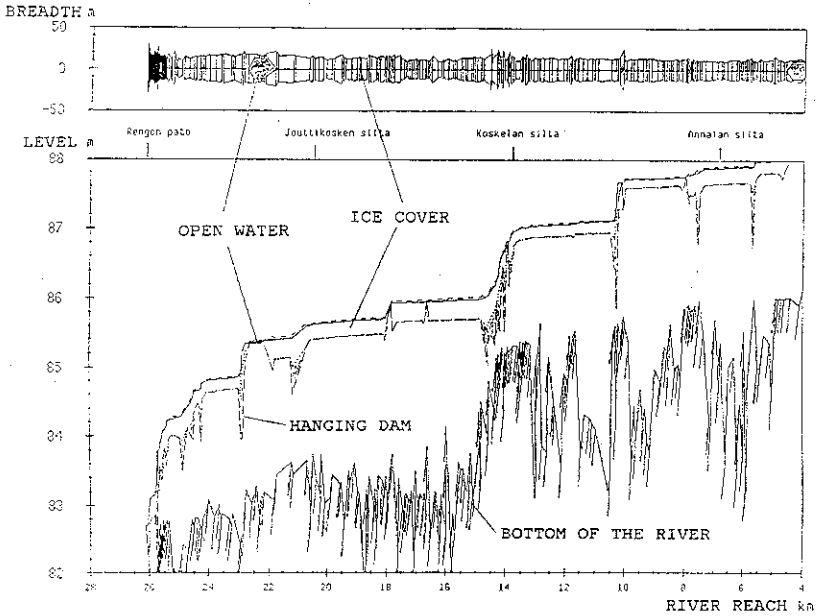

Figure 7. The calculated formation of ice cover in River Seinäjoki, Q = 7 m^3/s after constructed the weirs.

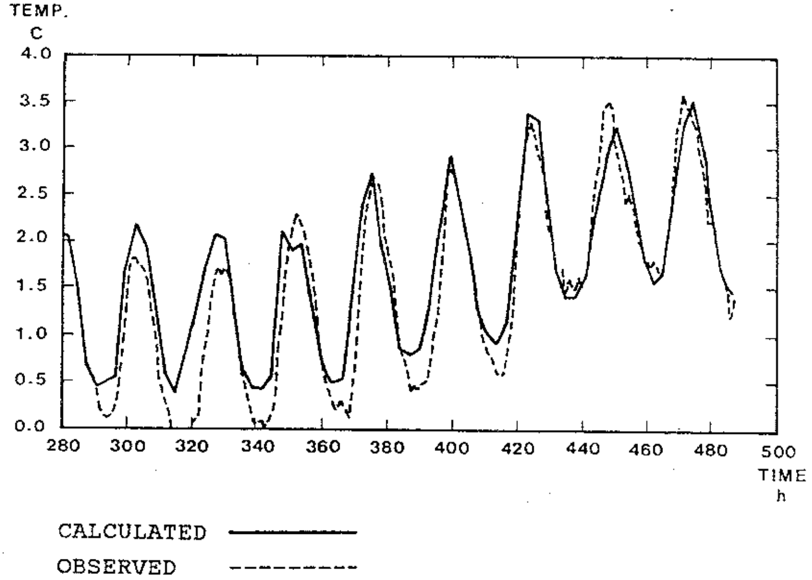

Figure 8. Calculated (————) and observed (----) water temperature hydrograph for the syphon 13 km downstream of reservoir from February 1 to February 9, 1989, Jing-Mi Canal