RIVICE MODEL UPDATE

K. Martinson[1], M. Sydor[1], Numa Marcotte[2] and Spyros Beltaos[3]

[1]Environment Canada, Hull, QC, Canada
[2]Hydro-Québec, Montréal, QC, Canada
[3]NWRI, Environment Canada, Burlington, ON, Canada

ABSTRACT

Environment Canada, with several private and government agencies, has been involved in the development of a River Ice Model (RIVICE) since September, 1988. The development of the model to-date was conducted by a consortium of five major consulting firms to a point where some of the components were tested with data from actual rivers. Due to the importance of establishing a coordinated effort in the development of a non-proprietary numerical model on river ice, funding has been provided by a variety of organizations including; Environment Canada, Supply and Services Canada, Transport Canada, Department of Indian and Northern Development, Canadian Electrical Association, Ontario Hydro, New York Power Authority, Hydro Québec, Manitoba Hydro, SaskPower, U.S. Geological Survey and the Swedish State Power Board.

This model is intended to be a comprehensive numerical river ice model designed to simulate the time-varied ice regime and corresponding hydraulic conditions as a function of meteorologic conditions, bathymetry of the river, and hydraulic/heat/ice input conditions provided at the boundaries or along the river channel system. The ice processes which are modelled through user input parameters encompass water cooling, ice generation, transport, ice cover formation, thickening, shoving, eroding, melting and break-up.

Proceedings of the Workshop on Environmental Aspects of River Ice, T.D. Prowse (Editor), National Hydrology Research Institute, Saskatoon, Saskatchewan, 1993, NHRI Symposium Series No. 12, p. 127-144.

The model is presently composed of twelve well-defined modules which are designed to simulate distinct ice processes or control the input/output data and the computation procedure.

This paper will outline the global design of the model and provide an indication of the extent of work required both in the short and long term on the model. It is presently proposed that Environment Canada and several other agencies will direct the completion of Phase One of the RIVICE model by 1994.

The potential applications of this model are diverse. The model is intended to be used for hydrotechnical studies relating to flood damage reduction, hydro-electric generation and river control, flood warning, river ice crossing evaluation, research applications and as a valuable tool for environmental impact assessment of various river projects. The model will be a useful instrument for a large number of potential users including; hydro-electric utilities, other types of river engineering project personnel, river basin planning and management agencies, river ice survey personnel and researchers.

INTRODUCTION

RIVICE is a non-proprietary comprehensive numerical river ice model designed to simulate the time-varied ice regime and corresponding hydraulic conditions as a function of meteorological conditions, bathymetry of the river and the hydraulics/heat/ice input conditions at the boundaries of the river channel system (inlet, outlet and tributaries of the river).

Environment Canada, in collaboration with several private and government agencies, has been involved in the development of RIVICE since 1988. Development to-date has involved a consortium of five major consulting firms to a point where some of the components were tested with data from actual rivers. A substantial portion of work has been completed on the model and is documented in a series of 4 volumes which include a User's manual, Technical Appendices, Programmer's Manual and a Listing of the Current Coding of the Model.

The major processes which are modelled through the aid of user input parameters are:

- water cooling
- ice generation
- transport
- ice cover formation
- thickening
- shoving
- eroding
- melting
- break-up

MODEL STRUCTURE

The structure of the model is modular and is currently composed of 11 separate modules. Each module is designed to simulate specific ice processes or control the input/output data and the computation procedure. Each module is semi-independent of the other modules and can be tested independently with test data.

A variety of options for linking the modules are available to the user to simulate the required ice processes, without employing modules which may not be required in a particular situation. Future changes to the model can be facilitated as advancements in current ice knowledge are made or if the user wishes to make changes to the model for a particular application.

A list of the modules which compose the RIVICE model are:

- input
- output
- hydraulic modelling modules:
  steady-state and time-varied
- heat balance
- border ice
- open water ice generation
- initiation of ice cover
- ice cover evolution:
  ice cover progression and breakup ice jams
- ice cover break-up

MODEL FEATURES

The model sub-divides the computational river reach into two different types of reaches (with and without ice cover). The heat balance, border ice, open water ice generation and anchor ice modules are used to simulate the ice regime in reaches without a stable ice cover. For reaches with an ice cover and experiencing freeze-up, the ice cover evolution module is implemented, whereas, for reaches with an ice cover under breakup conditions, the ice cover breakup and breakup jams modules are used.

The time-varied hydrodynamic model could not be directly coupled with all of the ice modules due to the number and complexity of ice processes. As a result, a "loosely-coupled" approach where the local changes in the calculated ice cover are a function of the corresponding calculated approximate changes in hydraulic conditions during each computational time step was developed. Currently, only the ice cover progression calculations are "loosely-coupled" with the hydraulic conditions. Border, anchor and solid ice covers are directly coupled with the time-varied hydrodynamic module but only preliminary testing has been completed to-date.

The subdivision of river cross-sections into sub-sections is a vital element for the analysis of ice generation and decay. The hydraulic components of the RIVICE model distinguish zones of low flow velocity from zones of intermediate or high flow velocity. Accordingly, the different types of ice progression and regression or melting can be computed.

DRIVER

The driver, although not considered as a separate module, is the main program that controls the simulation logic of the RIVICE model and the data flow of variables between the modules. Through the driver the input data is verified. Options for specifying the initial conditions through either the steady-state or transient hydraulic modules are available in addition to the initialization of ice and temperature conditions. The control of the simulation time interval used by the model if significant changes in hydraulic and/or ice conditions are encountered is through this program. Simulation of hydraulic conditions through either the steady-state or transient hydraulic modules is also controlled through the driver.

The ice cover conditions which may be fixed by the user or vary according to the simulation results are managed by the driver. Printing of intermediate output after each principle computations module can aid in successful model runs. Start-stop capabilities such that a reload file is generated to continue simulation from the last time step is another key feature of the driver. A simplified flowchart of the driver is shown in Figure 1.

SUMMARY OF THE MAIN MODULES

Pre-processing Phase (input)

Three main steps are required to generate an executable computer program module and to complete an input data set. The arrays in the source code must be dimensioned followed by a compilation. Input card groups are then required which produce both geometrically interpolated cross-section coordinates and hydraulic tables of cross-section data characteristics. And finally, the initial water temperature and ice conditions must be specified.

Output

The model will produce a large range of output. This output includes: warnings related to the input files, printouts from running through the input files which include geometrically interpolated cross-sections and hydraulic table values, intermediate printouts after the major modules are executed and a possibility of up to six summary output tables.

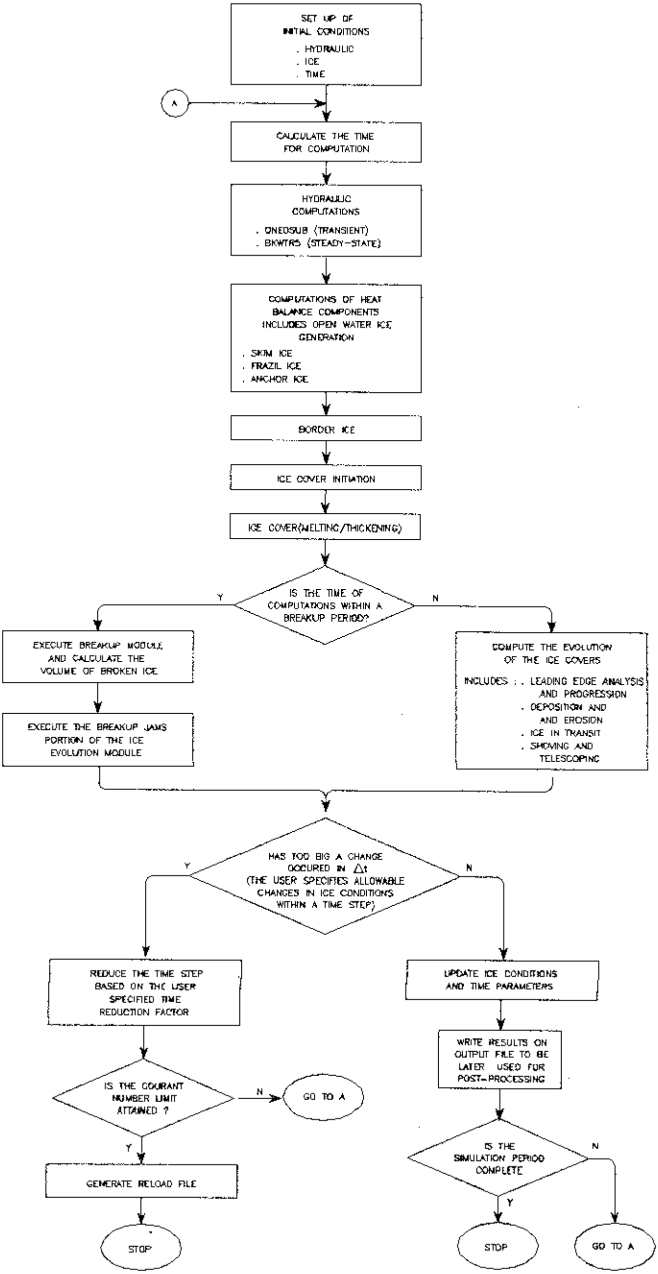

FIGURE 1

SIMPLIFIED DRIVER FLOWCHART

BKWTR5 (Steady-State) Hydraulic Module

The steady-state hydraulic module was developed specifically for the RIVICE program. This module is capable of simulating supercritical flow conditions and includes the distribution of the mean values of the hydraulic characteristics at the cross-sections along the transversal direction thereby making the module PSEUDO-2D. The computations within the module are based on the direct step method for calculating water surface profiles. The steady-state hydraulic computations proceed from downstream to upstream.

ONE-D (Time-Varied) Hydraulic Module

Transient hydrodynamic flow computations are performed with a modified Environment Canada One-Dimensional (ONE-D) Hydrodynamic Model. The model originated from the works of Gunaratnum and Perkins (1970) and Wood, Harley and Perkins (1972) of M.I.T. The model incorporates a finite-difference scheme which integrates the St. Venant equations over a wide range of transient flow conditions. Duplicate solution procedures use the Galerkan techniques of weighted residuals in solving the linearized St. Venant equations.

The model has been used to solve transient flow conditions in rivers and tidal estuaries or multiple-channel network situations where conventional routing models often cannot be applied. The model can be structured to accommodate dams, weirs, bridges, pumping stations and other structures described by equations or curves for both steady-state and transient conditions. The ONE-D model has been successfully applied to a variety of river systems across Canada including the St. Lawrence River, Fraser River, Salmon River in Nova Scotia, Peace-Athabasca Delta and, more recently, the Serpentine and Nicomekl rivers in British Columbia.

The open-water model has been supplemented by additional routines which take into account the effects of the ice cover on the flow hydrodynamics. The computations of hydraulic parameters such as the wetted perimeter, the composite roughness and the submerged thickness of ice cover form part of these routines. In addition, when the model is computing in an ice-covered mode, the elevation of the phreatic water level and the flow discharge are determined. This is similar to the open-water calculations, however, certain terms from the St. Venant equations are neglected. This does not appear to be a serious shortcoming but could be further investigated in the future.

Heat Balance Module

This module is based on extensive work undertaken by Hydro-Québec on the steady-state river ice program, RHIVER, which was used for the Archipel Project in the mid 1980's. Hydro-Québec provided financial support over a period of several years to make the ice observations required for writing, analyzing and validating this program.

The main function of this module is to calculate the change in water temperature between two successive cross-sections. This is done by computing the heat exchange fluxes at the air-water interface or at the ice-water interface if there is a partial or a total ice cover. The module also calculates the water temperature of the tributaries by making a distinct thermal budget computation. Presently, the the computations are made under steady-state conditions, neglecting the temporal gradient of the water temperature in the equation of heat conservation for transient conditions.

When the water temperature reaches below 0°C, the open-water ice generation subroutines are called and the super-cooling is applied to generate the appropriate type of ice. A water temperature above 0°C induces ice melting and the release of anchor ice. Finally, the module merges all types of floating ice in order to predict total quantities of ice and update the thermal budget.

Open-Water Ice Generation

In this module, the possibility of skim ice generation is examined first. If certain criteria are satisfied, skim ice starts to form, extends, thickens and can be broken into pieces in rapids. As a net result, the module calculates quantities and dimensions of floating ice at every cross-section.

Similarly, if certain conditions are satisfied, frazil ice starts to form, continues to grow, agglomerates, floats to the surface and thickens by freezing. The quantity of generated ice and the approximate dimensions of frazil floes are computed at every cross-section.

The anchor ice subroutine consists of two separate parts. When water is super-cooled and certain conditions are satisfied, the anchor ice starts to grow and then continues to thicken and densify. When the water temperature is above 0°C, anchor ice is progressively released from the channel bottom. The module predicts ice thickness on the river bed, the volume of anchor ice, approximate ice density, river areas where it grows and the time at which the ice is released.

Border Ice

The prediction of border ice growth is not well understood and, as a result, several options were incorporated in RIVICE to offer flexibility to the user. The user may specify the border ice width at each cross-section at specific times during the winter simulation or specify a relationship between cumulative degree-days of freezing and total border ice width for individual cross-sections based on known or observed conditions in the river, user's judgement or from the product of an externally devised methodology. One of the methods is a recently developed theory (Matousek, 1984) which relates the maximum streamwise flow velocity into which border ice can advance laterally, to local conditions of heat loss at the open water surface, water temperature, air temperature and wind speed.

Ice Cover Initiation Module

The initiation module checks on the possibility of an ice bridge formation due to border ice coverage and also allows a user imposed bridge at any location and at any time during the simulation period. This module has been formulated as a user specification of ice cover initiation since state-of-the-art in predicting bridging of moving ice in a channel is not considered sufficiently advanced to justify a detailed simulation of this process.

Ice Cover Evolution Module

This module is based on the ICESIM model developed and used by Acres International Ltd. This module includes the important process of collapse and "telescoping" which no other model attempts to do. The ICESIM model has been applied to many river studies and its parameters have been extensively quantified.

The evolution module predicts leading edge accumulation, ice cover thickness changes due to hydraulic forces, ice transport and deposition and erosion of ice cover at high velocity zones. The upstream advancement of an ice cover due to accumulation of incoming ice pans or floes, changes in thickness due to hydraulic forces and transport of ice under the cover, including effects of deposition and erosion are all simulated with this module.

A second part of this module simulates the accumulation of an ice cover resulting from the supply of broken ice from upstream, otherwise known as breakup jams. Key parameters such as leading edge stability and cohesion are specified as having different values from those used for formation.

Ice Cover Breakup

Through this module the user is able to either specify the breakup of the ice cover in a selected river section or have the program identify breakup on the basis of shear stresses which may exceed a user specified limit or increases in water level above a user specified maximum. Ice breakup is represented as an instantaneous conversion from stationary ice into moving ice on the surface of the river.

TESTING OF THE MODEL

All of the major modules have been tested individually and some of the modules have been linked together through the Driver which controls the computation logic and flow of information between modules.

Initial testing has been undertaken on a simple 4 reach theoretical channel system 270 km in total length. As part of this initial testing, the steady-state module (BKWTR5) was used to theoretically test the linking between various ice processes. The water depths computed by the BKWTR5 module were slightly lower than theoretical values. This was attributed to the non-uniform velocity distribution across the channel which is a function of the conveyance of each sub-section and a common slope of the energy grade line.

Following the establishment of initial hydraulic conditions, the heat balance, ice generation and anchor ice conditions were computed successfully without invoking border ice and the other ice cover modules.

FUTURE WORK

Short-term

A computational scheme that accounts for the temporal gradient of water temperature is required since it is omitted in the existing formulation of the heat balance module. The "marching downstream" scheme was intended to accomplish this, but short-comings due to numerical dispersion have been discovered. The feasibility of using the finite-difference temperature scheme inherent in the ONE-D model or a modified Lagrangian scheme are presently being investigated. The advantages of using the finite-difference scheme include its ability to handle multi-channel flows, reversal of flows, storage of water under ice covers (volume of inflow not necessarily equal to volume of outflow), its ability to operate at small time-steps (less than one hour) and its established effectiveness on a variety of water quality studies to-date. The Lagrangian scheme for computing water temperature in rivers appears to require significant programming in order to handle channel networks and the reversal of flows.

The Driver will likely require a considerable amount of work in its present state to ensure that it is completely interactive with all of the other modules. The viability of using the ONE-D hydrodynamic module as a modified Driver for the model is presently being examined. The routine within the Heat Balance module which computes solar radiation must be modified to make computations on an hourly basis with the ability to interpolate between these values.

The BKWTR5 module should be modified to account for lateral inflows into the system. Some of the empirical constants in the heat balance and open water ice generation routines inherent in the code should either be eliminated or input by the user. The inclusion of a changing Manning's "n" value of ice cover to represent realistic increases in roughness from the thin leading edge to the equilibrium thickness further downstream in the ice cover would be advantageous.

Improvements to the running time of the model will be considered. The testing of each of the modules and the overall linkages to the Driver has yet to be completed for the steady-state case. Once satisfactory results have been obtained with the model under steady-state conditions, then the model should be thoroughly tested under transient conditions. Using available data on both the St. Lawrence and Nelson rivers the model can be tested against actual ice conditions.

Long-Term

As developments in research are made, improvements can be made to the model. Inclusion of an algorithm which simulates the bridging of an ice cover and representation of the strengthening of an ice cover (increase in cohesion value) with age during the ice formation would be beneficial.

The development of credible means to represent declining ice cover strength in spring and link it to the break-up potential should also be included. The accommodation of grounding forces and its effects on ice cover shoves could be added to the ice evolution module. The refinement of erosion/deposition modes to be driven by varying velocities across a cross-section could also be appended.

In essence, since the RIVICE model is modular, modifications and additions can be easily accommodated or carried out.

CONCLUSIONS

The RIVICE model will prove to be a valuable tool for the environmental impact assessment of various river projects. It is anticipated that the projected short-term work will be completed by 1994.

REFERENCES

Carson, R., 1991. Design of Ice Cover Evolution Modules for RIVICE. Proceedings of the 6th Workshop on the Hydraulics of River Ice. Ottawa, Ontario, October 23-25, 55-68.

Gunaratnum, D.J. and F.E. Perkins, 1970. Numerical Solution of Unsteady Flows in Open Channels. Report No. 127, Hydrodynamics Laboratory, Dept. of Civil Engineering, M.I.T. Cambridge, Massachusetts, 260 pages.

Holder, G. and R. Saadé, 1991. Design of Heat Balance, Ice Generation and Cover Modules. Proceedings of the 6th Workshop on the Hydraulics of River Ice. Ottawa, Ontario, October 23-25, 35-50.

Ko, P., G. Holder and M. Sydor, 1991. Hydraulic Model of "RIVICE". Proceedings of the 6th Workshop on the Hydraulics of River Ice. Ottawa, Ontario, October 23-25, 27-32.

Marcotte, N., 1986. A Simple Mathematical Model of Moving Sheet Ice. IAHR Ice Symposium. Iowa City, Iowa, August 18-22, 89-100.

Marcotte, N. and S. Robert, 1986. Elementary Mathematical Modelling of Anchor Ice. Proceedings IAHR Symposium on Ice. Iowa City, Iowa, August 18-22, 493-506.

Matousek, V., 1984. Types of Ice Run and Conditions for their Formation. Proceedings of IAHR Ice Symposium. Hamburg, Germany, August 27-31, 315-327.

Petryk, S., R. Saadé, M. Sydor and S. Beltaos, 1991. Global Design of the Numerical River Ice Model "RIVICE". Proceedings of the 6th Workshop on the Hydraulics of River Ice. Ottawa, Ontario, October 23-25, 3-18.

Petryk, S., M. Sydor, B. Korbaylo, T. Quach, R. Carson and G. Holder, 1991. Proceedings of the 6th Workshop on the Hydraulics of River Ice. Ottawa, Ontario, October 23-25, 71-81.

Tecsult Inc., Acres International Ltd., LaSalle Consulting Group Inc., SNC-Shawinigan Inc. (TALAS) and Environment Canada, 1993. RIVICE Model Documentation for Volumes I, II, III and IV. Prepared for River Ice Project Steering Committee.

Wasantha, M. and T. Shen, 1991. Mathematical Model for River Ice Processes. ASCE, Journal of Hydraulic Engineering, 117(7).

Wood, E.F., B.M. Harley and F.E. Perkins, 1972. Operational Characteristics of a Numerical Solution for the Simulation of Open Channel Flow. Report No. 150, Department of Civil Engineering, M.I.T. Cambridge, Massachusetts, 186 pages.

DISCUSSION

Rick Cunjak:

Can RIVICE work on small streams (i.e. mean annual flow of approximately 1 cms) which are often the most biologically productive of river systems?

Reply:

The model could be applied to small streams but the amount of data required for such a study would be extensive and may be cost prohibitive. The RIVICE model is initially being designed for use in hydrotechnical studies relating to flood damage reduction and the environmental impact of proposed structural and flow regulation changes in medium to large river systems. Hydraulically, the numerical model is capable of solving flow problems of 0.1 cms in 1 meter wide channels.

K.S. Davar:

One of the transparencies stated that the RIVICE model can accommodate dams, please elaborate on this statement.

Reply:

Using the steady state (BKWTR5) hydraulic portion of the RIVICE model, a dam would be modelled by considering the spillway section as a super-critical reach, which would have its ice generation capabilities. In the case of the dynamic (ONEDSUB) portion of the model, several possibilities exist. If the dam is upstream of the river section being modelled, the flow, water temperature and quantities of ice discharged would be used as upstream boundary conditions for the model. If the dam is located within the river system, the dam is treated as a junction node where flow from upstream is moved downstream and the control is either through a rating curve, discharge with respect to time or an elevation with respect to time relationship (the model can handle both a turbine discharge and spillway discharge at the same time). In the event of the dam being located downstream, a similar relationship would also be beneficial to model the amount of flow leaving the system. The RIVICE ice regime theory could allow for the transfer of ice from upstream to downstream of the dam.

Darryl J. Calkins:

How is overbank flow handled by the two hydraulic models?

Reply:

The steady state hydraulic section of the model doesn't take into account storage regions in the channel cross-section. The dynamic hydraulic section of the model can effectively model conveyance and storage areas within a channel cross-section. Adjacent separate channel sections between which overflow can happen under flood conditions can be modelled with the dynamic section of the model.

Darryl J. Calkins:

There are at least 2 other river ice simulation models (RICE (Clarkson University) and JJT (Finnish versions)). What are the advantages/disadvantages of RIVICE versus these other two models?

Reply:

The main difference between these other models and RIVICE is the degree of model usage and testing. Both of these models are relatively new and have only been minimally tested with actual field data. The RIVICE model incorporates the logic and parameters of specialized models that had already been developed in Canada and used for many years in various rivers, in order to simulate certain specific processes. The model RHIVER was developed by Hydro-Québec to predict water cooling and ice production, including anchor ice and was calibrated by means of data taken under a comprehensive data collection program. Similarly, the model ICESIM, developed and used by Acres International Ltd., predicts the evolution of an ice cover, including the very important process of collapse and "telescoping" which no other model attempts to do. ICESIM has been applied to many river studies and its parameters have been extensively quantified. The Environment Canada ONE-Dimensional hydrodynamic model which models the dynamic hydraulic regime has also been successfully used on an extensive number of river studies across Canada including the St. Lawrence River, Fraser River, Red River, Salmon River in Truro and the Peace-Athabasca Delta.

In addition, both JJT and RICE have some limitations that render them less representative of Canadian conditions. For example, JJT is exclusively a freeze up model. It does not check the stability of an ice cover and therefore, cannot simulate the "wide" type of ice jam but it appears that this phenomenon, very common in Canada, is infrequent in Finnish Rivers. The RICE model does consider the wide jam case but uses the "equilibrium" thickness equation and selects the lesser of the two possible roots, which could lead to significant errors.