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GLOBAL DESIGN OF THE NUMERICAL RIVER ICE MODEL "RIVICE"

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ABSTRACT

Since September 1988, TALAM has been working on a three year project with Environment Canada and several other industrial and government agencies on the development of a non-proprietary comprehensive numerical river ice model called "RIVICE". This model is 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 at the boundaries of the river channel system (inlet, outlet, and tributaries of the river).

The model mainly consists of the following components : (1) the "driver" or main program which controls the computation logic and flow of information between the modules, and (2) the individual modules whose main function is to compute the evolution of hydraulic and ice conditions as a function of time. These modules are : steady-state backwater hydraulics, time-varried hydraulics, heat balance, open water, ice generation, border ice, initiation of an ice cover, freezing/melting of the ice cover, ice cover evolution during freeze-up, ice cover breakup, and breakup ice jams.

This paper presents the global design of the model including : the list of modules representing the various ice processes; a description of the preprocessing phase concerned with the input of the various data files; the design of the driver which controls the computation logic and the user interaction with the model during simulation; and finally the input data requirements and output data format. Four other papers in this Workshop describe the design of the respective modules and a fifth paper will give examples of simulated results.

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INTRODUCTION

"RIVICE" is the name of a comprehensive non-proprietary numerical river ice model which has been programmed and is current by undergoing testing. This model development project started in September 1988, and a preliminary version of the model is expected to be completed at the beginning of next year (1992).

OBJECTIVES OF THE MODEL

The numerical river ice model "RIVICE" has been designed to simulate the complex phenomena of water cooling, ice generation, transport, ice cover formation, thickening, shoving, eroding, melting and break-up. The model is principally based on existing state of the art knowledge on river ice. In addition, every effort is being made to introduce important new concepts. For example, advancements are foreseen in the capability of modelling the evolution of ice conditions under time-varied flow conditions. The modelling of the associated transients is required for the proper evaluation of hydrodynamic conditions, and the corresponding forces and effects on the ice cover.

The model is composed of eleven semi-independent modules in order to facilitate future improvements to the model. A detailed outline of the capabilities of each module is given in the "Model Definition Report" (TALAM 1989), the various programming instructions reports, and a recently completed draft of the "User's Manual".

At the conclusion of the project, a non-proprietary numerical river ice model will be available which may be used by a relatively large number of users. This should encourage its application on a large number of rivers and encourage a common forum for exchange of future modelling experience. In turn,

PROJECT ORGANIZATION

The project is being sponsored by the River Ice Project Steering Committee. The agencies which make up the Steering Committee, and are financially supporting the work of the consultants, are : four Federal government agencies (through Department of Supply and Services, Environment Canada (Inland Waters Directorate - IWD), Department of Transport, and Department of Indian Affairs and Northern Development - DIAND), the Canadian Electrical Association, Ontario Hydro, New York Power Authority, Manitoba Hydro, Hydro-Québec, SaskPower, U.S. Geological Survey, and Swedish State Power Board.

The model development is being done by a Project Group consisting of "TALAM" (which represents the consultants consisting of Tecsult, Acres International Ltd., LaSalle Hydraulic Laboratory and MacLaren Plansearch (Lavalin), and a relatively large number of representatives of the sponsoring agencies. TALAM is primarily responsible for designing, testing and documenting the model. The Inland Waters Directorate is responsible for the programming, and providing assistance in the testing and documentation of the model. The other sponsoring agencies will furnish field data and provide numerical modelling and river ice expertise related to their particular experiences, which include 13 agencies as follows: IWD, DIAND, B.C. Hydro, Manitoba Hydro, Ontario Hydro, New York Power Authority, Hydro-Québec, Alberta Environment, Ministère de l'Environnement du Québec, Ontario Ministry of Natural Resources, N.B. Department of Municipal Affairs and Environment, Department of Fisheries and Oceans and U.S. Cold Regions Research and Engineering Laboratory. The Alberta Research Council, Trans Alta Utilities, and the Government of Northwest Territories (Department of Public Works) have offered access to river ice data for this project. Finally,

Reaches Without an Ice Cover

The heat balance (Module D), generation and breakup of border ice (Module E), and open water ice generation and anchor ice (Module F) modules are used to simulate the ice regime in reaches without a stable ice cover. Ice transported downstream and an ice cover is initiated via the module used to initiate the ice cover (Module H).

Reaches With an Ice Cover

For reaches with an ice cover, the evolution of ice cover thickness is evaluated depending on whether freeze-up conditions or break-up conditions are being calculated. For freeze-up calculations, ice cover evolution, including progression and ice cover thickness changes are evaluated in Module I.

The break-up of the ice cover (user specified) and the formation of break-up ice jams (ice cover progression and evolution of thickness changes) are performed in Module K.

COUPLING BETWEEN HYDRODYNAMICS AND ICE CONDITIONS

Certain changes in the ice cover thickness and/or extent can produce relatively sensitive changes in the hydraulic conditions. All the ice modules cannot be directly coupled with the time-varied hydrodynamic module. The number and the complexity of ice processes do not make this technically feasible.

The alternative of having all the ice cover calculations uncoupled results in a two-fold problem :

1) The simulation time interval would have to be extremely small for certain rivers, as experienced on the Peace River for ice progression

calculations with the original version of SIMGLACE (Petryk 1988).

2) The solution obtained may not be correct since false intermediate values of ice cover thickness may give corresponding false hydraulic conditions. (However, the ice cover may be computed to be theoretically stable and the computed hydraulic conditions are theoretically correct).

Therefore, a "loosely-coupled" approach has been adopted for "RIVICE". In this approach, local changes in the calculated ice cover are a function of the corresponding calculated approximate changes in hydraulic conditions during each computational time step. Currently only the ice cover progression calculations are loosely coupled with the hydraulic conditions. However, depending on the results to be obtained from simulation tests, other ice processes which modify the ice cover may be eventually included in the future versions of the model.

The loose coupling of ice cover progression calculations with the hydraulic conditions is carried out by assuming steady state conditions at the leading edge of the ice cover as the ice cover progresses upstream. The discharge at the leading edge is a function of its position in the river; the discharge values for each time step are obtained from the time-varied module ONEDSUB. Subsequently, the computed values of ice cover thickness are evaluated with the Newton-Raphson method whereby the juxtaposition condition for the progressing ice cover is matched with steady-state backwater conditions. The approximate hydraulic conditions are subsequently re-evaluated with the time-varied flow computations with ONEDSUB in the next time interval.

Subsequent to the ice cover progression calculations, the stability of the downstream cover is checked for shoving

(Pariset, Hauser, and Gagnon 1966). If shoving occurs, the previously calculated ice cover thicknesses are adjusted to attain ice cover stability and the ice cover regresses downstream. Then progression upstream may again be considered to repeat this process.

DESIGN OF THE MODULES

References 2, 4, and 5, presented in session A of the workshop proceedings, gives a description of each of computation modules concerned with hydrodynamic, heat balance, and ice processes.

PRE-PROCESSING PHASE

Before running RIVICE, the user should go through a pre-processing phase, as illustrated in Figure 1. This phase is a preparation phase such that the user performs several manipulations to set up the input file and the source code of RIVICE ready to be compiled, linked and run.

This phase consists of three main steps leading to an executable program and a complete set of input data file. These steps identified in Figure 1 are :

A) Generation of a compilable RIVICE source code;
B) Completion of input card groups;
C) Specification of initial water temperature and ice conditions.

A) <u>Generation of Compilable RIVICE Source Code</u> : The RIVICE model uses dummy array sizes which are found in relevant label-common blocks, certain DATA statements, and certain memory storage specification statements. Therefore, the user's first function is to define the basic variables, which determine these dummy array sizes.

Upon calling the RIVGEN routine, the RIVICE source code is read and the variable array dimensions are substituted by their corresponding user-specified values, thereby generating a fixed size version of RIVICE source code. Now RIVICE can be compiled and linked.

B) <u>Completion of Input Card Groups</u> : Before running RIVICE, RCD1X.EXE and RCD2.EXE should be executed. These are two fortran programs that are respectively employed to generate :

- Geometrically interpolated cross section coordinates;

- Hydraulic tables of cross section data characteristics.

C) <u>Specification of Initial Water Temperature and Ice Conditions</u> : The initial water temperature and ice conditions are specified through UINI1.TXT. The program also has a temporary stop capability where the user can stop halfway through the simulation run, examine the results and restart the model halfway through the simulation run. In this case a reload file called UINI2.TXT is generated automatically which has the same format as UINI1.TXT. The user can edit this file and thus restart the simulation with user modified restart conditions.

DESIGN OF THE DRIVER

The "Driver" is the main program that controls the simulation logic of the model.

This section presents the Driver including its flow chart and a corresponding description of the computational procedure of RIVICE. The points where the modules are invoked in the computation procedure are illustrated along with the key options available to the user. This description also helps to illustrate the model's main simulation capabilities.

Figures 2(a) and 2(b) present the Driver logic flowchart. Each block in the flowchart is identified by a number and a corresponding text describing the logic of each block, as follows :

1. The input file is read containing the input card groups which were previously prepared in a preprocessing phase.

2. The initial hydraulic conditions are computed through either the hydraulic transient ONEDSUB module or the steady state BKWTR5 module, and the initial ice cover conditions are imposed by the user.

3. Option to print the initial conditions.

4. If this run is a reload run, then read in the reload file.

5. Initialize the computation starting time and time step, and calculate the present time of computation (step 6).

7. Calculation of hydraulic conditions. The transient ONEDSUB module or the steady-state BKWTR5 module is utilized according to the specified user option.

8. Option to print the detailed intermediate results of hydraulic variables.

9. Check if the user specified maximum allowable changes in velocity or water level have been exceeded when the solution proceeds from time "t" to "t+dt". If big changes in the hydraulic conditions have occured beyond the user specified limits, then the reload file is generated (9.1) and the program is stopped.

10. The Heat Balance for open water or ice covered conditions are computed. This module controls the logic to Skim Ice, Frazil Ice, and Anchor Ice generation, as well as the calculation of water temperature. The calculation of Border ice follows (10.1), and the initiation of Ice Covers is evaluated (10.2). For ice covered reaches, the melting or thickening of the ice cover is computed based on the evaluated heat budget (10.3).

11. Option to print a detailed intermediate output of the heat balance, open water ice generation, and/or ice cover conditions variables.

12. Check whether the new time is in a breakup period.

13. If the simulation time has reached a breakup period, then breakup and breakup jamming (step 14) calculations are performed.

15. Option to print the detailed intermediate results of Breakup and Breakup Jamming conditions variables.

16. If simulation time is outside of a breakup period then ice cover evolution during freeze-up is determined. This step of calculations

include ice cover progression, deposition and erosion, ice in transit, and ice shoving. These processes are similar to those occuring during breakup ice jam evolution except that different computation criteria is used for each process.

17. Option to print the detailed intermediate results of ice cover evolution during freeze-up conditions.

18. If "Big Changes" in ice conditions, based on user specified limits, have occured between time "t" and "t+dt" then the change in ice conditions is defined to be too rapid, and the computational time step is reduced. The reduction is either based on the user specified factor (step 20) or on the maximum Courant number (step 21).

19. Option to print the "Big Changes" parameters.

21. If the maximum Courant Number is close to the user specified value, then generate the reload file (step 23) and stop the program for user inspection of results.

22. If the Courant Number limit has not been reached, then go to step 6 to repeat the simulation with the new reduced time step.

24. If no "Big Changes" have occured, then accept the ice and hydraulic conditions, and update these values in order to proceed to simulation of conditions for the next time interval.

25. If the time step has been previously reduced and is less than its original value, then increase

gradually until the original user specified time interval is attained (step 27).

26. Update the time of computations.

28. The post-processor is called to produce the user specified summary output tables in their corresponding files.

29. Check if a start-stop option has been specified. Verify if the present time of computations is the user specified time to stop the program (step 30). If so (step 31), then generate the reload file (step 32) and stop the program.

33. If a start-stop option has not been specified or if the user specified time to stop does not correspond to the current time of simulation, then check if the simulation period is complete. If not then go to step 6 of the flow chart and compute the hydraulic, heat balance and ice conditions for the next time interval.

The above solution scheme was derived from previous experience of ice modelling and a function of the modular design of RIVICE. It may change following linking tests of the modules of RIVICE, theoretical tests of the complete RIVICE model, and testing of RIVICE for river simulation cases.

INPUT DATA REQUIREMENTS

The complete set of input data for RIVICE requires the user to prepare a total of five input files :

a) Input file "BAS22.TXT" which specifies the array sizes of the RIVICE variables, and used by RIVGEN to create a fixed size RIVICE program;

b) Input file "INRCD1X.TXT" which includes input options, river reach identification, interpolation specifications, and cross section information, and used by RCD1X.FOR to calculate the interpolated bathymetry of cross sections;

c) Input file "INRCD2.TXT" which considers the estimated initial hydraulic conditions for the reaches, in conjunction with the river characteristics generated by RCD2.FOR to produce the hydraulic tables for every cross section of the river;

d) Input file "UINI1.TXT" which utilizes the user specified reaches, and cross sections to initialize the water temperature and ice variables through the subroutine SYSINI;

e) Input file "INRIV.TXT" which is composed of the following Card Groups :

Card group	**Description**
A	Solution Options, Time Parameters, Network Topology
B	Hydraulic Description of the Reaches
BB	Meteorological and Border Ice Conditions of the Reaches
C	Orientation of Reach Related Data
D	Lateral Inflow Data
F	Hydraulic Boundary Conditions at the Nodes
H	Ice Related Constants
I	Ice Cover Regime Solution Options
J	Specification to Big Changes Criteria
K	Specification for Reloading Conditions
L	Specification of Detailed Printouts
M	Input to Summary Output Tables

The complete set of input data required for RIVICE is given in the "Users Manual".

Output Data Specifications/Options

The output data include the following capabilities available to the user :

1. Print-outs of warnings related to the improper input to files RCD1X.FOR, RCD2.FOR and RIVIN.

2. Printouts from running RCD1X.FOR and RCD2.FOR which respectively include the geometrically computed interpolated cross sections, and the corresponding calculated hydraulic tables.

3. Intermediate printouts after each of the following modules :

   - initial hydraulic and ice cover conditions;
   - hydraulic computations for the next time interval;
   - heat balance, open water ice generation, border ice, and ice cover initiation conditions;
   - ice cover evolution during freeze-up;
   - break-up and break-up jamming;
   - big changes in ice cover conditions.

4. Summary output tables consisting of six tables which are available for the user.

CURRENT STATUS OF THE MODEL AND CONCLUDING REMARKS

This paper presents an outline of a comprehensive numerical river ice model which will simulate the main ice processes with a pseudo two-dimensional hydraulic model. At publication time (Sept. 26, 1991), the detailed programming instructions have been completed except for a few remaining details, coding work is about 90% complete, the modules have been tested individually in a preliminary manner. Linking tests of the simulation capabilities of the model have been completed about 50% through the model. More specifically the driver has been linked and tested "from the top down" to the point where the following conditions are being simulated: steady state back water, heat balance, ice generation and anchor ice. A complete version of the model is expected to be ready in February, 1992.

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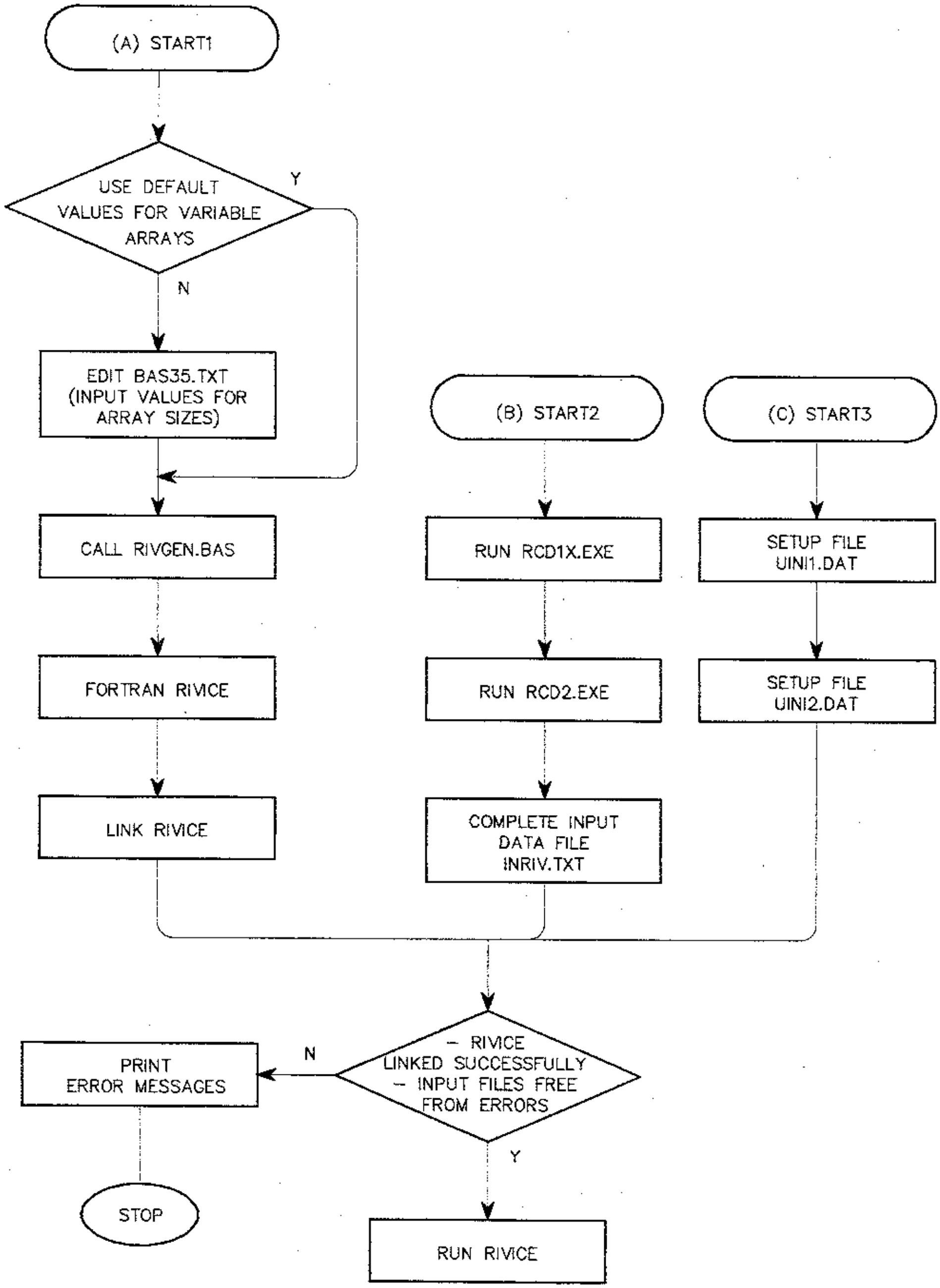

Figure 1. Pre-processing Sequence of Events

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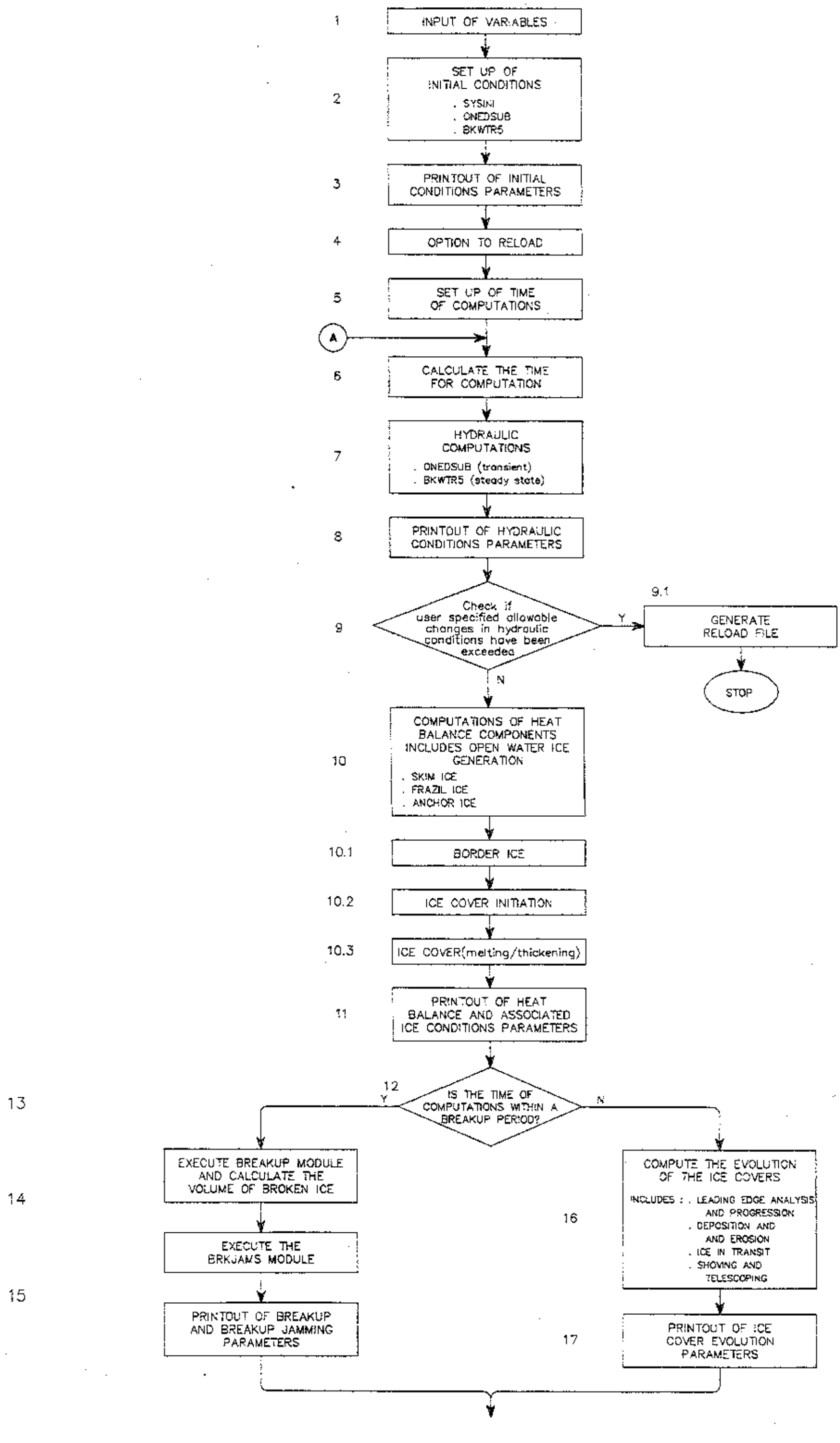

Figure 2(a): RIVICE Driver Flow Chart

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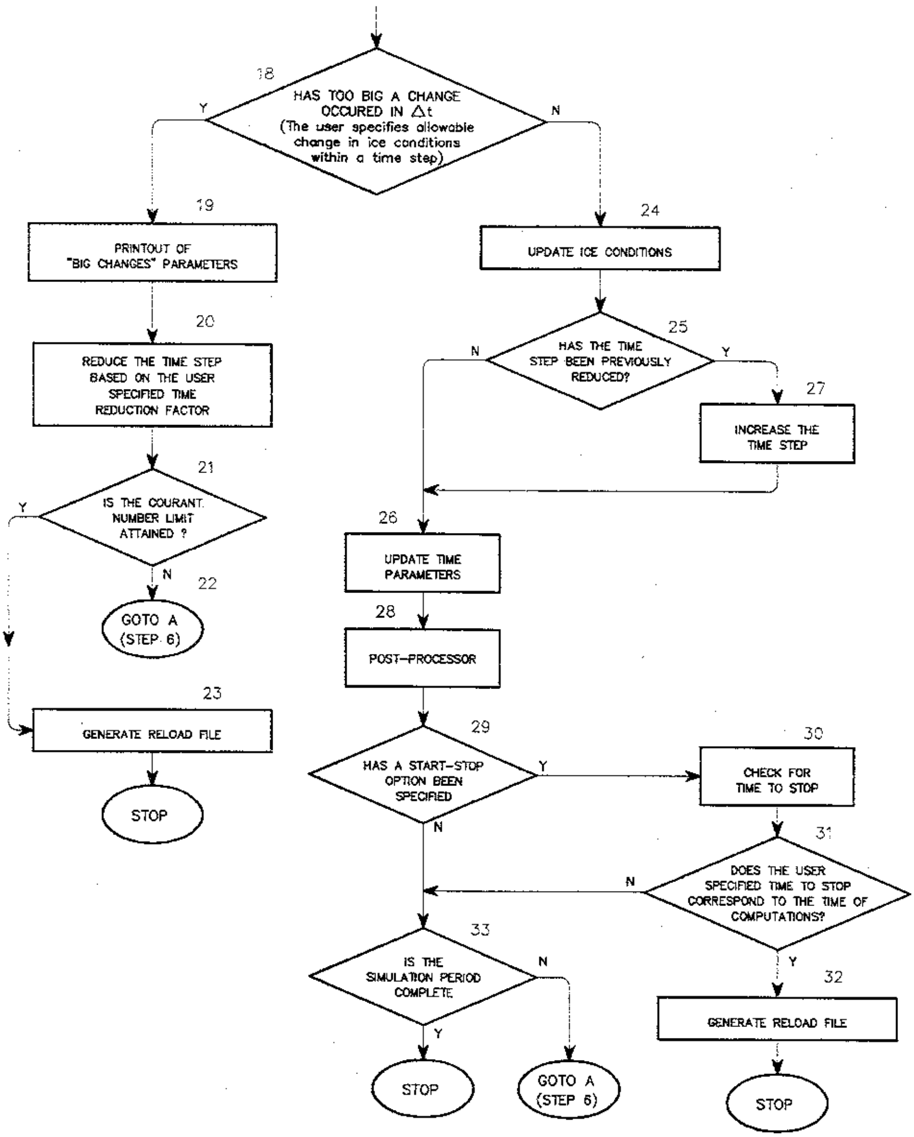

Figure 2(b): RIVICE Driver Flow Chart

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