EVOLUTION OF THE ICESIM MODEL

R.W. Carson[1] and J.L. Groeneveld[2]

Abstract

In 1973, Acres International Limited developed a computer model called "ICESIM" for the study of river ice problems. That program evolved during its early applications to several hydroelectric design problems on the Nelson River as well as later to other problems involving ice jams on numerous rivers across Canada. The program was initially developed and used to represent steady state hydraulic conditions. Recently a supplementary version of the program has been prepared to address time-varying river flows and their effects on ice cover accumulation. The technique is similar to that incorporated in the "RIVICE" Project.

This paper describes the evolution of the "ICESIM" technique, along with several short case histories, and the framework of the new program, called "ICEDYN". Examples of initial tests of the model are also included.

[1]Hydraulic Department Head, Acres International Limited, 6th Floor, 500 Portage Avenue, Winnipeg, Manitoba R3C 3Y8.

[2] Senior Hydraulic Engineer, Acres International Limited, 6th Floor 500 Portage Avenue, Winnipeg, Manitoba R3C 3Y8.

1 Introduction

In 1973, Acres International Ltd. developed a computer program which could numerically simulate the processes of river ice formation under steady state conditions of flow. Its purpose initially was to address river ice problems associated with the construction of the Limestone Hydroelectric Generating Station on the Nelson River. The technique that was used by the program, called "ICESIM", evolved over two decades and was used as a design and analytical tool on numerous river ice problems. However, experimentation has recently been made of the next level of technique. That is a model of ice processes which uses a hydrodynamic module to address time-varying flows in the river during the evolution of the ice cover. This paper describes that experimentation.

2 "ICESIM" Model

There have been several technical papers in the past that have described the "ICESIM" model and its applications: Korbaylo and Carson (1992), Gerrard and Carson (1987), Carson (1982), Carson and Jonassen (1979), and Breland and Carson (1995). A brief description of the computer model is also given within another paper prepared for this conference, entitled "River Ice Jams - Where Will They Occur?".

The model has been used very successfully as a tool to examine river ice mechanics. Major applications are described briefly in Table 1. The program continues to be used in situations where assumption of steady state conditions does not cause unrealistic results.

3 "ICEDYN" Model

Use of the "ICESIM" model has been hampered in some applications by its inability to consider varying river flows during a simulation. To eliminate this shortcoming, the model has been restructured into a new version, called "ICEDYN", which uses a hydrodynamic module to compute the river hydraulics. A description of the model follows in Section 3.1 and early results of its application in Section 3.2.

TABLE 1: Summary of Noteworthy Applications of "ICESIM"

Location	River	Problems Addressed	Successful Calibration ?	Year of Application	References
Limestone	Nelson	winter ice cover-effect on cofferdam	Yes	1974, 1985	2,3,4
Ogdensberg	St. Lawrence	effect of extension of navigation season on ice formation	Yes	1978	-
Fort McMurray	Athabasca	spring ice jams-flood mitigation measures	Yes	1982	-
Nipawin	Saskatchewan	spring ice jams-effects on coffer-dams and bridge crossings	Yes	1984	-
Woodstock/ Perth-Andover	St. John	spring ice jams-means to control	Yes	1987-92	-
Conawapa	Nelson	winter ice cover-effects on coffer-dams	Yes	1984	-
Whitehorse	Yukon	ice jamming due to hydro plant peaking	Yes	1993	6
Churchill	Churchill	spring ice jams-effects on construc-tion of a control weir	Yes	1993	

3.1 Program Methodology

The "ICEDYN" program uses the same approach as its predecessor, "ICESIM", to represent the processes of ice generation and accumulation in a river reach. However, the river hydraulics, which are affected by both changes in inflow to the reach under study, and the accumulation of ice, are computed through a hydrodynamic solution of the St. Venant Equations. These hydrodynamic calculations are then loosely coupled with the calculations of ice mechanics in "ICEDYN". This means that the calculations are done separately but are interfaced such that a compatible solution between the ice and the hydraulics is achieved. This is similar to the methodology proposed for the RIVICE model by Carson (1991). It is a practical compromise which overcomes the complications of direct simultaneous solution of the differential equations pertaining to the river hydrodynamics and to the river ice accumulation.

The "ICEDYN" computer model considers a series of ice processes which affect the water surface profile along a river, in the same way that "ICESIM" considered them. Modifications were, however, made within the "ICEDYN" logic to allow simulation of the recession of an ice front during periods in which the flow may alternate rapidly between high and low flow values. Such a situation is common downstream of hydroelectric developments which may support some form of peaking operation.

The unsteady hydraulics in a reach are represented through a solution of the St. Venant equations. These are a set of differential equations representing open channel flow, and are based on the principles of conservation of momentum and mass. The model uses a "weighted 4 point" implicit finite difference technique to represent the differential terms in the above equations, creating a system of equations that can be solved to give discharge and elevation at each point along a reach for each point in time. These are solved to determine the discharge and elevation at each computational point for each time interval using a Newton Raphson technique. The "weighted four point" scheme is advantageous since it can readily be used with unequal distance steps, and therefore surveyed cross sections along a river reach can be used directly without the need for time-consuming interpolation and pre-processing. The ice thicknesses for the hydrodynamic module are supplied by the loosely coupled ice mechanics modules. The module uses these thicknesses in determining the appropriate waterway areas and frictional resistance to use in the routing calculations.

4 Application of "ICEDYN"

4.1 Model Setup

The "ICEDYN" model was applied to a reach of the Nelson River located in northern Manitoba to test whether the numerical methods incorporated in the model can successfully represent field conditions. The site selected for testing was the river reach between the Long Spruce and Limestone Generating Stations, shown in Figure 1. During the winter of 1989-90, the Nelson river was diverted through the Limestone Spillway as a part of the Stage II Diversion scheme devised for construction of the plant. During this time, the Limestone headpond was controlled within 0.2 m of el 76.0 m, and an ice observation program was initiated along the 22 km reach separating the Limestone plant from its upstream neighbour, the Long Spruce plant. Data collected during this period included:

- hourly outflow records at Long Spruce and Limestone, water levels at three different gauge sites along the river (CAE 17,CAE 12, and CAE 9), as well as continuous readings of the Limestone forebay level and the Long Spruce tailrace level

- records of ice front advancement

- periodic measurement of ice thicknesses along the river.

During the winter period, the ice front advanced relatively rapidly over the tranquil reservoir, eventually stalling at a narrowing in the river located approximately 6 km downstream of Long Spruce. Subsequent to this, advancement of the ice front was relatively slow, and by winter's end had only advanced to a point approximately 3 km downstream of the Long Spruce plant.

Like "ICESIM", the "ICEDYN" model requires a relatively extensive data set to describe the particular reach being simulated. The river bathymetry of the 22 km reach between Long Spruce and Limestone was represented by a series of 52 cross sections. Hourly Long Spruce outflows were input to the model, and a stage discharge relationship selected as the downstream boundary condition for the reach. This relationship between water surface elevation and model outflow was represented with a very flat curve to represent the relatively constant Limestone headpond level maintained throughout the winter. Other parameters for the model were selected through a process of calibration. Past studies of this river reach provided a good initial guess for most of these parameters, with some adjustment necessary within established limits in order to better represent the dynamic conditions modelled with the ICEDYN model.

4.2 Model Results

The performance of the "ICEDYN" simulation of this reach was evaluated based on a comparison of:

- the actual and observed ice advancement rates in the reach

- computed and observed hydrographs at the three gauge locations and at the Long Spruce tailrace

- actual measured ice profiles at the gauge locations, and computed profiles for the corresponding survey dates.

The results of this comparison are summarized on Figures 1 through 7.

Upon examining these figures, the following observations can be made:

- Figure 2 compares final computed and observed ice cover advancement rates in the reach. The rates computed by "ICEDYN" compare reasonably well with observed rates. The cyclic advancement and recession of the leading edge shown in the figure is due to the peaking operation of the plant.

- Figures 3 and 4 summarize computed and observed stages at the sites of gauges CAE9, CAE12, and CAE17, the locations of which are shown on Figure 1. These stages have been compared over the period from December 1 through to January 31. Overall the fit between computed and observed stages is relatively good. The model appeared to have some difficulty in modelling early staging at Gauge CAE 17, as shown in Figure 4. Observed data indicates that substantial increases in water level took place at this gauge location within approximately 3 weeks of ice cover initiation at Limestone. Eventually the "ICEDYN" simulation does match levels at CAE17, but only after an additional month of ice generation. Subsequent investigations indicated the source for this discrepancy may be in the representation of the bathymetry of this local area. Further refinement of the underwater topography may lead to a better overall match.

- The simulation of Long Spruce tailwater levels, as shown in Figure 4, appears to be relatively good, with average deviations of only 0.1 m.

- Figure 5 presents a comparison between computed and observed water level profiles for February 7, 1990. The match is reasonably good. The ice thickness profile shown also compares favourably with the observed profile.

- Figure 6 presents a comparison of computed and observed discharges at the Limestone site for the period from December 20 to December 30, 1989. The observed Limestone discharges have been back calculated from recorded gate operations, using diversion structure rating curves and recorded Limestone forebay elevations. Although the travel times appear to be modelled reasonably well, the observed values appear to be consistently higher than the computed values. However, it would appear that the reason for this inconsistency is the inaccuracy produced by back calculating the Limestone flows. A comparison of the observed Limestone flow data with the actual Long Spruce releases, also shown on Figure 6 shows a similar trend, with the Limestone data being consistently higher than the Long Spruce data. It is unreasonable to assume that the small local basin contribution between the two stations could account for this difference, and therefore it is likely that the observed Limestone outflows may be in error.

- Figure 7 presents a comparison of a typical Long Spruce release hydrograph, routed through to the Limestone site under both ice covered and open water conditions. As can be seen in the Figure, the resulting Limestone flow hydrograph is considerably different if these releases are made under open water conditions as compared to ice covered conditions. As expected, the ice cover has increased the travel time in the reach, as well as attenuating peaks and troughs in the hydrograph.

In summary, the overall fit between the simulated ice processes and actual observed data was considered satisfactory, except for the simulation at gauge CAE 17. The gathering of additional (or refinement of) cross sectional data may be required to better model water levels in the vicinity of this gauge.

5 Conclusions

"ICESIM" has proven to be useful and effective tool to analyse river ice problems. It has now been refined to address time-varying flows. Initial application on the Nelson River show encouraging results. However, additional experimentation and refinement is required.

6 References

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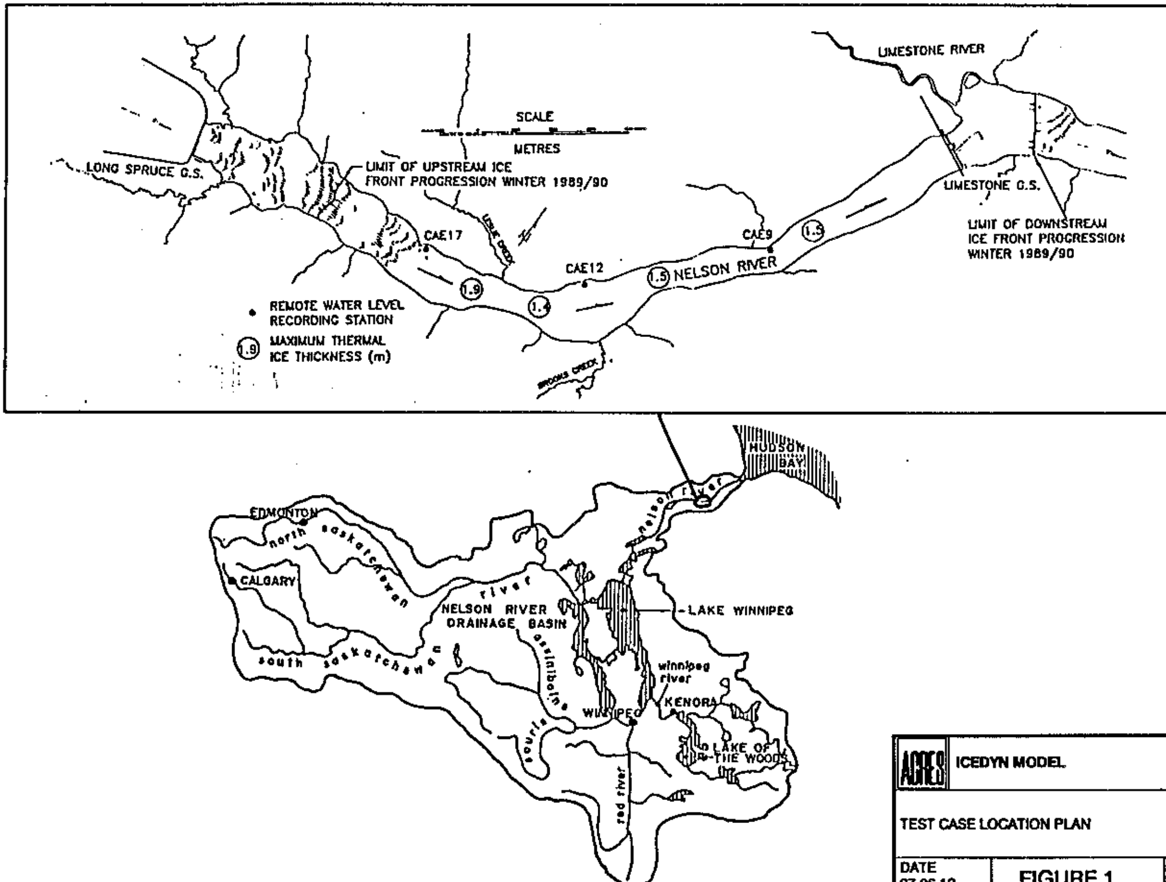

ACRES

ICEDYN MODEL

TEST CASE LOCATION PLAN

DATE
97-06-12

FIGURE 1

REV.
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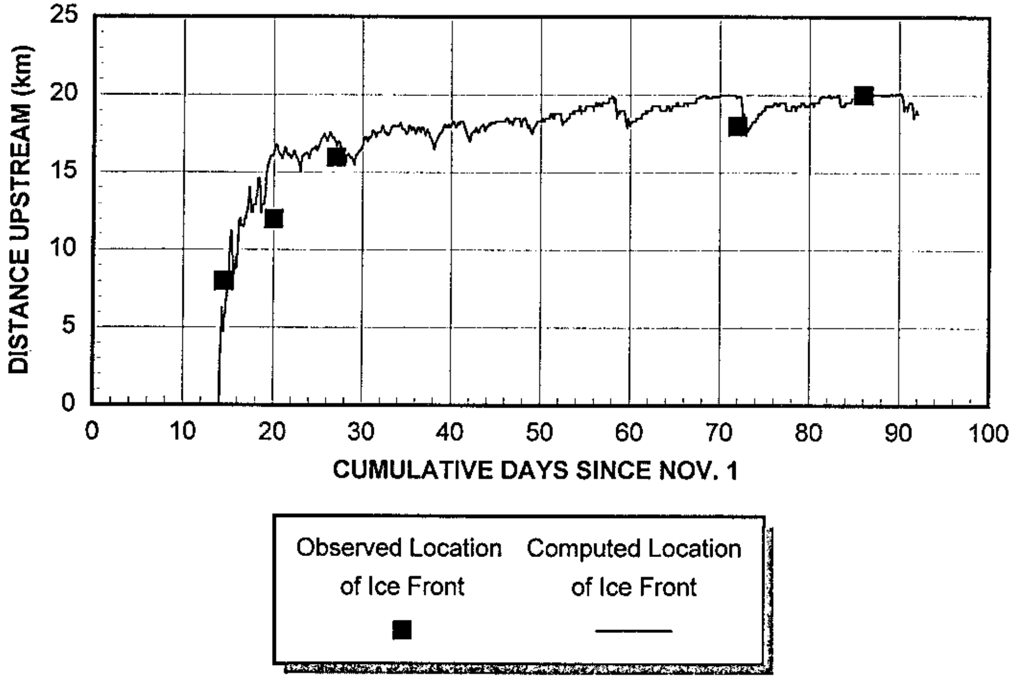
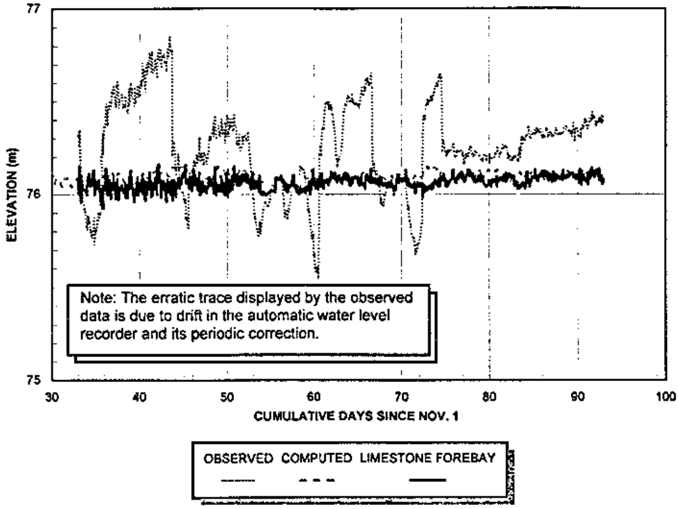


NOTES: LONG SPRUCE TO LIMESTONE REACH DURING WINTER OF 1989/90

ACRES	ICEDYN MODEL
TEST CASE ICE FRONT ADVANCEMENT COMPARISON	
DATE 97-06-12	FIGURE 2 — REV. 0

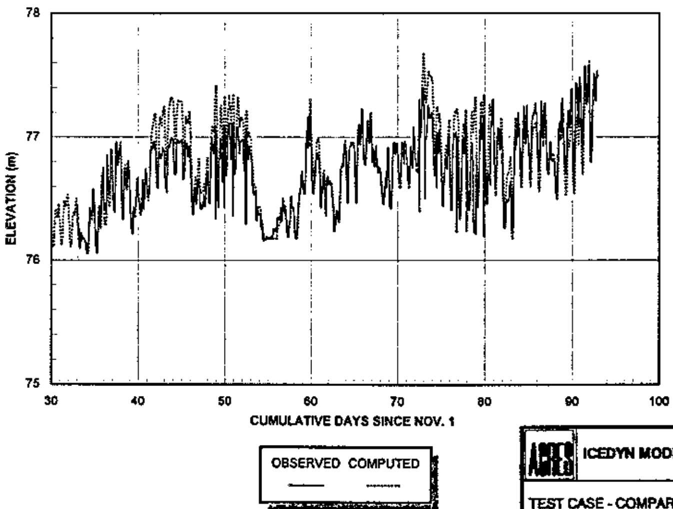
GAUGE CAE 9 COMPARISON

DEC 1,1989 TO JAN 31, 1990



GAUGE CAE 12 COMPARISON

DEC 1,1989 TO JAN 31, 1990



ACRES ICEDYN MODEL

TEST CASE - COMPARISON OF WATER LEVELS AT GAUGES CAE9 AND CAE12

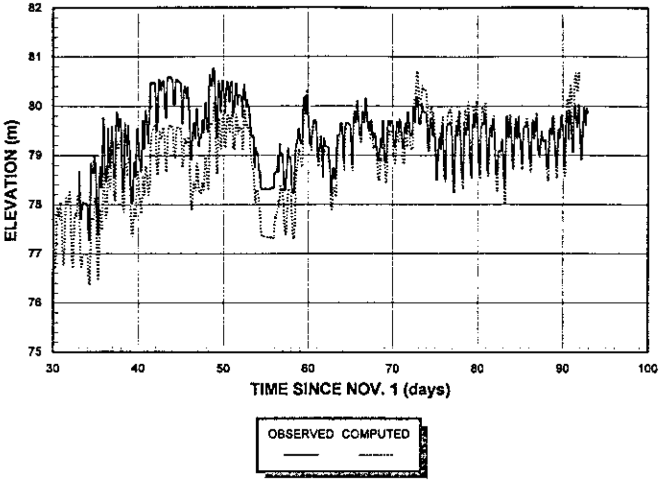
DATE 97-06-12

FIGURE 3

REV. 0

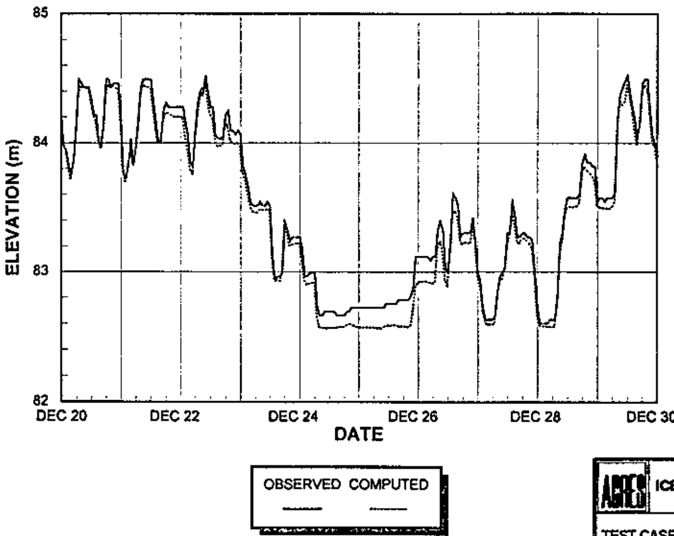
GAUGE CAE 17 COMPARISON

DEC 1,1989 TO JAN 31, 1990



LONG SPRUCE TAILWATER COMPARISON

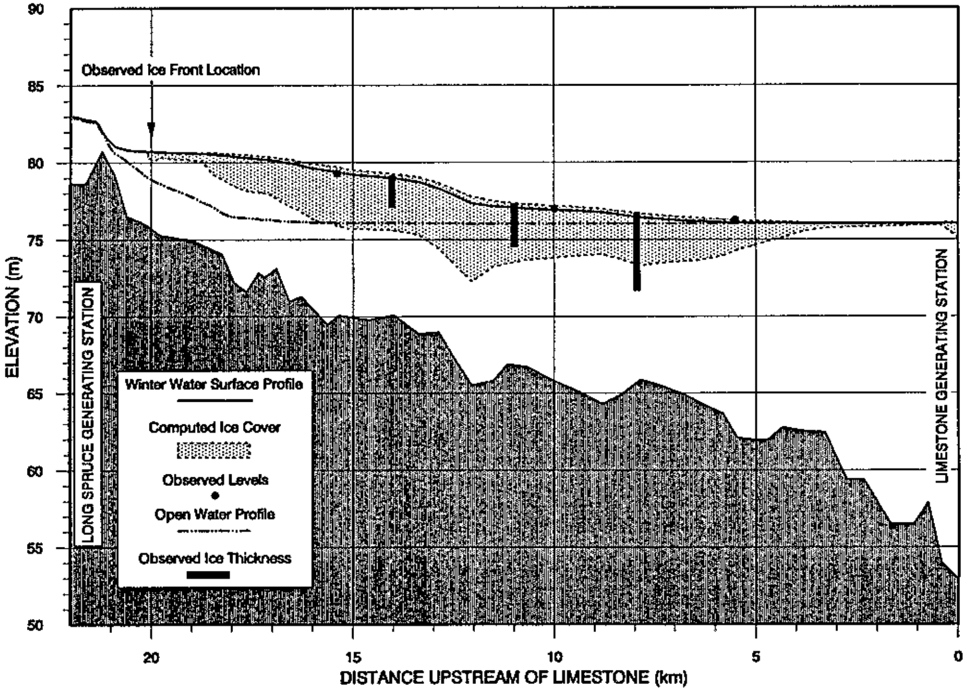
DEC 20,1989 TO DEC 30, 1989



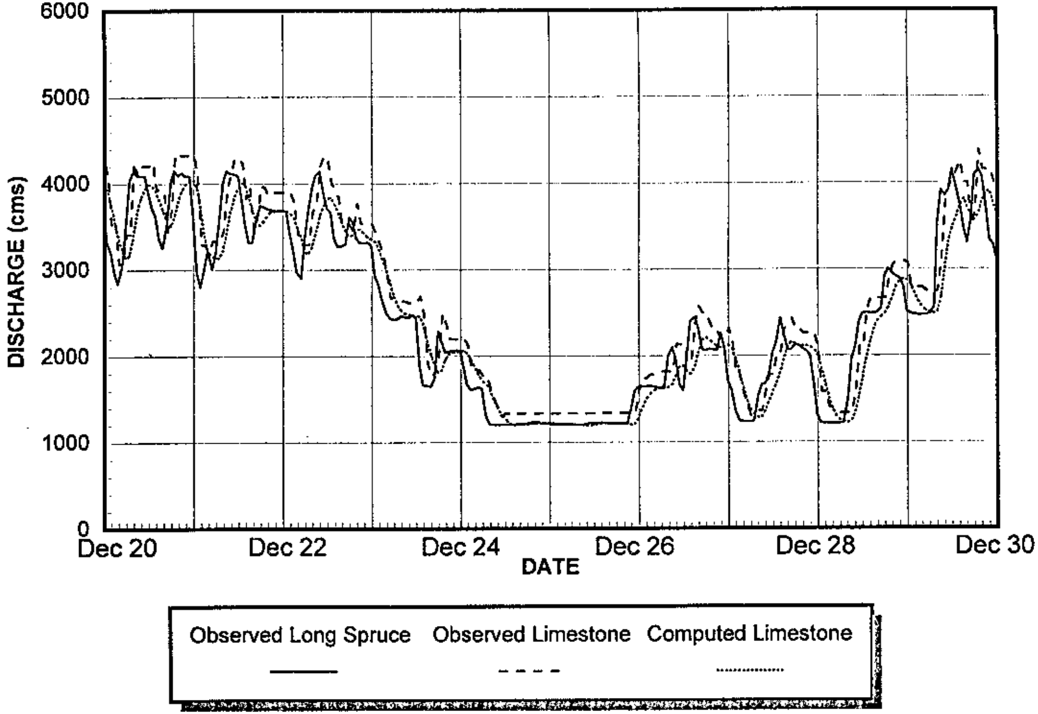
AGES ICEDYN MODEL

TEST CASE - COMPARISON OF WATER LEVELS AT CAE17 AND LSGS TAILWATER

DATE 97-06-12	FIGURE 4	REV. 0



ACRES	ICEDYN MODEL
WINTER ICE PROFILE FEBRUARY 7, 1990	
DATE 97-06-12	FIGURE 5 — REV. 0

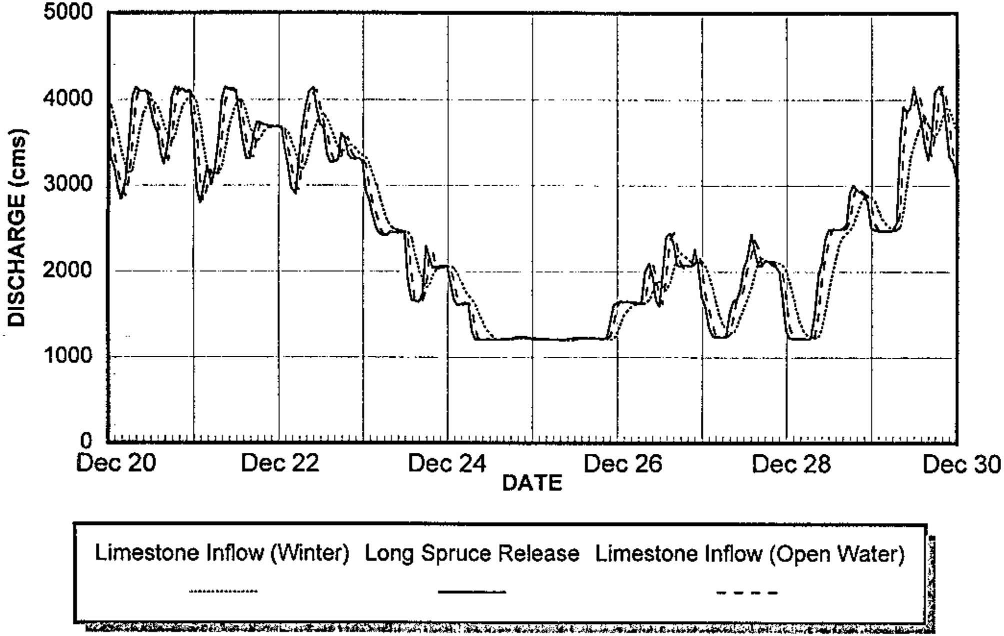


Note: Based on actual Long Spruce releases, for the period from Dec. 20 to Dec 30, 1989

ACRES ICEDYN MODEL

TEST CASE - COMPARISON OF COMPUTED AND OBSERVED LIMESTONE DISCHARGES

DATE 97-06-12 | FIGURE 6 | REV. 0



Note: Based on actual Long Spruce releases, for the period from Dec. 20 to Dec 30, 1989

ACRES ICEDYN MODEL

COMPARISON OF COMPUTED SUMMER AND WINTER SIMULATIONS

DATE 97-06-12

FIGURE 7

REV. 0