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US Army Corps
of Engineers®
Cold Regions Research &
Engineering Laboratory

ICETHK User's Manual

Version 1

Andrew M. Tuthill, James L. Wuebben,
and John J. Gagnon

September 1998

Abstract: This report describes the ICETHK computer model that is used in conjunction with the HEC-2 backwater model to simulate equilibrium ice jam profiles. The ICETHK model fulfills an important need in studies that require the calculation of ice-jam-affected stage. This report presents the theory and limitations of ICETHK and serves as a user's manual, and concludes with a discussion of river ice modeling using ICETHK.

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Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Andrew M. Tuthill and James L. Wuebben, Research Hydraulic Engineers, and by John J. Gagnon, Research Technician, Ice Engineering Research Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire.

The initial version of ICETHK was written in the QUICK BASIC programming language by Mr. Wuebben and Mr. Gagnon. The current FORTRAN version of ICETHK was prepared by Mr. Tuthill.

The work was funded by Civil Works Program Work Unit 32822, *Inclusion of Ice Effects in Corps Numerical Programs*. Dr. Jon E. Zufelt and Kathleen D. White served as technical reviewers.

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ICETHK User's Manual
Version 1

ANDREW M. TUTHILL, JAMES L. WUEBBEN, AND JOHN J. GAGNON

INTRODUCTION

ICETHK is an ice utility program that is used in conjunction with the HEC-2 backwater model (U.S. Army 1990) to simulate an equilibrium ice jam profile. ICETHK uses the results of hydraulic calculations from HEC-2 with an ice cover to produce new estimates of ice thickness and ice roughness for the reach of river being modeled. HEC-2 is then used to recalculate the hydraulic conditions with the updated ice values from the previous ICETHK run. The HEC-2/ICETHK iteration cycles continue until the change in ice thickness between successive iterations is acceptably small.

ICETHK, like HEC-2, models one-dimensional, steady-state flow. There is no provision for ice motion. Figure 1 depicts an equilibrium ice jam profile. The algorithms within ICETHK assume an "equilibrium reach" of ice jam, where the flow is uniform, ice thickness is constant, and downstream forces acting on the ice cover are resisted entirely by friction at the banks (Beltaos 1983). The user must specify the downstream and upstream locations of the jam, based on field observation of past jams, channel characteristics, or estimates of ice jam volume and length. The transition areas at the downstream and upstream ends (toe and head) of the jam may not be adequately described by equilibrium ice jam theory. ICETHK is a con-

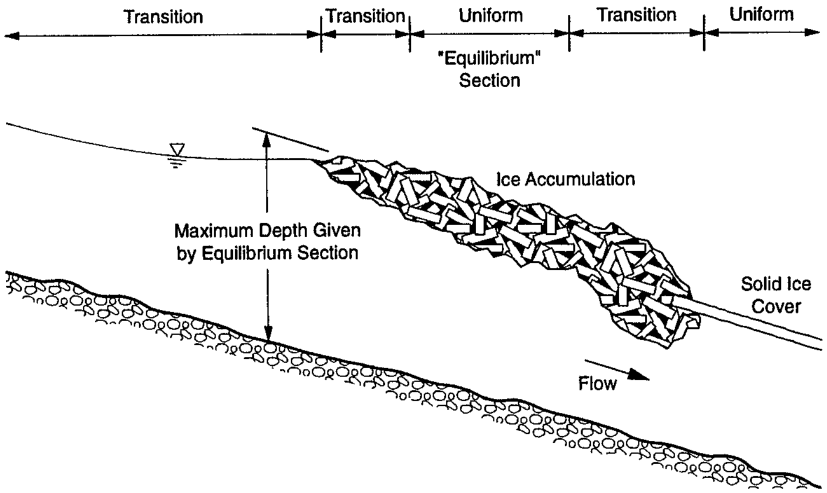

Figure 1. Schematic profile of an equilibrium ice jam. The theory underlying the ICETHK model applies to the "equilibrium" section of the jam where ice thickness and flow are relatively uniform.

servative predictor of stage, however, because the maximum stage for a static jam typically occurs in the equilibrium reach of the profile.

ICETHK is a useful engineering tool because many flood studies and hydraulic design projects require the calculation of ice-affected stages. Before the development of ICETHK, the calculation of ice-affected backwater profiles using HEC-2 was painstaking, requiring many iterations. The basic theory underlying ICETHK is well established. The model has two strong points. First, ICETHK is used in conjunction with HEC-2, the most commonly used backwater model in the United States. River geometry data in the HEC-2 format are widely available. Second, ICETHK is designed to help the user understand ice jam processes, and is relatively easy to use.

EQUILIBRIUM ICE JAM THEORY AND ICETHK

Definition of an equilibrium ice jam

Figure 1 depicts an equilibrium ice jam, showing a central equilibrium reach of uniform flow and constant ice thickness. The transition zones at the head and toe of the jam are characterized by nonuniform flow and variable ice thickness. ICETHK treats each reach between adjacent cross sections as individual equilibrium reaches. Because the ice is considered stationary, its momentum is not considered. Equilibrium ice jam theory assumes that the downstream forces on the ice cover are resisted by the accumulation's internal strength and bank shear. The downstream forces are the water drag on the ice accumulation's underside and the downslope component of the ice accumulation's weight. The ice accumulation's ability to transfer these downstream forces to the banks depends on its internal strength and thickness, and the model's governing equations determine the minimum ice thickness at which this force balance can occur.

Ice thickness calculation

ICETHK calculates ice thickness by three processes: juxtaposition, thickening by shoving, and thinning by erosion.

Juxtaposition, as the name implies, describes a cover formed of ice pieces pushed edge to edge, in conditions of relatively low slope and low water-current velocity. Field observations have shown that an ice cover of juxtaposed pieces will remain stable when the surface velocity is less than 2.3 ft/s and the channel Froude number is less than about 0.08. A cover formed of juxtaposed pieces is typically not much thicker than the minimum dimension of the individual pieces.

The second process is termed "shoving thickening." Downstream acting forces become great enough to cause the accumulation to collapse or "shove" and thicken, until strong enough to resist failure and downstream motion.

In cases of high water-current velocity, ice thickness may actually be reduced by erosion. For this situation, the amount of thinning is calculated. ICETHK asks the user for the thickness of the pre-breakup ice cover (ITHICK). If the calculated thickness by juxtaposition or shoving is less than ITHICK, the final thickness defaults to ITHICK. A similar convention prevents the ice cover from thinning to a value less than the initial ice cover thickness.

Juxtaposition

ICETHK uses two methods to calculate ice cover thickness by juxtaposition. The first method uses a stability criterion developed by Michel (1978):

$$F = \frac{V}{\sqrt{gH}} \leq \sqrt{2\left(1-\frac{\rho_i}{\rho}\right)(1-e)\frac{h}{y}}\;\left(1\frac{h}{y}\right) \qquad (1)$$

where F = Froude number of the river
V = average velocity upstream of leading edge at which underturning and submergence occur
h = thickness of ice accumulation's leading edge
H = upstream flow depth
g = acceleration due to gravity
y = depth of flow under the ice cover leading edge = $H - S_i h$
S_i = Specific gravity of ice (assumed to be 0.916)
ρ, ρ_i = densities of water and ice, respectively
e = porosity of accumulation.

Juxtaposition typically occurs in situations where ice accumulation thickness is small relative to under-ice depth. As an upper bound, ICETHK first checks to determine whether a juxtaposition solution is possible by assuming an ice accumulation thickness that is one-third the under-ice depth, i.e.,

$$\frac{h}{y} = \frac{1}{3}. \qquad (2)$$

If the upstream Froude number

$$\frac{V}{\sqrt{gH}}$$

is less than or equal to the right-hand side of eq 1, a solution by juxtaposition is assumed possible. The accumulation's leading edge thickness h, which satisfies eq 1, is then found by trial and error.

The second method, derived by Ashton (1974), is based on the particle Froude number F_p:

$$F_p = \frac{V_c}{\sqrt{gh\left(1-\frac{\rho_i}{\rho}\right)}} \leq \frac{2\left(1-\frac{h}{H}\right)}{\sqrt{5-3\left(1-\frac{h}{H}\right)^2}}. \quad (3)$$

Again, ICETHK checks to determine whether a solution is possible, i.e., left-hand side less than or equal to right-hand side for $h/y = 1/3$, then solves for h, the leading edge thickness.

Shoving

Thickening due to shoving is calculated by eq 4. The underlying theory was developed through the work of many, including Kennedy (1958), Pariset and Hausser (1961), Michel (1965), Pariset et al. (1966), Uzuner and Kennedy (1976), and Beltaos (1978).

As stated earlier, the equations describing thickness by shoving apply only to the equilibrium reach of the jam (see Fig. 1). Assumptions include uniform flow, constant ice thickness, and the transfer of all downstream forces on the ice accumulation to the banks. It should be restated that difficulties arise when using ICETHK to model the head and toe of the jam, where conditions of varied flow and changing ice thickness exist.

Under steady-state conditions, the uniform section of an ice accumulation, compressed by shoving, can be described as

$$\mu\left(1-\frac{\rho_i}{\rho}\right)gh^2 - (g\rho_i SB - 2C_i)h - \tau B = 0 \quad (4)$$

where h = thickness of the ice accumulation
μ = coefficient related to the internal strength of the accumulation, ranging from 0.8 to 1.3
ρ, ρ_i = densities of ice and water
g = acceleration due to gravity
S = energy slope
B = channel width at bottom of ice cover
C_i = cohesion factor for ice (can range from zero for breakup jams to 20 lb/ft^2 for freezeup jams)
τ = shear force on underside of accumulation, approximated by $\rho g(y_i/2)S$, where y_i = under-ice depth.

Ice thinning

The water velocity beneath an ice cover may be high enough to erode ice pieces and thin the accumulation in a manner analogous to sediment transport. The user inputs a threshold velocity (VEROS), above which erosion or thinning of the ice cover takes place. The "thinned" ice cover thickness is estimated by the following form of the continuity equation:

$$h_t = \frac{1}{S_i}\left[H - \left(\frac{V}{V_c}\right)(H - S_i h)\right] \quad (5)$$

where h_t = thickness of "thinned" ice cover
H = open water depth
V = average water-current velocity
V_c = maximum non-eroding velocity (input by user) (VEROS)
h = ice thickness before thinning
S_i = specific gravity of ice, assumed to be 0.916.

Typical values for VEROS range from 3 to 5 ft/s for freezeup-type jams and 4 to 8 ft/s for breakup. If the HEC-2 calculated water-current velocity is greater than VEROS, eq 5 will reduce the ice thickness, but not to a value less than the thickness of the initial (pre-jam) ice cover (ITHICK).

Roughness of the ice accumulation

Of the four roughness options available in ICETHK, two involve direct assignment of Manning's n values and two involve calculation of roughness. Ice roughness can be calculated as a function of ice thickness or as a function of ice piece size.

Existing field data show that thick jams are typically made up of larger ice pieces and are hydraulically rougher than thin jams. Relationships in the ICETHK model, based on Nezhikovskiy's (1964) data, relate Manning's n values for the ice cover to the ice accumulation thickness. The relationships take the form of a similar equation by Beltaos (1983). Nezhikovskiy's data were measured in wide canals 6.6 to 9.8 ft deep for ice floes, dense slush, and loose slush. For breakup situations with ice accumulations greater than 1.5 ft thick,

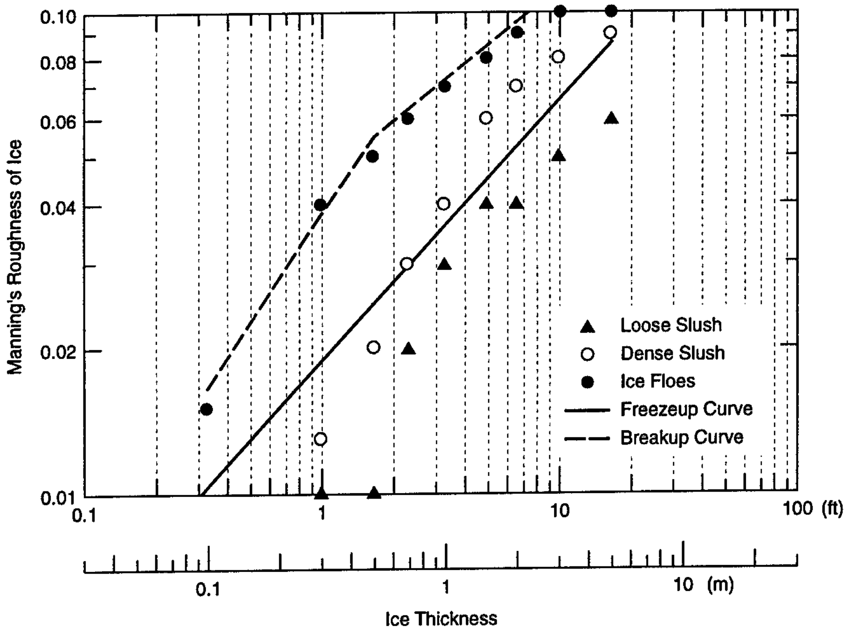

Figure 2. Nezhikovskiy's data plotted in log–log format with the ice-thickness-to-ice-roughness relationships used in the ICETHK model.

$$n_{\mathrm{i}} = 0.0588\left(\frac{H}{2}\right)^{-0.23} t_{\mathrm{i}}^{0.40}$$

$$= 0.0690\, H^{-0.23}\, t_{\mathrm{i}}^{0.40} \qquad (6)$$

where H = total water depth
t_{i} = measured thickness of the ice accumulation.

A second breakup relationship applies to ice accumulations less than 1.5 ft thick:

$$n_{\mathrm{i}} = 0.0506\left(\frac{H}{2}\right)^{-0.23} t_{\mathrm{i}}^{0.77}$$

$$= 0.0593\, H^{-0.23}\, t_{\mathrm{i}}^{0.77}. \qquad (7)$$

A third relationship predicts the roughness of a freezeup ice jam:

$$n_{\mathrm{i}} = 0.0249\left(\frac{H}{2}\right)^{-0.23} t_{\mathrm{i}}^{0.54}$$

$$= 0.0292\, H^{-0.23}\, t_{\mathrm{i}}^{0.54}. \qquad (8)$$

Nezhikovskiy's data and the curves produced by these three equations are plotted in Figure 2.

Ice in overbank areas

Once flow depth in the floodplain reaches a threshold value, ice thickness in the overbank areas is determined by the same steps and equations as the channel ice thickness. The threshold floodplain depth is defined by the multiplier XTo times the pre-breakup ice thickness ITHICK. Using the same calculation method to calculate ice thickness in the overbank as is used for the main channel area relies on the assumption that the ice-on-ice shear between the channel and floodplain ice is approximately equivalent to the bank shear of a jam remaining in the channel.

STRUCTURE AND OPERATION OF ICETHK

ICETHK is designed as a utility program for HEC-2. Figure 3 shows the program's overall structure and the interaction between ICETHK and HEC-2. Boxes within the shaded line signify ICETHK subprograms while boxes with rounded corners indicate external input and output files. Overall the structure is fairly simple: ICETHK's READT95 subprogram reads hydraulic data from a HEC-2 T95 (output) file. The important work takes place in the ICETHN, SHOVE, JUXT, JAMSEL, and RUFCALC subprograms. Here the

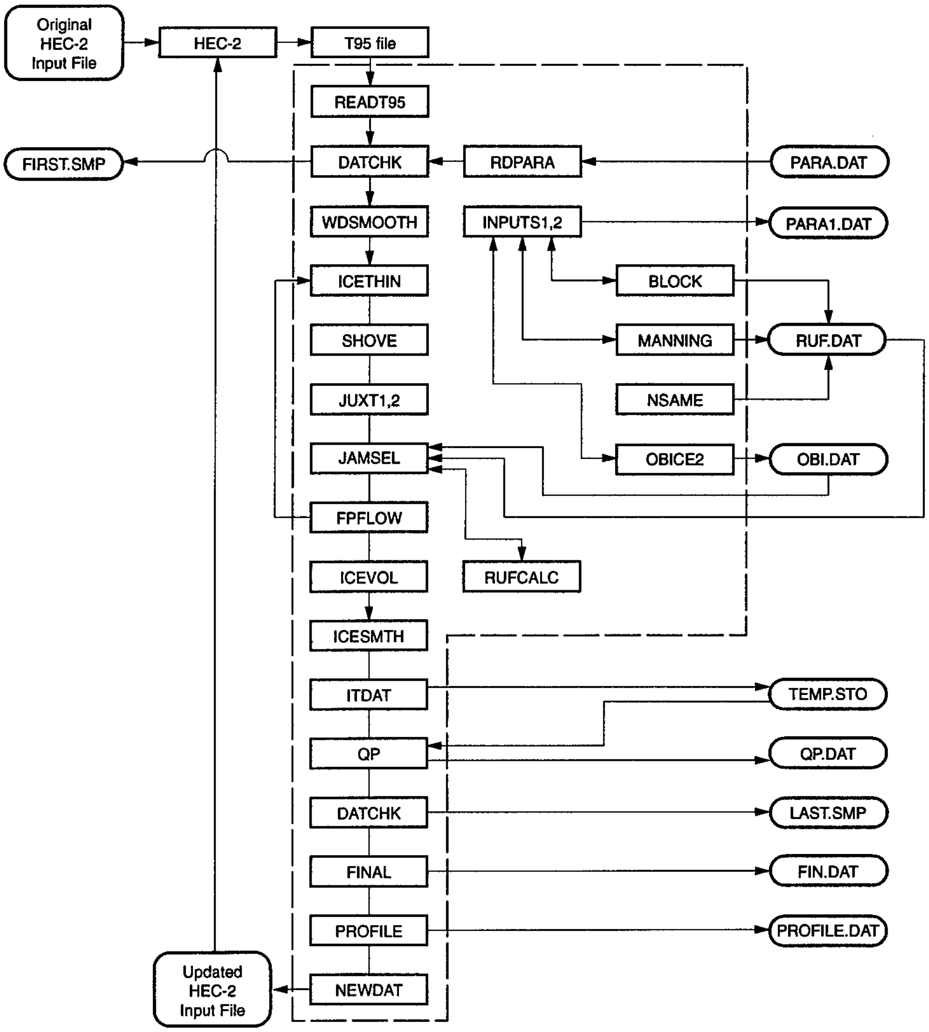

Figure 3. Structure of the ICETHK model. Square-cornered boxes indicate programs and subprograms. ICETHK subprograms lie within the large dashed-line box. External files (both input and output) are indicated by round-cornered boxes.

thickness and roughness of the equilibrium ice accumulation are calculated.

If water-current velocity is greater than the threshold velocity for thinning (VEROS), ICETHN calculates thinning of the ice accumulation, as previously described. After checking if juxtaposition is possible, thickening due to juxtaposition is found in the JUXT1 and JUXT2 subprograms. The SHOVE subprogram then calculates the shoving thickness of the accumulation and the subprogram JAMSEL selects the greater of the shoving and juxtaposition thicknesses. ICETHK uses the thickness of the initial (parent) ice cover as a minimum. This means that the cover cannot thin beyond the parent ice thickness. It also means that, if a solution is not possible by juxtaposition or shoving, the parent ice thickness will be used.

The subprogram RUFCALC calculates the ice roughness as a function of accumulation thickness. If floodplain flow depth is greater than a user-defined threshold value, the process described in the previous paragraph is repeated to calculate ice thickness in the overbank areas.

Finally, the subprogram NEWDAT inserts the resulting ice data into the appropriate IC lines of the original HEC-2 input file, creating a new input file.

ICETHK contains the additional subprograms DATCHK, WDSMOOTH, ICEVOL, ICESMTH, ITDAT, QP, FINAL, and PROFILE. ICETHK also creates and uses a number of external files for data output and for data storage between iteration cycles. The purpose of these additional subprograms and the external files will become clearer in the following sections on inputs and outputs to ICETHK.

The HEC-2 ICETHK cycle repeats itself a user-specified number of times. Several programs, external to the main ICETHK program, such as START.EXE and BIGBAT.EXE, accomplish the multiple HEC-2 ICETHK iteration cycles by writing and executing DOS batch files such as MAKE.BAT and WRITE.BAT. These batch files in turn run HEC-2 and ICETHK the desired number of times.

Inputs

ICETHK has many input options. Ice parameters may be input through a conventional input file, PARA.DAT, or through an interactive screen-prompted session, driven by the INPUTS 1 and 2 subprograms. The example PARA.DAT input file in Appendix A contains typical parameters for a breakup ice jam. Input options include selection of ice parameters such as the ice pack porosity, the internal strength of the ice accumulation, and the cohesion. A number of methods are available for calculating ice roughness, and the user may also choose among methods of calculating ice thickness in the overbank areas. These and other input parameters are described below. The actual mechanics of loading and running the program are covered later in this report.

Channel width smoothing

While natural channels can have significant variations in width, the moving ice is often confined between shore-fast shear walls during an ice run. The top width between these shear walls tends to be much more uniform than the open water width. It is the width between the shear walls that governs the thickening process during shoving events. The WDSMOOTH option can be used to account for the formation of shear walls where the variation in top width between adjacent cross sections is large. At a given cross section, the width at the bottom of the ice cover (bottom width) is reduced to the lesser of the bottom widths at the upstream and downstream cross sections. A further constraint limits the width variation between adjacent cross sections to 10 percent.

Thickness and roughness of the initial ice cover

ICETHK requires estimates of the thickness and roughness of the parent ice cover or ice floes, ITHICK and NOLD. These values are used to represent the ice cover in river reaches where it is determined that the ice does not thicken beyond a single layer. A range of probable Manning's n values is given in Table 1.

Table 1. Typical Manning's *n* values for ice covers.

Type of ice cover	*Description*	*Manning's* n *range*
Sheet ice	smooth underside	0.008–0.012
	rippled underside	0.01–0.03
	fragmented	0.015–0.025
Frazil ice	new—1 to 3 ft thick	0.01–0.03
	3 to 5 ft thick	0.03–0.06
	aged—	0.01–0.02

Presence of ice in overbank areas

Ice can be expected to enter the floodplain areas if the depth is slightly greater than the ice thickness. The user enters a multiplier (XTo) controlling the presence of ice in the overbank area. Once the floodplain flow depth exceeds XTo times the parent ice thickness, overbank ice thickness calculations will be made by ICETHK. If XTo times the parent ice thickness is less than the floodplain flow depth at a particular cross section it is assumed that the floodplain area is free of ice at that location. XTo should be at least 1.0 while the 1.5 to 2.0 range is probably more reasonable. Trees lining the banks, or natural levees, may keep ice in the channel, requiring much higher values of XTo. For cross sections with floodplain flow above the threshold depth, ICETHK provides five options:

1. No ice in overbank areas.
2. User-defined overbank ice thickness.
3. Overbank ice thickness equals channel ice thickness.
4. Overbank ice thickness determined by ICETHK.
5. Retain overbank ice thicknesses (ZITL and ZITR) from the SUMPO file of the previous HEC-2 run.

If option 2 is chosen (user-defined overbank ice thickness), the external file OBI.DAT must be created to store overbank ice thicknesses. (Appendix B contains a sample OBI.DAT file.) It is easiest to use the interactive inputs method, in which case OBI.DAT will be created automatically.

Properties of the ice accumulation and constants

Table 2 gives default values and typical ranges for additional ice properties. Constants used by the ICETHK program are also listed.

Table 2. Typical ranges for ice properties and constants.

Property	*Symbol*	*Default value*	*Typical ranges*
Internal strength coefficient	μ	1.2	0.8–1.3 (Beltaos 1983) Lower μ gives thicker jams.
Porosity of ice accumulation	e	0.5	0.4–0.5 at breakup 0.5–0.7 for slush pans during freezeup
Cohesion factor for ice pieces	C_i	0 lb/ft^2	0 for breakup jams 0–25 lb/ft^2 for freezeup accumulations
Maximum non-eroding water velocity: Hydraulic limit on jam thickness.	VEROS	4.0 ft/s	3–5 ft/s for freezeup 4–8 ft/s for breakup
Specific gravity of ice	S_i	0.916	
Density of water	ρ	1.94 slugs/ft^3	
Acceleration due to gravity	g	32.2 ft/s^2	

Maximum thickness increase per HEC-2/ICETHK iteration cycle

In certain instances, limiting the allowable thickness increase in a single HEC-2/ICETHK iteration cycle will improve the stability of the solution or reduce the number of iterations necessary to arrive at a stable solution. This is accomplished by adjusting the input variable Del *T*. The default value for Del *T* is 1.0 ft.

Ice smoothing option

The smoothing option employs a three-point moving average to smooth ice thickness, if the thickness difference between adjacent sections exceeds a threshold value (ISDEL). Abrupt changes in thickness are unlikely to occur in the natural ice jam case. Ice is likely to be eroded from thicker parts of the accumulation to be redeposited at downstream locations where the jam is thinner. The smoothing option attempts to model this process.

Ice accumulation roughness options

The user can choose between the following four ice roughness input options:

1. Let ICETHK calculate *n* of ice (NICE), no user input.
2. Let ICETHK calculate NICE, user estimates fragment size.
3. User estimates NICE directly.
4. Retain NICE values from SUMPO file of previous HEC-2 run.

Option 3 will require the preparation of the external ice roughness input file, RUF.DAT. Using the interactive inputs method, this file is created automatically. An example of RUF.DAT is included in Appendix C.

Roughness multiplier

A roughness multiplier (RMULT) is used to calibrate ICETHK to observed field data. If RMULT is non-zero and positive, all ICETHK calculated roughnesses are multiplied by a single RMULT. In some cases, however, calibration to field-observed water levels requires different multipliers at different cross-section locations. In this case a zero (0) value is entered for RMULT and the file RUFMULT.DAT must be prepared by the user. Appendix D gives an example RUFMULT.DAT file.

Ice jam type

The user must indicate whether the jam is a freezeup or breakup type. This information determines which equation (6, 7, or 8) is used. ICETHK calculates roughness.

Depth factor

The depth factor (DFACT) limits the maximum possible thickness due to shoving to DFACT times water depth. The depth option can be used to prevent the modeled ice accumulation from approaching a grounded condition.

Outputs

ICETHK includes a number of output options. The most important product is the updated HEC-2 input file containing ice thicknesses and roughnesses calculated by the previous ICETHK run. The ICETHK summary output file FIN.DAT also lists important ice parameters, as well as cautionary notes on the stability of the ice accumulation. Ice and hydraulic data from the first and last iterations are written to the files FIRST.SMP and LAST.SMP. The comma-delimited files QP.DAT and PROFILE.DAT are designed to export data to spreadsheets for plotting. QP.DAT contains data from successive iterations and is used to check solution stability. An ice jam profile can be easily plotted by importing the file PROFILE.DAT into a spreadsheet. Additional external files used to store data from one iteration to the next include TEMP.STO, RUF.DAT, and OBI.DAT. The following section describes ICETHK's output options in detail.

Updated HEC-2 input file created by ICETHK

The original HEC-2 deck (App. E) contains only one IC card following the first QT line. The IC card is the record in the HEC-2 input file that provides ice thickness and roughness data (U.S. Army 1990). This single IC record signifies a single-layer sheet ice cover of constant thickness and roughness over the entire river. Appendix F shows the first page of a HEC-2 input file, created after five HEC-2/ICETHK iteration cycles. Note that two IC lines appear before each X1 card, providing ice data for each cross section. On the updated deck an NC card has been inserted above each pair of IC lines for any cross sections where an NC record did not exist in the original HEC-2 deck. NC records provide HEC-2 with information on channel bed roughness. This channel bed roughness information is used by ICETHK to calculate overbank ice thickness. Each HEC-2/ICETHK iteration creates a new HEC-2 input file that serves to transfer the updated ice data to the next HEC-2 run (see Fig. 3). For example, if the original file is WINDN.DAT (App. E) and there are five iterations, the files WINDN1, WINDN2, WINDN3, WINDN4, and WINDN5 will be created. To conserve space in memory, it's a good idea to periodically delete intermediate files that are not being used. ICETHK is capable of up to nine iterations at a time. If a stable solution is not reached after nine iterations, it is unlikely that additional iterations will improve convergence.

ICETHK's summary output file: FIN.DAT

The ice data from the final ICETHK run are listed in ICETHK's summary output file, FIN.DAT (App. G). The user can assess the stability of the solution by comparing final ice thickness to the thickness found in the previous iteration. Overbank ice thickness, channel ice roughness, velocity of water flow, and cumulative ice volume are listed. The TMODE column lists the mode of thickening for each reach. The THIN message indicates that current velocity is high enough to erode the underside of the ice accumulation. The SHOVE and JUXT messages tell that the calculated ice thickness is the result of shoving or juxtaposition, respectively. The notes included in FIN.DAT are important because they point out some of ICETHK's limitations. They are listed and explained below:

1. Ice thickness = 0 due to VCH > VEROS (= 5 ft/s) with no ice. This comment tells that the average channel velocity (VCH) is greater than the maximum non-eroding velocity (VEROS) and that the ice cover has entirely eroded away.
2. Ice thickening mode is SHOVING and VCH > VEROS: Ice pack unstable. Thickness required for stability is greater than that listed. This condition may occur in high discharge and/or high channel slope situations. In the actual river, this condition may correspond to an ice-free reach.
3. Water entering floodplain, channel ice thickness nearing maximum. Channel ice not stable. As the water level increases above the floodplain elevation, the area of ice in contact with the channel banks decreases or disappears. With the resisting force decreased or eliminated, the ice accumulation is increasingly likely to move downstream.
4. Floodplain depth > XTo (1.5) × initial ice thickness or floe thickness. Ice in floodplain? This alerts the user that overbank flow is occurring and that ice in the floodplain is possible. FIN.DAT includes the summary of run conditions and initial values found at the end of Appendix G.

Summary output files: FIRST.SMP, LAST.SMP

The ICETHK subprogram DATCHK produces the summary output files FIRST.SMP and LAST.SMP during the first and last iterations

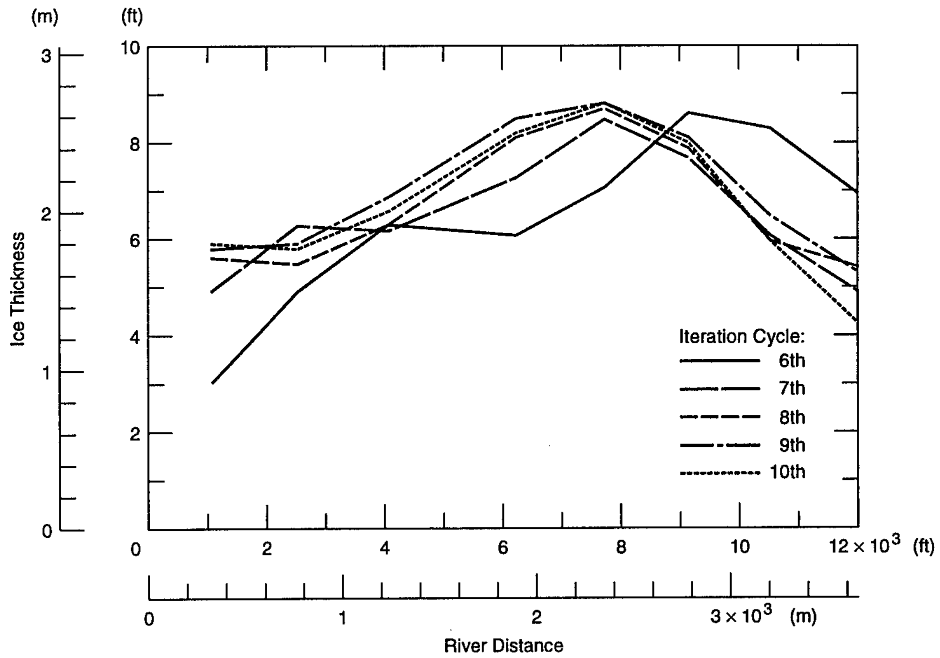

Figure 4. Ice thickness convergence of successive HEC-2/ICETHK iteration cycles.

(App. H and I). The HEC-2 variable names used include

SECNO	cross-section number
CWSEL	channel water surface elevation
VCH	average channel water-current velocity
DEPTH	channel depth
10K*S	channel water surface slope * 10,000
XLCH	channel reach length
CHBW	channel (ice) bottom width
XLBEL	elevation of left bank station
CNICE	channel ice roughness
ZITCH	channel ice thickness
THIN	ice thickness if thinning takes place
ZITL	left overbank ice thickness
ZITR	right overbank ice thickness
LNICE	left overbank ice roughness
RNICE	right overbank ice roughness.

These and other data may also be viewed using the SUMPO option within HEC-2.

Output files for use with spreadsheets: QP.DAT and PROFILE.DAT

The file QP.DAT contains depth (DPTH), channel velocity (VCH), channel water surface elevation (CWSL), slope (CSLP), and channel ice thickness (ZTCH) from successive iterations. QP.DAT is designed for export to a spreadsheet taking the form shown in Appendix J. Thickness profiles for various iterations can then be made (Fig. 4), showing the stability of the solution.

By a similar process, ice-jam profiles may be quickly produced from the file PROFILE.DAT (App. K). The current version of PLOT2, within HEC-2, is not capable of plotting ice profiles at this time. As an alternate method, HEC-2 SUMPO files resulting from the final HEC-2/ICETHK iteration can be imported to a spreadsheet, and ice profiles made. Figure 5 is an example.

The output files FIN.DAT, FIRST.SMP, LAST.SMP, QP.DAT, and PROFILE.DAT are produced each time the ICETHK program runs. *To save any or all of these files, they must be copied to a new name before the next ICETHK run.*

USING ICETHK

This section describes the actual mechanics of using the ICETHK program. Also included are instructions on loading the program on a PC equipped with DOS.

Loading ICETHK

A diskette is available that contains the 26 files listed in Appendix L. (To obtain this diskette, please write to U.S. Army CRREL, ATTN: CECRL-IE, 72 Lyme Road, Hanover, NH 03755-1290.) FICETHK.EXE contains the main program. The

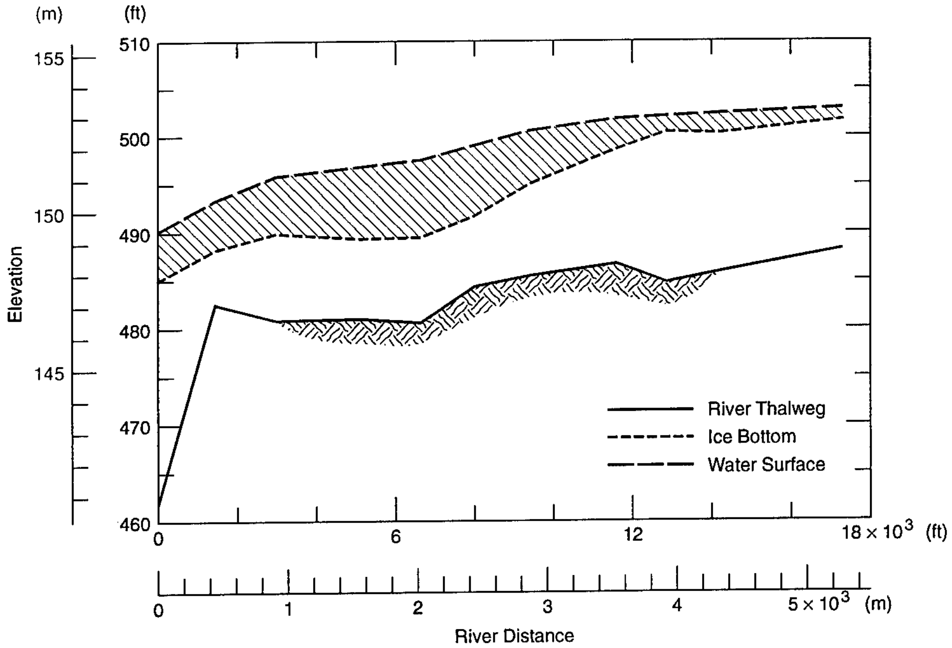

Figure 5. Ice-jam profile produced by importing ICETHK output file, PROFILE.DAT, into a spreadsheet.

other executable and batch files drive the HEC-2/ICETHK iteration process. Also included are external files for storage of data between iterations, as well as sample input and output files. The HEC-2 executable HEC2.EXE is provided in case your version of HEC-2 does not have the bottom-width option. ICETHK uses the bottom-of-ice width variables rather than river-top width in ice thickness calculations.

Because many files are created in the execution of ICETHK, it is a good idea to create a separate directory for the program. This directory must be accessible to HEC-2. Copy the contents of the ICETHK diskette into this directory. Again, if your version of HEC-2 has bottom-width variables, you will not need to copy HEC2.EXE.

Running ICETHK

Once the program and data files are installed, start execution by typing MAIN, at the DOS prompt, within the ICETHK directory. You will be asked for the number of HEC-2-ICETHK iterations (1 to 9 is the possible range). Next you will be asked for the name of the original HEC-2 data file. WINDN.DAT, TOSTON.DAT, and FWJ4700.DAT are provided as samples. Each input deck initially contains one IC line after the first QT card. Type in the data file name with the DAT extension. HEC-2 should run once, then you will be asked if you want an interactive inputs session or if you want ICETHK to take ice parameters directly from the PARA.DAT input file.

HEC-2 and ICETHK should then cycle the desired number of times. Forms of output are described in the previous section of this report. The ICETHK summary output file FIN.DAT lists ice thicknesses for the final and second-to-last iterations, as well as notes on the stability of the ice accumulation for individual reaches.

RIVER ICE MODELING WITH ICETHK

ICETHK can be a useful tool in synthesizing stages associated with ice jam flooding. This section describes some important aspects of modeling river ice processes using ICETHK and HEC-2. Also described are some of the model's limitations.

Limitations

The ICETHK model, like HEC-2, is steady state and does not address ice motion or transport. The model cannot predict where an ice jam will form. ICETHK simply calculates the equilibrium thickness for a floating ice accumulation, reach-by-reach, for a given set of hydraulic conditions and ice parameters. Although ice runs and ice jams are often extremely dynamic processes, ICETHK does not consider the effects of momentum transfer. Ice jams may be grounded, particularly at the downstream end, presenting modeling difficulty, because the theory behind ICETHK applies to floating jams. These limitations force the modeler to draw from other information sources, such as historical ice jam data and reports from field observers.

If the toe of the jam is grounded, ICETHK may underpredict thickness in this area. Similarly, ICETHK tends to overpredict ice thickness at the jam's upstream end, where the ice supply may be limited. ICETHK may underpredict ice thickness along bends, because no provision is made for the added friction along the outside of the bend. Finally, some uncertainty surrounds the model's ability to accurately reproduce ice thickness while matching field-measured stage, because field-measured ice-thickness data sets are rare.

Ice jam location

The user must decide on the location of the ice jam being modeled. Historical records, eyewitness accounts, and field observations are potential information sources on jam location. Lacking this kind of information, the user may have to infer likely ice jam locations from channel characteristics, such as zones of reduced bed slope or channel bends. Deposition of sediment often occurs in these slope change areas, thereby further increasing the ice jam potential. Once an observed or potential jam location is chosen, the HEC-2 input deck may be prepared, with its starting cross section at the toe of the jam to be modeled.

Calibration to observed ice conditions

Ideally some ice event field data will exist. Important items, in addition to ice jam location, are stage and discharge during the event period, as well as estimates of ice piece size and accumulation thickness.

Ice-affected stage

ICETHK can be calibrated to match observed or gaged water levels, or top of ice elevations, along the ice-jam reach. Water levels downstream and upstream of the jam are also important. Ideally, a recording stage gage will be located near or within the ice-jam reach. Because this is rarely the case, however, the modeler must often rely on photographs and the accounts of observers.

Discharge

Care must be taken in assigning a discharge value to a particular ice jam event. Stage gages may be affected by ice, contributing to inaccuracy in the discharge estimate. For this reason, gages significantly upstream or downstream of the jammed reach may provide the best estimate of the average discharge during the event. A 15-minute to hourly discharge record is useful for estimating the flows at the time of breakup, jam initiation, and jam release. A stable discharge while the jam is in place, sometime before the peak, is most appropriate for modeling equilibrium conditions, rather than the peak discharge itself. The peak may be associated with the release of the jam. The relationship between the discharge hydrograph and the timing of the ice event is discussed in a later section on the construction of ice-affected stage discharge curves. Ice thickness during a jam event is difficult to measure. A good estimate of accumulation thickness may be possible, however, by observing shear wall height along the channel sides, after the jam goes out.

Calibration parameters and variables

The effects of parameters and variables used to calibrate ICETHK to observed water levels are described below.

The parameter μ is the coefficient related to the internal friction of the accumulation and the ice shear along the banks. Lower μ means less internal strength and less bank shear, so the accumulation needs more thickness to withstand the downstream-acting forces.

The variable VEROS is the maximum non-eroding velocity. Thickness is fairly sensitive to this variable, particularly in reaches of high current velocity.

The variable RMULT is the roughness multiplier. For all cross sections, roughnesses calculated by ICETHK are multiplied by RMULT, unless RMULT = 0. If RMULT = 0, then ICETHK refers to the external file RUFMULT.DAT for a list of roughness multipliers, one RMULT value for each cross section.

DFACT is the depth factor, which limits thickness due to shoving to a fraction of the total water depth. This option may be useful if the user wants to limit ice thickening at cross-section locations.

The parameter C_i determines the cohesion between ice pieces. This influences the internal strength and thus the thickness of a freezeup ice accumulation.

These calibration parameters are explained in greater detail in the section titled Inputs.

Ice jam volume and ice supply

As discussed in the section on limitations, ICETHK calculates the thickness of an equilibrium ice accumulation reach-by-reach and does not address ice motion or transport, assuming an unlimited ice supply. In a natural river system, the ice supplying a jam is finite, however. There may be an ice-jam site or dam upstream, which limits the ice supplying a jam downstream. Through field observation or a process of assumptions, the modeler may want to define the source reach supplying ice to the jam being modeled. For a breakup event, the volume of the pre-breakup (parent) ice cover may be calculated by multiplying the source reach area by a pre-breakup ice thickness. The pre-breakup ice volume may be found by running HEC-2 with a sheet ice cover of the desired thickness, at a typical midwinter base discharge. It is important to note that there may be losses. A significant portion of the parent ice volume (V_p) may melt during the run or be deposited as debris along the banks. With this in mind, the user can estimate the volume of ice in the jam being modeled (V_j), accounting for the ice pack porosity:

$$V_j = \frac{V_p(1-\%\ \text{losses})}{1-e}. \qquad (9)$$

ICETHK's FIN.DAT output file (App. G) accumulates ice volume, starting at the toe of the jam and working upstream. Once this cumulative ice volume exceeds the previously estimated parent ice volume, the user may want to zero out the ice cover at upstream sections. This is done by removing the IC lines from the appropriate cross sections of the final HEC-2/ICETHK run. A search-and-replace function, available with many text editors, is useful for this task. A final HEC-2 run then gives the combined profile of ice jam and open water reaches.

Construction of ice-affected rating curves

The ICETHK model may be used to construct ice-jam rating curves. The accuracy of this effort depends on many factors, some of which have already been mentioned. It is important to have a knowledge of the range of discharges at which an equilibrium jam will exist. The case of the 11 March 1992 ice jam at Montpelier, Vermont, is used here to illustrate.

The jam initiated at 0700 hr when the discharge hydrograph (Fig. 6) showed a flow in the 2000- to 3000-cfs range. The jam released at 1700 hr, at a discharge of roughly 8000 cfs. The ICETHK model was calibrated to observed water levels along the ice-jam reach using the daily average flow of 4700 cfs. After model calibration, ice-jam stages were found for discharges within the known ice-jam range, and an ice-jam rating curve was constructed (Fig. 7). The open water and sheet-ice rating curves were found using HEC-2

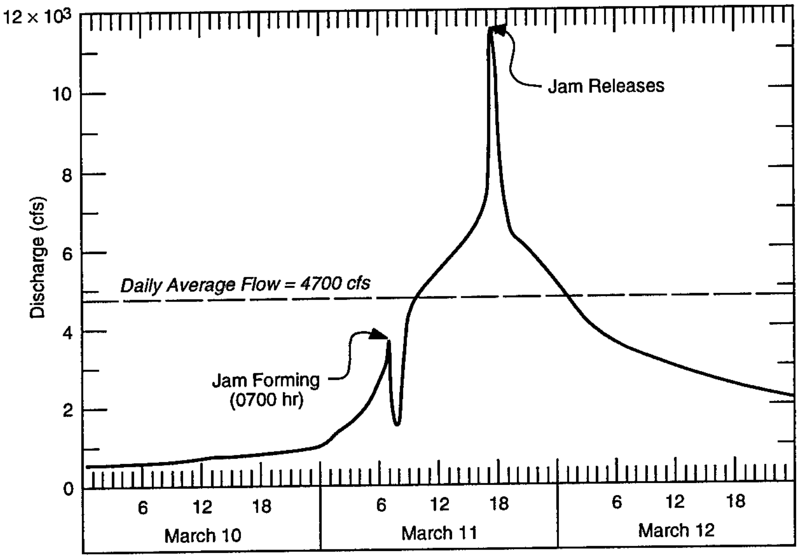

Figure 6. Discharge hydrograph for the Winooski River at Montpelier, Vermont, during the 11 March 1992 breakup ice jam.

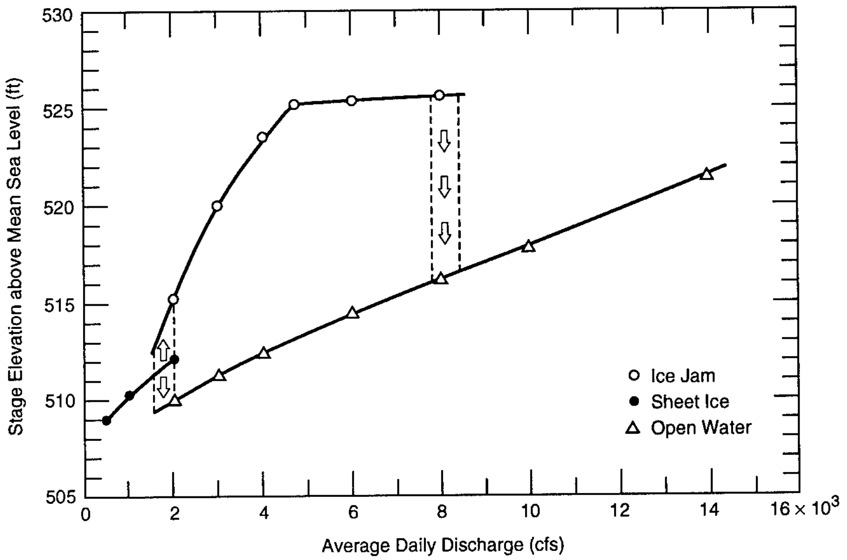

Figure 7. Ice-jam rating curve for the Winooski River at Montpelier, Vermont, calculated using HEC-2 and ICETHK. Stage follows the sheet-ice rating curve until the breakup discharge is reached. The ice-jam rating curve is then used to predict stage until the release discharge is reached and stage drops to the open water curve.

for open water and sheet-ice conditions. Note that the combined rating curve follows the sheet-ice curve until breakup at approximately 2000 cfs, then follows the ice-jam curve until release at about 8000 cfs. At flows in excess of the estimated breakup discharge, the open water rating curve is used.

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APPENDIX A. CONVENTIONAL INPUT FILE TO ICETHK: PARA.DAT

```
INPUT PARAMETERS FOR ICETHK-FORTRAN

Interactive inputs session ? (1. = yes, 2. = no)       2.     RAM(1)

Unused parameter
Width-smoothing option ? (1. = yes, 2. = no)           1.     RAM(2)
                                                       2.     RAM(3)
Initial ice conditions (for all cross sections)
    Initial ice thickness (ft)          (ITHICK}       1.50   RAM(4)
    Initial ice roughness (Manning's n) (NOLD)         0.025  RAM(5)

Unused parameter                                       1.     RAM(6)

Water depth above floodplain at which ice
    goes overbank (No. of ice thicknesses) (XTo)       1.5    RAM(7)

Coefficient related to internal
    friction of ice accumulation        (μ)            1.2    RAM(8)

Ice pack porosity                       (e)            0.5    RAM(9)
Cohesion factor for ice (0 @ breakup)   (C_i)          0.     RAM(10)
Maximum non-eroding velocity (ft/s)     (VCRIT)        5.0    RAM(11)
Specific gravity of ice                 (S_i)          0.916  RAM(12)
Maximum ice thickness increase allowed
    in a single iteration (ft)          (DEL T)        3.     RAM(13)

Unused parameter                                       2.     RAM(14)

Ice roughness (Select one of the 4 alternatives):      1.     RAM(15)
                (NFLG)
    1. ICETHK calculates n (no user input).
    2. ICETHK calculates n (user estimates size).
    3. User estimates Manning's n directly.
    4. Retain n values from the previous HEC-2 run.

Overbank ice (Select one of the 5 alternatives):       4.     RAM(16)

    1. No ice in overbanks.
    2. User-defined overbank ice thickness.
    3. Overbank ice thickness = channel ice thickness.
    4. Overbank ice determined by ICETHK.
    5. Retain thickness from previous HEC-2 run.

Unused parameter                                       1.0    RAM(17)

Roughness multiplier                                   1.00   RAM(18)
    If zero, differential roughness multipliers
Density of water (slugs/ft^3)           (ρ)            1.94   RAM(19)
Acceleration due to gravity (ft/s^2)    (g)           32.2    RAM(20)

Freezeup or breakup jam? 1 = freezeup   (JTYPE)
                         2 = breakup                   2.0    RAM(21)

Employ ice-smoothing option? 1 = yes, 2 = no           1.     RAM(22)

Ice redistribution threshold (ISDEL). If change        3.     RAM(23)
    in thickness between two adjacent sections is
    > ISDEL, then ice thickness will be smoothed.

Depth factor (DFACT). Limits maximum shoving           0.8    RAM(24)
thickness to DFACT * DEPTH.
```

APPENDIX B. SAMPLE OF THE FILE OBI.DAT CONTAINING USER INPUT ICE THICKNESS IN THE OVERBANK AREAS

ICETHK reads only the right-hand column. (FORTRAN format: 10X,F10.1)

```
    1.062        1.0
    2.537        1.0
    4.057        1.0
    6.207        1.0
    7.727        1.0
    9.127        1.0
   10.502        1.0
   12.672        1.0
   13.937        1.0
   15.327        1.0
   18.357        1.0
   19.157        1.0
   20.082        1.0
   20.232        1.0
   20.257        1.0
   20.382        1.0
   21.342        1.0
   22.342        1.0
   24.102        1.0
   25.642        1.0
   10.000        1.0
  240.000        1.0
 1060.000        1.0
 1080.000        1.0
 1370.000        1.0
 2010.000        1.0
 3300.000        1.0
```

APPENDIX C. SAMPLE OF THE FILE RUF.DAT CONTAINING USER INPUT ICE ROUGHNESS DATA

ICETHK reads the data in the second column only. (FORTRAN format: 10X,F10.3)

```
  8421.000      .055
  8689.000      .061
  8761.000      .063
  8821.000      .068
  9101.000      .079
  9459.000      .075
  9610.000      .079
  9640.000      .082
  9791.000      .084
  9927.000      .078
 10185.000      .075
 10255.000      .076
 10295.000      .077
 10451.000      .151
 10792.000      .150
 10883.000      .119
 11004.000      .112
 11070.000      .108
 11090.000      .098
 11140.000      .089
 11190.000      .076
 11260.000      .066
 11390.000      .073
 11540.000      .083
 11789.000      .079
 12189.000      .076
 12619.000      .000
 12919.000      .000
 13419.000      .000
 13965.000      .000
```

APPENDIX D. SAMPLE OF THE FILE RUFMULT. DAT, USED TO CALIBRATE THE ICETHK MODEL

The value in the right-hand column is multiplied by the computed ice roughness. For this option to be used, the variable RMULT, entered in the PARA.DAT, must be zero. (FORTRAN format: 15X,F10.2)

```
123.75      1.30
123.76      1.20
123.76      1.10
123.78      1.00
123.78      1.00
123.79      1.00
124.08      1.00
124.38      1.00
124.70      1.00
125.41      1.00
126.00      1.00
127.00      1.00
127.60      1.00
128.00      1.00
128.57      1.00
129.03      1.00
129.36      1.00
129.38      1.00
129.88      1.00
130.29      1.00
130.64      1.20
130.70      1.30
131.00      1.40
131.15      1.30
131.16      1.20
131.18      1.10
131.19      1.00
131.23      1.00
131.36      0.90
131.37      0.80
131.39      0.80
131.40      0.80
131.49      0.80
131.94      0.80
132.20      0.80
```

APPENDIX E. SAMPLE OF THE ORIGINAL HEC-2 INPUT FILE, WINDN.DAT

The single "IC" line near the top of the file indicates a pre-breakup sheet-ice cover of constant thickness and roughness.

```
T1   WINOOSKI RIVER-POND @ MIDDLESEX TO MONTPELIER CORP BNDRY
T2   PREPARED FEB 1993, BY CRREL; MODIFIED DEC 1993 BY DUBOIS & KING, INC.
T3   ORIGINAL DATA WITH 1.5-FT-THICK SHEET-ICE COVER
J1       0       2       0       0       0       0       0       0     490       0
J2       1       0      -1       0       0       0       0       0       0       0
NC     0.1    0.07    0.03     0.1     0.3       0       0       0       0       0
QT       1    3000
IC                     1.5     .02
     Starting cross section is 1062 ft U/S of Middlesex Dam.
X1   1.062      24     152     309       0       0       0       0       0       0
GR   542.6       0   519.5      49   516.4      93   508.5     100   507.3     129
GR   505.5     145     497     152   488.1     167   478.6     169   462.3     179
GR   461.4     189   463.6     199   469.1     209   470.4     219   483.7     229
GR   488.1     239   490.1     309   515.3     341   520.3     391   524.1     399
GR   527.9     449   531.2     509   531.3     569   531.6     619
NC    .070    .060    .040    .100    .200       0       0       0       0       0

X1   2.537      40     580     919  1450.0  1350.0  1475.0       0       0       0
GR   542.1       0   528.1      35   515.5      60   514.6      90   515.2     110
GR   516.1     125   519.2     175   519.8     260   519.8     300     506     390
GR   497.5     520     493     580     488     605   485.4     612     484     622
GR   483.1     632   482.7     642   482.4     672   482.6     682   483.1     692
GR   484.4     702     485     742   486.1     762   486.6     772   486.3     782
GR   486.3     812   485.7     842   484.6     852     483     882   488.1     900
GR   496.4     919   496.6     925     497     947   523.1     997   524.4    1009
GR   526.2    1015   526.2    1023   523.7    1027   525.2    1047   552.5    1082
NC    .060    .070    .040    .100    .200       0       0       0       0       0
     Great Brook confluence is 700 ft D/S of Section 4057.
X1   4.057      40     585     760  1470.0  1320.0  1520.0       0       0       0
X2       0
GR     548       0   519.3      45   510.4      65   500.4     110     499     355
GR   490.6     440     488     585   486.5     590   485.5     600   484.5     620
GR   483.6     640   483.6     670   482.9     680   483.4     710   482.3     720
GR   480.6     730   487.7     740   486.2     750   495.3     760   502.9     780
GR   510.2     813   512.2     835   515.7     910   512.5    1000   510.9    1060
GR   511.6    1085     516    1101   517.7    1115   516.6    1121     516    1125
GR   503.8    1145   511.1    1175   505.5    1200   521.9    1240   523.6    1275
GR   519.7    1295   525.9    1320   526.4    1360   525.2    1367     536    1400
NC    .070    .070    .040    .200    .300       0       0       0       0       0

X1   6.207    38.0   578.0   813.0  1500.0  2100.0  2150.0       0       0       0
GR   530.0       0   514.0    14.0   502.6    54.0   493.9    56.0   494.6    80.0
GR   489.4    93.0   492.9   118.0   492.3   303.0   493.5   468.0   496.4   578.0
GR   487.3   593.0   485.5   603.0   484.8   623.0   484.2   683.0   484.1   723.0
GR   480.8   783.0   483.4   793.0   486.0   803.0   497.9   813.0   500.7   893.0
GR   498.2  1003.0   504.5  1053.0   506.9  1163.0   510.7  1273.0   508.6  1488.0
GR   510.0  1578.0   510.0  1603.0   514.4  1608.0   514.7  1618.0   510.9  1633.0
GR   510.1  1653.0   520.0  1676.0   521.0  1711.0   521.5  1733.0   524.1  1750.0
GR   524.0  1793.0   522.0  1813.0   553.0  1876.0
NC    .060    .060    .040    .100    .200       0       0       0       0       0

X1   7.727      35    1470    1685  1470.0  1350.0  1520.0       0       0       0
GR   535.5       0   521.2      30   510.2     110     503     150   502.7     175
GR   492.1     205   495.9     550   493.8     730   495.1     815   495.9     945
GR   498.5    1405   493.8    1455   497.7    1470   488.9    1490   486.5    1501
GR   487.5    1520   487.1    1560   485.6    1570     485    1590   483.7    1610
GR   481.4    1620   480.3    1640   484.6    1670   488.5    1680   497.8    1685
GR   509.1    1690   510.1    1810   512.3    1820   512.5    1840   515.2    1860
GR   512.2    1890   523.2    1925   523.2    1975   527.5    2005     535    2060
```

APPENDIX F. SAMPLE HEC-2 INPUT FILE CREATED BY THE ICETHK PROGRAM, WINDN5.DAT

Note that each cross section has two "IC" lines containing ice thickness and roughness values from the previous ICETHK run.

```
T1  WINOOSKI RIVER-POND @ MIDDLESEX TO MONTPELIER CORP BNDRY
T2  PREPARED FEB 1993, BY CRREL; MODIFIED DEC 1993 BY DUBOIS & KING, INC.
T3  INPUT FILE CREATED AFTER 5 HEC-2/ICETHK ITERATION CYCLES
J1       0       2       0       0       0       0       0       0     490       0
J2       1       0      -1       0       0       0       0       0       0       0
QT       1    3000
    Starting cross section is 1062 ft U/S of Middlesex Dam.
NC    .100    .070    0.03     0.1     0.3       0       0       0       0       0
IC                                     .01
IC      .0      .0     3.0    .049    .916
X1   1.062      24     152     309       0       0       0       0       0       0
GR   542.6       0   519.5      49   516.4      93   508.5     100   507.3     129
GR   505.5     145     497     152   488.1     167   478.6     169   462.3     179
GR   461.4     189   463.6     199   469.1     209   470.4     219   483.7     229
GR   488.1     239   490.1     309   515.3     341   520.3     391   524.1     399
GR   527.9     449   531.2     509   531.3     569   531.6     619

NC    .070    .060    .040    .100    .200       0       0       0       0       0
IC                                     .01
IC      .0      .0     3.1    .065    .916
X1   2.537      40     580     919  1450.0  1350.0  1475.0       0       0       0
GR   542.1       0   528.1      35   515.5      60   514.6      90   515.2     110
GR   516.1     125   519.2     175   519.8     260   519.8     300     506     390
GR   497.5     520     493     580     488     605   485.4     612     484     622
GR   483.1     632   482.7     642   482.4     672   482.6     682   483.1     692
GR   484.4     702     485     742   486.1     762   486.6     772   486.3     782
GR   486.3     812   485.7     842   484.6     852     483     882   488.1     900
GR   496.4     919   496.6     925     497     947   523.1     997   524.4    1009
GR   526.2    1015   526.2    1023   523.7    1027   525.2    1047   552.5    1082
    Great Brook confluence is 700 ft D/S of Section 4057.
NC    .076    0.70    .040    .100    .200       0       0       0       0       0
IC                                     .01
IC     2.1      .0     2.8    .058    .916
X1   4.057      40     585     760  1470.0  1320.0  1520.0       0       0       0
X2       0
GR     548       0   519.3      45   510.4      65   500.4     110     499     355
GR   490.6     440     488     585   486.5     590   485.5     600   484.5     620
GR   483.6     640   483.6     670   482.9     680   483.4     710   482.3     720
GR   480.6     730   487.7     740   486.2     750   495.3     760   502.9     780
GR   510.2     813   512.2     835   515.7     910   512.5    1000   510.9    1060
GR   511.6    1085     516    1101   517.7    1115   516.6    1121     516    1125
GR   503.8    1145   511.1    1175   505.5    1200   521.9    1240   523.6    1275
GR   519.7    1295   525.9    1320   526.4    1360   525.2    1367     536    1400

NC    .070    .070    .040    .200    .300       0       0       0       0       0
IC                                     .01
IC      .0      .0     2.2    .051    .916
X1   6.207    38.0   578.0   813.0  1500.0  2100.0  2150.0       0       0       0
GR   530.0       0   514.0    14.0   502.6    54.0   493.9    56.0   494.6    80.0
GR   489.4    93.0   492.9   118.0   492.3   303.0   493.5   468.0   496.4   578.0
GR   487.3   593.0   485.5   603.0   484.8   623.0   484.2   683.0   484.1   723.0
GR   480.8   783.0   483.4   793.0   486.0   803.0   497.9   813.0   500.7   893.0
GR   498.2  1003.0   504.5  1053.0   506.9  1163.0   510.7  1273.0   508.6  1488.0
GR   510.0  1578.0   510.0  1603.0   514.4  1608.0   514.7  1618.0   510.9  1633.0
GR   510.1  1653.0   520.0  1676.0   521.0  1711.0   521.5  1733.0   524.1  1750.0
GR   524.0  1793.0   522.0  1813.0   553.0  1876.0
```

APPENDIX G. SAMPLE OF ICETHK SUMMARY OUTPUT FILE FIN.DAT

```
PROGRAM ICETHK Summary Printout
   Input file: WINDN8.DAT   Total Iterations = 9
     SECNO    Channel Ice    Overbank Ice  Manning   Vch    VolIceCh  TMODE     SLOPE
            Previous Final   Left    Right    ni    (ft/s)  (Cu Yds)
--------------------------------------------------------------------------------
      1.06   4.80    4.30     .00     .00     .057    4.68  0.0000E+00 SHOVE   .006698
      2.54   7.60    7.15     .00     .00     .087    8.88  6.7014E+04  THIN  1.117856
Notes 2
Notes 3
      4.06  10.30   10.16    4.50    1.50     .086    2.19  2.0231E+05 SHOVE   .015242
Notes 3
Notes 4
      6.21  10.10    9.79    3.00    1.50     .084    1.17  4.7582E+05 SHOVE   .003306
Notes 3
Notes 4
      7.73  11.00   10.75    3.71    1.50     .086    1.06  7.8813E+05 SHOVE   .003417
Notes 3
Notes 4
      9.13  13.30   13.17    2.56    1.70     .097    1.53  1.1179E+06 SHOVE   .013411
Notes 3
Notes 4
     10.50  14.30   14.02    1.50    3.33     .099    1.19  1.4125E+06 SHOVE   .008538
Notes 3
Notes 4
     12.67  11.90   11.87    4.30    3.14     .091    3.24  1.7432E+06 SHOVE   .033313
Notes 3
Notes 4
     13.94  10.10   10.15    1.50    2.40     .083    1.98  1.8561E+06 SHOVE   .006317
Notes 3
Notes 4
     15.33   9.30    9.02    1.50    1.50     .079    2.22  1.9643E+06 SHOVE   .007030
Notes 3
Notes 4
     18.36   9.40    8.17    2.91    1.50     .076    1.84  2.2905E+06 SHOVE   .005577
Notes 3
Notes 4
     19.16   7.10    4.00    1.50    1.50     .060    1.16  2.3777E+06 SHOVE   .001357
Notes 3
Notes 4
--------------------------------------------------------------------------------

Notes:
1. Ice thickness = 0 due to VCH > VEROS (= 5.0 ft/s) with no ice.
2. CAUTION: Ice thickening mode is SHOVING, and VCH > VEROS: Ice pack unstable!
          Thickness required for stability is greater than that listed.
3. Water entering floodplain channel ice thickness nearing maximum. Channel ice not stable.
4. Floodplain depth > 1.5 x initial ice thickness or floe thickness. Ice in floodplain?

Run Conditions:  Width smoothing option was not employed.
                 Channel width option was employed. XTo = 1.5
                 Jam type: Breakup
                 Ice roughness (ni) calculated by ICETHK.
                 Overbank ice thickness determined by ICETHK. Tdist = 1.0
                 Ice smoothing was employed.

Initial values: Tio = 1.5, ni = .025, μ = 1.2, e = .50, Ci =.00
                VEROS = 5.00, Del T = 3.0
```

APPENDIX H. SAMPLE OF ICETHK OUTPUT FILE FIRST.SMP

```
SUMPO file produced from WINDN5.DAT

 SECNO    CWSEL     VCH    DEPTH    10K*S      XLCH     CHBW    XLBEL  CNICE  ZITCH  THIN    ZITL   ZITR   LNICE   RNICE

  1.06   490.00    3.00    28.60    10.94       .00    63.30   497.00   .081   5.30  5.90     .00    .00   .0000   .0000
  2.54   493.35    3.05    10.95    72.60   1475.00   294.94   493.00   .074   5.89  5.80     .00    .00   .0000   .0000
  4.06   495.78    1.25    15.18     6.49   1520.00   168.89   468.00   .077   5.79   .00    2.50    .00   .0000   .0000
  6.21   496.73     .93    15.93     4.39   2150.00   215.87   496.40   .083   6.68  8.20     .00    .00   .0000   .0000
  7.73   497.45     .87    17.15     5.41   1520.00   191.60   497.70   .089   8.35  8.80     .00    .00   .0000   .0000
  9.13   498.95    2.62    14.75    35.48   1400.00   219.27   498.60   .084   8.73   .66     .00    .53   .0250   .0250
 10.50   500.57    1.56    15.37     5.99   1375.00   168.39   491.50   .075   7.12  1.46    1.50   1.33   .0250   .0250
 12.67   501.71    1.95    15.21     5.37   2170.00   145.00   497.50   .058   5.06   .00    1.50   1.50   .0250   .0250
 13.94   502.04    1.32    17.54     1.29   1265.00   183.03   499.20   .045   3.04   .83     .73    .00   .0250   .0000
 15.33   502.25    1.42    16.65     1.88   1390.00   185.00   499.10   .049   2.08   .00    1.50   1.50   .0250   .0250
 18.36   502.97    2.16    14.87     3.24   3030.00   157.17   503.30   .025   2.50  1.50     .00    .00   .0000   .0000
 19.16   503.08    1.74    10.09      .51    800.00   190.08   501.00   .000   1.60   .00     .00    .00   .0000   .0000

NS =   12
MS =  150
```

APPENDIX I. SAMPLE OF ICETHK OUTPUT FILE LAST.SMP

```
SUMPO file produced from WINDN.DAT

  SECNO    CWSEL    VCH   DEPTH    10K*S      XLCH     CHBW    XLBEL  CNICE ZITCH  THIN   ZITL  ZITR   LNICE   RNICE

   1.06   490.00   2.55   28.60     3.42       .00    69.89   497.00   .049   .00   .00    .00   .00   .0000   .0000
   2.54   491.46   4.45    9.06   267.40   1475.00   288.26   493.00   .078   .00   .00    .00   .00   .0000   .0000
   4.06   496.42   1.82   15.82    11.19   1520.00   169.89   488.00   .076   .00   .00   2.50   .00   .0631   .0000
   6.21   497.20    .85   16.40     2.00   2150.00   221.82   496.40   .075   .00   .00    .00   .00   .0000   .0000
   7.73   497.56    .88   17.26     3.07   1520.00   196.27   497.70   .078   .00   .00    .00   .00   .0000   .0000
   9.13   498.62   3.03   14.42    63.77   1400.00   216.37   498.60   .088   .00   .00    .00   .00   .0000   .0000
  10.50   501.21   1.60   16.01     9.65   1375.00   166.30   491.50   .085   .00   .00   1.50  1.50   .0000   .0000
  12.67   503.22   2.11   16.72    10.73   2170.00   144.66   497.50   .076   .00   .00   1.70  1.20   .0000   .0000
  13.94   503.78   1.31   19.28     2.08   1265.00   182.31   499.20   .064   .00   .00   1.50   .00   .0000   .0000
  15.33   504.14   1.52   18.53     3.41   1390.00   185.00   499.10   .066   .00   .00   1.50  1.50   .0000   .0000
  18.36   506.22   2.64   18.12    21.56   3030.00   151.73   503.30   .078   .00   .00    .40  1.50   .0000   .0000
  19.16   507.75   1.68   14.75    15.43    800.00   187.76   501.00   .089   .00   .00   1.50  1.50   .0000   .0000

NS =   12
MS =  150
```

APPENDIX J. SAMPLE SPREADSHEET CREATED FROM ICETHK OUTPUT FILE QP.DAT

SCNO	XCHL	DPTH1	VCH1	CWSL1	CSLP1	ZTCH1	DPTH2	VCH2	CWSL2
1.06	0	28.6	2.34	490	0.000141	1.5	28.6	2.48	490
2.54	1475	8	2.33	490.42	0.000859	1.5	8.6	2.58	491.02
4.06	1520	10.9	2.48	491.52	0.000621	1.5	13	2.19	493.6
6.21	2150	11.6	1.94	492.45	0.000312	1.5	13.8	1.33	494.6
7.73	1520	12.7	2.34	493.02	0.000499	1.5	14.9	1.74	495.15
9.13	1400	9.6	2.29	493.74	0.000535	1.5	11.9	1.87	496.06
10.5	1375	9.4	2.86	494.58	0.000763	1.5	12.1	2.16	497.26
12.67	2170	9.9	3.39	496.45	0.001037	1.5	13	2.39	499.47
13.94	1265	12.7	2.06	497.19	0.000272	1.5	15.7	1.63	500.19
15.33	1390	12	2.29	497.64	0.000397	1.5	15.1	1.78	500.7
18.36	3030	11.5	3.46	499.56	0.001245	1.5	14.6	2.49	502.72
19.16	800	7.6	3.1	500.6	0.001241	1.5	10.6	2	503.58

CSLP2	ZTCH2	DPTH3	VCH3	CWSL3	CSLP3	ZTCH3
0.000294	2.5	28.6	2.52	490	0.000324	2.8
0.003306	2.6	8.8	2.74	491.16	0.004267	3
0.001009	2.6	13.4	2.17	493.96	0.000997	2.9
0.000261	2.1	14.1	1.27	494.91	0.000242	2.4
0.00058	2.7	15.1	1.62	495.38	0.00045	2.6
0.000753	2.6	12	1.91	496.19	0.000805	2.9
0.0011	3.3	12.2	2.16	497.43	0.001094	3.6
0.001004	2.5	13.5	2.6	500.01	0.001402	3.6
0.000319	2.4	16.4	1.64	500.86	0.000345	3.2
0.000452	2.6	15.8	1.71	501.38	0.000405	3
0.001106	2.5	15.3	2.57	503.39	0.00133	3.5
0.000934	2.5	11.6	2.17	504.6	0.001577	4.4

APPENDIX K. TYPICAL SPREADSHEET FILE PRODUCED FROM ICETHK OUTPUT FILE PROFILE.DAT

SECNO	LENGTH	BEDEL	BODICE	CWSEL	ICEVOL
1.06	0	461.4	487.25	490	0
2.54	1475	482.4	488.39	491.23	828552
4.06	2995	480.6	491.36	494.01	2144273
6.21	5145	480.8	492.88	494.9	3520168
7.73	6665	480.3	493.3	495.32	4194303
9.13	8065	484.2	493.34	496.08	4954086
10.5	9440	485.2	494.31	497.33	5798405
12.67	11610	486.5	496.67	499.78	7044881
13.94	12875	484.5	497.66	500.68	7804235
15.33	14265	485.6	497.69	501.35	8787415
18.36	17295	488.1	499.64	504.58	11290330
19.16	18095	493	500.52	506.1	12270670

APPENDIX L. LISTING OF OUTPUT FILES INCLUDED IN THIS RELEASE OF THE ICETHK PROGRAM

```
.            <DIR>        10-22-96   9:45a
..           <DIR>        10-22-96   9:45a
BATINFO              288 10-22-96  10:08a
MAIN     BAT          99 07-17-92  12:14p
MAKE     BAT         740 10-22-96  10:07a
WRITE    BAT         222 10-22-96  10:08a
FWJ4700  DAT      36,217 02-16-94   8:22a
PARA     DAT       3,919 05-20-94   1:48p
RUFMULT  DAT       1,906 04-19-94   8:26a
TOSTON   DAT       9,671 02-10-94   2:02p
WINDN    DAT      22,497 05-20-94   2:55p
BIGBAT   EXE      22,967 07-15-92  11:20a
BLDBAT   EXE      24,015 07-15-92  10:33a
FICETHK  EXE     209,096 07-24-96  12:21p
HEC2     EXE     392,256 07-03-95  10:50a
START    EXE      23,807 11-09-92   3:52p
H        OUT      36,718 10-22-96  10:08a
PARA1    DAT       3,929 10-22-96  10:08a
FIRST    SMP       2,092 10-22-96  10:07a
TEMP     STO      27,054 10-22-96  10:08a
OBRUF    DAT         504 10-22-96  10:08a
TEMP     DAT      11,074 10-22-96  10:08a
QP       DAT       2,457 10-22-96  10:08a
FIN      DAT       2,648 10-22-96  10:08a
PROFILE  DAT         851 10-22-96  10:08a
LAST     SMP       2,092 10-22-96  10:08a
     26 file(s)         837,119 bytes
                    146,685,952 bytes free
```

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13. ABSTRACT (*Maximum 200 words*)

This report describes the ICETHK computer model that is used in conjunction with the HEC-2 backwater model to simulate equilibrium ice jam profiles. The ICETHK model fulfills an important need in studies that require the calculation of ice-jam-affected stage. This report presents the theory and limitations of ICETHK and serves as a user's manual, and concludes with a discussion of river ice modeling using ICETHK.

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