DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-EH

ETL 1110-2-363

Technical Letter
No. 1110-2-363

31 January 1994

Engineering and Design
DATA COLLECTION FOR RIVER ICE FORECASTING

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1. Purpose

The purpose of this engineer technical letter (ETL) is to describe the data collection program necessary to install and support an operational river ice forecasting system. This ETL should be used to evaluate existing data collection programs for suitability and completeness and to identify unmet data collection needs. With a completed data collection program in place, a river ice forecasting system can be established quickly, efficiently, and at a minimum cost.

2. Applicability

This ETL applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibilities for planning, design, and operation and maintenance of civil works projects.

3. Discussion

A river ice forecasting system is a collection of existing software procedures that process forecasts of relevant hydrologic and meteorologic parameters to produce forecasts of the production and transport of river ice. River ice forecasts will provide the resulting extent, thickness, and duration of any stable ice covers along the river reaches of interest. The system (Figure 1) is composed of three main numerical models, plus supporting procedures and pre- and post-processors. The three main models are a hydraulic model, a thermal model, and an ice distribution model. The supporting procedures include initial condition and boundary condition generators. The pre- and post-processors are procedures designed to allow the models to interface with existing databases.

a. Introduction. The formation, extent, and thickness of stable river ice covers result from the interaction among the river hydraulics, the heat transfer to the atmosphere, and the mechanics of how a river ice cover forms. To produce accurate forecasts, the models that simulate these processes must be based on actual field data, fully calibrated over a wide range of conditions, and operated using accurate information from the field.

b. Development of the hydraulic model. Because of the dynamic interaction between the river ice formation and the river ice hydraulics, a dynamic unsteady flow model is required to model the ice-covered river. Hydraulic modeling of an ice-covered river is similar to applying and calibrating a one-dimensional unsteady flow model for open water conditions. If such a model exists or can be developed for the river reaches of interest, it can be incorporated (with modification) into the ice forecasting system. The following field data are required to develop such a model:

(1) An overall hydraulic and geometric description of the river system for which forecasts are made. Generally, the river system will have a mainstem and perhaps several major tributaries. The tributaries should be modeled as far upstream from the mainstem as necessary to cover the reaches where navigation or other factors, such as ice jam flooding, are a concern. If a tributary is not included in the model, the discharge contributed by that tributary to the mainstem can be included as a lateral inflow. The upstream ends of the modeled mainstem and of tributary reaches should be locations where discharges are known. This is called the upstream hydraulic boundary. The downstream end of the mainstem should be at a location where the stage is measured and a rating curve is available.

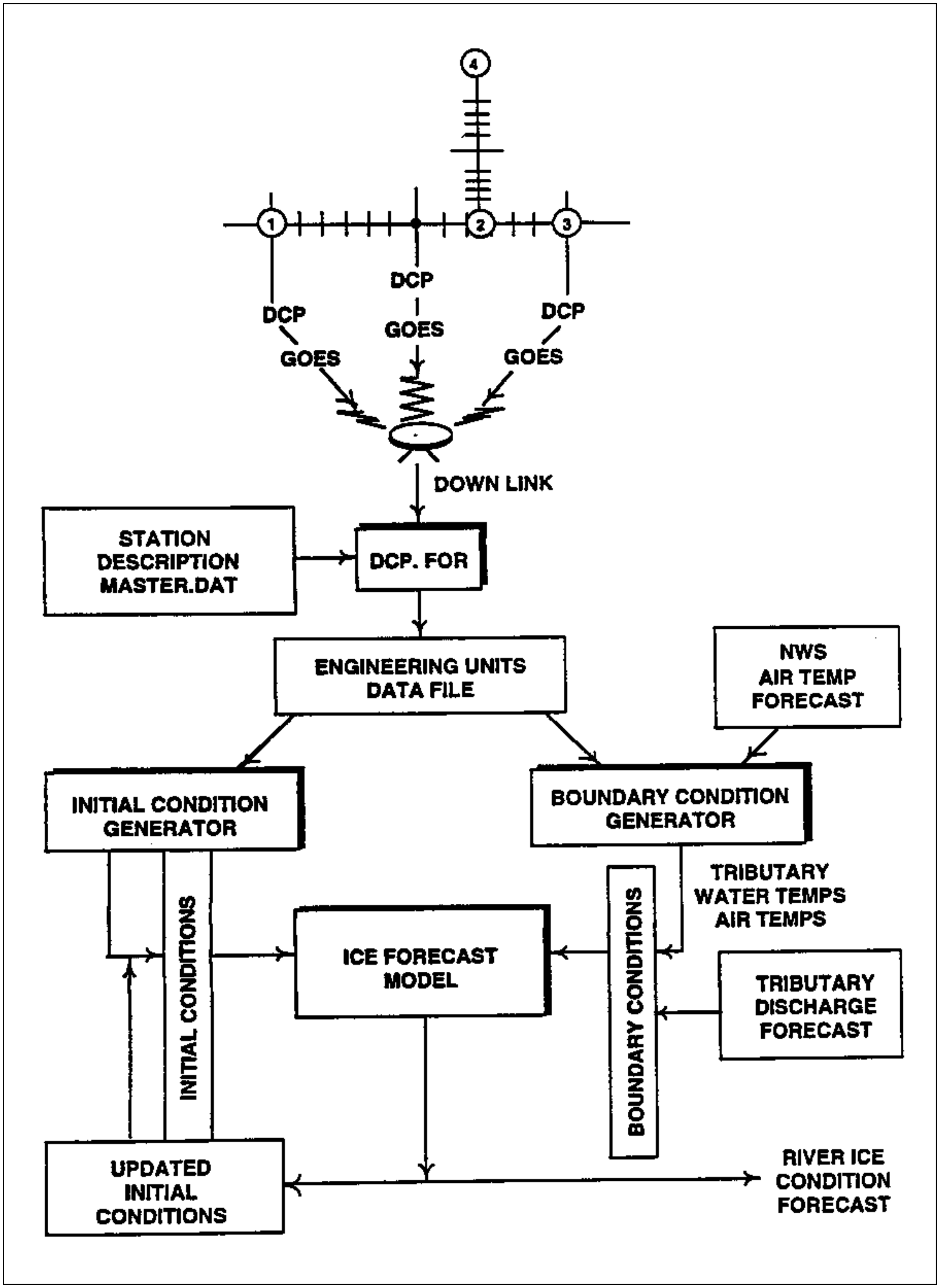

Figure 1. Flow chart diagram of the ice forecasting system

(2) Locations and descriptions of river cross sections on the mainstem and tributaries. Generally, cross section descriptions, referenced to known elevations, must be provided every 5 to 20 river widths. In reaches where the river geometry varies significantly along the river, the cross sections must be spaced closer together. All geometric features known to influence the flow should be included.

(3) Location and operation rules of hydraulic control structures such as locks and dams.

c. Calibration of the hydraulic model. To calibrate an unsteady flow model, the channel roughness or resistance to flow under a variety of flow conditions must be determined. Energy loss coefficients may also have to be determined. The minimum data required to calibrate an unsteady flow model are records of discharges and their associated stages during at least three flow events, which should comprise low, medium, and high flows. For each flow event the following is needed:

(1) A record of the designated boundary conditions at the upstream and downstream ends of the mainstem, and at the upstream end of each tributary. Typically, the upstream boundary conditions are known discharges, and the downstream condition is a known stage or rating curve.

(2) Records of the discharges at each lateral inflow.

(3) Records of stages at several locations, including the downstream end of the mainstem. The channel roughness can be estimated only for reaches upstream of each measured stage location.

d. Calibration of the thermal model. The thermal model determines the river water temperature at each location of interest, and calculates the volume of ice produced once the water temperature has declined to 0°C (32°F). The heat transfer between the river water and the atmosphere is usually the most important factor in the change of water temperature. This heat transfer rate is calculated simply as a linear calibrated function of the temperature difference between the air and the water. This approach is sufficiently accurate and relies only on air temperature, which is separately available from meteorological forecasts. The heat transfer rate must be calibrated during the time when no ice exists in the river. This requires:

(1) A record of the daily average water temperature at the upstream and downstream ends of the mainstem, at the upstream end of the modeled reach of each tributary, and at selected intermediate points.

(2) A record of the daily average air temperature during the same period. A record of the high and low temperature recorded each day is usually sufficient because the average of these measurements is a good indication of the daily average air temperature. The air temperature should be measured at a sufficient number of locations so that the actual air temperature variations along the river system are well represented. If the air temperature normally has strong gradients -- for example, if the river rises rapidly in elevation, or if the river travels directly north and south -- more air temperature measurement stations are required.

e. Calibration of the ice model. One of the greatest uncertainties in river ice forecasting is applying river ice mechanics to specific situations. This is because there is no broad, underlying, physically based theory, but rather a series of rules determined through observation in the field and the laboratory, plus theory based on analogies that apply in certain limited situations. As a result it is important that data on the ice conditions be as thorough as possible. This requires:

(1) A record of the location and extent of ice along the river. It is important to note the reaches where the ice is moving, and estimate the surface concentration of ice; the locations where the ice has bridged across the channel and formed a stable cover; the upstream progression rate of the leading edge of the ice cover; and the locations where the ice cover cannot progress, such as regions of high velocity. Frequent aerial surveys using video cameras can collect this information.

(2) An estimate of the ice thickness at as many locations as possible. It is not possible to estimate the ice thickness by just looking at it; direct measurement is required. This is a labor-intensive process that must be conducted with due regard to safety. However, these measurements are very important for model calibration. Generally, it is better to have measurements over a wide area at a few points in time rather than to have many measurements at one location. Measurements of thickness should indicate

the solid ice thickness and the thickness of frazil ice deposited under the solid ice cover.

f. Ice model data collection. How frequently ice data are collected depends entirely on the rate at which the ice conditions change. Rivers that freeze up in early winter and maintain a stable ice cover throughout the winter season may be surveyed weekly or even monthly. However, rivers on which the ice conditions change rapidly, and that form and break or melt several ice covers in a given winter, may require daily surveys of the ice conditions, with the most surveys concentrated during the times when the ice conditions are changing most rapidly. This ice record should be concurrent with the record of discharges, air temperatures, and water temperatures.

g. Modes of operation of the river ice forecast model. The river ice forecast model is operated in two modes: a forecast mode and an update mode. The forecast mode starts with the existing conditions, and uses forecasted values of the boundary conditions to produce the model output. The update mode starts with the initial conditions that existed the last time the model was run. If the model is operated daily, for example, the initial conditions are those that existed on the previous day. The actual values of the boundary conditions measured at the field sites are then used to produce the model output. In this way the previous conditions are updated to reflect the present conditions. Generally, the model is run twice on any day a forecast is made, once to update the initial conditions and once to forecast the future ice conditions.

(1) Typical data required for update mode. The following new data are required to update the model:

(a) Discharge at the upstream end of the mainstem.

(b) Discharge at the upstream end of the modeled reach of each major tributary and the discharge from each lateral inflow.

(c) Ice discharge at the upstream end of the mainstem and the upstream end of the modeled reach of each major tributary.

(d) Water temperature at the upstream end of the mainstem.

(e) Water temperature at the upstream end of the modeled reach of each major tributary.

(f) Air temperatures over the entire region of interest.

(g) Downstream water level.

(2) Typical data required for forecast mode. The following data are required to obtain a forecast from the model:

(a) Forecasts of the discharge at the upstream end of the mainstem.

(b) Forecasts of the discharge at the upstream end of the major tributaries.

(c) Air temperature forecasts.

(d) Forecasts of the water temperature at the upstream end of the mainstem and each tributary. Supporting procedures are available to produce these forecasts based on the air temperature forecasts, the known water temperature at the time of the forecasts, and the watershed response coefficients determined from previous water and air temperature measurements.

(e) Forecasts of the ice discharge at the upstream end of the mainstem and at the upstream end of the major tributaries.

h. Data accuracy. The following are minimum requirements for the accuracy and resolution of data collected.

Parameter	Resolution	Accuracy
Water temperature	0.1°C (0.2°F)	±0.1°C (±0.2°F)
Air temperature	0.5°C (1°F)	±0.5°C (±1°F)
River stage	0.003 m (0.01 ft)	±0.003 m (±0.01 ft)
Ice thickness	0.03 m (0.1 ft)	±0.03 m (±0.1 ft)
Discharge		±5%

i. Establishment of field data collection sites. Based on the above discussion, locations of field data collection sites can be determined. There is a minimum number of sites that must be provided. However, it is desirable to have additional sites located at intermediate points on the mainstem and the reaches of the tributaries. At the intermediate sites, stage (from which discharge can be estimated), water temperature, and air temperature should be measured. The minimum data collection sites are:

(1) Upstream end of the mainstem. At this location, discharge, water temperature, and air temperature must be measured. Hourly measurement is best. This will allow the daily average values of each parameter to be accurately determined.

(2) Upstream end of the reach of each tributary to be included in the model. At these locations, discharge, water temperature, and air temperature must be measured.

(3) Downstream end of the mainstem. At this location, stage, water temperature, and air temperature must be measured.

j. Duration of a data collection program. Before an ice forecasting system is established, it is best if data from several winters have been collected. These should include at least one year when severe ice conditions were experienced. Winters during which no ice formed on the rivers are also valuable for calibration of the hydraulic and thermal models. However, it is very important that the data be collected during the winters when ice is present and that these ice conditions be documented as described above.

4. Summary

A river ice forecasting system can be established most efficiently if a comprehensive data collection program is in place over several winters prior to its establishment. It is often true that water temperature data and data on ice conditions are the most limited. The U.S. Army Cold Regions Research and Engineering Laboratory has developed effective, economical, and accurate means of collecting both.

FOR THE DIRECTOR OF CIVIL WORKS:

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