Forecasting the effects of river ice due to the proposed Susitna Hydroelectric Project

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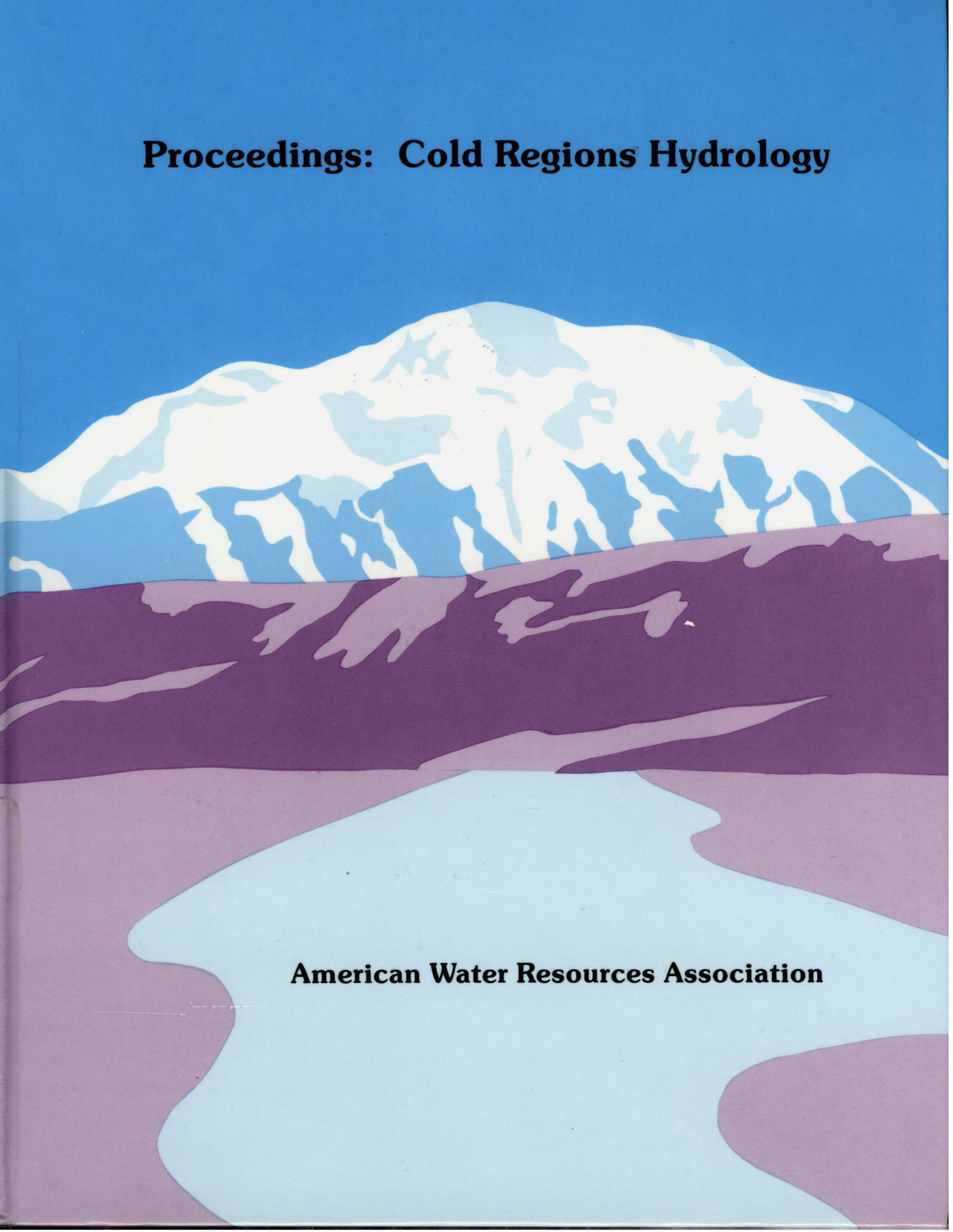

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FORECASTING THE EFFECTS ON RIVER ICE DUE TO THE PROPOSED SUSITNA HYDROELECTRIC PROJECT

Ned W. Paschke and H.W. Coleman*

ABSTRACT: River ice processes affect the physical and hydraulic properties of many of the world's rivers. Although winter flows are characteristically low, the additional friction and ice displacement within an ice-covered river can greatly increase the water surface elevation. The Susitna River, located in south-central Alaska, is generally subject to river ice processes for 6 or 7 months of each year. Environmental studies in connection with the proposed Susitna Hydroelectric Project (Alaska Power Authority, 1985) included documentation of natural (pre-project) river ice conditions and forecasting the effects of the project on river ice. In this regard, a numerical river ice model was calibrated and applied to an 85-mile reach of the Susitna River downstream of the proposed project. This paper presents a summary of the river ice modeling process, observed trends in natural ice conditions and the expected effects of the proposed project.
(KEY TERMS: cold regions; river ice; winter hydro operation, river ice modelling.)

INTRODUCTION

Proposed Susitna Hydroelectric Project

The proposed Susitna Hydroelectric Project includes the construction of two large dams on the Susitna River (Figure 1). Watana Dam, an earthfill structure with an ultimate planned height of 885 feet, would be located 184 river miles upstream from the river mouth at Cook Inlet (i.e., "RM 184"). Devil Canyon Dam, a 645-foot high concrete arch structure, would be located at RM 152, i.e., 32 miles downstream of Watana Dam.

The project is planned for construction in 3 stages as follows:

- Stage I - Watana Dam would be constructed to an initial height of 700 feet.
- Stage II - Devil Canyon Dam (full height) would be constructed.
- Stage III - Watana Dam would be raised to its ultimate height of 885 feet.

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Stage I is planned to begin operation in the year 1999. Stages II and III would be added in accordance with energy demand.

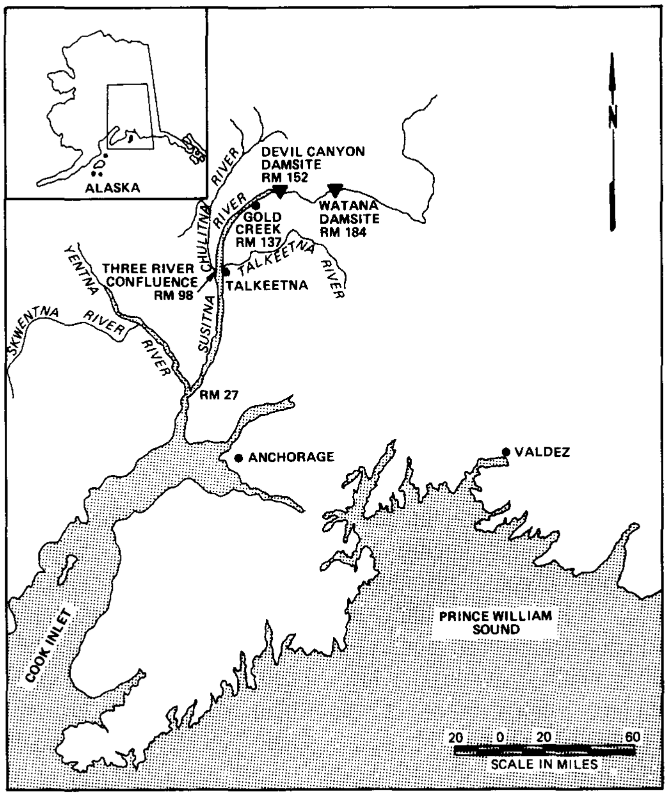

Figure 1. Susitna River Location Map

Environmental Background

Environmental concerns regarding ice processes on the Susitna River include potential effects on the salmon population. A number of slough and side channel areas along the river provide habitat for spawning and juvenile overwintering. These areas are generally isolated from the mainstem by a natural berm at the upstream entrance to the slough or side channel. During the winter, these areas are often warmer than the mainstem due to upwelling of relatively warm (e.g. 3°C) groundwater. Ice-induced stage increases periodically overtop some of the berms under natural conditions, flooding the slough with 0°C mainstem water and possibly harming the developing salmon. With the proposed project in operation, changes from the natural flows and stream temperatures will affect the river ice conditions and the frequency and severity of the slough overtopping events. The river ice model therefore focuses on the timing and magnitude of ice-induced river stage variations at the slough and side channel locations.

METHODOLOGY

Study Reach

River ice modeling was limited to the "middle reach" of the Susitna River, i.e., the 85-mile reach from the Watana damsite to the "three-river confluence" formed by the Susitna, Chulitna and Talkeetna Rivers (Figure 1). Downstream of this confluence, the substantial incoming tributaries are expected to lessen the relative effects of the future project. Typical natural river flow rates in the vicinity of the damsites range from 30,000 cfs in June to less than 2,000 cfs in March. With the project operating reservoir releases would generally be 8,000 to 13,000 cfs year-round.

Susitna River Ice Observations

Ice observations on the Susitna River have been documented for the past five winters (R&M Consultants 1981, 1982, 1983, 1984, 1985). Natural ice processes on the Susitna typically begin in early October with the generation of frazil ice, i.e., small ice crystals probably formed in supercooled surface water exposed to subfreezing air temperatures (Ashton, 1978). Frazil ice is first observed in the middle and upper reaches of the Susitna which are subject to the coldest air temperatures. Reaches of low solar radiation and high water turbulence appear to be highest in frazil ice production.

As the frazil is carried downstream, it coalesces into pans or rafts of "slush" ice which are often 2 to 5 feet in diameter and which may cover as much as 80% of the river surface. Border ice is observed to form as some of the slush ice pans come to rest and freeze together in low velocity zones along the river banks.

Typically late in October, an accumulation of slush ice becomes jammed and freezes together near the river mouth, forming a stationary ice bridge across the river. Formation of the ice bridge appears to be triggered by a high concentration of slush ice pans, low air temperatures and a high tide event in Cook Inlet which substantially reduces river velocities for several miles upstream. Following formation of the ice bridge, slush ice pans accumulate against its upstream edge and thereby advance the ice cover in an upstream direction. Some slush is observed to be swept beneath the ice front and is apparently deposited downstream on the underside of the cover, thereby thickening the ice cover. Periodic mechanical compression or "shoving" of the advancing ice cover (Pariset et. al., 1966) is observed, whereby as much as 2000 feet of the slush ice cover consolidates and thickens.

The advancing ice cover often reaches the three-river confluence (RM 98) in November and the vicinity of Gold Creek (RM 137) in late December or January, but varies with weather and flow conditions. Observed ice front progression rates in the middle reach typically range from 0 to 2 miles per day. Ice front progression generally becomes undefined upstream of Gold Creek, where intermittent bridging of border ice precedes the arrival of the ice front.

River stage increases of 2 to 6 feet in the middle reach are common during progression of the ice front, and overtopping of some slough and side channel areas has been observed. Slush ice cover thicknesses are observed to vary substantially along the river and particularly across the channel width. Often little or no ice is observed in a central, high velocity core area whereas accumulations as great as 12 feet thick reaching the channel bottom have been observed closer to the river banks. Following progression, the upper surface of the slush ice cover begins to freeze into solid ice. The solid ice portion of the ice cover is observed to reach typical thicknesses of 2 to 4 feet by February or March.

Spring breakup of the ice cover typically occurs in early May and is largely due to the natural flow increases which lift and fracture the cover. Sporadic ice jams caused by blocks of the fractured ice cover are observed to cause greater stage increases and more frequent slough overtoppings than those of the initial ice cover progression.

River Ice Model

The numerical river ice model was based on the work of Calkins (1984) on the Ottauquechee River and was modified and calibrated by Harza-Ebasco (1984) for application to the Susitna River. The model provides a daily summary of hydraulic and ice conditions throughout the study reach during the period from November 1 to April 30. A detailed description of the model and its governing equations has been presented by Calkins (1984). The general features of the model are briefly summarized as follows:

1. Hydraulic profiles are computed daily based on the Bernoulli and Manning equations (standard step method). Computations include the effects of the ice cover and border ice where appropriate.
2. Frazil ice production within reaches of 0°C open water is computed by a heat transfer coefficient approach (Ashton, 1978). Cumulative frazil flow rates are tabulated as the ice travels downstream.
3. Border ice growth is computed as a function of air temperature and water velocity and is calibrated to Susitna observations.
4. Hydraulic conditions at the ice front determine if the slush ice pans are swept beneath the ice cover or accumulated at its upstream edge, thereby advancing the ice front (Figure 2). Deposition of slush ice beneath the cover is computed based on the ice supply and water velocity under the ice cover. Thicknesses of the advancing ice cover are computed in accordance with

Pariset, et. al. (1966). Ice front progression rates are based on river geometry and the supply of ice reaching the front.
5. Solid ice growth within the slush ice cover is computed (Figure 2).
6. Melting of the ice cover and retreat of the ice front are computed when warm water (i.e. above 0°C) reaches the ice front. Water temperature decay beneath the ice cover is also computed. Mechanical breakup of the ice cover is not simulated by the model.

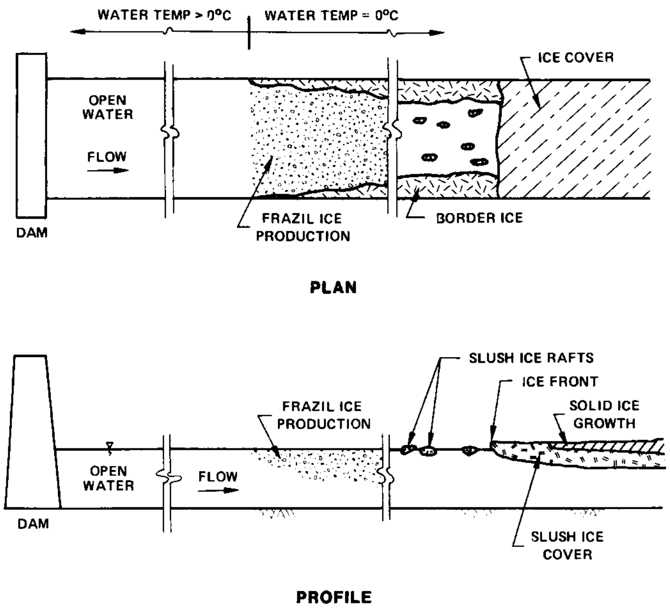

Figure 2. River Ice Schematic

Surveyed river cross-sections at 102 locations between Watana damsite (RM 184) and the "three-river confluence" (RM 98) were used in the model. Manning's "n" values ranging from .022 to .065 were selected to calibrate the open-channel portion of the model to stage-discharge measurements. Daily air temperatures and wind speeds recorded at 3 locations along the study reach were used for the various ice processes in the model. For simulations of natural (pre-project) conditions, daily flow rates and frazil ice discharges were input at the upstream boundary based on observations at Gold Creek (RM 137). For with-project conditions, flow rates and water temperatures upstream of the ice front were provided by corresponding reservoir and stream temperature simulations. Starting dates for the simulated with-project ice front progression at the three-river confluence were based on tabulation of the total ice volumes supplied to the lower Susitna River and the time required to advance the lower Susitna ice front from Cook Inlet to the three-river confluence.

The river ice model is primarily intended to simulate the timing and magnitude of river stage variations associated with ice. Simulated natural ice conditions show reasonably good agreement with field observations (Figure 3). Limitations of the model relate primarily to its one-dimensional nature. Velocities and ice cover thicknesses computed by the model are mean or characteristic values intended to represent an entire cross-section. Actual velocities and ice thicknesses are likely to be quite nonuniform within the cross-section.

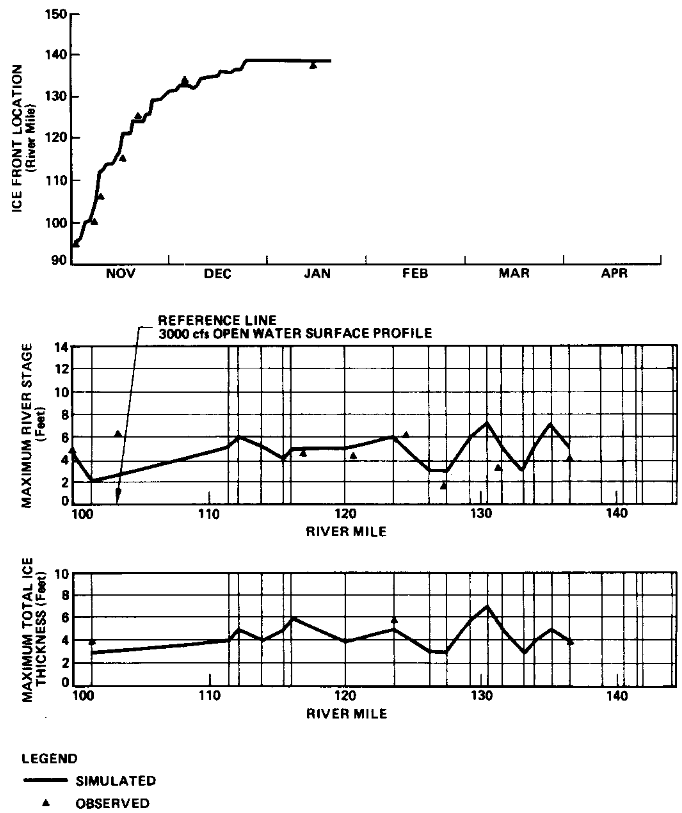

Figure 3. Sample River Ice Calibration Winter 1982–1983

RESULTS

Sample results of river ice simulations for natural conditions and the three stages of the project are shown in Figures 4 and 5. These simulations are based on weather conditions of 1981-82 (an average winter in terms of mean air temperatures) and show typical trends.

With Stage I in operation, ice front progression at the "three-river confluence" during an average winter is expected to be delayed until mid-December, about 3 weeks later than that of natural conditions (Figure 4). With the operation of the project Stages II and III, respectively, the ice cover progression is expected to be further delayed until late December or early January (Figure 5).

Spring meltout in the middle reach of the Susitna River with Stage I operating is expected to be completed by late April (Figure 4), about 2 weeks earlier than the natural breakup. With operation of Stages II and III, the meltout would be further advanced (Figure 5), occurring in late to early March, respectively. The delayed ice front progression and the earlier-than-natural ice meltout with the project operating is due primarily to warmer-than-natural water temperatures released from the project reservoirs during the winter months.

The maximum upstream extent of the ice cover during an average winter is expected to be in the vicinity of RM 139 with Stage I operating. This ice cover extent would be reduced to near RM 133 with Stage II operating and further reduced to the vicinity of RM 114 with Stage III operating (Figure 5). Little or no ice is expected upstream of these locations with the project operating, whereas under natural conditions these reaches become covered by border ice growth.

The total thickness of the river ice cover with Stage I operating is expected to be generally similar to that of natural conditions (Figure 4). Ice cover

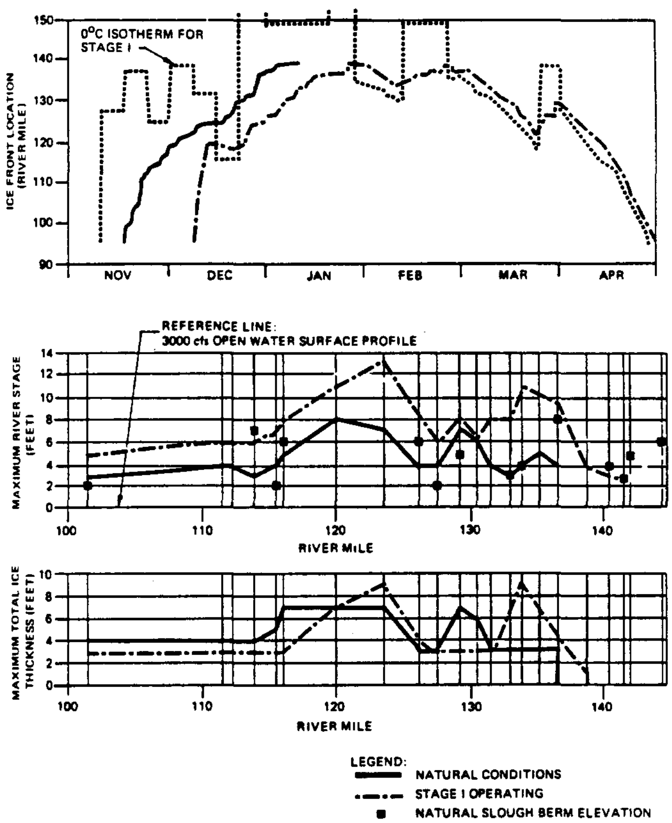

Figure 4. Simulated River Ice Conditions
Stage I vs. Natural
1981–1982 Weather Conditions

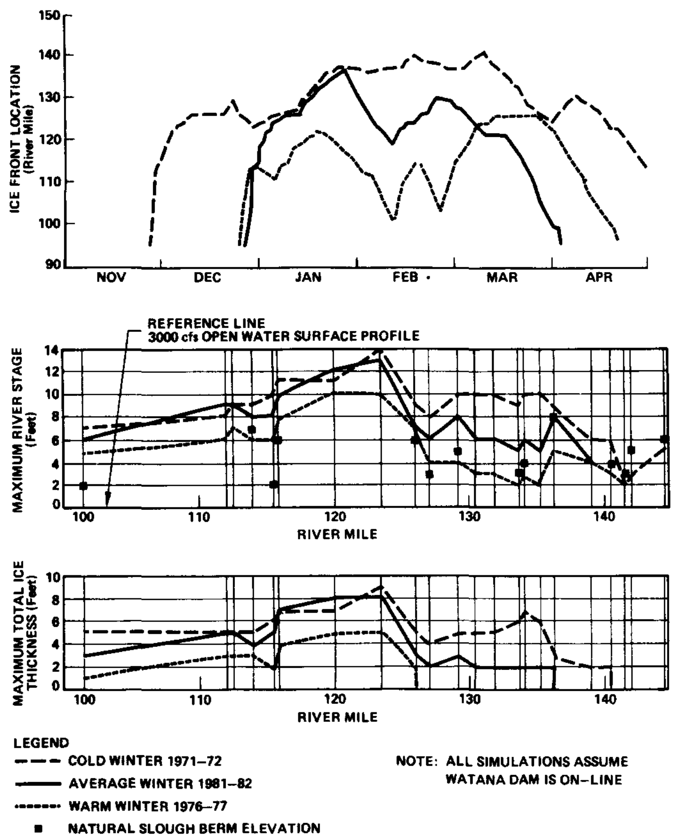

Figure 5. Simulated River Ice Conditions
Stages I, II and III
1981–1982 Weather Conditions

thicknesses are expected to be progressively reduced with the addition of Stages II and III (Figure 5). The reduced extent and thicknesses of the ice cover with the project operation again primarily reflect the warmer-than-natural reservoir release temperatures.

Maximum river stages within the ice-covered reaches during operation of Stages I, II and III are expected to be generally several feet higher than those of natural conditions. This is due primarily to the greater-than-natural flow rates with the project in operation. The frequency and magnitude of the slough overtopping events upstream of the ice front with the project operating are therefore expected to be less than or equal to those of natural conditions.

The simulation results discussed above are based on the average winter weather conditions of 1981-82. Simulations were also made for a cold winter (1971-72) and a warm winter (1976-77). Although these simulations (Figure 6) were based on a different construction and operational schedule than Figures 4 and 5, they serve to indicate the sensitivity of the simulated river ice processes to weather conditions. With the project in operation during a cold winter, for example, the ice front would be expected to begin several weeks earlier and would extend several miles further upstream than for an average winter. Maximum ice cover thicknesses and river stages during a cold winter would also be about 2 feet greater than those during an average winter. During a warm winter, conversely, ice cover thicknesses and river stages are likely to be about 2 feet less than for the average winter.

SUMMARY

A numerical river ice model was applied to the Susitna River to forecast the effects of the proposed Susitna Hydroelectric Project. The model simulations predicted delayed ice cover formation, reduced ice cover extent and earlier and milder spring meltout relative to natural conditions. Greater than natural river stages were predicted for some reaches, and mitigation measures will be proposed therein. Weather conditions and project stage were shown to substantially affect the expected river ice conditions.

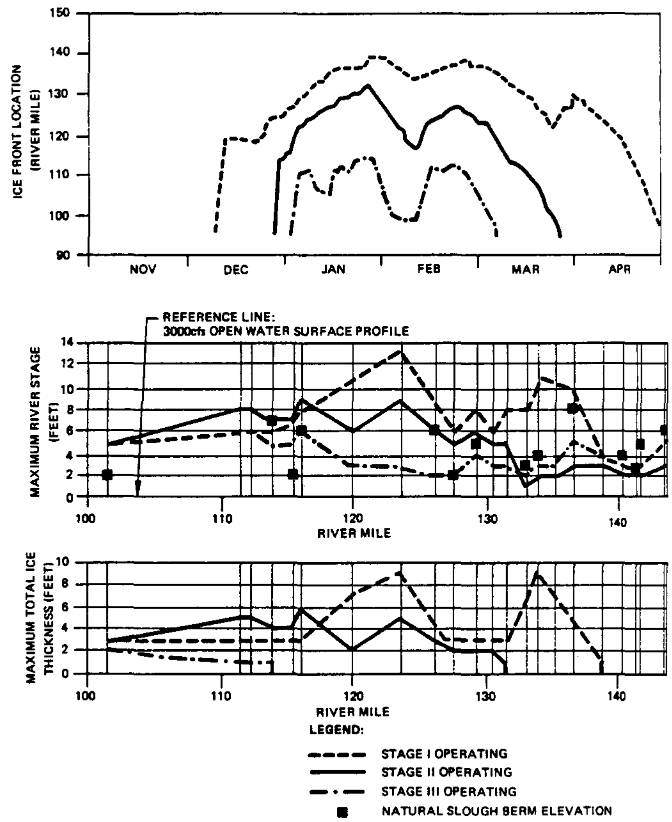

Figure 6. Simulated River Ice Results For Various Weather Conditions

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