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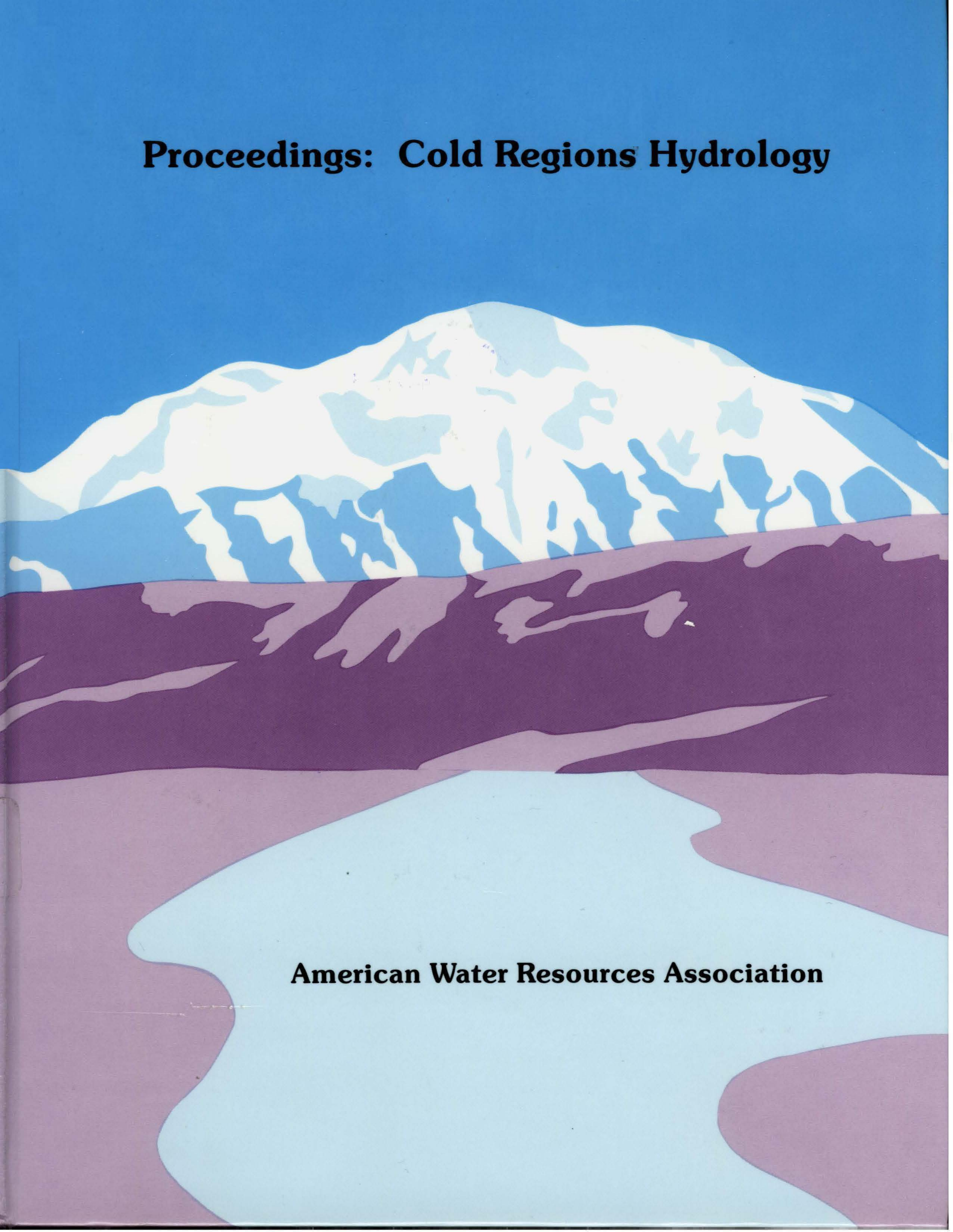

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HYDROLOGY AND HYDRAULIC STUDIES FOR LICENSING OF THE SUSITNA HYDROELECTRIC PROJECT

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ABSTRACT: The planning for and licensing of a major hydroelectric project require many hydrologic and hydraulic studies. These range from observations of existing conditions in the watershed, to estimates of project related effects on water use, water quality and impacts on the ecosystem. The number and breadth of these studies for a project located in a cold region is discussed. Examples of analyses used to predict changes to plants and animals resulting from the construction and operation of this major hydroelectric facility are presented. Hydrologic considerations in the design and operation of such a facility which are additional to considerations in a more temperate zone are included. For example, the effects of glaciers on streamflow and on sediment and the effects of ice on river stage and reservoir heat transfer are topics which are not addressed in temperate region hydro-projects. Evaluation of such a development in a cold region, therefore, requires the coordinated efforts of hydrologists, hydraulic engineers, fishery, wildlife and plant biologists.
(Key Terms: Cold Regions Hydrology, Hydroelectric Projects, Licensing, Environmental Impacts, Alaska Railbelt.)

INTRODUCTION

Project Description

The Susitna Hydroelectric Project has been proposed by the Alaska Power Authority to provide for the projected electrical energy needs of the Railbelt region in the 21st century. The Railbelt region is the area of southcentral Alaska extending from Homer at the southern tip of the Kenai Peninsula to Fairbanks and including the large metropolitan area of Anchorage. The region is so-named because its principal cities are linked by the Alaska Railroad (Figure 1).

The project would consist of two dams, powerhouses and appurtenant facilities, to be located on the Susitna River about midway between Anchorage and Fairbanks. The upstream development at the Watana site is located 296 km (184 miles) upstream of the river's mouth at Cook Inlet. This dam would be an earth and rockfill structure and would be built in two stages. In the initial stage the dam height would be raised approximately 214 m (702 ft.) above its foundation to El. 617.2 m (2,025 ft. msl). A powerhouse with four turbine/generator units (units) having a total average capability of 440 MW at a discharge of approximately 340 m^3/s (12,000 cfs) would become operational in 1999. This dam would be raised to El. 672.1 m (2,205 ft. msl) in the third stage of the project, following completion of the downstream dam. Two additional units would be added to the powerhouse increasing the total average generating capability of the Watana development to 1,110 MW at a discharge of approximately 650 m^3/s (23,000 cfs). The two additional units would become operational in 2012. The downstream development at the Devil Canyon site is located 245 km (152 miles)

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upstream of Cook Inlet. The dam at this site would be a thin concrete arch structure with a crest at El. 446 m (1463 ft. msl) 197 m (646 ft.) above its foundation. The downstream impoundment would extend to the upstream dam. The powerhouse at Devil Canyon would contain four units and have a total average generating capability of 680 MW at a flow of 430 m^3/s (15,200 cfs). These units would become operational in 2005.

The Watana dam site is located in a broad U-shaped canyon and the Devil Canyon dam site is located in a narrow, steeply incised canyon. The Watana reservoir would provide the flow regulation for its own and the Devil Canyon powerhouses. The Devil Canyon dam would provide little flow regulation but would develop additional head. The Watana reservoir would impound $5.3 \times 10^9 m^3$ (4.3×10^6 ac-ft) of water in Stage I and 11.7×10^9 m^3 (9.5×10^6 ac-ft) of water when it is raised in Stage III. The Devil Canyon dam would impound 1.4×10^9 m^3 (1.1×10^6 ac-ft) of water (APA 1985).

History of Project

The proposed project is a result of a series of reconnaissance, prefeasibility and feasibility studies performed by various agencies of the Federal Government and the State of Alaska (Acres 1981). The initial reconnaissance level work by the U.S. Bureau of Reclamation (USBR) identified five damsites from a list of 25 as being most appropriate for further investigation. These sites were all located in the river reach upstream of the major confluences with the Chulitna and Talkeetna Rivers. These areas were considered appropriate because the site characteristics generally allow for high heads to be developed and substantial flow regulation to be achieved with dams located in relatively narrow canyons. Additionally, dams located in this reach would have less effect on the river's large anadromous fishery than dams at downstream sites. Later studies by the USBR, Alaska Power Administration and H. J. Kaiser Co. for the State of Alaska built upon the original USBR study with some slight refinements to the site locations. All proposed the Devil Canyon site as the initial damsite with upstream sites to be developed in the future. The U. S. Army Corps of Engineers (COE) prepared comprehensive basin studies in 1975 and 1979 and proposed the damsites at Watana and Devil Canyon as the most appropriate. Following the COE's 1979 study the State of Alaska formed the Alaska Power Authority (APA) for the purpose of planning for the power needs of Alaska and developing the projects to meet the needs. The APA reassessed the previous studies and confirmed the conclusions of the COE. The initial License Application before the Federal Energy Regulatory Commission (FERC) was filed by the APA in 1983 (APA 1983). This application was amended to include refinements and staging the Watana dam (APA 1985). The latest application has recently been withdrawn in favor of a study of alternative energy sources for the region.

The Basin

The drainage basin upstream of the Devil Canyon site is located approximately between latitude 62°05′ and 63°40′ North and between longitude 146°10′ and 149°30′ West in south central Alaska, approximately 225 km (140 miles) north-northeast of Anchorage and 177 km (110 miles) south-southwest of Fairbanks (Figure 1). The drainage areas upstream from the Devil Canyon and Watana damsites are about 15,050 and 13,400 square kilometers, (5,810 sq. mi. and 5,180 sq. mi) respectively.

The basin is geographically bounded by the Alaska Range to the north and west, and the Talkeetna Mountains to the south and east. The topography is varied and includes rugged mountainous terrain, plateaus, broad river valleys and lakes. Mount McKinley (El. 6,194 m) is located on the northwest divide of the basin. Elevations within the basin upstream of the Devil Canyon site range from approximately 260 meters above mean sea level (850 ft, msl) at Devil Canyon site to over 2,100 meters, msl (7,000 ft. msl) near the head reach of the Susitna River.

Approximately 5% of this basin is covered by glaciers. Three major glaciers - West Fork Susitna, East Fork Susitna and Maclaren, exist in the basin. The landscape consists of barren bedrock mountains, glacial till-covered plains and

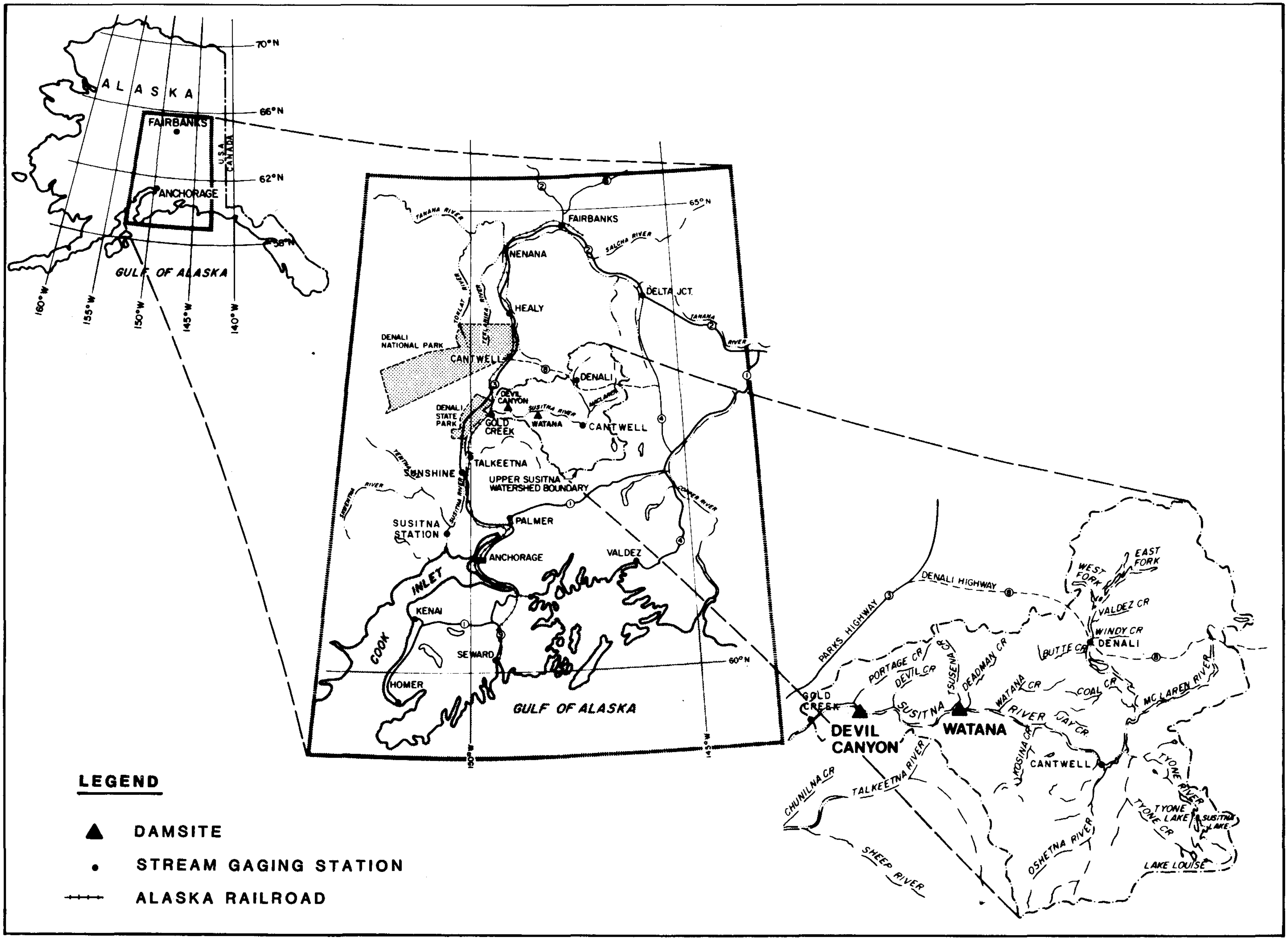

FIGURE 1 **LOCATION MAP**

exposed bedrock cliffs in canyons and along streams. Soils are typical of those formed in cold, wet climates and have developed from glacial till and out-wash. They include the acidic, saturated, peaty soils of poorly drained areas, the acidic relatively infertile soils of the forest and gravels and sands along the river. The basin is generally underlain by discontinuous permafrost.

The River

The Susitna River originates in the East Fork and West Fork Susitna Glaciers at an altitude of approximately 2,380 m (7,800 ft. msl) and travels a distance of about 512 km (318 miles) before discharging into Cook Inlet. The head waters of the Susitna River and the major upper basin tributaries are characterized by broad, braided, gravel flood plains below the glaciers. Several glacierized streams exit from beneath the glaciers before they combine further downstream. Below the confluence with the West Fork Susitna River, the river develops a split-channel configuration with numerous islands and is generally constrained by low bluffs for about 89 km (55 miles). The Maclaren River, draining the Maclaren Glacier and a few small lakes, and the non-glacial Tyone River draining Lake Louise and swampy lowlands of the south-eastern part of the basin, join the main river downstream of Denali. Below this confluence, the river flows west for about 155 km (96 miles) through steep-walled canyons before reaching the mouth of Devil Canyon. River gradients average about 0.3 percent in a 87 km (54-mile) reach upstream of Watana, about 0.2 percent from Watana to the entrance of Devil Canyon and about 0.6 percent in a 19 km (12-mile) reach between Devil Creek and the outlet of Devil Canyon.

The Susitna River is typical of glacial rivers with high turbid summer flow and low, clear winter flow. The discharge generally starts increasing during early May. The base flows during July through September are due to groundwater, glacial melt and melt of long term snowpack. Peak flows during this period are associated with general frontal type of thunderstorm activities. The river flow rapidly decreases in October and November as the river freezes. The break-up generally occurs in early May. The May through June flows are caused by snowmelt combined with rainfall. Melting of snow, firn and ice from the glaciers has accounted for about 13% of the annual streamflow at Devil Canyon. The average summer and winter flows at a few selected stream gaging stations are given in Table 1. Figure 1 shows the locations of the stream gaging stations.

Project Operation

The project will operate by storing the high summer flows in Watana Reservoir to provide a dependable source of power in the winter for the Railbelt. The reservoirs will generally be full in late August or September and the Watana Reservoir will be drawn down throughout the winter. It will reach its lowest level in early May and begin to fill as river flows increase from snowmelt and rainfall. Filling will continue throughout summer until the water level reaches its normal maximum level. This can occur as early as late June in a wet year or as late as early September in a dry year.

When the reservoir is full, inflow in excess of power and environmental flow requirements must be released. High inflows in July and August may often exceed these requirements resulting in the need to release flows through outlet works to prevent the reservoir water level from encroaching on dam safety requirements. Table 1 compares natural and with-project flows for the Susitna River at Gold Creek for summer (May - September) and winter (October - April) periods based on 34 years of record and simulations of project operation (Wu et. al. 1986). Gold Creek is 26 km (16 miles) downstream of the Devil Canyon site and is the location at which environmental flow requirements will be gaged. There are no major tributaries between the damsites and Gold Creek.

Average monthly flows and floods during Stage I, II, and early Stage III would be similar. Energy demands are projected to increase in late Stage III and the summer flows would decrease accordingly.

Flood peak discharges would also be reduced due to the storage capacity of the Watana Reservoir as shown by Table 2.

Susitna River Gaging Station	Drainage Area	Summer (May - Sept) Natural	Summer Stages I, II	Summer Stage III	Winter (Oct - Apr) Natural	Winter Stages I, II	Winter Stage III
	(Sq. km)						
Near Denali	2,460	179	179	179	11.7	11.7	11.7
Near Cantwell	10,700	365	365	365	37.8	37.8	37.8
At Gold Creek	16,000	572	374	285	64.1	207	271
At Sunshine	28,700	1,380	1,180	1,090	153	296	360
At Susitna Station	50,200	2,680	2,480	2,390	354	497	561

Table 1. Average Summer and Winter Flows (m^3/s) at Selected Stream Gaging Stations for Natural and With-Project Conditions

Return Period (Years)	Natural[1/] Gold Creek	Natural[1/] Sunshine	Gold Creek Stages I, II[2/]	Gold Creek Stage III[1/]	Sunshine Stages I, II	Sunshine Stage III
2	1,360	4,050	1,030	626	3,650	2,970
5	1,790	4,700	1,220	844	4,190	3,430
10	2,090	5,180	1,250	968	4,560	3,770
25	2,470	5,670	1,270	1,080	4,930	4,160
50	2,770	6,060	1,320	1,210	5,270	4,500

Table 2. Natural and With-Project Floods Susitna River (m^3/s)

1/ Annual series, occurs in May - June at Gold Creek and July - September at Sunshine.

2/ July - September series. Under natural conditions the highest peak floods occur in June as a result of snowmelt and precipitation runoff. Regulation of floods by the reservoir will delay the highest floods until the July - September period except in late Stage III. In late Stage III regulation by the project will be so large that July - September floods will be less than those in June.

Overview of Hydrologic Studies

The planning for and licensing of a major hydroelectric project require many hydrologic and hydraulic studies. The initial requirement, during the reconnaissance level studies, is for a reasonable estimation of streamflow quantity, time distribution and reliability. As the need for the project increases and the proposed sites must be screened to develop plans worthy of more detailed and costly investigation, the scope of the hydrologic studies must also increase. More accurate knowledge of flows is required in these prefeasibility level studies and potential project effects on the ecosystem must be more accurately evaluated. For the feasibility and licensing level of work, the selected development will be compared to other projects on the bases of economic and engineering feasibility and environmental impacts. For a large, capital intensive project located in an ecologically sensitive area to survive comparison against smaller, less capital intensive projects with less visible environmental impacts requires accurate determination of the hydrologic resource available to produce energy and comprehensive studies of how project operation will affect the environment.

During feasibility and licensing of the project, hydrologic studies are carried out for three purposes: one, to develop information on flows required to judge the project economics; two, to develop information necessary for the planning and preliminary design of project structures; and, three, to estimate potential project effects on the water resource and resulting impacts to humans, animals and plants which use the water.

From an engineering or project design standpoint there are many hydrologic considerations. The most important is the time distribution and reliability of river inflow and how this affects the need for active storage capacity in the reservoir. This was a factor in the selection of possible dam sites and in the scheduling of Watana dam construction ahead of Devil Canyon.

Other hydrologic considerations in design were the potential for glacial outbreak floods and the influence of mass glacial wasting on streamflows. The location of the project in a cold region with its great variation in summer and winter streamflows, the importance of snowmelt and glacier melt and the presence of glaciers which could surge or cause jokulhlaups has resulted in studies which would not be carried out in a more temperate climatic region.

The proposed project is located in a wilderness like area on a stream which supports a diverse anadromous fishery in a basin which contains much wildlife. The potential for affecting this ecosystem is an important issue and is addressed primarily by hydrologic and hydraulic studies coordinated with biologic studies. Such factors as the project influence on downstream flows, water temperature, sediment concentration, river ice regime, and dissolved gas concentration have been evaluated in great detail with hydrologic and hydraulic studies and have influenced the proposed project design and operation. Again, the breadth of these studies is larger in a cold region than in a more southerly area because of the occurrence of ice on the river and proposed reservoir, and its affect on water levels, river and reservoir temperatures.

Hydrologic studies will not end with project licensing. In fact, they will likely increase as project operators and fish and wildlife agencies seek to use the water resource to greater advantage. Efforts will be made to forecast reservoir inflows (Hydex, 1985). Project effects on temperature, ice, sediment, etc. will be monitored and predictions made during licensing will be refined. Effects on fish and wildlife will be observed. Energy demand growth, now just a prediction, will occur. Project operation will need to be modified to meet the need for energy and to preserve and enhance the environment.

HYDROLOGIC STUDIES FOR PROJECT ECONOMICS

The hydrologic studies required to evaluate project economics center on three subjects: one, the quantity of flow in the river, two, the distribution of this flow throughout the year, and three, the reliability of this flow from year to year. These three factors along with the topographic features of a reservoir site (depth, volume, surface area) determine the average energy which can be generated, the reliable or firm energy, the amount of storage which must be provided in the reservoir and the manner of reservoir operation. The location of the Susitna Project in a cold region influences the three parameters.

The first parameter, average quantity of flow, is a function of precipitation, evaporation and transpiration since, over the long term, runoff must equal precipitation minus the other losses. This is largely controlled by the basins' geographic location, topography and large scale weather patterns. The main influences on the quantity of flow due to the cold climate, which are different than in a more temperate climate, would be the effects on evaporation and transpiration losses.

For the Susitna Project the estimation of streamflow quantities was relatively simple. The U.S. Geological Survey has collected streamflow information at a site near the proposed project since the potential project was first considered. Thus, thirty-four years of flow data are available (USGS, 1949-1984). These values were transposed to the project site using multi-site regression analyses (Harza-Ebasco 1985a).

While its location in a cold region may not affect the quantity of flow, the location does affect the distribution of flow within the year and the reliability of flow from year to year. The location of the energy demand centers in a cold region also affects the demand for the power over a year and thus affects the project operation. In a warmer climate, such as in some areas of the 48 contiguous U.S. states, summer temperatures are typically hot enough to require air conditioning. These areas may experience their highest electrical energy demands in the summer. In contrast, the Alaska Railbelt has mild summers not requiring air conditioning. Winters are cold, long, and relatively dark resulting in highest electrical energy demands in December and January. This pattern of energy consumption is expected to continue in the future and contrasts with the pattern of streamflows.

The long period of subfreezing air temperature (October - April) results in extreme differences between summer (May - September) and winter streamflows. Average summer streamflows are 470 m^3/s cfs compared to average winter flows of approximately 53 m^3/s. Therefore, the Watana Reservoir must provide an active storage equal to 0.6 of the average annual inflow in order to provide a dependable capacity equivalent to 211 m^3/s in the winter of a very dry year. While the extreme seasonal distribution of inflow results in the requirement of a large storage capacity, other factors offset this. These are the minimal net evaporative loss from the reservoir surface and the presence of glaciers and occurrence of long term snow pack. In effect, the river streamflow is regulated by the glaciers and snowpack. Studies were undertaken to estimate the net difference between evaporation from the reservoir surface and evapotranspiration from the same area under natural conditions (Harza-Ebasco 1985a). These established that net loss of water would be less than 0.1% of the annual inflow. Thus, this was not a factor in sizing the reservoir as in warmer climates.

Studies were also made to determine how the glaciers act to regulate streamflow (R&M 1981, 1982, Clarke et.al. 1985, Clarke, 1986). Although they cover only 5% of the basin they have a significant regulating effect. In wet years they tend to accumulate snowfall and in dry years they tend to waste. A study of the mass balance of the glaciers was undertaken to determine whether there were any discernible trends in the glacier's behavior to indicate whether the streamflow estimates during the 34 years of record were influenced by any gain or loss of glacier mass. These studies were, by necessity, carried out on a reconnaissance level since the only aerial photos of the glaciers in 1949 were uncontrolled, and the only controlled photographs of the glaciers in 1980 comprised less than 5% of the glaciated area. Additionally, a reconnaissence level study of the glacier surface elevations was undertaken. These studies tended to confirm that the streamflow measurements were probably not unduly influenced by changes in the glacier mass (APA 1985). Studies were also made to determine the influence on project economics if the glacier melting were to diminish (Harza-Ebasco 1985b). These confirmed the project's viability even if the glaciers' mass balance were to change.

HYDROLOGIC STUDIES FOR PROJECT DESIGN

Basin hydrology affects the design of major project features in addition to reservoir size.

The most prominent hydraulic structure in a major hydroelectric project is the spillway or outlet works which must pass flood flows through the project without endangering the dam. In the Susitna Project there are two means for passing non-power releases. Outlet works controlled by fixed cone valves are planned at both dams to release all floods up to the 50-year event. Less frequent floods would be released through gated overflow spillways. The outlet works are provided so that the more frequent floods can be discharged to the river through the cone valves which disperse the flow over a large area and minimize the potential for elevated gas concentrations in the river downstream. High gas concentrations can be deleterious to the fish.

Hydrologic studies included development of the 50-year flood hydrograph for annual, spring and fall series and routing of these floods through the project reservoirs. These studies established the necessary outlet works and flood storage capacities (Harza-Ebasco 1985c).

Project spillways were designed to pass the Probable Maximum Flood (PMF) without endangering the dam as set out in guidelines of the COE and the U.S. Committee on Large Dams (COE 1965, USCOLD 1970). Hydrologic studies included estimation of the PMF hydrograph (Acres, undated) and routing of the PMF through the projects to establish required spillway capacities and surcharge levels (APA 1985).

An important factor in the PMF determination was the estimation of snowpack and the manner of snowmelt since the PMF would occur during the May-June period (Acres, undated). A probability approach was adopted to estimate the total snowpack during the event and snowmelt was assumed to occur in a manner to maximize runoff.

The PMF was estimated by assuming the maximum possible precipitation concurrent with a 1000-year snowpack and various antecedent conditions and the runoff routed through the basin. This is a standard, accepted method. However, in a glaciated basin, there is always the potential for a jokulhlaup or flood caused by the break-out of a glacially dammed lake. Discharges from such occurrences can be very high, potentially exceeding a PMF. Therefore, a survey was made to determine the potential for glacial dammed lakes which might affect the project (R&M 1981). The study indicated little likelihood of this.

Almost all large reservoirs are subject to some degree of sedimentation and the Susitna Reservoirs would be no exception. Hydrologic studies were made to estimate the suspended and bed load in the river (Knott and Lipscomb 1983, 1985) and to determine the effects on reservoir life (Harza-Ebasco 1984a, 1985d). The average annual sediment load of approximately 6.0 x 10^9 kg. (6.5 million tons) would require 1,400 years to fill Watana dead storage and 2,300 years to fill the Devil Canyon dead storage. The average suspended sediment concentration in the inflow is 800 mg/l and is comprised of a high percentage of very fine rock flour (27% less than 10 microns). This is the result of glacial weathering of underlain rock. This material has a very slow settling velocity (10^{-6} - 10^{-5} m/sec) and much is expected to remain in suspension in the reservoir. The trap efficiency of the reservoir is expected to be about 80% - 90% (APA 1985) as contrasted to reservoirs of similar characteristics in areas with coarser sediment which have trap efficiencies near unity (USBR 1977). A mathematical model was developed, and is described below, to more accurately estimate the potential sediment concentrations downstream of the project, for estimating impacts to fish.

Another important project feature is the means of handling water during project construction. The diversion facilities will consist of tunnels to pass normal river flows around the construction areas and cofferdams at the upstream and downstream ends of the areas. These facilities will be sized using risk/cost analyses to minimize their cost and the potential losses resulting from failure. This means that cofferdam heights and tunnel sizes will be determined for various frequency floods to assign probabilities to the risk of failure. Another hydrologic consideration in diversion tunnel design is it's elevation relative to the streambed and the potential for bed load material to become trapped in the tunnel, if it is set too low, thus reducing its capacity and affecting the hydraulics at the tunnel outlet. The Susitna tunnels have been located to prevent this (Wang, et. al 1986). The diversion facilities design must also consider the need to pass ice and the potential for ice jam floods. The diversion tunnel intakes at both Watana and Devil Canyon would be located on the outsides of bends for reasons of economy in tunnel construction. They are thus well located for passing incoming frazil ice in October and November and broken ice sheets in April and May (USBR, 1974). The tunnel sizes are believed wide enough (11 m.) to handle ice sheets during breakup. Nevertheless, careful consideration will be given to the intake design, to minimize potential jamming in this area.

Breakup jamming is also a potential problem downstream of the diversion tunnel. A bend in the river downstream of the tunnel outlet may provide a site for jamming of broken ice passed through the tunnel. Therefore, consideration was given to this and the downstream cofferdam crest elevation was set to prevent overtopping and flooding of the construction site by water backed up behind the potential jam.

Other hydraulic considerations due to the project's location in a cold region are also primarily the result of ice. The design of the power intake towers includes heated floating ice booms to prevent ice forces on the trashracks and gates. The potential for entrainment of frazil and broken ice in the flow through the intake may dictate the submergence of the operating intake below the water surface at some times. However, as the intake has openings at several levels this will not preclude safe operation of the powerhouse.

HYDROLOGIC AND HYDRAULIC STUDIES FOR ENVIRONMENTAL IMPACT ANALYSIS

The primary environmental concern is the potential effect of the project on the downstream fishery. Other concerns include the project's potential effect on terrestrial wildlife and riparian vegetation. The mechanisms responsible for the potential impacts are the proposed project's effects on the quantity and quality of water in the Susitna River. The primary concerns relate to the potential impacts on river flows, floods, water temperature, river ice conditions, suspended sediments, turbidity, and river morphology.

Salmon utilize the peripheral areas of the river (such as sloughs which have favorable velocities, depths, temperatures, turbidities and substrates) for spawning, rearing and incubation. The amount of area available for fish use is related to the magnitude and stability of river flow. In conjunction with fisheries experts, who developed models of fishery habitat versus flow, the amount of habitat for all stages of project opèration was estimated by simulating flows with project operation from initial construction to full use of project capacity, approximately 30 years (Trihey, et. al. 1985). Flow constraints were developed to provide fishery habitat of equal or greater value than natural conditions.

The quality of the water can also affect the fishery. For example, temperature can be lethal in the extremes or can affect fish growth. Suspended sediment can affect fish gills. Settling of sediment in spawning beds can affect intergravel flow through these areas. Turbidity can provide protection from predators and can retard production of waterborne insects which provide food for the fish. The hydrologic and hydraulic evaluation of the effects of the Susitna Project on water quality were evaluated with a system of three models: a reservoir water quality model, a river temperature model and a river ice model.

Reservoir water quality was evaluated using the Dynamic Reservoir Simulation Model (DYRESM) (Imberger and Patterson, 1981). Modifications were made to the model to handle cold regions conditions and features of the Susitna Project (Harza-Ebasco 1984b Wei and Hamblin 1986). The model was modified to include:

- Formation of an ice cover on the reservoir and winter stratification,
- Outflow from the reservoir through multiple level offtakes, and
- Simulation of suspended sediment including settling and the effect of sediment on density and thus, reservoir stratification.

This latter modification was necessary because of the small size of inflowing sediment and the need to estimate the downstream sediment concentration. A program of collection of hydrological and meteorological data was undertaken at Eklutna Lake (R&M 1985b) a small, glacially fed, lake-tap hydroelectric project near Anchorage to provide the data needed for development and testing of the modifications. Upon completion of testing, the model was applied to the proposed sites using hydrologic and meteorologic data collected for the purpose at the sites (R&M 1985a). Extensive studies were made, at the request of regulatory agencies, to provide information for evaluating impacts and to determine the most favorable method for operating the multi-level offtake.

Temperatures in the river downstream of the reservoirs were evaluated using the Stream Network Temperature Model (Theurer, et. al. 1984), driven by output from DYRESM. The modeled reach extended from the Watana and Devil Canyon dam faces to

Sunshine, 23 km (14 miles) downstream of the confluence with the Chulitna River a distance of about 160 km (100 miles). The potential for lethal temperatures to occur was found to not be a problem and the modeling effort focused on the potential for effects on growth. While the DYRESM model provided outlet temperatures on a daily basis, the SNTEMP model was used on an average weekly basis. Several refinements were made to the SNTEMP model as well (AEIDC 1983). These include:

- o Estimation of solar radiation from radiation incident at the edge of the atmosphere corrected for atmospheric and topographic effects,
- o Inclusion of frictional heating,
- o Inclusion of tributary temperature effects on mainstem temperature and regression modeling of tributary temperatures, and
- o Inclusion of air temperature lapse rates between the site of the temperature recorder and the upstream end of the study reach.

River temperatures were measured both in the mainstem and tributaries to allow calibration and verification of the model.

The SNTEMP model was used to estimate river temperatures downstream of the reservoir throughout the year for all DYRESM simulations. In the summer the downstream end of the study reach was at Sunshine. Modeling of temperatures was not considered necessary downstream of that point because with-project temperatures were generally found to be within 1°C of natural. In the winter the downstream end of the SNTEMP modeled reach was the location of 0°C.

Modeling of winter river conditions, with ice, was done using a model developed for the project (ICECAL) (Harza-Ebasco 1984c). This model computes the amount of ice produced, hydraulic conditions in the channel, development of border ice, formation of an ice cover from frazil ice and staging of water levels due to the ice cover. The model was used primarily to determine how peripheral habitat areas would be affected by the increase in winter flows (from 60 m^3/s - 250 m^3/s) coupled with the change in the extent of ice cover. There was concern that increased water levels in the river area affected by ice would overtop peripheral habitat areas and introduce cold water into the sloughs thus stressing the salmonids. The results of the modeling allowed prediction of the impact, and development of mitigation measures.

During development and testing of the model an extensive program of field observations was carried out (R&M 1981-85) to develop information for verifying the model and to better understand the basic ice processes in the river.

Several other hydrologic studies were undertaken in conjunction with the evaluation of biologic impacts. A mailed survey was undertaken and a site visit was made to determine the experiences of other hydroelectric project operators in cold regions (Gemperline et. al. 1986). Riverbed stability was evaluated to estimate potential aggradation and degradation (Harza-Ebasco 1984a, 1985e). This involved determination of bed load, bed material sizes and bed material transport equations. Impacts evaluated included the potential for aggradation near tributary mouths possibly affecting fish access and degradation in the mainstem possibly affecting peripheral habitat. Potential effects of project operation on riparian vegetation were evaluated using notes on vegetation types observed during river surveys. The observed elevations of various types of vegetation were correlated to river flows and floods. Based on a model of vegetation succession and predicted with project flood flows, the vegetation encroachment on the river was, to some degree, quantified.

CONCLUSION

This paper presents some of the more important hydrologic and hydraulic studies which have been made for the licensing of the Susitna Hydroelectric Project, including considerations because of the project's location in a cold region. For the purpose of the paper the studies were separated into those required for economic, analyses, engineering design and environmental impact analyses. However, in reality, the studies were not separated. For example: the evaluation of fishery habitat and the establishment of minimum flows affected estimated project energy production; the design of power offtakes and release facilities affected estimated downstream water quality. Coordination was required between all participants to develop the information necessary for licensing of the project.

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