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METHODOLOGICAL APPROACH TO QUANTITATIVE IMPACT ASSESSMENT FOR THE PROPOSED SUSITNA HYDROELECTRIC PROJECT

RCTIC ENVIRONMENTAL INFORMATION AND DATA CENTER

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METHODOLOGICAL APPROACH TO QUANTITATIVE IMPACT ASSESSMENT FOR THE PROPOSED SUSITNA HYDROELECTRIC PROJECT

March 12, 1983

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INTRODUCTION

In accordance with guidelines from the Federal Energy Regulatory Commission (FERC), licensing of the Susitna Hydroelectric Project (Suhydro) must be based upon a specified environmental assessment process. This assessment process must include (1) description of the present aquatic resources, (2) assessment of the project impacts upon those resources, and (3) mitigation of impacts where possible. Through subcontract with Acres American (ACRES) Corporation and Harza-Ebasco Susitna Joint Venture, the Arctic Environmental Information and Data Center (AEIDC) of the University of Alaska has been charged with assessment of Suhydro aquatic impacts. This paper presents the approach as of March 1983 toward quantitative impact assessment and gives a detailed description of study plans, conceptual relationships, and the identified computer models or model systems. Receipt of final data from other study group members will allow for assessment completion at a later date.

SUSITNA AQUATIC STUDIES PROGRAM

STUDY PROGRAM MEMBERS AND TASKS

The Susitna aquatic studies group consists of the following members.

1. Alaska Department of Fish and Game (ADF&G) to provide baseline information on the aquatic habitat and resources of the Susitna River and its tributaries.
2. E. Woody Trihey, P.E., to supervise the field phase of the aquatic habitat and instream flow study.
3. AEIDC to assess Suhydro aquatic impacts.
4. Woodward-Clyde Consultants to prepare Exhibit E for the FERC licensing application and to develop the Suhydro aquatic mitigation plan.
5. R&M Consultants to provide data collection and retrieval services in hydrology, meteorology, and related areas.

ACRES, the major feasibility study contractor, also has directly subcontracted for studies concerning ice and groundwater. All of these contractors provide data for use in simulation models and quantitative impact assessment. Harza-Ebasco will provide future engineering data.

AQUATIC STUDIES CURRENT AND FUTURE

Exhibit E of the FERC license application and the ADF&G completion reports summarize results of biologic and aquatic habitat studies conducted since 1979 (ACRES 1982; ADF&G 1982, 1983a,b,c). The aquatic studies program includes investigation of mainstem, tributary, and slough habitats in all segments of the Susitna River. Project emphasis to date has been on side-slough habitats associated with the mainstem above the Chulitna-Talkeetna River confluences. Information has been gathered on species distribution, slough accessibility, substrate distribution, and extent of acceptable spawning and rearing conditions at various discharges. Emphasis will shift to other river reaches and habitats, primarily in the lower Susitna River. The objective is to provide the basis for some quantitative impact assessment in all habitat types in all reaches of the river system likely to be affected by project operations.

THE SUSITNA RIVER BASIN HABITAT SIMULATION MODEL

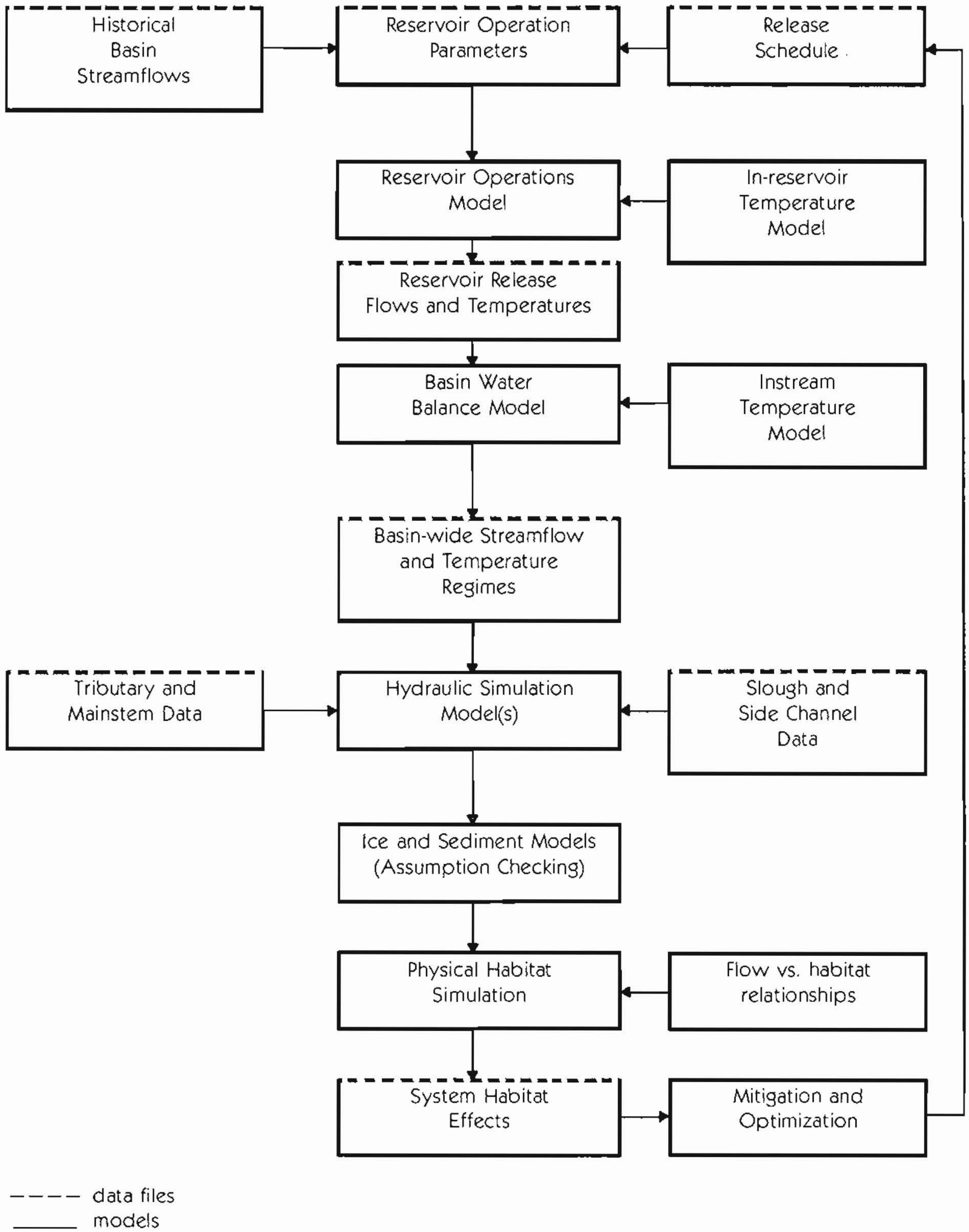
As described in detail in the following section, AEIDC will assess impacts in two major areas: (1) instream--emphasis on predicting stream habitat change with respect to changing flow, temperature, sediment, and ice and (2) peripheral--those construction-related impacts on aquatic habitats not in the Susitna downstream from the impoundment(s) but which may be impacted by some project activity. This division is obviously somewhat synthetic but allows separation of emphasis while providing analysis of all areas of potential impact. The instream impact analysis will rely on results of simulation models to predict changes in aquatic physical habitat (accounting for project effects on ice formation, sediment transport, and streamflow and temperature regimes; to interpret these changes in terms of fishery impacts over long-term project operations; and to suggest feasible changes in project operations to minimize negative effects on the fishery.

Impact assessment results should be directly usable in the mitigation planning process. Design of the final impact assessment should correspond with the needs of the mitigation contractor to the greatest extent possible. To meet these needs, AEIDC has developed the Susitna Aquatic System Simulation Model (SUSIM). This model system resulted from consideration of the special aquatic habitat relationships in the Susitna River basin and the need to account for ice, sediment, and temperature changes which will accompany construction, filling, and operation of the dam complex. The proposed modeling system includes data-model linkages necessary to generate and analyze effects of each potential project operation (Figure 1).

Reservoir operation parameters are considered to be fixed within economic feasibility limits, whereas the release schedule component represents the avenue through which reservoir operations respond to fishery or other streamflow requirements downriver. The reservoir operations model serves to integrate operating parameters, inflow (from the historical streamflow record), and desired fishery release flows into a time-series of monthly (or other frequency) flows immediately below the dam. An in-reservoir temperature model provides temperatures associated with the flows. To route the reservoir release discharge downstream, a water balance model utilizes basin streamflow data (measured and synthesized) to account for tributary and groundwater inflow and to more accurately predict discharge patterns at various points of fishery interest. The basinwide streamflow and temperature data base serves as the input to hydraulic simulation models that are the basis for habitat analysis. (The specific interplays among physical process models and habitat evaluation are described in the next section.)

Descriptions of systemwide aquatic habitat effects will result from interpretation of both long- and short-term habitat variations associated with each operational schedule. As fishery information accumulates, it should be possible to link postproject characteristics of fish habitats with consequent population effects and determine commercial and sport fishery consequences of each proposed operating

Figure 1. General Susitna system modeling and analysis approach.



regime. The most important feature of the system model is the capability to iteratively change proposed flow regimes through incremental changes in the release schedule based on feedback of habitat and population effects.

THE SUSITNA AQUATIC SYSTEM SIMULATION MODEL (SUSIM)

Development of AEIDC's SUSIM has progressed to the point that certain specific models, computer programs, and data sources have been identified, and functional relationships between models and certain assessment needs have become clearer. This paper gives details about models, programs, linkages, and outputs to more clearly define (1) the function of the simulation system, (2) data sources and deficiencies, and (3) the need for additional information.

The general assessment process involves two major steps. First, the physical changes expected to result from the dams are predicted throughout the reaches to be impacted. This process includes simulations of streamflow, temperature, ice dynamics, and hydraulic geometry for as many operating schedules as might be feasible. Next, these physical conditions are interpreted in terms of fishery habitat or population effects to be evaluated in the impact assessment process. The distinguishing feature of the model system approach is in the utilization of many process models normally involved in project design (reservoir operation, water routing, stage prediction, etc.) to credibly predict the environmental changes likely to result from dam construction, filling, and operation. Use of these models in close cooperation with project engineers provides (1) a view of project effects at the level of resolution required to do biological assessment, (2) the ability to generate a sufficient range of project operations to bound most potential impacts, and (3) the basis for planning and mitigation by iteration of desired fishery flows through the reservoir operations model.

The models will be discussed as two basic types--those in the linked iterative subsystem and those which may be run independently to provide interpretative support or to insure that other modeling assumptions have been met. For each model type introduced in the previous section a specific model has been selected for incorporation in SUSIM. Figures 2 and 3 show specific models and the sources of their computer programs and input data. Model categories may represent assemblages of similarly functioning models.

Figure 2. Selected linked SUSIM component models, computer programs, identified data sources, and requirements as of February 1983.

Model category	Source, computer program or model concept (computer program name)	Data source	Data to be provided
Reservoir operations	ACRES (Susitna energy simulation models, one and two reservoir, monthly and weekly)	ACRES	Initial runs, operation, logic, inflow,
		R&M	Revised raw inflow data
		Harza-Ebasco	Revised energy demand estimates, revised operations logic, refined inflow, revised project design specifications.
Reservoir temperature	ACRES (DYRESM)		Results of initial DYRESM model runs
		ACRES	Revised DYRESM runs, ice cover additions
		Harza-Ebasco	Revised operation schedules, inflow and outflow estimates
Instream temperature	U.S. Fish and Wildlife, Instream Flow Group (SNTEMP)	R&M	Streamflow, temperature simulations and compilations
		ACRES	Streamflow and temperature records
		U.S. Geological Survey	Recent streamflow and temperature records
		ADF&G Aquatic Habitat and Instream Flow (AHIF)	Slough and tributary temperature records
		NOAA and AEIDC	Meteorologic records
		AEIDC	Shading, tributary contribution estimates

Figure 2 (continued)

Model category	Computer program or model concept (computer program name)	Data source	Data to be provided
Hydraulic simulation	U.S. Fish and Wildlife Service (IFG)		
	(IFG-4)	ADF&G (AHIF)	Slough cross-section measurements, discharge, depth, velocity, substrate
	(WSP)	ADF&G (AHIF)	Slough cross-section measurements, discharge, depth, velocity, substrate
	ADF&G (stage-discharge model)	ADF&G (AHIF) Woody Trihey	Main channel stage vs. Gold Creek discharge at several locations
	U.S. Army Corps of Engineers (HEC-2)	R&M Consultants	Main channel cross-sections, calibrated model results at more than 50 locations
Habitat	AEIDC, ADF&G (flow-habitat relationships to be developed)	ADF&G Adult Anadromous (AA)	Passage needs, relative salmon habitat utilization
		ADF&G Resident Juvenile (RJ)	Relative juvenile salmon utilization of zones in sloughs, habitat relationships for mainstem resident species (burbot, rainbow trout, grayling)
		AHIF	Slough and tributary hydraulic model results
	U.S. Fish and Wildlife Service (IFG, HABTAT).	ADF&G AA, RJ, AHIF	Habitat preference curves for selected assessment species

Figure 3. Selected unlinked SUSIM component models, computer programs, identified data sources, and requirements as of February 1983.

Model category	Computer program or model concept (computer program name)	Data source	Data to be provided
Slough ground-water and temp-erature	Tony Burgess, ACRES Consultants (Susitna slough groundwater finite element models)	ACRES	Initial model results, current model, revised data input
		ADF&G (AHIF)	Slough discharge measurements
Sediment-Channel Morphology	Models not yet selected	U.S. Geological Survey	1982 bed and suspended sediment data for Chulitna, Talkeetna, Susitna
Ice	Thomas Lavender, ACRES Consultants	ACRES	Results of Lavender's study
		R&M Consultants	1982-83 ice observation data

THE LINKED MODEL SYSTEM

Computer linkage of the models in this system facilitate input/output processing and time efficiency when analyzing several iterations of operating schedules but are not necessary to complete an assessment. The models in the linked system are conceptually related because they function sequentially; that is, output from the first model is directly usable as input to the second and so on. Results of models outside the linked system require interpretation and are not directly usable by other models unless they are refined or in some way altered.

Each model in the linked system will be discussed in the following sequence: (1) general description of the model or type of model; (2) proposed function of the model in the impact assessment process; and (3) a brief description of the model operation, available computer software, and data input requirements. The exact details of certain highly complex models are referenced in basic texts, user-related material, or program documentation. Also, the models described are those selected as of February 1983. Other or additional models or computer programs may be selected as the project continues.

RESERVOIR OPERATION MODEL

General Description

Reservoir operation models have become important in hydroelectric aquatic impact assessment because they provide the link between project operation and both the reservoir and streamflow conditions upon which the impact assessment is based. Properly utilized, such models can serve to guide project design and evaluation of environmental and mitigation planning.

Generally, hydroelectric project feasibility is initially determined by use of models which account for available water supply, storage characteristics of the reservoir, power generating capabilities at various storage levels, and specified downstream demands such as municipal water needs, irrigation, interstate water compacts, or instream flow requirements. The computer model accounts for the complex interactions among these factors to help delineate what size (in terms of power production) hydroelectric project might be constructed within the constraints of available inflow and required releases.

Current water allocations and demands in the Susitna River basin are negligible (Dwight 1981); therefore, accounting for water rights, interstate compacts, and municipal demand is unnecessary, greatly simplifying the process of integrating fishery flow requirements into the Susitna project design. The Susitna reservoir operation model, then, is essentially an energy production simulation model which predicts electrical power output relative to reservoir storage over a 32-year forecast period described as having the same streamflow pattern as the recorded past. Power generation is convertible to streamflow (monthly or weekly, and the streamflow simulations serve as the basis for aquatic impact assessment.

The reservoir operation model can be used to check whether releases which meet power needs also meet downstream demands for instream and offstream water uses. AEIDC's assessment approach requires the capability to iteratively change the reservoir operation to insure that downstream demands are met relative to their priorities. The ACRES model allows for this.

Results of reservoir operation models usually include reservoir elevation and head tables (useful in reservoir temperature and fishery assessments), power production tables, and monthly release tables for a period of record similar to that used in the inflow.

Uses in Susitna Aquatic Assessments

The tables of reservoir releases provide the basis for all streamflow assessments below the proposed dam. They depict stream discharge both before (using the inflow record only) and after dam construction, and they represent the monthly or weekly flow patterns expected during postproject time periods, thereby serving as the basis for sophisticated fishery population assessments. Above all, reservoir operation model results represent a common ground upon which both project design engineers and environmental analysts may exercise planning flexibility within a rigorous framework. Reservoir operation models have not generally been widely developed or utilized as integral parts of aquatic impact assessments; thus, many are not entirely compatible in terms of resolution, ease of operations, and flexibility. It has been demonstrated, however, that cooperation between biologists and design engineers can almost always lead to development of models whose features improve not only environmental analytic capabilities but project design flexibility as well.

Available Models and Data Requirements

AEIDC has reviewed the ACRES energy simulation models and found them to be suitable for many parts of the aquatic impact assessment. First, input and output time units may be either weekly or monthly, for a 32-year forecast period. Weekly model results can greatly facilitate assessment of maximum and minimum flow events and allow detailed evaluation of releases during the critical salmon migration and spawning period. Second, the downstream demand input (at this time used solely for fishery flow requirements) allows changes in the required flow regime and resulting ease in initial feasibility assessment. Further, the reservoir rule curve and drawdown levels can be easily changed in accordance with accepted changes in project design or load forecast. Finally, the model provides a table of predicted monthly reservoir elevations necessary in determining in-reservoir temperature patterns and inundation areas. Data for the ACRES reservoir operation model are currently available, and the computer software and associated user material (in the form of personal instruction) have been provided.

WATER BALANCE MODEL

General Description

The water balance model is a functional component process which accounts for gains or losses in streamflow throughout the river network. In regions with complex water demand structures, the water balance model must account for tributary and groundwater, evaporation, appropriated water rights, consumptive use, and return flow lag. However, in the Susitna system, only tributary, ground, and surface inflow are considered significant, and water balancing becomes a process of simply adding in water from those sources. The process is made less reliable in the Susitna system by the paucity of both surface and groundwater data.

Uses in Susitna Aquatic Simulation

The water balance model provides streamflow patterns at any desired point on the Susitna River. It accounts for all significant inflow between the dam and the point of interest. Because this component adds in tributary flow instead of simply incrementing Susitna discharge by a constant downstream factor, more precise analysis of the effects of the variation attributed to tributaries is possible.

Available Models and Data Requirements

AEIDC has computerized the mechanics of water balancing, and a water balance component based upon incremental discharge from all significant tributaries is available. The tributary streamflow simulation process, however, has necessarily been simplistic (1) because of the short or nonexistent gage records for both the tributaries and some mainstem Susitna sites and (2) because tributary discharge has been simulated based on tributary watershed area alone. This has resulted from a lack of precipitation and other meteorological data for each tributary watershed. Availability of such data would allow a more reliable estimate of monthly discharge patterns for ungaged tributaries. The problem is not considered crucial at this time but will ultimately reduce the confidence in predictions of postproject streamflows, especially in the middle and lower Susitna basins.

RESERVOIR TEMPERATURE MODEL

General Description

Reservoir temperature models are used primarily to predict the thermal characteristics of lakes, ponds, and reservoirs. Unlike other components of the assessment system, reservoir temperature and the stream temperature modeling capabilities described later arose from the need to address environmental and water quality issues and are not strictly necessary in the design and operation of hydroelectric projects. Typically, reservoir temperature models utilize the physical relationships between meteorologic conditions and lake or reservoir dimensions (primarily surface area and depth) to estimate the lake's heat transfer characteristics and yearly stratification pattern. Most reservoir temperature models predict monthly patterns of the depths of the thermal stratification layers (epilimnion, metalimnion, or thermocline and hypolimnion) and their respective temperatures.

Uses in Susitna Aquatic Simulation

Reservoir temperature models have two principal applications: (1) to assess conditions within the impoundment and (2) to provide the outlet water temperature which together with outlet discharge serve to simulate initial postproject downstream conditions. Questions regarding temperature within the Susitna impoundments have been limited to those addressing littoral zone conditions and mean reservoir temperatures. AEIDC believes it to be more important at this time to determine the temperature patterns at the dam face to predict stream temperatures immediately below the dam.

Available Models and Data Requirements

Prediction of Watana or Devil Canyon reservoir temperatures during the open water season is currently possible using the ACRES DYRESM (Figure 1) reservoir temperature model. DYRESM is a one-dimensional dynamic model which predicts daily salinity and temperature variations with depth in a reservoir. Though input data are required on a daily basis, the model may use smaller time steps to more accurately model meteorological influences and mixing processes among the thermal zones. The model approximates a set of horizontal reservoir layers of different thicknesses. Based on variations in input meteorology, inflow, outflow, or reservoir water surface elevation, daily changes in the vertical location, volume, temperature, and salinity of the layers can be predicted.

Although the model operates on one-day time intervals, changes in certain variables occur on a much shorter time scale and are calculated in quarter-hour time steps at the beginning of each daily simulation. In subdaily simulation the effects of surface heating (heat budget), epilimnetic mixing, and hypolimnetic thermal and saline diffusion effects are calculated. Following this the effects of the daily inflow and outflow are determined and a final daily stratification pattern predicted.

Reservoir temperature simulations for winter conditions require predictions of ice cover (extended thickness) which are not currently available. When these predictions become available, it will be feasible to estimate the temperature stratification patterns in either Watana or Devil Canyon reservoir based on normal meteorologic conditions and steady-state operating patterns for each month. Because of the high cost of each simulation run, however, it will probably not be cost-effective to run the DYRESM model in a linked fashion.

INSTREAM TEMPERATURE MODEL

General Description

Instream temperature simulations are important in any stream impact assessment but particularly so when dealing with salmon species whose life history patterns are so closely tied with temperature cues or cumulative temperature effects. When possible, it has been very valuable to predict temperature downstream from the reservoir at least to the point at which project-induced temperature changes are no longer apparent. Instream temperature models predict downstream temperatures using the structure, hydrology, and meteorology of the stream network.

Instream temperature models which have been applied in aquatic studies are usually steady state; that is, the conditions of the independent variables are assumed not to change during the selected model time period. For example, a mean predicted monthly temperature at a certain point downstream from a reservoir would have been calculated on the basis of single, mean monthly values for the climatologic and hydrologic variables. If mean weekly values were input, temperatures could not be predicted at locations greater than one week travel time downstream since these locations would have been subjected to conditions not represented by the weekly average. To achieve finer resolution it would be necessary to measure travel times at such closely spaced intervals as to be prohibitive within the cost-time framework of most studies. Therefore, stream temperature models are useful to predict mean monthly or perhaps mean weekly temperatures but not downstream daily temperature patterns resulting from peaking power generation or other pulsed inflow.

Uses in Susitna Aquatic Simulation

Clearly, instream temperature modeling capabilities are necessary to determine main channel water temperatures downstream from the reservoir. The predicted temperatures are necessary to assess suitability for inmigration, spawning, rearing, and outmigration of all fish species which utilize the main channel for these purposes. Also, main channel temperature modeling is necessary to predict the time and location at which water temperature reaches 0° C during winter, which is in turn necessary to predict ice formation. A major concern exists regarding the effects of main channel temperature upon inmigration and passage through possible temperature barriers created at tributary mouths by the gradient between altered Susitna temperatures and those from unaltered tributaries.

The most consequential biological effects of water temperatures are upon spawning, incubation, emergence, and rearing of salmon species. Temperature is a primary spawning stimulus, and changes in stream temperature also affect development rates of embryos and may change mortality rates during incubation, emergence and outmigration. Most Susitna River spawning occurs either within tributaries, beyond the influence of Susitna River temperatures, or in side sloughs where temperatures appear to be remotely related to those in the adjacent Susitna mainstem. Recent studies have indicated that slough water temperatures are relatively stable and equal to the seasonal mean temperature of the Susitna River. It is not known precisely how and at which rate Susitna temperatures influence those in sloughs, however, making it especially difficult to predict monthly or weekly slough temperatures based upon similar data for the mainstem Susitna.

Available Models and Data Requirements

Mainstem Temperature. The Stream Network Temperature Simulation model (SNTEMP), developed by the U.S. Fish & Wildlife Service (Theurer and Voos 1983), has been selected for use in SUSIM. SNTEMP was designed to predict average daily and daily extreme water temperatures at selected points within a river network. The model requires meteorologic, hydrologic, and stream geometry data to compute heat flux relationships and to transport the heat content through the stream network.

The following SNTEMP features make it particularly applicable for use in the Susitna system.

1. A temperature regression technique which allows use of incomplete or noncontinuous input temperature data.
2. Solar shading by vegetation and topographic features (e.g., canyon walls) throughout the year.
3. A calibration technique which provides the ability to adjust low-confidence input parameters to obtain minimum error when matching observed vs. historical temperature predictions.
4. The ability to predict daily average, maximum, and minimum water temperatures for periods ranging from as short as one day to as long as one year (continuously variable in one-day increments). Thus, short yet critical river reaches can be modeled in daily detail, and the full length of the system is simulated with longer averaging periods.

For the Susitna system, SNTEMP will be configured to simulate monthly and weekly average temperatures at any location between the Watana dam site and Cook Inlet. Historical data at Gold Creek and recent temperature data collected at various locations by ADF&G will be available for validating and calibrating the model. The model utilizes either historical mean weekly or monthly hydrology and meteorology or hydrologic and meteorologic data from a specific year or period. In this latter mode of simulation, historical variability is used as an approximation of future conditions.

Slough Temperature. The study sloughs of the Susitna system will be modeled as separate physical systems and perhaps necessarily included in the unlinked model system. The thermal properties of these sloughs must be defined by the ongoing slough/groundwater data collection efforts and modeling efforts by ACRES, ADF&G, and R&M Consultants. These study results will support selection or development of the models and techniques which will be used to determine whether or not slough temperatures will vary significantly under project stream-temperature regimes.

HYDRAULIC SIMULATION MODELS

General Description

Hydraulic simulation models have become increasingly valuable in instream assessments. When changes in the discharge pattern of a river are expected, the aquatic biologist needs to know the associated changes in stream depth, velocity, and wetted width. Changes in these variables as well as substrate and temperature result in changes in stream physical habitat, which represent the most definable impact of altered discharge regimes.

Applications of hydraulic simulation models in instream assessments have increased in recent years, primarily due to interest in the field of instream flow methodologies. Stalnaker and Arnette (1976) and Wesche and Rechard (1980) provide good summaries of the instream flow methods which utilize hydraulic simulation models.

The Instream Flow and Aquatic Systems Group (IFG) of the U.S. Fish and Wildlife Service has made the most notable contribution to hydraulic simulation in instream flow assessments. The IFG Instream Flow Incremental Methodology (IFIM) (Bovee 1982) is a conceptual framework for resolution of streamflow regulation and allocation problems. The IFIM is largely based upon use of the PHABSIM (Physical HABitat SIMulation) computer system (Bovee and Milhous 1978; Milhous, Wegner, and Waddle 1981). Use of PHABSIM requires extensive hydraulic simulation capabilities based upon measurements taken at selected representative or critical fish habitat reaches. The PHABSIM computer program system automates the process of coupling predicted depths, velocities, and substrates with habitat preference curves for those variables for a given fish species or life stage. The resulting value, Weighted Usable Area (WUA), is a measure of the areal extent of physical habitat for the species/life stage at the modeled discharge.

Uses in Susitna Aquatic Simulation

Though there are extensive hydraulic simulation field efforts, the Susitna assessment process will probably not be based extensively upon WUA as calculated using the PHABSIM system. The use of hydraulic simulation at this time appears to be limited to prediction of stage (water surface elevation) in the main Susitna for use in (1) determining depth and wetted area in an adjacent slough or side channel, (2) prediction of slough wetted area and available substrate relative to slough discharge, and (3) prediction of main channel depth at various discharges. Presently, for sloughs 8A, 9, 11, 21, Rabidoux Creek and Chum Channel (ADF&G 1983c), hydraulic simulation for the above purposes is possible.

Available Models and Data Requirements

Data for four documented hydraulic simulation models have been collected for the Susitna assessment. These are HEC-2 (USCOE 1976), IFG-4 (Main 1978), Water Surface Profile (WSP) (US Bureau of Reclamation 1968; Spence 1975) and a stage regression model utilizing available linear regression techniques. These models are of two types--backwater models and empirical models.

Backwater or energy balance models utilize measured dimensions at multiple cross sections (width, cross-section geometry, water surface elevation at a known stream discharge) to predict stage and other hydraulic characteristics at unmeasured flows. The process usually requires extensive use of large computer models because of the detail of the input data and the iterative calculation process employed. Of the available Susitna models, WSP and HEC-2 are of this type. Backwater models require measurements taken at only one discharge but gain considerably in reliability if calibration information from several discharges is gathered.

Empirical hydraulic models are based on measurements of target variables (stage or velocity) at various discharges and development of predictive discharge-velocity or discharge-stage regression models. This modeling approach requires that measurements be taken at a minimum of three different discharges. For further detailed discussions of either backwater or empirical models, the reader is referred to Chow (1965) and Bovee and Milhous (1978). Of the current Susitna assessment models, IFG-4 and the stage regression model are of this type (Figure 4).

Both the WSP and IFG-4 models have been modified to couple, through a program called HABTAT, with habitat preference curves to produce WUA values. Because of a lack of specific habitat preference curves for the

Figure 4. Hydraulic simulation models available for Susitna aquatic assessment with specific estimates of predictive accuracy.

Hydraulic Model	Major Category	Data Available	Output (acc.)
HEC-2	backwater	51 main channel	mean depth velocity, stage (± 0.6 ft.)
IFG-4 (alone)	empirical	6 slough and side channel sites	depth velocity substrate
Stage regression	empirical	3 sloughs, 9 mainstem sites (ADF&G 1983c)	stage (± 0.1 ft)

Susitna assessment, however, any mention of IFG-4 or WSP refers to their use in prediction of stage, velocity, or wetted area.

THE UNLINKED MODELS - ICE AND SEDIMENT

ICE

The Need for Ice Simulation Modeling in the Susitna Assessment Process

The need to simulate and otherwise account for ice processes in the Susitna analysis is one common to all arctic assessments. Whereas river icing is not even considered in assessment of impacts in most temperate climates, ice processes in areas such as the Susitna Basin may be the single most important determinant of stream channel morphology, riparian vegetation distribution, and, perhaps, yearly mortality of some aquatic species. Also, ice processes are unlike other instream mechanical processes in that they are difficult to predict in a site-specific manner. Finally, though the environmental effects of ice in large northern rivers such as the Susitna are expected to be great, little study is available detailing the ways in which ice, its movements and presence, affects aquatic organisms.

The following section on ice, then, instead of presenting a finalized program of study, presents the problem in three steps. First, historical and expected ice processes in the Susitna are presented, emphasizing ice effects upon habitat suitability and stability; second, the expected sources of ice impact upon aquatic resources are presented; and third, the capabilities attainable through ice modeling are presented and evaluated in terms of required cost and time.

Description of Present and Future Ice Processes

Background. The data base pertaining to ice processes on the Susitna River is extremely limited. Observations for the last few years have been made at various gaging stations by the Water Resources Division of the USGS as well as by R&M Consultants of Anchorage. The Alaska Railroad has informal records dating back roughly 20 years which describe ice jamming and flooding events that affected the rail. This section summarizes the available information concerning freezeup and breakup patterns on the river.

Freezeup. The upper, middle, and lower basins of the Susitna are characterized by a stream temperature gradient that results from differences in elevation and latitude and from the initial cold temperatures of glacial melt. This gradient affects the sequence and timing of ice cover events in that there is a period during late October and early November when temperatures in the upper basin are below freezing while those in the lower basin are still above freezing (R&M 1982b). During this early stage of freezeup (second or third week of October), frazil ice (individual ice crystals) is generated only in the upper basin, particularly in the colder turbulent reaches such as Vee Canyon, Watana, and Devil Canyon. The areal coverage and strength of the ice from then until early December is determined by local climatic conditions. Frazil ice generation usually continues for three to five weeks, and sheet ice develops simultaneously in areas of slower water. Slush ice floes may form, and anchor ice may appear in shallow (4 to 5 ft) but fast water as a result of frazil contact with the streambed. Toward the end of this period, the jamming of frazil ice pans or sheets causes the formation of a solid ice cover in the lower river. Ice accumulates above the leading edge of a jam, and the ice cover progresses upstream. Water elevations at and above the ice front are often raised, or staged, by as much as 2 to 4 ft (Bredthauer and Drage 1982; R&M 1982a). A continuous ice cover has usually formed by early December.

Available data show that ice seems to jam in the same places every year--near constrictions due to bedrock outcrops, channel configuration, and border ice (Bredthauer and Drage 1982). The solid ice cover progresses from the confluence with the Chulitna River upstream to Devil Canyon within about two to three weeks. Leads may still occur even after this cover has developed, and some side channels and sloughs above Talkeetna never freeze. The thickness of the ice increases throughout the winter, and though it averages more than 4 ft by breakup, thicknesses of more than 10 ft have been measured near Vee Canyon. The upper Susitna may contribute roughly 75 to 85 percent of the ice load of the combined Susitna, Chulitna, and Talkeetna rivers (R&M 1981a, 1982b). Freezeup on the Chulitna and Talkeetna normally begins several weeks after freezeup on the middle and upper Susitna River.

Breakup. Breakup is the process whereby the ice cover of a river fractures due to increasing temperature and hydraulic forces in the river. Once the ice has fractured and is afloat, breakup is complete. The process is often rapid and awesome on large rivers such as the Susitna. Because the lower basin experiences warmer temperatures earlier than the upper basin, the snowpack at lower elevations melts first, increasing river discharge and causing the ice cover to fracture. Generally, breakup on the Susitna commences close to the mouth in mid-May, progressing upstream over about a week, thus causing little severe ice jamming. The severity of breakup is influenced by the snowpack depth and melt rate as well as by the amount of rainfall. For example, in 1981 breakup was mild because of the shallow snowpack, warm spring air temperatures, and limited precipitation, which caused the ice to slowly disintegrate in situ and leads to develop gradually (R&M 1981). In 1982, however, severe ice jamming and resultant erosion and flooding occurred because melting of the deep snowpack and late but rapid rise in air temperature caused a sudden increase in water level and, in turn, ice movement (R&M 1982b). While the severity of the breakup jams may vary, they tend to recur in the same places every year, often the same areas where ice accumulates during freezeup.

Effects of Ice Processes on the Stability of Side Channels and Sloughs

Freezeup. As the ice front forms between Talkeetna and Devil Canyon and progresses upriver, the water level (stage) in the main channel rises due to the ice cover. Water and ice may flow into side channels and sloughs which were previously isolated from the main channel due to low winter stage (Bredthauer and Drage 1982). Upstream progress of the main channel ice cover then slows while frazil floes accumulate and thicken in the side channels.

Ice fails to form in substantial portions of some side channels and sloughs above Talkeetna due to upwelling of groundwater. Groundwater temperatures vary between 2 and 4° C and contribute enough heat to prevent formation of ice and to open leads. These areas are often salmonid egg incubation areas (Trihey 1982a). Even when air temperatures become cold enough to form an ice cover over these sloughs, the substrates are not expected to freeze (Trihey 1982b).

River ice cover is important in maintaining groundwater flow into the sloughs. Increased stage main channel ice cover causes a hydraulic head (pressure differential) between the mainstem and nearby sloughs during low winter flows. This differential is similar to that which exists during much higher normal late summer flows (Trihey 1982b) and maintains groundwater upwelling into the sloughs throughout much of the winter.

Breakup. River breakup processes, such as flooding and erosion associated with high runoff flows and ice jams, are considered the primary factors influencing river morphology in the reach between Devil Canyon and Talkeetna (Bredthauer and Drage 1982). During this period very large short-duration flows pass through side channels and overtop the berms separating sloughs from the main channel. These flows remove fine sediments that may have accumulated in the sloughs during low winter flows. Periodically flows are large enough to redistribute streambed gravels, remove debris and beaver dams, and at times alter the thalweg profile or alignment of a slough (Trihey 1982b). Ice blocks carried in these flows probably exacerbate this effect.

The most severe flooding events appear to be caused by dry ice jams (ice jams that become grounded). These usually occur at constrictions or sharp bends in the river. High-water velocities cause ice blocks from upriver to be submerged mid-channel under the ice cover. Some submerged blocks become grounded, preventing the passage of additional ice, and newly arriving ice blocks accrete to the upstream edge of the jam. Passage of water through the ice jam is restricted, and water upstream rises rapidly until it overflows into existing side channels or creates new channels. Slough 11 below the Gold Creek bridge on the Susitna River was apparently formed this way within the past 30 years (R&M 1982a). The berm at the head of this slough is unusually high and apparently overtopped only at very high main channel stages.

Breakup flooding events frequently result in the deposition of unconsolidated cobbles, sand, and silt upon berms and river bars that are above normal high-water levels and even well up into the forests of vegetated islands and riverbanks. Extensive damage due to water and ice block erosion has been reported both in channels and overbank vegetation. At slough 21 scarring of cottonwood trees to heights of 5 ft above ground was observed (R&M 1982a). These trees were well away from the normal channel.

Ten ice jam sites have been observed in the Susitna River between Talkeetna and Devil Canyon. Jamming apparently occurs there nearly every year, causing various degrees of flooding and erosion, depending on breakup conditions (Bredthauer and Drage 1982). Ice jam induced flooding and erosion events appear to be the principal causes of change and evolution in side channel and slough morphology.

Potential Aquatic Impact Issues

Instream. Potential instream impacts related to ice processes are expected to be: (1) staging-overtopping, (2) breakup timing, and (3) tributary mouth and slough morphological changes. Although not limited to any one section of the river, the impacts are expected to be greater above Talkeetna.

Staging-Overtopping. Staging is the process whereby the surface elevation (stage) of a stream becomes higher at some discharge due to increased channel roughness, instream structures, or ice. Staging due to ice may result from flow impediment caused by surface ice or anchor ice. Susitna River staging, due primarily to surface ice, may exceed 4 ft, that is, the stage for a given discharge may be as much as 4 ft higher after formation of an ice cover than during the ice-free period.

Increases in winter discharge would range between 115 percent in the lower river to more than 600 percent in the upper river under postproject conditions (ACRES 1982a). Areas with an ice cover might experience staging due both to increased discharge and ice staging. This would almost certainly lead to the phenomenon of overtopping in certain side sloughs. Overtopping occurs when the main channel stage exceeds the elevation of the berm at the upstream end of a slough, causing main channel water to flow through the slough. This results in (1) increased frazil production, (2) local anchor icing, (3) reduced temperatures, and (4) increased ice cover in the sloughs. These conditions are clearly unfavorable for successful salmon egg incubation. Slough overtopping due to staging occurs naturally as the ice front passes a certain slough during freezeup. Slough 8A was overtopped during the winter of 1982-83, and a thick ice cover and 0° C substrate temperatures were observed. Postproject operations may make slough overtopping a common rather than an isolated occurrence.

Breakup. As discussed in the previous section, increased ice thickness and reduced postproject spring and summer flows could change the timing and magnitude of breakup. If breakup were delayed due to increased ice thickness and longer melting times, delays in fish migration would occur. Spring spawning fish, such as grayling and longnose sucker, would be delayed access to their spawning grounds if ice masses remained near tributary mouths. Early chinook salmon runs would have difficulty reaching spawning tributaries if breakup and ice flows were still in progress. Increases in the amount of ice in sloughs and side channels could delay the outmigration of salmon smolts. Changes in the timing patterns of fish that have evolved over long periods of time could result in substantial mortality.

Tributary Mouth Morphologic Changes. Because the Susitna River tributaries are such important fish habitats, it is vitally important to assess potential impacts upon the fish populations which utilize them. Clearly, conditions in the tributaries will not change with project-induced changes in the main Susitna, but structural conditions at tributary mouths might change either directly with Susitna discharge changes or indirectly through effects of altered ice and/or sediment dynamics.

Ice effects at tributary mouths result from combinations of the processes described earlier and are generally expected to arise as follows. (1) Increased winter discharges and staging would increase the lateral extent of the ice cover, the extent of which would vary with the degree of discharge change and the slope of the instream and nearstream topography. Therefore, effects would probably differ in the upper, middle, and lower Susitna basins. (2) If lateral ice extension reached tributary mouths, especially in the lower and middle Susitna reaches, it would remain until breakup. (3) If breakup discharge levels were not sufficient to carry the ice out, large quantities of ice would degrade thermally and remain at the tributary mouths. If spring flows are high enough to transport the ice, the additional ice volume might scour or otherwise disrupt the tributary mouth areas, again causing potential access problems to immigrating fish.

In-Reservoir. The filling of Watana Reservoir would inundate 54 mi of Susitna River mainstem and 28 mi of tributary habitat, converting it from a lotic to a lentic system. Habitat development in the reservoir would be limited as the continuous filling and drawdown cycle would inhibit development of a productive littoral zone. This would be compounded by the continuous formation of ice ledges along the drawdown zone. These layers of ice might further erode and scour the shoreline, disrupting the littoral zone and preventing the establishment of a productive habitat.

Grayling and longnose suckers could be expected to use the reservoir for overwintering, and water level fluctuations probably would affect them adversely. Both grayling and longnose suckers spawn in tributary habitats during late spring. The reservoir would be rapidly filling during this time of year, and their spawning areas would be inundated. This inundation along with increased sediment deposition from the tributaries could result in increased mortalities to the developing embryos. Any surviving fry would probably have a low survival rate because of the lack of a productive rearing habitat in the reservoir. The addition of shoreline and in-channel ice to this tributary area would compound the detrimental effects on the habitat by increasing erosion and scouring and producing potential fish migration barriers.

An increase in the amount of tributary ice in the inundation area could cause larger-than-normal ice accumulation. These larger ice jams would take longer to melt and wash out and could block the upstream passage of fish to their spawning grounds. The incubation and rearing success of fish utilizing tributary habitats above the inundation zone would not be affected by water fluctuations or sediment deposition, but increased ice accumulation could affect the timing of their access from overwintering areas to spawning grounds.

Ice Models - Capabilities and Cost

Answers to ice questions probably cannot be provided by model output alone. Regardless of the degree of ice modeling sophistication, actual assessments of ice impacts would be based on combinations of model results and professional opinion. The kinds of ice models available are discussed here to familiarize the reader.

There are four levels of ice modeling efforts:

Level 1. Statistical analysis of historical air temperature and ice formation and/or breakup data.

Level 2. Empirical/physical process models for heat loss and frazil ice prediction.

Level 3. Empirical/physical process models for ice cover, formation, stability, progression, and breakup.

Level 4. Physical analog (scale model).

The first level of modeling determines the most probable date of the first appearance of ice and the first shore-to-shore cover at previously observed locations. The date of the start of breakup can also be predicted. This level is data intensive and assumes that flow and climatic conditions will not change beyond historical variations.

Level 2 models predict heat loss and frazil ice production. Varying degrees of sophistication exist with respect to heat budget computations. A low level of heat budget analysis would involve approximating the total heat loss from the water by estimating atmospheric conduction. Under winter conditions, conductive heat loss to the atmosphere is the major source of heat exchange. A more detailed approach would consider solar and atmospheric radiation, water back radiation, streambed conduction, convection, evaporation, and groundwater exchanges as sources/sinks of heat. The heat transferred to and from the water determines both the temperature of the water and the amount of frazil ice which can be produced.

The third level of modeling uses empirical or physical process equations to predict ice cover stability and advancement as determined by structural and hydrodynamic forces. This level of modeling requires level 2 estimates of the frazil ice supply.

Level 4 modeling involves construction of a scale model of a river reach and observation of synthetic ice flows. This kind of modeling can be used to predict ice cover stability and advancement as well as the extent and location of ice jams. Level 4 also requires level 2 estimates of the ice supply.

Various ice processes which are of interest are related to the capabilities of these modeling levels in Figure 5.

Several conclusions can be drawn from this table.

1. Level 1 modeling is generally inappropriate for systems where the flow or temperature regime would deviate from the historical conditions.
2. Ice processes which involve deviation from historical conditions require level 2 effort.
3. Ice processes which involve simulating the mechanical and hydrodynamic forces are expensive to model.
4. Level 4 analyses are expensive and require site specific models; level 3 is relatively expensive but can be performed for a large stream system in one model setup.

Based on available data and expected future field activities, AEIDC can provide level 1 and 2 modeling capabilities. Higher-level efforts would require considerable additional time and funding. To answer the questions posed on the fishery assessment, levels 2 and 3 at least will be required to the level at which certain events can be excluded from further consideration.

CHANNEL MORPHOLOGY AND SEDIMENT ISSUES

General Description

In most aquatic impact assessments the term sediment has meant fine particles which, when suspended, cause increased turbidity, reduced fish vision, feeding efficiency or gill function and, when deposited, cover spawning and incubation areas or limit aquatic invertebrate production. Most hydroelectric projects reduce suspended sediment concentrations and, therefore, ameliorate conditions which may have been degraded by high suspended sediment concentration. The extent to which reservoirs reduce downstream turbidity is predictable if sediment storage rates within the reservoirs are known. A competent estimate of postimpoundment suspended sediment conditions is normally possible

Figure 5. Predictive capabilities provided by various combinations of ice modeling levels[1] with predictive reliability and estimated relative cost.

Modeling Process	Level	Prediction Reliability	Relative Cost[2] (1 to 10)	Comments
frazil ice formation	2	high for both location and quantity	1	Wide range of sophistication among different models.
anchor ice	2	unknown	1	Applications not recorded in literature. A relatively large assumption would have to be made as to areas affected. Professional judgment required.
initial ice cover bridging	1	moderate	1	Site specific. Large historical data base required; cannot be applied to altered flow or water temperature conditions.
	2+3	moderate	4	Requires professional judgment and historical data for determining potential lodgement sites.
	2+4	high	10	Separate model necessary for each potential site.
ice cover advancement	2+3	moderate	4	Requires model output plus professional opinion
	2+4	high	10	Separate model necessary for each reach of interest.
ice cover thickening	2+3	moderate	4	Thickening by juxtaposition, frazil accumulation, and static growth.
	2+4	high	10	Thickening by juxtaposition only; separate model necessary for each reach of interest.

Figure 5. (cont.)

Modeling Process	Level	Prediction Reliability	Relative Cost[2] (1 to 10)	Comments
aufeis	2+4	?	?	New application, reliability, and costs unknown.
ice jamming	2+4	high	10	Separate model necessary for each potential site.
staging	2+3	moderate	4	Requires model output plus professional opinion
	2+4	high	10	Separate model necessary for each reach of interest; site specific
timing of breakup	1	moderate	1	Large historical data base required; cannot be applied to altered flow or water temperature conditions.
	2+3	low	4	Requires running level 3 for entire winter season resulting in low reliability of ice cover estimates.
breakup water levels	2+3	low	4	Requires running level 3 for entire winter season resulting in low reliability of ice cover estimates.
	2+3+4	low	1	Confidence in estimate of water levels would be higher than above. Separate model necessary for each reach of interest.

1. See preceding text for description of modeling levels.
2. Cost based on relative scale of 1 to 10.

without the need for extensive field work or sophisticated computer modeling.

Large impoundments such as the Susitna project reservoirs alter downstream sediment dynamics through transport of streambed material that can ultimately change the configuration of the stream channel and substrate division. Though the impacts of changes in suspended sediment concentration are usually assessable, effects of substrate distribution and channel configuration changes are often difficult to evaluate. Even more difficult to predict are structural changes which could take place. Therefore, not only are channel and substrate changes harder to predict in themselves, but their effects upon the aquatic environment are also less certain.

Application in Susitna Aquatic Assessment

Impoundments as large as Watana and Devil Canyon reservoirs would undoubtedly change both the discharge and sediment regimes of the Susitna River. Relatively small changes in suspended sediment concentrations could be expected, primarily because the dams are located in the upper reaches of the Susitna River where natural sediment concentrations are low or moderate (50 to 500 ppm) (R&M 1981b). The Susitna River acquires most of its sediment load from the Chulitna and Talkeetna rivers which would be unaffected by the Susitna dams. The reduction in upper Susitna River suspended sediment concentration could have a positive effect upon the aquatic habitat in that section of river. Because gravel-cobble substrate predominates in the reaches above Talkeetna, little channel change could be expected other than establishment of a local area of scour immediately below the dam (ACRES 1982b).

All major channel configuration and substrate distribution changes would occur below the Chulitna-Talkeetna confluences and are discussed below as either streambed elevation changes or channel configuration substrate changes.

Streambed Elevation Changes. Streambed elevation changes are a widely recognized result of operation of large reservoirs. The process popularly invoked is that of scour below the impoundment resulting from releases of clear water with high transport competency. Scouring reduces the bed elevation, which results in degradation. Scour or degradation is often predictable immediately below an impoundment, but predictions are less reliable further downstream, where it is difficult even to predict whether the change will be degradation or aggradation. For example, hydroelectric dams usually reduce peak discharge levels and raise base flows. Because most sediment is transported by peak flows, the downstream effect is to reduce sediment transport to the extent that the bedload normally carried away during runoff peaks remains in the river reach of interest. Aggradation or raising of the bed elevation has, in fact, been the major effect of many large reservoirs, especially when tributaries below the reservoir were major sources of the impounded river's sediment load.

Aggradation in the lower Susitna could have three effects. First, coupled with reduced summer discharges, the aggraded bed might cause passage problems. As the lower Susitna mainstem is a very important migration corridor (ADF&G 1982; ACRES 1982a) any impediment to passage might affect very large numbers of fish. Second, aggradation near tributary mouths might cause access problems or changes in tributary mouth habitats. Finally, significant aggradation would violate the assumptions of fixed bed-elevations upon which any hydraulic simulation models would be based.

The extent of postproject aggradation in the Susitna below the Chulitna-Talkeetna confluence is probably not predictable without results of specific sediment studies. Studies suitable to provide data for this analysis are discussed in the next section.

<u>Channel Configuration-Substrate Effects</u>. Long term changes in sediment-discharge equilibrium also result in changes in channel configuration. Channel changes are always to varying degrees associated with streambed elevation changes and relate to the previously discussed concerns. Channel configuration changes are more difficult to predict than aggradation/degradation process changes and their effects more subtle and less known to fishery biologists.

Channel changes which are positively associated with fishery characteristics usually involve increasing stream habitat diversity in terms of depth, velocity, substrate, and cover. Because significant channel changes are not expected in the upper Susitna, and because they would be difficult or impossible to predict in the lower Susitna, channel change modeling will probably not be employed.

Available Models and Data Requirements

Simons et al. (1981) presented a review of available technologies to predict either aggradation/degradation or measurable channel change in river systems. In general only qualitative or semiquantitative results are possible within present engineering capabilities. Quantitative channel-change modeling appears to require field data collection and computer modeling beyond the scope of most environmental assessments. Suspended sediment and aggradation-degradation studies are feasible within most project scopes and are discussed here in terms of data requirements and expected capabilities.

Suspended Sediment Only. Only a detailed compilation of suspended sediment gage records is required, along with the expected storage of such particles in the reservoir. The reservoir storage study is usually accomplished during the feasibility phase of the project but may not offer enough resolution to provide particle-size distinctions required by fishery biologists. The approach is usually quantitative but unsophisticated; suspended sediment concentrations below the dam are computed on the basis of the difference between inflow concentrations and total storage. Qualitative estimates of postproject Susitna River suspended sediment concentrations are available (R&M 1982b) and will be refined as project specifications change.

Aggradation/Degradation Studies. This approach normally involves determination of a preproject sediment budget for all stream reaches (mainstem and major tributaries) and categorization of the reaches in terms of their equilibrium status. From the present discharge/sediment equilibrium relationships, the postproject relationships are assumed or calculated based on projected sediment storage, water discharge, and tributary sediment inflow. Normally, a fairly extensive water-sediment discharge record is required for all mainstem sites and tributaries of interest. In-channel data (cross sections with bed particle sizes) and available stage rating curves from USGS gages are required at certain locations. Computations and analyses utilize one-dimensional computer models which predict bed elevations along the length of the river, although some generalized, preprogrammed statistical packages are quite helpful. Results are both site- and river reach-specific and are useful to define the reaches where aggradation or degradation might occur and to estimate relative magnitude of the process. Results are valuable in sensitivity testing to determine whether the processes will be significant under various reservoir operating regimes.

THE SUSITNA INSTREAM IMPACT ASSESSMENT APPROACH

Because the aquatic studies program and associated field data collection efforts are presently at an intermediate stage, it is difficult to describe an exact impact assessment approach. Because consensus has been reached on certain major aquatic impact concerns, the approach described at this time emphasizes near-term (fiscal years 1983-84) activities. The assessment impact approach is expected to be a combination of those herein presented, and alternative avenues as necessary.

SUSIM APPLICATIONS

SENSITIVITY TESTING

The SUSIM system, as described in the foregoing sections, incorporates components which should address the majority of Suhydro aquatic impacts. The system is clearly quite complex and would be very cumbersome to run if all of the linked models were required for analysis of each operating regime. The separation between linked and unlinked models results from the necessity to run as few models as possible during the task of iteratively "tailoring" flow regimes to minimize impacts.

As initial runs of certain models become available, we find that some parameters might not change significantly under project operations. As an initial project analysis we will perform sensitivity testing on all parameters prior to structuring SUSIM in the assessment configuration (Figure 6). For example, if through application of a reservoir temperature model it is determined that winter release temperatures will range only between 2^{o} and 4^{o} C with high likelihood of 3^{o} C, it might be unnecessary to run the reservoir temperature model in a costly linked fashion. Similarly, if slough temperatures seem to respond little to mainstem temperature changes, the highly complex groundwater temperature model will not be linked to the instream temperature model--slough temperatures will be fixed at some long-term average for all conditions except when overtopping occurs, at which time they would be predicted as main channel temperatures. In each

Figure 6. Expected sensitivity testing of SUSIM models and components

Model or component	Independent variables to be varied	Output whose variation is to be checked
Reservoir operation model	Inflow	Release discharge
Reservoir temperature model	Reservoir stage, inflow temperature	Outlet temperature[1]
Instream temperature	Reservoir release temperature, discharge	Downstream temperature variation
Slough temperature	Main channel temperature, discharge	Slough temperature discharge

1. To be obtained from Acres American DYRESM results.

sensitivity test, the independent variables will be input under the range of expected natural or project-induced conditions, whichever is greater. For example, the instream temperature model will be run under the range of expected temperatures and reservoir outflows for each month. Variation of the predicted instream temperature will be evaluated in terms of significance both at the dam site and downstream. If total temperature variation during critical periods is within bounds considered to be biologically acceptable, the reservoir temperature model will not be run for each successive reservoir operation, and a seasonal mean temperature will be assumed.

ICE AND SEDIMENT STUDIES

Similar to model sensitivity testing, ice and sediment studies should result in conclusions regarding potential effects of these components. Because the sediment issue is expected to center around aggradation in the lower river, a credible prediction of that process may assist in concluding that aggradation would not be a problem. If, however, it is predicted that aggradation would be problematical, this suggests additional effort to either reduce effects (through changes in reservoir operations) or to more clearly define their magnitude. Similarly, if ice study results do not suggest significant occurrence of any of the three expected ice problems, it will not be necessary to continue ice modeling efforts. Ice process predictions can be expected to be much more difficult and subjective than those from any other component and dismissal of the ice issue likely will not be achieved in the near future.

LINKED MODEL RUNS AND IMPACT ASSESSMENTS

Actual impact assessment runs of SUSIM will not be accomplished until sensitivity and ice-sediment studies are complete enough to insure SUSIM reliability; however, the general process of quantitative impact assessment is known at this time. Though a variety of approaches exists, only those which pertain to the current aquatic studies emphasis on quantitative instream flow assessments will be presented.

THE SUSITNA INSTREAM FISHERY IMPACT ASSESSMENT APPROACH: CONJUNCTIVE USE OF THE SIMULATION MODELS

The instream impact assessment will be accomplished in three phases. First, a sensitivity testing and preliminary analysis will be used to determine which parameters are likely to change significantly throughout the Susitna River. Second, through use of the simulation models described in the following section, these changes will be predicted at all selected fish habitats in terms of habitat structure resulting from changes in streamflow, temperature, ice, and channel morphology. Third, these predicted changes will be interpreted in terms of fish habitat and/or population impacts.

QUANTITATIVE ASSESSMENT TOOLS

Recent developments in instream flow assessment have led to a variety of standardized methodologies, each of which might have some applicability to the Susitna assessment. Each requires output from the simulation model system. Under each habitat type (main and side channel, tributary, and slough), the following potential methodologies (or combination thereof) will be discussed with respect to (1) applicability, (2) data requirements and current or expected sufficiency of data, and (3) need for interpretive refinement. Details about methodologies follow.

Hydrologic Methodologies

Evaluation of postproject streamflow is based on frequency of preproject flow events and knowledge of the habitat or population effects of those events. For example, the Tennant method (Tennant 1976) suggests that flows equaling 60, 40, and 20 percent of mean annual discharge levels provide "optimum," "maintenance," and "minimum" habitat levels for trout species in certain Rocky Mountain streams. Hoppe and Finnel (1970) found certain high-flow recurrence intervals to be necessary for gravel flushing to insure salmonid incubation success. Data required are pre- and postproject streamflow records, available from the reservoir operation model. Such hydrologic methodologies have not been considered for use on the Susitna project in general because (1) the evaluation criteria have not been applied or verified in Alaska or other Pacific salmon habitat types and (2) the overall Susitna assessment approach has been toward comprehensive and quantitative studies which preclude the simpler "office" approaches. Such methods may be of value on this project, however, especially in reaches for which detailed data might be unavailable.

Hydraulic Simulation Methodologies

These methodologies base their impact evaluation on changes in certain hydraulic variables (depth, velocity, substrate, etc.) at sites of known importance. Use of such methodologies requires considerable hydraulic data but often only limited or general knowledge of fish habitat preferences. Many states have used either single or multiple cross-section applications of these methodologies (U.S. Forest Service 1973; Spence 1975), and interpretations are based upon calculations of predicted depths or velocities or passage requirements related to the body depth of the target species. The Susitna slough studies are actually a form of this methodology in their calculation of depth and access into sloughs at given flows but without dependence on detailed, species-specific habitat requirements or incremental calculation of habitat suitability or area.

Hydraulic Simulation Methodologies with Habitat Preferences

Exemplified by the U.S. Fish and Wildlife Service (USFWS) instream flow incremental methodology (Bovee 1975, 1982), these studies provide quantified habitat output based upon prediction of hydraulic habitat variables (depth, velocity, and substrate) and interpretation of those variables in terms of habitat preferences defined by suitability-of-use or habitat utilization curves (Bovee and Cochnauer 1977). The output, usually surface area of preferred physical habitat at a given flow level, supports a highly quantified impact evaluation.

Habitat Index Evaluations

Associated primarily with habitat evaluation procedures (HEP) developed by USFWS Project Impact Evaluation Group, this method is primarily for habitat accounting. It may have predictive value in aquatic impact assessment if enough is known of the postproject streamflow and hydraulic conditions (USFWS 1980). Quantified results from some hydraulic-based assessment usually are used as habitat units in the HEP analysis; however, HEP analysis might be valuable in project areas to be inundated or where hydraulic information (from physical habitat analysis) provides estimates of postproject riparian or other terrestrial habitat.

Miscellaneous Approaches

Most standardized instream or reservoir analysis methodologies do not deal directly with many aspects of project construction or operation which must be addressed in a formal impact evaluation process. For example, building and maintenance of roads and construction camps may not directly affect aquatic habitat but often result in increased access and corresponding fishing pressure. Similarly, quantifiable effects of dam construction may be difficult to factor into a prestructured methodological approach but must be considered among potential impacts. Therefore, any truly comprehensive impact evaluation must avoid restriction by structured approaches to assess all possible impacts.

ASSESSMENT APPLICATION

Any impact assessment in a large complex river system such as the Susitna should provide accounting for postproject watershed effects, such as multiple operational schedules, variable release temperatures, ice processes, and postproject channel changes and sediment dynamics. The methods for accounting for such watershed effects using simulation models have been presented in a previous section, but no single approach for the Susitna impact assessment can be recommended.

Data and interpretation limitations and unique Susitna River habitat relationships preclude a comprehensive analysis in terms of geographic scope and species using any single or prestructured assessment methodology. A number of potential impact assessment approaches could be used, and this section describes several of the most applicable. The final assessment method will be a mixture of approaches. The emphasis will remain on quantitative evaluations where possible.

Potential assessment methods seem to vary more by habitat and geography than by target species. For example, data are probably complete enough to allow quantification of habitat values in certain sloughs based on detailed hydraulic and habitat measurements; however, for the mainstem above Talkeetna data are not sufficient for a similarly quantitative assessment. Data concerning lower Susitna sloughs are even scarcer. Therefore, the kinds of assessment approaches will be presented under mainstem-side channel, slough, and tributary headings. Slough habitats above Talkeetna are presented last because of their relative abundance of data and potential assessment approaches.

Mainstem-Side Channel

The small numbers of salmon so far observed spawning in main channel areas suggest limited utilization, but the amount of mainstem salmon spawning is not known at this time. Mainstem areas, especially those near channel margins, may provice access for juvenile salmon between sloughs and between tributaries and sloughs. Overwintering of fry or juvenile salmon may be a significant mainstem activity. Far less information exists for fish utilization in the mainstem below Talkeetna than in the upstream reach.

Hydrologic Methodologies. Though hydrologic methods have not been considered, their most relevant use might be to evaluate impacts in the lower Susitna for resident populations and for such main-channel spawners as eulachon and Bering cisco. This is because (1) there are presently no quantitative habitat preference data for either species, (2) there is no cross-section information upon which to base species-specific physical habitat predictions in this reach, and (3) life history dynamics probably are not well enough understood to support a population predictive approach. A similar lack of data in the upper Susitna may increase the attractiveness of fixed-percentage approaches.

The actual means of evaluation using this approach would involve the following steps.

1. Determine the present flow regime from measured data at Gold Creek, Chulitna, and Talkeetna gages and determine mean annual, 20th, and 80th percentile exceedence flows.

2. Determine from literature sources percentages of mean annual flow associated with the population levels of the lower Susitna mainstem fish species and in similar situations elsewhere.
3. Establish flow ranges for maintenance of present population and for preservation of minimum population levels.
4. Evaluate project flows with respect to established ranges and determine the likely postproject population condition.

As stated earlier, this approach (or any other like it) may not be appropriate for the Susitna assessment because of the lack of relativity to Alaska situations. Its ultimate weakness may lie in the scarcity or absence of similar streamflow-climate situations upon which to base development of Alaska criteria.

Hydraulic Simulation Approaches. Few usable cross-section data exist for the lower Susitna mainstem, but some of the available single cross-section work (Bredthauer and Drage 1982) may help simulate passage conditions and determine expected channel morphology changes. Salmon passage assessments using single and multiple cross-section approaches have become quite common in Oregon and Washington. These assessments require predicted depth and velocity information with which to predict habitat conditions for the species in question. More complete cross-section data are available for upper Susitna reaches, but passage is likely to be less problematic there.

Hydraulic Simulation Plus Species Preference Approach. Lack of multiple cross-section hydraulic simulation data in the lower Susitna mainstem again precludes this approach entirely. In the upper Susitna, some cross sections are available, but substrate data are lacking and the general low level of specific life history data and mainstem habitat utilization makes the value of multiple cross-section data collection questionable. If greater utilization of this habitat were demonstrated, especially for critical activities such as spawning, considerable field effort might be justified.

Habitat Evaluation Indices. Instream habitat changes will probably be predicted using a hydraulic-based quantitative approach (PHABSIM, R2-cross, HEC-2), thus precluding use of the aquatic habitat evaluation procedures. Riparian habitat changes predicted using results of the hydraulic simulation may be used in a terrestrial impact assessment or in conjunction with the streamflow assessment if mainstem habitat units are calculated.

Miscellaneous Methodologies. Because effects other than flow or temperature alterations are expected in the Susitna mainstem, miscellaneous methodologies will probably not be employed.

Summary. Mainstem impact evaluations may be based on fixed-percentage approaches for resident species throughout the river, but relevant criteria will be a problem. Some passage evaluation will be possible using available hydraulic data and passage requirements from Alaska or other regions. More sophisticated habitat predictions will depend upon provision of mainstem cross-section data for both the upper and lower Susitna.

Tributaries

Two types of tributaries exist in the Susitna basin. These are defined as major tributaries (the Yentna, Chulitna and Talkeetna rivers) and minor tributaries (all other tributaries to either the Susitna or major tributaries). Tributary streams support a variety of fish species and life stages throughout the Susitna basin. Recent surveys indicate that all resident species utilize tributaries at all phases of their life history. Bering cisco are probably the only anadromous fishes which do not utilize tributaries at some time. Of the Pacific salmon, only sockeye appear to have limited involvement in minor tributaries, but sockeye habitat utilization is poorly known in areas other than upper river sloughs. Of the remaining salmon species, chinook, coho, chum, and pink salmon spawn primarily in minor tributaries. Chinook and coho may use tributaries, especially the mouths, as rearing or overwintering locations.

Because no tributaries will actually be dammed by this project, the expected impacts will be those associated with inundation, access and road building, or changes in mainstem Susitna River discharge patterns. Inundation effects are expected both during filling and seasonal fluctuation of the reservoir. Discharge effects are expected to result from decreased postproject mainstem water level and perching of tributary sediment deltas. In this case failure or delay of the tributary to erode through the perched delta would eliminate access into the tributary during periods when mainstem discharge fell below critical levels.

Hydrologic Methodologies. No previous use of such methodologies is known.

Hydraulic Simulation Methodologies. Some quantitative evaluations of tributary access may be made using sediment delta simulations based on cross sections measured near the tributary mouths. Unless there is some knowledge of postproject mainstem sediment dynamics, however, the degree of perching will not be well known and the predictive benefits of cross-section measurements limited. Questions regarding sedimentation on eggs deposited in tributary channels during low flow might be addressed using detailed cross-section information for affected tributaries plus sediment transport measurements for those tributaries. Such data are not currently available but may be collected in the near future.

Habitat Evaluation Procedures. Effects on tributaries in the impoundment area may be quantified by map-based estimates of losses of riverine habitat at various reservoir elevations. Habitat accounting might be applied through such indices as HSU's to evaluate tradeoffs between inundated tributary and main channel fisheries and those expected to arise as a result of reservoir existence and increased access near the access corridor. Regardless of the actual methodology used, it would be advisable to place habitat values in impoundment area tributaries and in the reservoir itself on an equal scale to facilitate evaluations of tradeoffs.

Miscellaneous Approaches. Perhaps the most valuable approach to tributary analyses would result from combining quantitative methodology mainstem information with tributary population and recruitment predictions. Changes in Susitna River discharges could affect the tributary fisheries in three ways: (1) through reductions in adult mainstem passage the number of tributary inmigrants might change; (2) if significant perching occurs, tributary inmigrants will again be reduced; and (3) changes in main channel flow might alter the efficacy of travel between tributary mouths and nearby sloughs thought to be important for juvenile tributary-spawning salmon species.

If mainstem-tributary mouth channel relationships were known, reductions (or additions) to normal tributary inmigration could be calculated and applied directly to escapement counts, which could form the basis for new population sequences. Time-series of project flows could then be evaluated with respect to long-term escapement and return trends in the tributaries and the various project operations compared in terms of tributary fish production. Such an analytic approach would require extensive hydraulic and fish population information with strong predictive capabilities in ice and sediment dynamics under project flow conditions.

Summary. Tributary impact assessments depend heavily on quantitative hydraulic information currently not available for the lower Susitna. Upper Susitna applications are possible.

Sloughs

The greatest amount of quantitative project-related habitat data is available for sloughs between Talkeetna and Devil Canyon; however, these data are not necessarily in proportion to the percentage of the total Susitna basin fish stocks that utilize sloughs. Based on recent ADF&G survey results, a total of fewer than 7,000 salmon (mostly chum and sockeye) utilize these habitats for spawning each year in the upper Susitna. The emphasis on upper river slough data collection has resulted primarily from the assumption that project effects will be most severe and definable on access, spawning, and incubation in the sloughs.

All salmon species utilize sloughs at some time in their life cycle, but the primary use is by chum and sockeye salmon for spawning, incubation, and early rearing. Sockeye salmon in the upper Susitna appear to utilize sloughs almost exclusively for spawning because no significant sockeye spawning has been demonstrated in the upper Susitna tributaries or main channel. Most Susitna basin chum salmon spawn in tributaries, and they are also the most numerous slough spawners. Pink, chinook, and coho salmon seldom spawn in sloughs but use them to various degrees for overwintering and juvenile rearing. The hydraulics associated with habitat conditions at certain sloughs are quite well studied and provide (for those sloughs) a credible and comprehensive basis for predictive modeling.

At the intensively studied sloughs it is possible to predict mainstem water elevation (stage) for any discharge and to relate that stage to an estimate of access to the slough by salmon. Wetted surface area within the slough can similarly be determined from mainstem discharge. Relative seasonal utilization by different salmon species is known for a number of sloughs. Because of the detailed physical-biological data base available and because project effects are likely to be great in the upper Susitna, these sloughs currently offer the best opportunity for quantified impact assessment.

Fixed-Percentage Methodologies. Little or no basis exists, either of necessity or by supporting technology, for use of "office approaches" to assess slough impacts.

Hydraulic Simulation Approaches. Most quantitative efforts to date have involved use of hydraulic simulation results related to mainstem discharge with access into certain sloughs. Through predictions of depth at slough mouths and observations of fish access at certain flows, it is possible to determine relative access efficiency (degree to which depth limits fish passage) for mainstem discharges from 8,000 to about 20,000 cfs. Because depth at the slough mouth is a function of discharges in both the slough and the main channel and because slough discharge may not be directly related to main channel discharge, the predictive modeling of access is not strictly deterministic.

Certain sloughs have been characterized by multiple cross-section measurements at several flows. From these it will be possible to predict surface area and spatial distribution of depth, velocity, and substrate at a range of slough discharges. These hydraulic simulation-based assessments and associated studies for slough discharge dynamics with respect to groundwater, upwelling, ice formation, and surface runoff have provided the major basis for simulation modeling in the Susitna basin.

Hydraulic Simulation with Habitat Preferences. At six sloughs for which multiple cross-section (IFG-4) data sets exist, it will be possible to calculate actual spawning, incubation, and rearing habitat using the IFG HABTAT program. This modeling process requires habitat preference or utilization curves which, though available through IFG for all Pacific salmon species, will probably not be acceptable for Susitna River populations. Calculation of WUA or a similar area-weighted habitat index will be relatively simple once decisions are made of acceptability of currently available habitat preference curves. A conceptual population model using WUA and/or slough surface area vs. mainstem flow relationships is presented later in this paper.

Habitat Evaluation Indices. The general guidelines of aquatic HEP are probably not applicable to slough assessments because of their highly unique and variable habitat characteristics for which HEP weighting factors and model formulations have not been developed. As in the other habitat types mentioned, however, quantification of habitat or population gains and losses in sloughs should be expressed in terms compatible with those developed for the mainstem and tributaries.

Miscellaneous Approaches - Proposed Slough Impact Assessment Designs. Because the hydraulics, dynamics, and fish utilization of sloughs are highly unique and because they cannot be considered simply as small streams or ephemeral lakes, the approach to assessment of slough impacts will necessarily be a combination of the above approaches and in many respects a collection of singular processes utilized on a slough-by-slough basis. Depending on requirements for analytic comprehensiveness and available information, numerous assessment approaches are possible for sloughs. Those presented are examples of potential levels of activity, listed with associated data needs and output limitations.

As mentioned earlier, two distinct analytic approaches exist where streamflow is the primary variable--those which analyze impacts based on changes in aquatic habitat and those which do so based on either interpretation of habitat in terms of fish population effects or by direct determination of population effects. Projects are often evaluated in terms of fish habitat changes alone without knowledge relating changes in habitat for a given life stage to effects upon fish population strength, commercial fishery economics, or sport fishery success. The following potential approaches range from those dealing only with habitat to those which might predict trends in salmon populations. The latter may seem unfeasible because of data limitations but may offer the most reliable assessments upon which to base decisions on project operations.

Habitat Dynamics Displays and Comparisons. This approach would require provision of mainstem discharge vs. slough habitat by ADF&G, based on observations and interpretation of quantitative material. For each species at each slough or slough type, ADF&G would provide a curve similar to the following. In this case, surface area of standing water would be related to mainstem discharge under the assumption that standing water surface area is equivalent to usable habitat (Figure 7). At each slough, postproject discharges in the form of mean monthly flows expected for a 32-year forecast period would be available for each potential project operational schedule. This discharge time series would be in the form given in Figure 8. A similar flow-time matrix is available for pre-project flows.

Habitat assessment of any project operation schedule could be done quickly by determining the habitat suitability value for each discharge in the matrix and then constructing a 32 x 12 matrix of habitat suitability values. Both pre- and postproject matrices could be constructed and comparisons made for each target species in pre- and postproject spawning habitats, for example. Comparisons could be made in a

Figure 7. Susitna River discharge (Q) vs. surface area (in 1000 sq. ft) for Slough 8A (extrapolated from ADF&G 1983c).

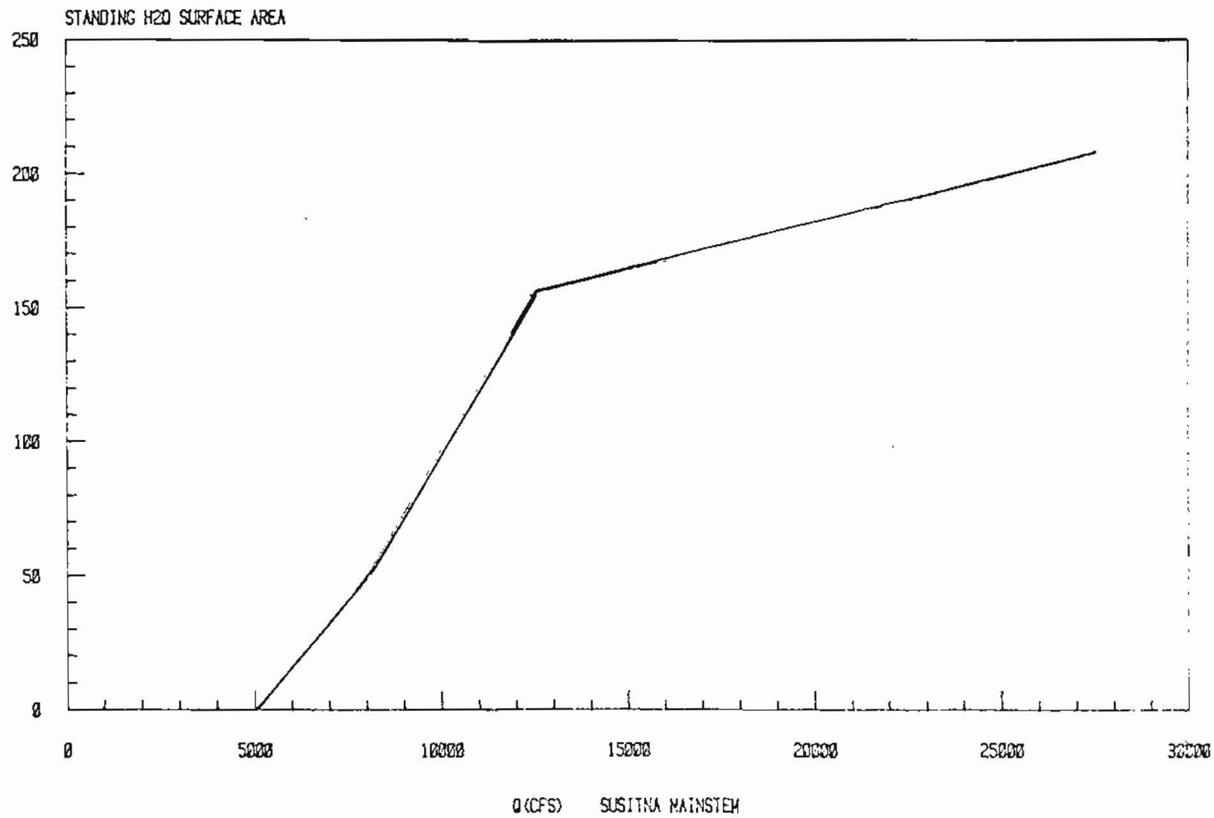


Figure 8. Mean September pre- and postproject Susitna River flow at Gold Creek. Surface area is assumed equal to usable habitat.

YEAR	PRE-PROJECT FLOW (cfs)	PRE-PROJECT SLOUGH 8A SURFACE AREA (standing water)	POSTPROJECT FLOW (cfs)	POSTPROJECT SLOUGH 8A SURFACE AREA (standing water)
1	8301	57.1	9300	80.6
2	21240	186.0	9300	80.6
3	14480	162.6	9300	80.6
4	15270	165.3	9300	80.6
5	12920	157.2	9300	80.6
6	14290	162.0	10444	107.5
7	18330	176.0	18330	176.0
8	19800	181.0	10173	101.1
9	7550	42.5	9300	80.6
10	16920	171.1	14603	163.0
11	20510	183.5	9300	80.6
12	13370	158.8	9300	80.6
13	15890	167.5	15890	167.5
14	12320	151.6	11551	133.5
15	9571	86.9	9300	80.6
16	19350	179.5	10645	112.2
17	11750	138.2	9300	80.6
18	16870	170.9	16870	170.9
19	8816	69.2	9300	80.6
20	9776	91.8	9300	80.6
21	9121	76.4	9300	80.6
22	14440	162.5	10053	98.3
23	12400	153.4	9300	80.6
24	9074	75.3	9300	80.6
25	12250	149.9	9300	80.6
26	16310	169.0	9300	80.6
27	6881	31.4	9300	80.6
28	12640	156.3	9300	80.6
29	8607	64.3	9300	80.6
30	10770	115.1	9300	80.6
31	13280	158.5	9300	80.6
32	13171	158.1	13171	158.1

strictly numerical way with means and t-tests, summation or integration processes, or cumulative frequency comparisons (Figure 9). In any case, project assessments would be made on a species-by-species, life stage-by-life stage, and slough-by-slough basis. Impact assessment could be based on weighting of the individual factors or could consider all species, life stages, and sloughs of equal value.

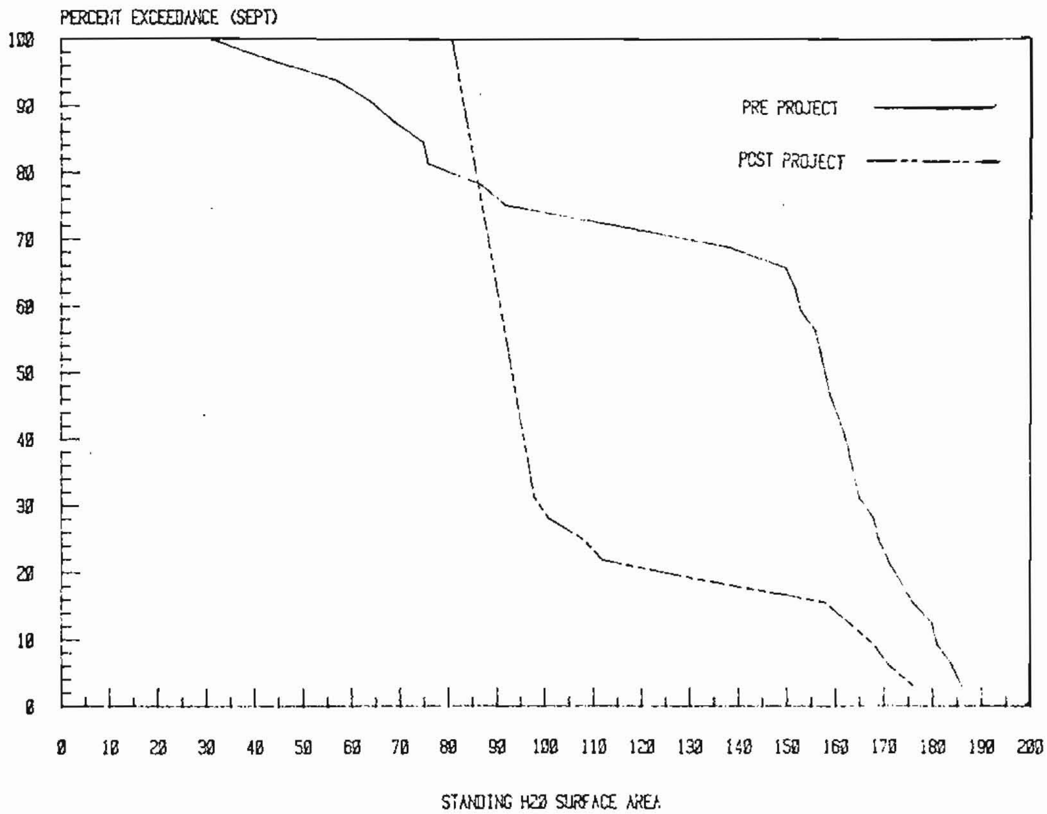
This process could be employed using WUA as the dependent habitat variable in sloughs, tributaries, or main channel locations if suitable cross-section data and habitat preference information were available. Since such data are not currently available, the spawning surface area dependent variable was used.

The described habitat comparison approach has certain advantages in the Susitna assessment. First, specific biologic data requirements may be low. Second, the resultant comparisons are relatively simple and demonstrable using computer graphics or summary statistics. Third, the time-series concept promotes consideration of the project in terms of monthly streamflow variation and not simply a single mean value likely never actually to occur (Trihey 1981).

As discussed in Bovee (1982), however, such habitat comparisons do not evaluate the effects of habitat changes, merely the fact that they have changed. Habitat changes affect life stages differently. Actual population effects range from zero to total mortality. Further, even if changes in habitat for all life stages were quantified, it would be difficult to evaluate those changes by simply assuming some linear relationship between habitat and abundance; numeric strength of fry requires knowledge of both fry habitat and numbers of fry available which, in turn, requires knowledge of numeric strength of eggs and both natural- and habitat-related reductions in that strength.

Population Trend Models. If a certain life stage were known to be especially sensitive or critical to maintenance of a salmon population, it might follow that provision of enough water for that life stage would minimize impacts while also reducing constraints on project operations because of the limited time frame for which flows must be provided. A good example involves slough access and spawning and the need for a certain minimum main channel discharge during August of each year to

Figure 9. Percent exceedance of Slough 8A surface area (in 1000 sq. ft for September) under 32-year pre- and postproject flow conditions.



provide access of sockeye and chum salmon to sloughs prior to spawning. Flow-related egg mortality is a function both of water elevations below critical levels (dessication) and other factors relating to upwelling, gravel permeability, and substrate stability.

Actual numbers of available inmigrating salmon, fecundity, or spawning densities are generally available but not necessary to predict project-induced trends because the primary objective is to predict population index trends, not actual populations. Therefore, any assumed value of inmigrants could serve as an initial index to be reduced or augmented by various flow and nonflow related factors.

A chum salmon trend model would sequence through the following steps using the indicated relationships.

Month	Time-step	Life stage sequence and reduction factors
8	i	$N_{ps} = N_{im} * A.E.F. * M_p$
9	i+1	$N_{as} = d_{redds} * A_{slough}$
		if $\frac{N_{ps}}{A_{slough}} \geq d_{redd}$
10-3	i+2	$N_{eggs} = N_{as} * \bar{X}$ fec
		(fec = 3,000 egg/fish)
		$N_{se} = N_{eggs} * M_e$ if $WSE \geq WSE_c$
		$N_{eggs} * f(Q) * M_e$ if $WSE \leq WSE_c$
4	i+3	$N_{out} = M_f * N_{se} * f(T)$

where: N = number

subscript ps = potential spawners

im = inmigrants

as = actual spawners

eggs = spawnable eggs

se = surviving eggs

out = outmigrating smolts

d_{redds} = density of redds in a slough

fec = fecundity

c = critical

WSE = water surface elevation

M = mortality

subscript p = passage

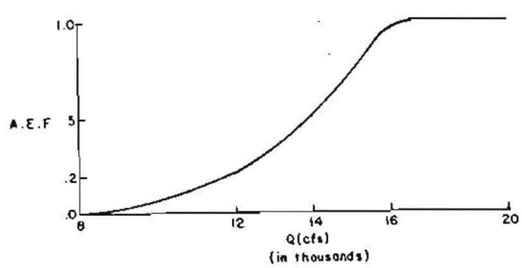
e = eggs

f = fry

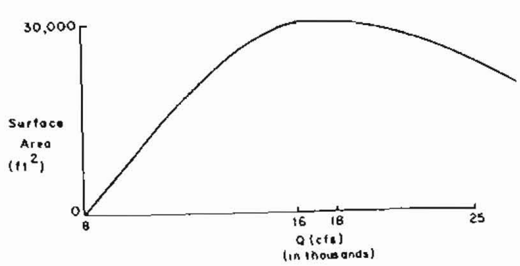
n = non-riverine (oceanic)

f(Q) = function of streamflow

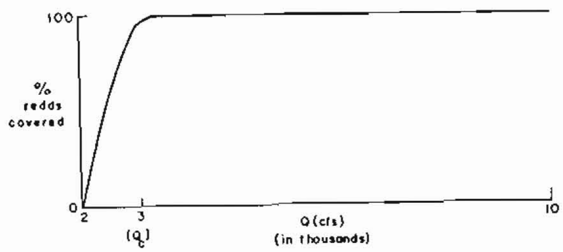
f(T) = function of stream temperature



A.E.F. = Access Efficiency Factor from the relationship



A_{slough} = Surface area (S.A.) of slough vs Q_{i+1}



Q_c = Critical Q minimum to incubate all eggs deposited at Q_i from relationship

Following is an example evaluating effects of pre- and postproject mean monthly flows with an imposed minimum of 12,000 cfs in August. For each project operation at a given slough either a number of potential spawners (N_{ps}) is assumed or the maximum number based on greatest surface area times redd density (A_{slough} * redds/Area) is calculated. The Slough Access Efficiency (S.A.E.) max is calculated for the predicted mean August discharge (time step i) from function 1. This Access Efficiency is multiplied times either the number of potential spawners (if known) or by the maximum effective spawning number to produce number of actual spawners, or the number likely to successfully enter the slough and be available for spawning. The number of actual spawners reflects correction by a sex ratio factor to more accurately indicate spawning pairs. At this point, any August discharge in excess of that offering Access Efficiency of 100 percent would become available for project operation or storage. Next, the surface area of the slough would be determined using function 2. If IFG-4 data are available, the September discharge will be converted to spawning WUA. Again referring to the redd density ratio, the number of actual spawners would then be compared with the maximum number of spawners at the September discharge (Q_{i+1}). Again, discharge providing greater surface area than could be utilized by the maximum number of spawners would be made available for storage or later accounting. Discharges creating surface area limitations would result in a reduction in the number of redds in direct proportion to losses in surface area. The resulting number of redds would then be multiplied by the average number of eggs per female (fec) to determine the number of potentially deposited eggs (N_e). At this point, all natural (non-flow-related) mortality on eggs could be accumulated and one egg mortality factor applied to determine the number of surviving eggs (N_{se}). The discharge table for the months October through May would then be searched to locate months when flows are at or below a critical minimum determined from function 3. If all flows during this period turn out to be above the minimum, only natural mortality factors would apply. Below this minimum, an additional egg mortality directly proportioned to loss of wetted area would be applied, reducing the number of surviving eggs.

Also during this period, the locations of the slough(s) under study would be checked for proximity to the predicted ice front. Water surface elevations for sloughs above the ice front would be determined from summer rating curves. Water surface elevations near or below the ice front would be derived from winter rating curves which reflected staging. Those at or quite near the ice front would be determined from rating curves which reflect maximum staging conditions. For each discharge, staged water surface elevations should be known and compared to the minimum elevation necessary to breech the head of the slough. If breeching occurs during incubation, total egg mortality could be assumed.

If breeching does not occur, N_{se} could be modified by fry mortality factors. If overtopping occurs during emergence, total mortality again could be assumed. If overtopping occurs when fry are free-swimming (a highly unlikely event), mortality could be estimated, based on predicted slough velocities and tolerance limits of salmon fry for velocities expected in the overtopped slough.

The final number of potential outmigrants (N_o) reflects all expected natural mortality factors plus effects of those attributed to changes in mainstem or slough discharge. Under preproject conditions, little flow-related limitation is implied, especially near the median or modal flows for each month. This does not mean that limiting factors do not now exist but that the current condition should be considered a base line upon which project effects might either improve or degrade fish populations. The extreme variation in preproject flows might easily be among the greater population limiting factors. Changes in discharge during the critical August through September period, and to a lesser extent during the rest of the year, should cause changes in the number of potential outmigrants, which after predictable oceanic mortality will return three or four years into the project operation. This reduced number of inmigrants will serve as a new initial number subject to reduction during August of the project's fifth year by the Q_i flow and associated access efficiency.

OTHER CONSTRUCTION-RELATED EFFECTS

INTRODUCTION

There are a number of potential impacts that may be related to peripheral construction activities. These activities take place away from the Susitna River course itself. These construction activities include service and access roads and corridors, transmission line routes, construction camps and other habitation areas, gravel removal sites, reservoir vegetation clearing, and other related human effects such as sport fishing along project access corridors. Effects caused by erosion/sedimentation and pollutant spills may impact aquatic habitats such as tributary streams and lakes within the Susitna basin. At this time, proposed peripheral construction activities are described only generally; specific details of routing or siting and specific construction techniques would be required before specific analyses can be completed. Potential impact areas and the related aquatic resources are identified in the following discussion.

POTENTIAL IMPACT AREAS AND RELATED AQUATIC RESOURCES

Access Corridors

The proposed access road to the dam sites would depart from the Denali Highway near Seattle Creek and proceed south to the Susitna River below the Watana Creek confluence, then traverse either the north or south side of the Susitna River to the Devil Canyon dam site. A rail extension from Gold Creek would be added for construction of Devil Canyon facilities (ACRES 1982c).

The access road corridor from Denali to Watana would be approximately 40 miles long and crosses or parallels at least 37 streams and rivers in both the Nenana and Susitna river drainages. Major streams crossed or paralleled in the Nenana drainage would be Lily Creek, Seattle Creek, and Brushkana Creek (ACRES 1982a). These streams support populations of grayling, northern pike, whitefish, burbot, and sculpin (Figure 10). Deadman Creek is the major system in the Susitna drainage that would be affected by the Watana access road. It is considered prime grayling habitat and also contains populations of longnose sucker, sculpin, and burbot. Between the Watana and Devil Canyon dam sites, the access road would cross Tsusena and Devil creeks. Tsusena Creek contains grayling, whitefish, burbot, and sculpin. The 16-mile-long railroad line between Devil Canyon and Gold Creek would cross or parallel six streams, including Jack Long Creek and Gold Creek. Jack Long Creek contains small populations of chinook, silver, chum, and pink salmon. Gold creek contains small populations of chinook, silver, and pink salmon.

Transmission Corridor

Transmission lines would be built from Watana and Devil Canyon power houses to Gold Creek and from there connect into the Anchorage-Fairbanks intertie. From Watana to Gold Creek the transmission line route would straddle the south side of the Susitna River. This recommended route is approximately 40 miles long and would cross the Susitna River and 17 small tributaries including Fog Creek, Jack Long Creek, and Gold Creek (ACRES 1982a). Fog Creek contains grayling, burbot, sculpin, and Dolly Varden. Jack Long and Gold creeks contain small populations of salmon.

Gravel Removal Sites

Floodplain and upland gravel mining has the potential to adversely affect aquatic habitats from related erosion and sedimentation problems. The extent of this effect would depend on the location of these sites (Figure 10). The alluvial fans at the mouth of Tsusena Creek, Cheechako Creek, and mainstem Susitna River have been proposed as material sites. Tsusena Creek would be rehabilitated but not the Cheechako Creek and Susitna River sites because they would be inundated by the reservoir (ACRES 1982a). Tsusena Creek contains grayling, whitefish, sculpin, and

Figure 10. Aquatic resources present in potentially affected areas from construction activities for the Susitna Hydroelectric Project.

Construction Activity	Access Corridors	Transmission Corridor	Gravel Removal Sites	Habitation Areas	Clearing	Potential Pollutant Spills	Sport Fishing	Species Present[1]
WATER BODY								
Susitna River	X	X	X	X	X	X	X	BB,SU,WF,GR,DV
Lily Creek	X				X	X	X	GR,BB,WF,NP,SC
Seattle Creek	X				X	X	X	GR,BB,WF,NP,SC
Brushkana Creek	X				X	X	X	GR,BB,WF,NP,SC
Deadman Creek	X			X	X	X	X	GR,SU,BB,SC
Tsusena Creek	X		X	X	X	X	X	GR,WF,BB,SC
Devil Creek	X				X	X	X	2
Fog Creek		X			X	X	X	GR,BB,SC,DV
Gold Creek	X	X			X	X	X	KS,SS,PS
Jack Long Creek	X	X			X	X	X	KS,SS,CS,PS
Cheechako Creek	X	X	X		X	X	X	KS,GR,DV
Watana Creek					X			GR,BB,WF,SU,SC
Kosina Creek					X			GR,BB,WF,SU,SC
Jay Creek					X			GR,BB,WF,SU
Goose Creek					X			GR,BB,SU,SC
Oshetna River					X			GR,BB,WF,SU,SC

1. Chinook (king) salmon KS; Coho (silver) salmon SS; Chum (dog) salmon CS; Pink (humpback) salmon PS; Arctic grayling GR; Northern pike NP; Longnose sucker SU; Burbot BB; Slimy sculpin SC; Whitefish WF; Dolly Varden DV

2. No data available.

burbot. Chinook salmon, grayling, and Dolly Varden are found in the lower portion of Cheechako Creek.

Habitation Areas

During construction of Watana Dam a construction camp and permanent village would be located near the dam site. Each development would occupy approximately 170 acres. The water source for both camps and villages would be Tsusena Creek. Wastewater effluent would be discharged into Deadman Creek. During construction of Devil Canyon Dam, both a construction camp and village would be located about a mile from the dam site. Water would be drawn from the Susitna River and the effluent from a biological lagoon system discharged back into the river (ACRES 1982a). Burbot, sculpin, and longnose sucker may occupy the Susitna River in these areas.

Spills

Toxic pollutants could be spilled into any water body along access corridors, near camps, fuel depots, and related facilities.

Clearing

In addition to the vegetation clearing activities to take place along the access and transmission corridors, a major clearing operation is proposed for the reservoirs. The Watana Reservoir would inundate 54 miles of mainstem and 28 miles of tributary habitat. Portions of six major tributaries would be cleared of timber including Deadman, Watana, Kosina, Jay, and Goose creeks and the Osetna River. These tributaries are prime grayling habitat and also contain populations of burbot, whitefish, longnose sucker, and sculpin (Figure 10). Impacts from vegetation clearing on these tributaries would be secondary to the actual inundation from the reservoir. Areas and methods of debris removal may affect water quality in local stream courses.

Sport Fishing

Operation of the camps and villages would increase access to waters that previously experienced little sport fishing pressure. Potentially affected would be Deadman, Tsusena, Jack Long creeks, and stretches of the mainstem Susitna River. Deadman and Tsusena creeks contain substantial grayling populations as well as longnose sucker, burbot, and sculpin. Jack Long Creek has small populations of chinook, coho, chum, and pink salmon. Major species of mainstem Susitna are burbot, longnose sucker, and whitefish.

GENERAL IMPACT PROBLEMS

Construction activities associated with the Susitna hydroelectric project could result in the introduction of sediment or pollution products into aquatic systems within the basin. These products could directly affect the fisheries resources present in these aquatic systems. The potential for erosion or pollution would vary with the types of construction techniques, the nature of local surficial materials, the topography at and surrounding specific construction sites, and the timing of the activities. The following potential impacts could result from construction and operation of the project and will be addressed by AEIDC when specific site and methodological information become available.

Erosion and Sedimentation

Wherever soil erosion takes place, the soil material breaks up and is carried away by water runoff. Coarse sediments may not be carried far before being deposited again, but fine-grained sediments, principally silt or clay particles, are carried in suspension for long distances and usually end up in local runnels and brooks that feed major streams. Thus, silt often finds its way into anadromous fish streams as far as several miles away from the erosional source. Sedimentation can affect development of fish eggs and benthic organisms as well as causing changes in species composition. These effects are well documented in the literature (ACRES 1982a).

The following construction activities have the potential for causing erosion and subsequent stream sedimentation.

Access Corridors and Habitation Areas. Construction of roads, staging areas, construction camps, and habitation sites generally requires removal of some surface vegetation, cutting and grading of slopes, filling of depressions, and sometimes a surface gravel pad or roadway. Areas underlain by permafrost are generally covered with an insulating surface gravel layer to prevent thaw slumping, and culverts can be placed to route runoff through the area.

Removal of the organic surface layer exposes mineral soils to erosion from surface runoff and wind. Desiccation of exposed soils can increase erosion potential. Proper culvert placement is important to prevent local runoff from crossing and eroding the surface. Exposed cut faces become prone to erosion unless stabilized by vegetation. Areas with permafrost, especially ice-rich fine grained soils, are subject to severe subsidence and erosion once the organic surface cover is removed unless insulated by gravel pads. Exposed fill slopes are highly erodable unless protected by vegetation.

Transmission Line Corridor. Transmission line corridors are generally cleared of any timber tall enough to fall on the lines. Felled timber is either left in place or skidded off the corridor. Roads or trails are usually constructed to provide access for vehicles and equipment for timber removal and other construction activities. These can vary from gravel roads that meet secondary road standards, to rough roads graded through the surface organic mat, to surface trails with no grading involved and low vegetation left in place. Surface trails often require all-terrain vehicles with large tires or tracks. In some instances helicopter access is required to reduce surface disturbance.

Clearing of vegetation, log skidding, and movement of vehicles on slopes could induce long-term processes that would eventually trigger severe erosion and mass wasting. Root systems of trees and other vegetation serve as cohesive binders within the soil, providing about 25 percent of the strength of the soil mass. If roots penetrate completely through the soil zone, they often anchor directly into cracks in the rock substrate, increasing their stabilizing influence.

Removal or destruction of surface vegetation exposes bare mineral soil to the direct effects of surface runoff and destroys the mechanical stabilizing effect of root reinforcing and anchoring within the soil mantle. Soils then become more susceptible to soil mass movement and gullying. A marked decrease in soil stability may not become noticeable for several years after vegetation clearing because roots of destroyed surface vegetation progressively deteriorate over time.

Clearing of trees from the transmission line corridor may cause wind channeling and windthrow problems during storms. Channeled winds can cause blowdown of trees along the margins of the corridor, increasing the corridor width and increasing soil erosion through further destruction of root binding in the soil. Where the organic mat has been removed or damaged, exposing bare mineral soil, wind channeling also increases soil desiccation in the corridor and dry soils are more prone to erosion.

Removal of streambank vegetation cover can also affect water temperature by exposing streams to direct sunlight. The insulating effect of the riparian vegetation is of primary importance in maintaining acceptable stream temperatures in small streams that serve as nursery areas for small fish. Streams with south-facing drainage basins are more likely to experience stream temperature increases and possible dewatering during the periods of high solar energy input. Removal of bank cover could also increase the exposure of fish to predators and lead to a change in the population (Joyce, Rundquist, and Moulton 1980).

Gravel Removal Sites. Gravel will be required for many purposes in construction of the Susitna hydroelectric project. For example, gravel is used for surface fill material in the construction of habitation areas, building pads, and construction camp and staging area pads. Roadbuilding requires gravel to fill depressions, insulate ice-rich frozen ground, and construct the surface course roadway.

Gravel is generally obtained from pit mines in river floodplains and upland gravel deposits. Bulldozers and backhoes extract the gravel, which is then transported by dump trucks. Floodplain gravel is usually removed from areas away from active river channels, but these areas may be inundated during floods. In upland areas surface soil is usually removed and either disposed of or stored for eventual reclamation of the site.

Gravel mining in floodplains can cause direct inducement of turbidity in the river system resulting from the mining operation and transportation of the resource. The presence of gravel pits within floodplains can alter sedimentation patterns within the floodplain during flood periods and alter stream channel morphology. Ponding of water in borrow pits can trap fish.

Gravel mining in upland areas can induce erosion of exposed mineral soils in the removal site and in the bounding walls. Erosion of bounding walls can cause slumping and extension of the site, exacerbating erosion problems. If an eroding borrow site should intercept local stream courses, fish could become trapped in the flooded site. If top soil removed from the site is not properly disposed of as spoil or stored for eventual reclamation, it becomes susceptible to erosion.

Pollution

Water Use. Construction and operation of camps and related facilities could impact aquatic resources in several ways. As part of these activities, water would be diverted from area streams or lakes for dust control, concrete batching, and gravel washing among other construction uses as well as for domestic use in the camps and villages.

Potential impacts would primarily be caused by increased turbidity due to erosion and discharge of effluent from concrete batching and gravel washing operations. Prolonged turbidity can reduce the productivity of a system and cause emigration of fish populations. Fish could also be impinged or entrained by improperly designed water intakes.

The extent of any potential impact from domestic water use depends on the treatment of sanitary waste. Wastewater effluents can affect the water quality of fish habitat by changing the BOD; however, point of discharge and type of treatment control the extent of impact. The effluent is not expected to cause any degradation of water quality as a secondary wastewater treatment facility is proposed to treat all wastewater prior to its discharge (ACRES 1982b).

Spills. Contamination of water courses from accidental spills of hazardous materials is a major concern. Spills during major construction projects commonly occur as a result of equipment repair, refueling, and accidents. Substances used in large quantities, like fuels and oils, would be most likely to be involved and then other materials such as solvents, antifreeze, hydraulic oil, grease, and paints. If more than 10,000 gallons are stored at a site (common for large projects) the contractor would be required to file a spill prevention, containment, and countermeasure (SPCC) plan with the U.S. Environmental Protection Agency.

Spills are generally short-term events but can have severe impact, depending on the substance spilled, quantity spilled, the season, species and life stages present, and the clean-up capabilities available. Incubating eggs and alevins are the fish life stages most likely to be affected by spills because adults and juveniles usually leave the affected area. Aromatic compounds in oils are particularly toxic, and there is a great deal of literature describing the deleterious effects on aquatic life caused by petroleum products (ACRES 1982a).

Clearing. Within the dam, spillway, and impoundment areas for Watana reservoir more than 12,000 ha of vegetation would be removed by construction and clearing operations, and more than 2,000 ha would be removed for the Devil Canyon reservoir (ACRES 1982a). An additional loss of approximately 300 ha of mixed vegetation types would be lost to access roads as well as about 2,000 ha to the camps and related facilities (ACRES 1982a). Unforested or sparsely forested locations would be utilized as much as possible for features located outside the impoundment area.

Vegetation/timber slash and debris from the reservoir would be stockpiled and burned over a three-year period during winter. Clearing would be confined to the area to be inundated during each following year. (Merchantable timber is not believed to occur in sufficient quantities to remove for sale.) Depending on the location of the burning, a potential impact on water quality is the possibility of large quantities of ash entering the lake or river system, especially during breakup.

Indirect Impacts

Sport Fishing. Operation of the camps would result in increased access to an area that has previously experienced little human pressure. Those portions of streams and lakes that are easily accessible from camps and roads would be subjected to increased fishing pressure. Studies on the streams in the proposed construction area indicate a relatively high percentage of older age class grayling (ADF&G 1981). Sport fishing may remove these larger older fish, resulting in a change in the age and size distribution of the population.

IMPACT ANALYSIS APPROACH

Analysis of the potential effects of erosion or pollution products into aquatic systems of the Susitna River basin is necessary to predict how aquatic resources in the basin might be affected. Heretofore, these topics have been addressed only in generic, qualitative terms since specific sites and methods of construction for access roads, gravel removal sites, transmission line corridors, habitation areas, and spoil disposal sites have not been identified. Descriptions and discussions of such anticipated impacts have so far addressed only the types of impacts that have occurred in similar projects or are likely to occur under the various developmental stages of this project. Those discussions have represented the collective understanding of the physical processes, habitat relationships, and likely response of fishery resources but have necessarily been speculative in nature (ACRES 1982a).

Once details of construction sites, routes, and methods are known, AEIDC will perform more site-specific analyses in an attempt to determine potential impacts to specific watercourses or portions thereof and their effects on fisheries habitat suitability and change. These analyses will include the following components.

1. Work with the engineers during the final design stages to become thoroughly familiar with planned project facilities and structure, their siting, and proposed construction methods and techniques. Consider design changes or modifications as they occur and incorporate them into the analysis.
2. Perform a comprehensive review of published and unpublished information and data on the effects of erosion and pollution resulting from similar engineering projects on aquatic and fisheries resources.

3. Consult with experts who have knowledge and experience related to specific erosion and pollution problems. Work closely with other agencies involved in data collection for the Susitna hydroelectric project in order to collect necessary data and to survey other professional opinion.
4. Perform site-specific field reconnaissance of all construction sites to define specific potential erosion and pollution problem areas. Determine types of local soils, slopes, aspects, vegetation cover, and surface runoff patterns to estimate the vulnerability to erosion and potential routing of erosion and pollution products toward watercourses. Determine specific watercourses and fisheries resources that might be impacted by specific erosion and pollution problems.
5. Perform site-specific analysis of potential erosion and pollution problems, quantifying these effects where possible. Make a sensitivity matrix to illustrate:
    a. potential site-specific or method-specific erosion or pollution problems with each potential problem ranked as low, medium, or high probability of occurrence.
    b. local watercourses or portions thereof that might be affected by erosion or pollution problems identified above, and rank potential effects as low, medium, or high severity.
    c. fisheries resources in local watercourses that might be impacted and rank potential impacts as low, medium, or high.
6. Assess the effects of human fishing pressure on project area streams that will result from increased access to the area. Identify the most likely areas to be impacted by increased fishing pressure and the fisheries resources present. It will be difficult to quantify these effects. It may be necessary to estimate preproject fish populations (presently there is a paucity of data on fish population estimates in streams that may be affected) and compare to a possible postproject population scenario in the absence of any altered fishing regulations.

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