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Before The
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Application For License For Major Project

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SUSITNA HYDROELECTRIC PROJECT

(PROJECT NO. 7114-000)

HARZA-EBASCO
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RESPONSES TO AGENCY COMMENTS ON LICENSE APPLICATION

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February 15, 1984

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FEDERAL ENERGY REGULATORY COMMISSION

SUSITNA HYDROELECTRIC PROJECT

PROJECT NO. 7114

RESPONSE OF THE ALASKA POWER AUTHORITY TO COMMENTS ON THE ALASKA POWER AUTHORITY'S APPLICATION FOR LICENSE FOR MAJOR PROJECT

REFERENCES

February 15, 1984

ARLIS
Alaska Resources
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PREFACE

On or before December 12, 1983, nine state and federal agencies each filed a letter with the Federal Energy Regulatory Commission on the Alaska Power Authority's Application for License for the Susitna Hydroelectric Project, Federal Energy Regulatory Commission Project No. 7114. The Alaska Power Authority's detailed responses to the more than 800 specific comments set forth in the nine agency letters are contained in the Alaska Power Authority's Comment/Response Documents filed with the FERC on January 19, 1984 and February 15, 1984. The document in which this Preface appears contains references cited in the Power Authority's Comment/Response Documents. Additional references are contained in separately bound reports.

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ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): A. 1

United States Department of the Interior

BUREAU OF LAND MANAGEMENT

Anchorage District Office
4700 East 72nd Avenue
Anchorage, Alaska 99507

2920/013

APR 1 5 1982

Alaska Power Authority
Board of Directors
334 West Fifth Avenue
Anchorage, Alaska 99501

Gentlemen:

The Bureau of Land Management appreciates the opportunity to address and comment to this board on the proposed Susitna Hydroelectric Project. Curt McVee, Alaska BLM State Director regrets that he is unable to attend and comment today due to other commitments. I am Dick Vernimen, Associate District Manager, BLM Anchorage District.

Since the Anchorage District will be the office making the recommendations on the project I will be speaking from that position.

The BLM's charge as a multiple-use agency is to allow the use of the public lands to its highest capacity and values and to mitigate impacts where possible. In the case of this project we are involved with a mixed land pattern requiring us to act as interim land managers in regards to unconveyed Native and State selected lands. Our charge is the same but the land status requires more concurrence concerning decisions on what is allowed to happen on these lands.

Based on what we know about the project today from reviewing documents and meetings with both ACRES and APA we do not forsee any reason why the continuation of project development should not proceed. We offer the following information for your use:

1. Pioneer Road Routes.
   As we understand the situation, for those routes that originate either on the Alaska Railroad or the Parks Highway, the Pioneer Road would have to be constructed during the years 1983-1984 in order to arrive at improved access during 1985 and early 1986, which would then provide for a state of continuous access from the middle of 1986 onwards. The Pioneer Road concept requires road rights-of-way and related permits during the year of 1982 which is prior to the FERC Licensing process. There are obviously several problems with the Pioneer Road concept. As we now understand the situation, they are as follows:

1. Early construction of the Pioneer Road would have to be permitted by a BLM right-of-way that would require an environmental impact statement separate from those documents now being prepared for the project. Approaching the Pioneer Road Project in a separate EIS without evaluating the entire Susitna Project may lead to a legal challenge of piecemealing a bigger project. In other words, we could be challenged that the road is merely a part of a larger overall hydroelectric project which should be analyzed at one time.

2. The Pioneer Road would deviate from the location of the final access road particularly on the route south of the Susitna River between Devil's Canyon and the Watana site.

3. The Pioneer Road concept requires decision making by the Cook Inlet Native Corporation, State of Alaska, and the Bureau of Land Management, prior to licensing by FERC. We are very much concerned that a decision on the pioneer road may lead to serious environmental and economic consequences prior to the actual licensing of the project. While it is not likely a FERC license will be denied after the feasibility of the project has been established, time has a way of changing the values set by many of our past decisions and we as separate agencies cannot take the Pioneer Road concept lightly. There are three other aspects of the Pioneer Road concept we should mention. Those are: 1) it is very likely a Section 10 permit will be required for crossing navigable waters (Susitna River), 2) a Section 404 permit for wetlands will be required from the Corp of Engineers, and 3) the decision on the Pioneer Road concept will be elevated to the level of the Secretary of the Interior. All of the mentioned problem areas take time and, as time is of the essence, it is extremely important that, if a route is chosen that requires Pioneer Road construction, that the decision be made as early as possible and that the application for right-of-way and other permits be made to the Department of Interior and Department of Defense agencies at the earliest possible moment.

2. Environmental Impacts:
We are concerned about the relative environmental tradeoffs that must be made if this project is to be constructed. We cannot at this time recommend to you a preferred access route and mode. There are obviously some routes however that pose relatively higher environmental costs. Those routes

are the one south of the Susitna River between Devil's Canyon and Watana and secondly, the corridor paralleling the Indian River. Also of significant environmental concern is the route proposed south from the Denali Highway. The impact here is somewhat mitigated by the western route as opposed to the route via Butte Lake. It is still unclear as to the relative magnitude of the impact on caribou posed by the western route south from the Denali Highway. While we are concerned as to the impact on that caribou herd, we feel that the environmental tradeoff in question is one of impacts on the caribou herd versus the impacts of more productive habitats in the area of Indian River or Fog Lakes area. From an environmental standpoint, the route southerly from the Denali Highway seems preferrable from the aspect of minimizing disturbance of productive habitat. The route from the Denali, however, poses a secondary impact, that of human access to the project area after construction. Public access to the project area is a two-edged sword. We recognize that the Watana Project may provide a valuable recreation source for people of the southcentral Alaska. It is also recognized however, that public recreation can be a very destructive activity. We submit that control of the access, the State Game Laws, and the project management, after construction, are tools that can be used to manage the adverse effects of increased recreation opportunities. The question of public access to the project area is a spinoff of the type of access that is developed for project construction. While many problems are present we submit to you the following conclusions:

a. Both rail and road access will be required for construction. We feel this concept provides adequate flexibility and logistics during construction phases.

b. It is improbable the State of Alaska can construct a project of this magnitude without some form of readily available public access as a residual product.

c. The entire Susitna project is surrounded by primarily two kinds of land ownership, approximately 215,000 acres of private lands, in Native ownerships, and a very large acreage of State Land. The Cook Inlet Region Corporation has indicated they prefer development of their lands as a means of generating revenue. We can deduce that the State of Alaska likewise is committed to the development of the highest and best use of its land. This land ownership pattern and the respective management philosophies lead one to believe that road access will be supported by these two very important landowners in the area of the project.

It is our position to work with you on the project proposal in the most expediant manner we can while working within the laws and regulations placed upon us. If there are further questions concerning our comments please contact me at (907) 267-1246. Thank you.

Sincerely yours,

Richard J. Vernimen

Richard J. Vernimen
Associate District Manager

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): B. 17

in. Third International Conference on Permafrost, Edmonton Alberta
1978

INITIAL SHORELINE EROSION IN A PERMAFROST AFFECTED RESERVOIR, SOUTHERN INDIAN LAKE, CANADA.

R. W. Newbury, K.G. Beaty and G.K. McCullough. Dept. of the Environment, Fisheries & Marine Services, Freshwater Institute, Winnipeg, Manitoba, Canada.

Field surveys of eroding shorelines in permafrost affected fine-grained materials indicate that during the initial impoundment of a lake basin, deep erosion niches are formed at and immediately below the water's surface. Eroded volumes correlate well with erosive wave energies exerted on the shorelines but appear to be lower than the volumes anticipated in more southern reservoirs, particularly in the western USSR. The lower erosion rates are partially accounted for by the initial phases of impoundment distributing wave energies over a range of shoreline, the formation of a protective matte of forest debris on the foreshore, and the limiting of erosive capabilities by the rate of thawing of frozen materials under high wave energy conditions.

ÉROSION INITIALE DU LITTORAL DANS UN RÉSERVOIR SUBISSANT LES EFFETS DU PERGÉLISOL, LAC SUD DES INDIENS, CANADA

R.W. Newbury, K.G. Beaty, G.K. McCullough, Ministère de l'Environnement, Services maritimes et des Pêcheries, Institut des eaux douces, Winnipeg, Manitoba, Canada.

L'étude sur le terrain de lignes de rivages édifiées dans des matériaux à grains fins soumis à l'action érosive du pergélisol, indique que pendant les premières phases de retenue des eaux dans un bassin lacustre, de profondes niches d'érosion se constituent à la surface et immédiatement au-dessous de la surface de l'eau. Le volume de matériaux arrachés par l'érosion correspond bien à l'énergie des vagues qui battent le rivage, mais il semble qu'il soit inférieur au volume habituellement mesuré dans les réservoirs situés plus au sud, en particulier dans l'ouest de l'URSS. Les vitesses moindres d'érosion sont probablement dues au fait que pendant la phase initiale de retenue des eaux, l'énergie des vagues se répartit sur une grande partie du littoral, qu'il se forme sur l'avant-plage une couverture protectrice de débris végétaux arrachés à la forêt et que le potentiel d'érosion est limité par la lenteur du dégel des matériaux gelés, même dans les lieux où l'énergie des vagues est élevée.

НАЧАЛЬНАЯ ЭРОЗИЯ БЕРЕГОВОЙ ЛИНИИ РЕЗЕРВУАРОВ С УЧАСТКАМИ МНОГОЛЕТНЕЙ МЕРЗЛОТЫ

Полевые испытания мерзлых мелкозернистых грунтов на берегу озера Саут-Индиан-Лейк /Канада/ показывают, что в процессе начального запруживания бассейна озера на поверхности и непосредственно под поверхностью воды образуются глубокие эрозионные ниши. Объемы разрушенных пород хорошо коррелируют с энергиями эрозионных волн, воздействующих на береговую линию, но меньше предполагаемых объемов в резервуарах, расположенных в более южных районах, в частности в западных районах СССР. Более низкая интенсивность эрозии отчасти обусловлена начальными фазами запруживания, распределяющими волновые энергии вдоль береговой линии, образованием защитного вала из древесного лома на затопляемой прибрежной полосе и оттаиванием мерзлых грунтов в условиях высоких энергий волн.

INITIAL SHORELINE EROSION IN A PERMAFROST AFFECTED RESERVOIR SOUTHERN INDIAN LAKE, CANADA

R.W. Newbury, K.G. Beaty and G.K. McCullough

Department of the Environment, Fisheries and Marine Service, Freshwater Institute, Winnipeg, Manitoba, Canada. R3T 2N6

INTRODUCTION

Impoundments in river valleys for water storage and the development of hydro-electric energy create a condition in which unconsolidated valley materials are exposed to the erosive power of wind generated water waves. Through erosion and deposition in the near-shore and backshore zones, stable shorelines are ultimately developed as the impoundment ages. Similar processes occur in lake basins that are raised or lowered in elevation beyond the natural range of water level fluctuation. If the valley or backshore materials are fine-grained (clays, silts) the effects of the erosion during the period of restabilization may be intense. The immediate shoreline is undercut, slumps, and rapidly retreats, providing coarse sediments which deposit to form offshore shoals, and finer sediments which are held in suspension and circulated throughout the water body. In large lake basins, the concentration of suspended sediments may increase by ten times the pre-impoundment value, dramatically lowering light penetration and transparency and affecting primary biological production and fish species composition (Hecky *et al* 1974). The rate of release of sediments, and the time required for the re-stabilization of shorelines are largely unknown.

Research dealing with the creation of stable shorelines has been generally confined to predicting the loss of storage potential due to increased sedimentation (van Everdingen 1969, SNBS 1972). A broader recognition of the factors of shoreline morphology, overburden materials and wave energy has been proposed for reservoirs in Poland (Cyberski 1973). A generalized terminal form of an eroded shoreline based on several reservoirs in the USSR was developed by Kondratjev (1966). The terminal form proposed by Kondratjev consists of an eroded backshore platform with a stable foreshore depositional shoal that dissipates incoming erosional wave energy. Although adequate surveys have not been made in older Canadian reservoirs, the shorelines in unfrozen erodable materials appear to agree with the Kondratjev model (Newbury *et al* 1973).

A comprehensive treatment of shoreline erosion in reservoirs of the Volga, Don, and Dnieper river valleys in the western USSR was presented by Kachugin (1966). Wave energies and shoreline morphology were correlated to produce a "wash out coefficient" for various shoreline materials (cu. m eroded per ton-metre of wave energy). The rate of erosion was established as decaying exponentially with time. The erosion rates presented in this paper are compared with those proposed by Kachugin.

Little or no research has been done on large northern impoundments in the sub-arctic climatic zone that is subject to widespread discontinuous permafrost conditions. Where permafrost is present in flooded shoreline materials, the processes of shoreline formation appear to be a combination of erosive and thermal phenomena. In the last two decades, six hydro-electric impoundments and one major river diversion have been constructed on

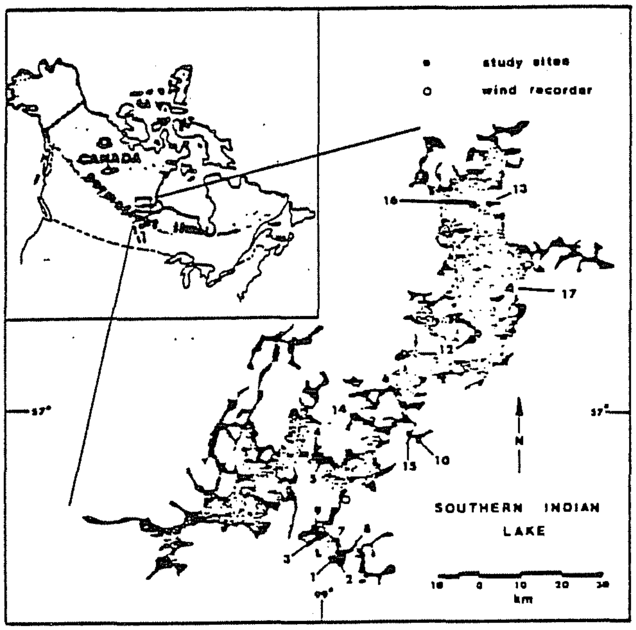

Figure 1: Southern Indian Lake in central Canada showing shoreline erosion monitoring sites selected prior to a 2 m impoundment in 1976.

the Churchill and Nelson Rivers in central Canada. The total impounded water area exceeds 5000 sq. km including 1500 sq. km of newly flooded terrestrial area, creating over 6000 km of new shoreline. The diversion of 850 cu. m per sec. from the Churchill River into the Nelson River is a major component of the project. The diversion was accomplished by raising the level of Southern Indian Lake, a major lake on the Churchill River system, thereby allowing the flow to cross the drainage divide to the Nelson River basin 300 km west of Hudson Bay. Southern Indian Lake (Lat. 57°N Long. 99°W, Figure 1) had a surface area of 1930 sq. km and fluctuated in elevation between 254.5 m and 256.0 m (msl) under natural conditions. In 1976, a control dam at the lake outlet was closed and the lake was raised 2 m to elevation 258.0 m (msl), flooding 600 sq. km of the adjacent shoreline. The shoreline affected was approximately 2900 km in length. The initial shoreline adjustments are reported in this paper.

SOUTHERN INDIAN LAKE BASIN

The Southern Indian Lake basin is located in the western arm of the Precambrian Shield. The geology of the area is dominated by massive intrusive granitic rocks in extensive areas of meta-sedimentary gneisses derived from greywackes and arkosic sequences (Frohlinger 1972). The bedrock surface has been heavily glaciated to a near uniform plain with a low relief (less than 50 m) of rounded hills and valleys. Surficial deposits of glacial, glaciofluvial, and glacio-lacustrine origin overlie the bedrock surface in thicknesses varying from 0 m to 5 m in high areas and up to 30 m in low infilled valleys. The upper surficial deposits of the southeastern two-thirds of the basin are dominated by fine-grained, varved silty clays varying from 0.5 m to 5 m in thickness deposited in an extensive glacial lake basin (Agassiz) of the late Pleistocene epoch (Klassen *et al* 1973).

The uplands surrounding the lake are generally forested with dominant boreal species (*Picea marianna, Populus tremuloides, Pinus banksiana*) interspersed with extensive muskeg areas. In near-shore zones, the forest complex is more diverse with the addition of deciduous species (*Populus balsamifera, Betula papyrifera, Alnus spp., Salix spp.*). A well developed organic layer overlying most deposits is composed of decaying feather mosses (*Pleurozium schreberi, Hylocomium splendens*), lichen (*Cladonia spp.*) and sphagnum moss (*Sphagnum spp.*). The organic layer generally exceeds 0.3 m in thickness and may exceed 4 m in low-lying areas (Beke *et al* 1973).

The lake region lies within the widespread discontinuous permafrost zone with a mean annual temperature of -4°C (Brown *et al* 1973). The ice free season for open water bodies is less than 6 months. Permafrost conditions generally occur within 1 m of the surface in all fine-grained shoreline materials (post-impoundment shorelines) where the organic cover is 0.3 m or greater. The average depth to permafrost at 14 sites widely distributed around the lake (mid-September 1975 and 1976) was 63 cm. In all fine grained materials regular ice banding a few mm in thickness occurred with occasional ice lenses up to 8 cm thick. The ice content of all frozen samples fell between 44 and 68 percent (percent of gross weight).

In 1972, a shoreline classification system developed for Precambrian lake basins was applied to Southern Indian Lake (Newbury *et al* 1973). Fifteen major shoreline categories based on morphology, surficial materials, and vegetation were mapped on the lake. In Table I, the categories have been regrouped into four general divisions depending on their susceptability to erosion. Over two-thirds of the flooded shoreline length consists of materials subject to solifluction on melting and subsequent erosion by water waves.

EROSION STUDIES

Seventeen locations were selected on Southern Indian Lake in 1975 for erosion monitoring during and following impoundment (Figure 1). The sites were selected from the three major divisions of shoreline types (Table I) in a variety of exposures to wind generated waves. Offshore mean fetch lengths ranged from 0.2 km to 12.8 km. The sites were surveyed in September 1975 and September 1976 on several cross-sectional lines running perpendicular to the shoreline and extending 50 m inland. Acoustic and line soundings were taken at each site as well to a distance of 500 m offshore. The volume of eroded material at each site (cu. m per m) was obtained from the change in the surveyed cross-sections at each site (averaged). A typical cross-section at Site 11 is shown in Figure 2.

Wind generated waves for each hourly wind during the open water period between successive surveys were developed using the forecasting technique of Sverdrup-Munk as revised by Bretschnieder (U.S.C.E. 1966). Hourly wind velocities and directions were recorded at two locations adjacent to the lake (Figure 1) and corrected for onshore and offshore directions (Richards *et al* 1970). The erosive component of wave energy perpendicular to the shoreline was combined with the

TABLE I Southern Indian Lake Shoreline Characteristics

	Shoreline Type	Site Number and Map Location (Figure 1)	Depth to Permafrost (September)	Total Length
I	Exposed Bedrock (granitic intrusive rocks, meta-sedimentary gneisses, etc.).	-	-	660 km
II	Varved Clays Overlying Bedrock (0-0.6 m forest peat, 2-5 m clays)	1 through 6	0.6 - 1.0 m	350 km
III	Boulder-Clay Till Overlying Bedrock (0-1.3 m forest peat, 2-5 m clay till)	7 through 13	0.5 - 1.2 m	1790 km
IV	Granular Glacio-Fluvial Deposits (0-0.1 m organic, up to 5 m sand and sandy silt)	14 through 17	generally absent near shore	120 km
			TOTAL SHORELINE LENGTH	2920 km

duration of winds causing onshore wave action to obtain the total erosive wave energy exerted on each site between successive surveys (ton-metres per m).

During the survey, samples of overburden materials were obtained at each site for grain size analysis. In addition, offshore water samples were obtained to determine suspended sediment concentrations.

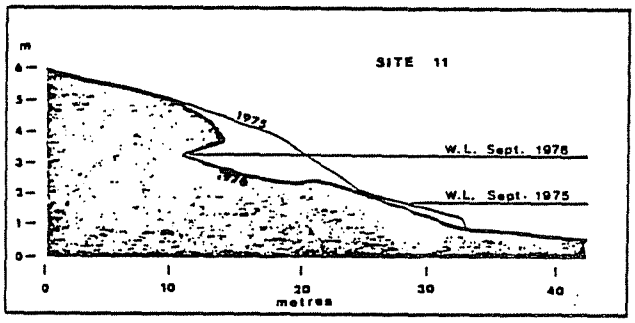

Figure 2: Erosion niche formed in permafrost affected bank materials at Site 11 as impoundment occurred between September 1975 and September 1976 water levels (W.L.)

DISCUSSION AND RESULTS

Shoreline erosion during the initial impoundment was highly variable at each survey site but generally correlated with the total erosive wave energy exerted on the shoreline (Figure 3). In permafrost locations, erosion takes place in a combination of thermal and mechanical processes that cause a deeply incised niche to form at and immediately below the water's edge (Figures 2 and 4). As the melting and eroding niche proceeds into the bank, the overlying mass of material increases until a large cuspate slump occurs, exposing new materials to the lake water. With further melting and erosion, the forested surface of the former backshore settles to form a semi-protective matte of debris in front of the shoreline that is slowly saturated with water and sinks below the surface or is carried away into the main body of the lake (Figure 5).

Shorelines forming in fine-grained overburden (generally 55 - 70% clay, 30 - 45% silt) contributed large amounts of suspended sediment to the main body of the lake. Offshore suspended sediment samples often contained 75% of the finer grain sizes being eroded at the shoreline. Long plumes of sediment were observed moving from the eroding shoreline into the main lake body (Figure 6). The formation of offshore depositional shoals was observed only at shoreline sites composed of granular deposits.

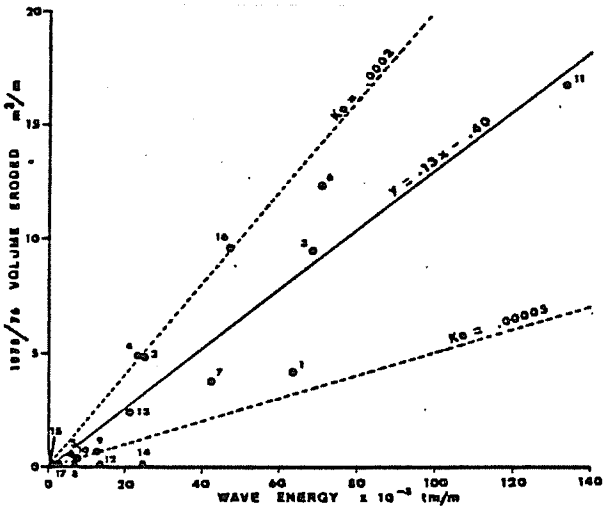

Figure 3: Shoreline erosion and wave energy relationship for surveyed sites on Southern Indian Lake. The mean washout coefficient, ke, is .00013 cu. m/ton-m of wave energy per metre of shoreline. The coefficient for 14 of the 17 sites falls in the range .00005 to .0002 (after Kachugin 1966).

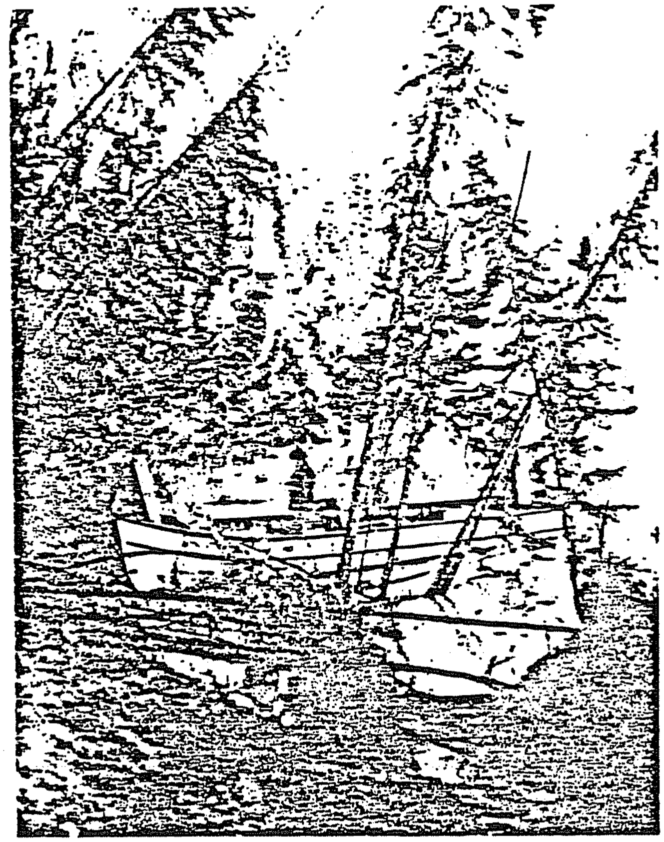

Figure 5: Slumping of undercut clay bank at Site 2 with fallen trees along the foreshore.

Figure 4: Niche developed in permafrost affected shoreline materials through melting and wave erosion at Site 11.

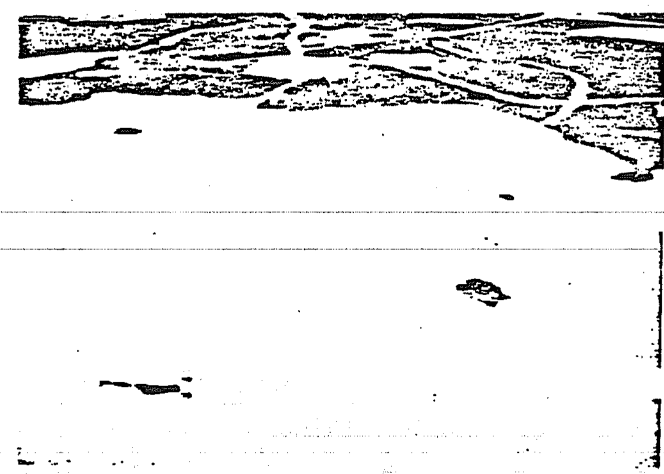

Figure 6: Eroded materials from fine-grained permafrost affected shorelines transported into the main body of the lake in sediment plumes extending from islands and the mainland.

In the relationship plotted in graphical form in Figure 3, a gross linear correlation exists between the volume eroded at each site and the wave energy exerted on the shoreline between successive surveys (coefficient of determination, $R^2 = 0.85$). Sites consisting of thick deposits of varved clays demonstrate high erosion rates and generally lie above the mean correlation line (Sites 2, 4, and 6). Sites at which a combination of bouldery clay till and exposed bedrock exist demonstrate moderate erosion rates and lie near the mean correlation line (Sites 3, 11, and 13). Sites in granular materials or where more dominant bedrock features are exposed lie below the mean correlation line indicating a relatively high resistance to erosion. Two notable exceptions occur; at Site 16 where a backshore sand berm was removed by wave action before a regular beach form was developed, and at Site 1 where a barrier of fallen forest debris existed prior to the impoundment due to frequently occurring bank failures. The lack of erosion at low wave energy sites implies that a threshold value of wave force may be required to destroy the protective forest cover and organic matte that protects the newly flooded foreshore.

On the basis of several years of observations in the western USSR, Kachugin (1966) suggested that an erodability index for reservoir bank materials could be formulated as a washout coefficient, "ke", expressing the volume of a particular bank material eroded per ton-metre of wave energy exerted on the shoreline. Values of "ke" range from .0065 for easily eroded fine sands and loams to .0005 or less for resistant bank materials defined as "clayey sandstones, fractured gaize sand with pebbles and boulders, clays, and dense marls".

On Southern Indian Lake where significant erosion occurred during the initial year of impoundment, the values of the washout coefficient generally ranged between .00005 and .0002 (Figure 3). This range of values lies well below Kachugin's proposed boundary for significantly erodable materials in the highly resistant bank materials category.

Several factors would contribute to producing low values for the erosion index, some of which may become more apparent as the impoundment continues: (1) in the first year of impoundment, new shoreline was exposed to erosion gradually as the lake level rose 2 m to its maximum stage. Thus the wave and thermal energies were distributed over a wide vertical range. This will not occur in subsequent years as the reservoir will be maintained at the impounded level, concentrating the erosional energy in a narrower range; (2) undercutting and slumping was widespread in fine-grained frozen shoreline materials causing large volumes of forest debris and organic materials to form a protective cover on the new foreshore; and (3) in the frozen state, the shoreline materials are consolidated and highly resistant to erosion. At high wave energy sites, where the active layer is removed and the bank retreat is greater than 2 m, it was observed that a frozen section of shoreline was constantly exposed, implying that the erosion rate may be limited by the rate of thaw of the materials. In subsequent years, this factor can be investigated more fully by comparing high and low wave energy sites when the frozen materials have been exposed to the lake water for longer periods of time at the impounded water level.

CONCLUSION

Shoreline erosion in permafrost materials occurs through a combination of thermal and mechanical processes that causes a deep niche to form at and immediately below the water's edge. As the niche enlarges, slumping occurs and frozen materials are exposed directly to warm lake water and wave action. Fine-grained frozen shoreline materials exhibit the highest susceptability to erosion, ranging up to .0002 cu. m per ton-m of erosive wave energy. Bouldery till and bedrock shoreline materials exhibit a high resistance to erosion. On the basis of the initial year of impoundment on Southern Indian Lake, the erosion rates of permafrost materials are lower than those experienced in similar unfrozen materials in the USSR.

The limitation of erosion at high wave energy sites by the rate of thaw of permafrost materials will prolong the period of re-stabilization of shorelines in flooded lake basins. Similarly the contribution of fine-grained sediments in suspension to the main lake body will be prolonged, extending the period of biological impact beyond that which would be anticipated in more southern reservoirs. On Southern Indian Lake, further investigations of erosion and sedimentation will be conducted annually to determine the long-term effects of impoundments on permafrost affected shorelines.

ACKNOWLEDGEMENTS

The authors are indebted to Mrs. S. Ryland who assisted in preparing this manuscript and to Dr. A.L. Hamilton (Freshwater Institute) for encouraging and allowing this study to evolve from the pre-development phase to the post-construction phase. Predictions of physical impact made for major hydro-electric projects are seldom compared to actual events.

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ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S):
B. 19

R&M
R&M CONSULTANTS, INC. 5024 CORDOVA • BOX 6087 • ANCHORAGE ALASKA 9950_ • PH 907-561-17__

ENGINEERS
GEOLOGISTS
PLANNERS
SURVEYORS

November 9, 1983 R&M No. 352333

Envirosphere Company
1617 Cole Boulevard, Suite 250
Golden, CO 80401

Attention: Mr. Don Beaver

Re: Susitna Hydroelectric Project, Slough Groundwater Studies

Dear Don:

I recently reviewed your report, September 1983 Site Visit and FY 1984 Plan of Study. In this report you requested the following 1983 data:

- Water levels and temperatures from wells.
- Slough and mainstem stage and discharge measurements.
- Seepage meter and piezometer data.
- Slough temperature and water quality data.

1. Water levels and temperatures from wells.

   This data is not yet complete and will be forwarded when possible. We are awaiting reduction of Datapod chips.

2. Slough and mainstem stage and discharge measurements. Enclosed are:

   a. Water discharge records for the Susitna River at Gold Creek for water year 1982 and provisional 1983.

   b. Water discharge records for 1983 for Sloughs 8A, 9, and 11 (provisional).

3. Seepage meter and piezometer data. Enclosed are:

   a. Seepage meter program summary.

   b. Seepage meter field data collected this summer in Sloughs 8A, 9, 11, and 21.

   c. Plots of data in "b" above.

   d. Comments on seepage meter data.

4. Slough temperature and water quality data.

   a. Selected portions of ADF&G report "Winter Aquatic Studies (October 1983 - May 1983). Covered in this report are intragravel and surface water temperatures for Sloughs 8A, 9, 11 and 21 for the period August 1982 to May 1983, and results of an incubation study which measured various water quality parameters of upwelling groundwater.

   b. A short review of ADF&G Preliminary Intergravel Temperature data for Sloughs 8A, 9, 11 and 21 covering the period June 1983 to August 1983.

Data that needed for groundwater analysis, but not yet reduced includes:

- Precipitation for 1983 at Sherman.
- Specific mainstem water surface elevations at various discharges in the areas of Sloughs 8A, 9, 11, and 21 (ADF&G data).
- Results of further ADF&G incubation studies.
- Water levels and temperatures from wells.

The above will be forwarded as available. Please call if you have questions or desire additional data.

Very truly yours,

R&M CONSULTANTS, INC.

Robert Butera
Staff Civil Engineer

RB/kys

cc: Dr. John Bizer
Mr. Wayne Dyok

RJB 5/17/83

Slough Seepage meter Program

Objective: To define the relationship between mainstem water surface elevation and upwelling rates in selected side-sloughs between Talkeetna and Devil Canyon.

Methods: Seepage meters to be set permanently into substrate in areas of sloughs which are main sources of water to the slough throughout the year. Measurement of seepage rates to be made at various mainstem water surface elevations.

The data to be obtained include:

- Date and time of sampling.
- mainstem Flow in Susitna River at Gold Creek,
- Water surface elevation in slough at seepage meter.
- water surface elevation in mainstem nearby to seepage meter.
- Temperature of upwelling water.
- seepage rate in ml./minute
- piezometric head in selected locations.

Locations: Determined from ADF+G mapping of observed upwelling locations and from slough surveys. As shown on attached maps

Report: Comparison of Q Susitna River at Gold Creek vs seepage rate.

Seepage meter 8-1

	Date	Mean Daily Qcc	Average Vol/min (ml.)	w.s.e. of slough (ft. msl.)	Temp °C	Piezometer Head (ft.)	comments
	5/20/83						Installed
1	5/22	19,000	169	573.64	3.1		
2	6/10	21,600	121	573.60	3.7		
3	7/14	19,800	28	573.57	5.5		
4	8/10	31,900	158	573.66	4.3		
5	8/11	27,700	152	573.64	–	0.14	piez. installed. Screen is 1' below substrate
6	8/24	24,700	–	–	–	0.09	
7	9/21	11,000	(1 sample) 12	573.57	–	–	sampled by W. Dioche
8	9/23	17,500	20	573.64	–	0.02	
9	10/11	9,300	18	573.65	–	0.02	
10	10/27	5,300	-7	573.33	3.1	-0.14	channel is now effluent

Comments:

- Seepage meter was located in gravel bed in area of a few small visible upwellings.
- Staff gage 0 elevation = 572.69' msl.

SEEPAGE METER 8-2

Date	Mean Daily Q Gold Creek	Average Vol/min (ml.)	wse of slough (Ft. msl.)	Temp (°C)	Piezometer Head (Ft.)	Comments
5/20/83						installed
5/22	19,000	122	574.76	3.4		
6/10	21,000	102	574.69	5.0		
7/14	19,800	60	574.37	7.0		
8/10	31,900	104	574.82	4.5		
9/21	11,000	–	–	–		channel dewatered
9/23	17,500	71	574.45	–		
10/11	9300	45	574.31	2.0		water held in pool by snow and ice control downstream
10/27	5300	–	–	–		channel dewatered

Comments:

- Seepage meter located 300' downstream of berm. 1-4" cobbles in channel.
- staff gage 0 elevation = 573.81' msl.

Seepage meter 9-1

location : Slough 9 at downstream end near area of large bank seepage and upwelling about 100' downstream of streamgage on RB.
staff gage 0 elevation =

Date	Q_{ac}	Average Volume/min (ml.)	wse of slough (Ft. msl.)	temp (°C)	piezometer head (Ft.)	Comments
5/20/83						Installed
5/21/83	20,000	169	592.70	—		
5/24/83	17,000	169	592.60	3.4		
6/8/83	22,000	75	593.00	3.0		Cover overtopped meter silted over
7/13/83	19,100	255	592.65	3.4	0.15	
10/11/83	9300	138	592.79	3.5	0.09	
10/27/83	5300	107	592.65	3.5	0.11	Good flow of water from banks

Comments :
- Seepage meter located at downstream end of slough 9 on right bank in area of large bank seepage.
- Staff gage 0 elevation = 591.15

SEEPAGE METER 9-2

location: Slough 9 in marshy area which feeds tributary at corner near RR tracks. Most downstream meter of two

Date	Mean Daily Discharge @ Gold Creek	Average Vol/min (ml.)	Staff gage	temp (°C)	Piezometer head (Ft.)	Comments
5/20/83						Installed
5/24/83	17,000	44	0.69	4.1	–	Q in stream = 11.9 cfs
6/10/83	21,000	25	0.70	4.0	–	Q in stream = 1.8 cfs
7/13/83	19,100	38	0.82	5.0	0.77	Q in stream = 1.1 cfs
8/10/83	31,900	66	1.11	5.5	1.17	Q in stream = 5c=1.5
9/23/83	17,500	51	0.95	7.0	0.88	recent rains
10/11/83	9300	85	0.98	6.4	0.28	recent 21" snow creek high
10/27/83	5300	36	0.87	4.8	0.73	Q in stream = 0.9 cfs

Comments:

Staff gage '0' elevation = (not surveyed to date)

Seepage meter 9-3

Location: Slough 9 in marshy area which feeds tributary at rear of slough 9 near RR tracks. Upstream meter of two. Set 6" into silt on upwelling.

Date	Q_{cc}	Average Volume (ml)	Staff gage	temp. (oC)	midi Piez.	Comments
5/10/83						Installed
5/24/83	17,000	180	0.69	4.1	> 0.4.	Q in stream = 1.9 cfs
6/10/83	21,000	110	0.70	4.0		Q in stream = 1.8 cfs.
7/13/83	19,100	53	0.82	5.0	0.72	Q in stream = 1.1 cfs

although flow in this stream is down the flow from marshy area has continued unabated. Rise in stage is due to retardation of flow by dense growth of grass.

Date	Q_{cc}	Average Volume (ml)	Staff gage	temp. (oC)	midi Piez.	Comments
8/10/83	31,900	149	1.11	5.5	1.15	Q in stream at SG = 1.5
9/23/83	17,500	84	0.95	7.0	0.90	recent rains
10/11/83	9300	71	0.98	6.4	0.93	recently snow creek high from rainfall
10/27/83	5300	90	0.87	4.8	0.81	Q in stream = 0.9 cfs.

Comments:

staff gage "0" elevation - (not surveyed to date)

Seepage Meter 11-1

location: Slough 11 at streamgage site. No visible upwelling at time of installation

Date	Qgc	Average Volume/ml (ml)	Staff gage	Temp (°C)	min Pct	Comments
8/12/83	27,500	138	671.16	5.5	0.04	Installed
9/21/83	11,000	–	671.07	–	0.065	No other measurements
9/22/83	13,600	77	671.08	–	0.015	Don Beaver
10/7/83	8300	70	671.08	3.0	0.04 (?)	... measured
10/11/83	9300	63	671.08	2.9	0.08	
10/27/83	5300	59	671.66	7.4	0.09	

Comments:

Staff gage '0' elevation = 670.18

Seepage meter 11-2.

location: 100' upstream of streamgage 20' downstream of ADF&G. thermograph in left bank in area of visible upwelling

Date	Qcr	Average Vol./min (ml.)	Staff gage	Temp. (°C)	Comments
8/12/83	24,500	60	1.11	5.2	Installed
9/22/83	13,600	41	1.04	–	w/Don Vance
10/7/83	8300	41	1.04	3.6	Wayne Dowds (1 inch ice cover)
10/11/83	9300	45	1.05	2.4	
10/27/83	5300	40	1.01	2.4	4" ice cover on pool

Comments:

Staff gage '0' elevation = (not surveyed to date)

SEEPAGE METER 21-1

Location: Slough 21, 200' downstream of staff gage 142.056B on right bank at staff gage 142.057C

staff gage zero elevation = 744.29

Date	Q (cfs)	Avg. Value (Volume/min flow)	Slough WSE (msl)	Mainstem Susitna WSE	Δhead	Temp	Comments
6-9-83	21,000	95	744.84	748.07	3.23	4.0	Installed today
7-12-83	19,700	132	744.79	748.18	3.39	4.5	
8-10-83	31,900	104	746.29	749.44	3.15	6.5	slough overtopped
8-12-83	24,500	147	744.91	748.60	3.69	4.1	
8-25-83	27,400	117	745.35	748.89	3.54	—	
9/7/83	15,200	166	744.79	747.25	2.46	3.5	recent rains
10/7/83	8300	158	744.79	746.66 (calculated)	1.87	3.8	measured by W.D.
10/11/83	9200	1[illegible]9	744.78	746.86 (calculated)	2.08	3.8	
[1]0/27/83	5300	172	744.79	746.11	1.32	3.5	lot of upwelling

Seepage meter 21-2

	Date	Mean Daily Q Gold Creek (CFs)	Average Vol/min (ml.)	Temp (°C)	Piezometer head (Ft)	WSE Slough (msl)	WSE mainstem (msl)	ΔH Ft	Comments
1	5/22/83	19,000	168	3.7	–	744.94	747.61	2.67	Installed
2	6/9/83	21,000	258	4.0	0.29	745.03	748.07	3.04	
3	7/12/83	19,700	390	4.5	0.31	745.03	748.18	3.15	
4	8/10/83	31,900	289	5.2	0.24	746.35	749.44	1.65	slough overtopped
5	8/12/83	24,500	435	4.0	0.39	745.12	748.60	3.48	
6	8/25/83	27,400	382	–	0.39	745.36	748.89	3.53	Slough not overtopped
7	9/24/83	15,200	310	3.3	0.35	745.04	747.25	2.21	
8	10/7/83	8300	327	3.6	0.19(?)	745.01	(calculated) 746.66	1.65	measured by Wayne Dieck
9	10/11/83	9300	356	3.6	0.35	745.03	(calculated) 746.86	1.83	
10	10/27/83	5300	337	3.5	0.38	745.03	746.11	1.08	lots of upwelling all over slough

Comments :

Location : In slough 21 nr. staff gage 142.056B along left bank

staff gage zero elevation = 744.15 Ft msl.

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): B. 34, I. 60

LAKE COMANCHE
DISSOLVED NITROGEN STUDY

Prepared for

Milo Bell
P.O. Box 23
Mukilteo, Washington 98275

Prepared by

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2150 John Glenn Drive
Concord, California 94520

June 1982

Nitrogen gas in the deep water of a reservoir may be slightly super-saturated due to the hydro-static pressure of the overlying water (Wetzel, 1975). Therefore water flowing from a dam with a deep intake may contain a super-saturated concentration of nitrogen. If this excess nitrogen gas is not rapidly released into the atmosphere, it may cause nitrogen gas bubble disease in fish residing below the dam outfall (Conroy and Herman, 1970).

A study was conducted at Lake Comanche Dam, Mokelumne River, California, to determine the efficiency of the Howell-Bunger Valve in removing super-saturated dissolved nitrogen (N_2) from the dam's tailwater.

The valves spray outfall water into concrete conduits before releasing the water to the stream. This was observed and photographed at Lake Comanche Dam on 28 May, 1982 ~~1981~~, at a flow of 4000 cfs into the Mokelumne River (see accompanying photos). This creates a turbulent and aerated flow with the purpose of facilitating nitrogen gas release to the atmosphere.

By sampling nitrogen gas in the reservoir near the intake, and at several locations below the outfall valves, the efficiency of the valve was obtained.

METHODS

In order to determine nitrogen gas concentrations at various depths in the reservoir, water samples were collected in Lake Comanche approximately 50 m from the dam directly over the river channel on 28 May 1982. A Van Dorn Bottle was lowered from a boat to collect water samples at depths of 0, 10, 20, 30, and 38.4 m. As reported by East Bay Municipal Utility District the dam intake was at a depth of 38.4 m (126 ft) at the time of the sampling.

Once taken aboard, each sample was poured with minimum turbulence into an airtight bottle and capped in a manner that left no air bubbles in the bottle. Bottles were placed in a cooler for transportation to the lab. Studies conducted by Steve Wilhelms of the Hydraulic Laboratory, U.S. Army Waterway Experiment Station, Vicksburg, Mississippi (personal communication) indicate that brief exposure of deep water samples to atmospheric conditions has little effect on nitrogen gas concentrations. However, he has found that periods of exposure to atmospheric air bubbles during transportation can cause significant changes in nitrogen gas concentrations, hence the need for removing all air bubbles before transportation. Excess water remaining in the Van Dorn Bottles was measured for temperature. The atmospheric pressure measured on site at the time of sampling was 753 mm.

At the tailwater below the dam, water was collected by immersing the sample bottles under the water and capping them in a manner that left no air bubbles in the bottles. Samples were taken at the outfall, 100 m below the outfall, and 200 m below the outfall. Water temperatures were taken at each of these locations. Bottles were placed in a cooler for transportation to the lab. At the time of sampling, the outfall flow was 4,000 cfs. The atmospheric pressure was 753 mm.

The water collected was analyzed for nitrogen gas (N_2) and oxygen (O_2) in a California State Certified Water lab using a Carle Model 8700 Basic Gas Chromatogram with a thermal conductivity conductor several hours after collection.

RESULTS

Location	Depth (m)	Temperature (°C)	N_2 (mg/l)	N_2 % Saturation	O_2 (mg/l)	O_2 % Saturat
Reservoir	0	22.0	14.9	101	9.2	105
	10	14.5	17.0	100	9.3	90
	20	13.2	17.3	99	10.0	94
	30	11.0	17.9	99	10.2	93
	38.4	10.0	18.5	101	9.3	82
Dam Tailwater						
At Valve	0	10.2	17.7	97	11.1	94
100 m downstream	0	10.5	17.3	95	11.2	98
200 m downstream	0	11.5	17.9	97	10.9	98

References

Conroy, D.A., and R. L. Herman. Textbook of Fish Diseases. 1970. T.F.H. Publications, Jersey City, New Jersey. 302 pp.

Wetzel, R. G. 1975. Limnology. W.B. Saunders Company, Philadelphia. 743 pp.

APPENDIX B

SPILLS AT WATANA AND DEVIL CANYON DEVELOPMENTS

B.1 - OPERATION OF WATANA AND DEVIL CANYON COMBINED (Beyond Year 2002)

(a) Spill Quantities and Frequency

The monthly reservoir simulation studies calculate spill volumes as the flow required to be discharged from the dam to satisfy downstream requirements less the maximum turbine capacity, and does not restrict the turbine flow in relation to the actual energy demand of the system. Total energy production, as calculated, is the energy potential of the schemes. Usable energy is then calculated as the potential or the maximum energy demand, whichever is smaller. The turbine flows are not readjusted to the level of usable energy production. Tables B.1 to B.9 present selected results of the reservoir simulation studies which indicate this.

Tables B.10 to B.12 are developed from the reservoir simulation studies for adjusted turbine flows for two alternative generation patterns at Watana and Devil Canyon for the months of August and September when spills are most likely to occur. Alternative A assumes that whenever the potential energy generation from Watana and Devil Canyon developments is greater than the usable energy level, each development will share the usable energy generation in proportion to their average heads. However, in the months when Watana outflow, as simulated, is not sufficient to generate energy in proportion to its average head, Devil Canyon will make up this difference. This operation is required in such years when Devil Canyon is being drawn down to meet the minimum downstream flow requirements (years 1, 2, for example). Alternative B assumes that Devil Canyon would generate all the energy possible consistent with downstream flow requirements, and Watana would only operate to make up the difference in years when energy potential is greater than usable. This assumes that all the energy from Devil Canyon is useable as base load on a daily basis. Battelle load forecast (1981) tends to confirm this assumption for the year 2010. However, during earlier years, such operation may not be fully possible.

It may be readily seen from Tables B.10 to B.12 that frequency of continuous spills (24 hours) from the reservoirs in the months of August and September is significantly greater than presented by the reservoir simulation (Tables B.3 and B.6).

The analyses summarized in Tables B.10 to B.12 indicate that Devil Canyon would spill in 30 out of 32 years in August and 16 out of 32 years in September for the Case "C" operation which maintains a minimum instantaneous flow of 12,000 cfs in August at Gold Creek. For downstream discharge requirements greater than 12,000 cfs at Gold Creek, it is estimated that the frequency of spills may not be increased significantly. However, the volume of spills will be larger to make up for increased flow requirement. The above spill frequency is simulated for a system energy demand in the year 2010 (Battelle Forecast) and assumes that the entire demand is met by Watana and Devil Canyon developments where possible. The spills will be greater and more frequent in the years between 2002 (Devil Canyon commissioning) and 2010.

It may be seen that operation Alternative 2, which provides for maximum possible energy generation from Devil Canyon while Watana is allowed to spill, results in significantly reduced spill frequency from Devil Canyon. This type of operation is expected to be advantageous with regard to downstream water quality (see Section B.2).

Several intermediate distributions of generation between Watana and Devil Canyon is also possible. A recommended operation will be derived after finalizing the downstream flow requirements and the refined temperature modeling studies which are currently in progress.

(b) Spill Quality

(i) Spill Temperature

Figures B.1 and B.2 are extracts from the project Feasibility Report (7) and present simulated temperature profiles in the Watana and Devil Canyon reservoirs for the months June to September. Refinement of reservoir temperature modeling is currently in progress, but the differences between the revised profiles are not expected to be very significant from the ones presented here for these months.

Temperature of spill waters at Watana is expected to be close to that of power flow, and hence, it is not expected to create temperature problems downstream when Watana is operating alone (1993-2002) or when it spills into Devil Canyon. At Devil Canyon, however, spill temperature is expected to be close to 39°F compared to a power flow temperature of 48-49°F in August and 45°F in September. This is based on the conservative assumption that the temperature of spill water does not increase significantly while in contact with the atmosphere despite the highly diffused valve discharge. It is, therefore, considered prudent to keep the spill from Devil Canyon to a minimum to maintain as high a downstream temperature as possible during spills.

The operation Alternative 2 indicates that by operating Devil Canyon to generate as much as possible during these months and with Watana generating essentially to meet peak demands and spilling continuously when necessary, it would be possible to maintain downstream flow temperatures below Devil Canyon close to that of power flow.

During major floods (1:10 year or rarer frequency), there will be significant spills from Devil Canyon (see Tables B.10 and B.11) in addition to the power flow resulting in cold slugs of water downstream for a few to several days. It will be necessary to establish criteria for acceptability of lower temperatures for short durations in August and September in consultation with fisheries study groups and concerned Agencies. Currently, downstream water temperature analyses are being refined, and when the results are available, the above spill temperatures and duration should be reviewed to confirm downstream temperatures during normal power operation as well as flood events. If the projected temperature regime downstream is unacceptable, alternative means to remedy the situation should be considered. These may include provision of higher level intakes to several or all fixed-cone value discharges at Devil Canyon, multilevel power intake at Devil Canyon, limited operation of main overflow spillway (for floods 1:50 year or more frequent) to improve downstream water temperature without serious increase in nitrogen supersaturation, etc.

(ii) Gas Supersaturation

It does not appear (from Table 6.1) that there would be significant advantage in spilling from Watana as compared to spills from Devil Canyon in terms of gas concentration.

B.2 - OPERATION OF WATANA ALONE (1993-2002)

Before Devil Canyon is commissioned, Watana would operate alone, and spills required to maintain downstream flows will have to be made through the fixed-cone valves. Reservoir simulations indicate that, generally, spills would be of lower magnitude during this operation due to greater percentage of flow being used to generate usable energy.

It is believed that the river reach of some 30 miles between Watana dam and Devil Canyon would lessen the impact of spill temperature and gas concentration below Devil Canyon and would pose less problems, if any, compared to the case when Devil Canyon development is also commissioned.

Table B.1 [illegible]

RESERVOIR 1

INFLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4719.9	2083.6	1168.9	815.1	611.7	589.1	680.1	8655.9	16432.1	15193.4	[illegible]	1320.4
2	3299.1	1107.3	906.2	808.0	673.0	619.8	1302.2	11649.8	16917.9	19756.6	16478.0	17265.5
3	4592.9	2170.1	1501.0	1274.5	841.0	735.0	803.9	4216.5	25773.4	22110.9	17356.3	11571.0
4	6285.7	2756.8	1281.2	818.9	611.7	670.7	1382.0	15037.2	21469.8	17355.3	16681.6	11513.5
5	4218.9	1599.6	1183.6	1087.6	803.1	638.2	942.6	11696.8	19476.7	16983.6	20420.6	9165.5
6	3859.2	2051.1	1549.5	1386.3	1050.5	866.1	940.8	6718.1	24851.4	23787.9	23537.0	[illegible]
7	4102.3	1588.1	1038.6	816.9	754.6	694.4	716.3	12953.3	27171.8	25831.3	19153.4	13194.4
8	4208.0	2276.6	1707.0	1373.0	1189.0	935.0	945.1	10176.2	25275.0	19948.9	17317.7	14841.1
9	6034.9	2935.9	2258.5	1480.6	1041.7	974.5	1263.4	9957.8	22097.6	19752.7	18844.4	5978.2
10	3668.0	1729.5	1115.1	1081.0	949.0	694.0	865.7	10140.6	18329.6	20453.1	23940.4	12466.9
11	5165.5	2213.5	1672.3	1400.4	1138.9	961.1	1069.9	13044.3	13233.4	19566.1	19334.1	16065.6
12	6049.3	2327.8	1973.2	1779.9	1304.6	1331.0	1965.0	13637.9	22764.1	19639.6	19480.2	10146.2
13	4637.6	2263.4	1760.4	1608.9	1257.4	1176.8	1457.4	11343.5	36017.1	23443.7	19887.1	[illegible]
14	5550.1	2508.9	1706.9	1308.9	1164.7	883.6	776.6	15299.2	20663.4	26767.4	21011.4	10600.0
15	5187.1	1789.1	1194.7	852.0	781.6	575.2	609.2	3578.8	42841.9	20082.6	[illegible]	[illegible]
16	4759.4	2368.2	1070.3	863.0	772.7	807.3	1732.4	10966.0	31213.0	23235.9	17393.1	12225.6
17	5221.2	1565.3	1203.6	1060.4	984.7	984.7	1338.4	7094.1	25935.6	16153.5	17350.9	9214.1
18	3269.6	1202.2	1121.6	1102.2	1031.3	689.5	849.7	12515.5	24711.9	21987.3	[illegible]	[illegible]
19	4019.0	1934.3	1704.2	1617.6	1560.4	1560.4	1576.7	12898.7	25704.0	22082.6	14147.5	7166.6
20	3135.0	1354.9	753.9	619.2	607.5	686.0	1261.6	9313.7	13962.1	14643.5	7771.9	[illegible]
21	2403.1	1026.9	709.3	636.2	602.1	624.1	986.4	9536.4	14399.0	16410.1	16263.8	7224.1
22	3768.0	2496.4	1687.4	1097.1	777.4	717.1	813.7	7857.2	27612.8	21136.4	27446.6	12188.9
23	4979.1	2587.0	1957.4	1670.9	1491.4	1566.0	1305.4	15973.1	27429.3	19820.3	17509.5	10955.7
24	4301.2	1977.9	1246.5	1031.5	1000.2	873.9	914.1	7267.0	26859.3	16351.1	18016.7	8099.7
25	3056.5	1354.7	931.6	785.4	689.9	627.3	871.9	13889.0	14780.6	15971.9	13521.7	9766.2
26	3088.8	1474.4	1276.7	1215.8	1110.3	1041.4	1211.2	11672.2	26689.2	23430.4	15126.6	13075.3
27	5679.1	1601.1	876.2	757.8	743.2	690.7	1059.8	8938.8	19994.0	17015.3	18393.5	5711.5
28	2973.5	1926.7	1687.5	1348.7	1202.9	1110.8	1203.4	8569.4	31352.8	19707.3	14807.3	10613.1
29	5793.9	2645.3	1979.7	1577.9	1267.7	1256.7	1408.4	11231.5	17277.2	18385.2	13412.1	7132.6
30	3773.9	1944.9	1312.6	1136.8	1055.4	1101.2	1317.9	12369.3	22904.8	24911.7	16670.7	9096.7
31	6150.0	3525.0	2032.0	1470.0	1233.0	1177.0	1404.0	10140.0	23400.0	26740.0	18000.0	11000.0
32	6458.0	3297.0	1385.0	1147.0	971.0	889.0	1103.0	10406.0	17323.0	27840.0	31435.0	12026.0
AVE	4513.1	2052.4	1404.8	1137.3	978.9	898.3	1112.6	10397.6	22922.4	20778.0	18431.4	10676.4

Table B.2 [illegible] Power Flows . Case 'C' Operation

POWERHOUSE FLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5276.3	8474.4	11285.3	8391.5	7254.9	[illegible]	[illegible]	6551.7	[illegible]	4548.5	[illegible]	4900.4
2	6234.5	7324.0	9102.0	8384.7	7326.2	6551.2	5554.2	7559.3				
[illegible]	6844.1	1630.2	6576.5	13051.6								
3	7568.3	9549.1	11617.4	8851.3	7494.2	6366.9	5457.6	6409.6	7389.9	5719.7	6135.3	10601.3
4	8881.8	10527.8	11397.6	8395.7	7264.9	6365.6	5846.8	9241.8	8943.6	4991.8	6326.2	8206.5
5	7194.3	8976.6	11300.2	8864.5	7456.3	6567.8	5404.4	7775.0	7265.2	4579.7	5917.9	7900.3
6	6834.6	9430.1	11665.9	8965.1	7703.7	6345.9	5648.4	6627.3	7933.7	6692.3	13289.8	13447.8
7	7077.7	8967.1	11155.0	8393.7	7408.0	6336.3	5422.2	8265.3	10712.1	8844.4	12744.0	13194.4
8	7183.4	9655.6	11823.4	8949.8	7842.2	6330.4	5719.3	7209.1	9352.7	6001.2	6328.7	14301.6
9	8805.9	10526.1	11738.1	9694.2	7694.9	6357.9	6051.0	7144.7	7949.2	5316.5	6441.1	5471.6
10	6643.4	9108.5	11231.5	8657.6	7602.2	6324.0	5417.5	7119.7	6419.6	4845.6	10300.0	12466.9
11	8140.9	9592.5	11788.7	8977.2	7792.1	6239.2	5861.9	8406.6	5632.4	4525.4	6138.6	12284.9
12	8931.7	9803.0	11622.3	9624.0	7958.0	6738.6	7139.7	6649.0	[illegible]	5659.0	7837.0	10146.2
13	7613.0	9642.4	11676.8	9185.7	7910.6	6343.1	6468.3	7719.1	[illegible]	9961.3	[illegible]	[illegible]
14	6535.5	9887.9	11825.3	8885.6	7637.9	6375.6	5475.6	9351.6	[illegible]	[illegible]	[illegible]	[illegible]
15	8162.5	9166.1	11311.1	8428.7	7434.8	6369.1	5452.9	5539.1	10761.9	9863.7	9051.8	7524.2
16	7734.6	9747.2	11166.7	8439.8	7425.9	6382.6	5820.5	7576.7	7810.9	6420.2	6734.3	16225.6
17	8196.6	8944.3	11320.0	8637.2	7637.9	6315.1	6179.7	6642.3	8515.5	4565.3	[illegible]	5613.0
18	6245.2	8581.2	11238.0	8679.0	7684.5	6316.6	5591.2	8196.3	9716.6	6866.1	16260.0	13672.9
19	6994.4	9313.3	11820.6	9194.4	8213.6	6568.2	6751.4	8306.3	10193.5	[illegible]	5880.7	6015.5
20	6110.4	8733.9	10870.3	8196.0	7260.7	6371.4	5736.1	6933.8	5600.2	4270.8	9821.8	5657.0
21	6385.6	7578.3	9136.9	8137.8	6651.3	6918.7	5961.7	4892.9	3631.4	5330.1	8263.8	4663.1
22	6198.0	7402.9	9021.9	8090.4	6616.0	6883.7	5897.4	5180.5	3262.7	6756.4	7536.6	4248.9
23	6163.2	7240.4	11277.0	9247.7	8144.6	6373.8	6480.1	9618.4	10679.2	7464.2	8595.5	10955.7
24	7276.6	9356.9	11362.9	8608.3	7653.4	6372.6	5581.6	7128.3	7541.5	4985.5	6715.3	5525.7
25	6196.2	7339.3	9516.4	8363.1	7343.1	6539.4	5595.7	8226.2	5565.6	3776.7	8332.6	4036.2
26	6243.9	7361.3	8813.6	7631.3	6351.8	6584.6	5620.6	8257.3	9538.8	7327.3	6402.3	12681.6
27	8654.5	8980.1	10992.6	8334.6	7396.4	6447.4	5564.0	6716.2	6784.5	4972.5	7569.4	5330.5
28	6157.1	7202.2	8673.1	8290.9	7856.1	6461.9	6023.4	6879.2	10725.5	7064.7	7247.5	10613.1
29	8769.3	10024.3	11855.3	9395.5	7920.9	6305.1	6541.2	7726.7	6311.4	4769.6	5470.6	5025.6
30	6096.7	7236.4	8767.4	7906.2	7708.6	6578.8	6007.2	8289.4	8874.4	7527.5	7678.1	9696.7
31	9099.8	10930.5	11921.9	9273.2	7886.2	6342.9	6415.4	7252.5	8524.9	8036.5	10151.7	11000.0
32	9082.6	11038.5	11501.4	8723.7	7624.2	6359.9	5799.2	7356.0	6092.8	7212.3	19491.0	12026.0
AVE	7346.5	8988.6	10944.3	8681.2	7543.7	6421.8	5872.6	7474.4	7895.0	6247.0	8846.7	9361.9

Table [illegible] [illegible] Monthly Spills

SPILLS (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2755.0	0.0
AVE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.1	0.0

Table E.1 [illegible] Monthly Energy Potential

ENERGY FROM RESERVOIR 1 (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	221.9	318.0	429.3	312.2	240.6	228.3	185.8	230.5	187.4	169.0	212.[illegible]	185.0	2921.2
2	243.1	273.5	345.4	312.0	241.6	235.0	189.9	281.0	239.2	180.8	253.6	475.4	3290.8
3	297.2	358.7	441.9	329.3	247.1	228.5	186.7	224.2	256.2	214.8	[illegible]	411.5	3434.3
4	348.9	395.6	433.5	312.4	239.6	228.4	300.0	327.4	314.9	187.7	344.5	311.9	3544.8
5	282.5	337.3	429.8	322.4	245.9	228.5	184.8	274.6	254.4	171.2	228.[illegible]	300.6	3260.9
6	268.4	354.2	443.7	333.6	254.0	227.8	193.3	232.8	276.4	252.2	517.5	411.8	3666.7
7	277.9	336.8	424.3	312.3	244.3	227.4	185.4	292.2	377.8	336.6	498.5	503.1	4016.7
8	282.1	362.7	449.7	333.0	256.6	227.3	195.7	254.3	328.2	226.4	245.9	545.0	3708.9
9	345.9	395.5	446.8	361.0	253.7	228.2	207.1	252.0	278.1	199.7	249.9	308.5	3426.4
10	260.9	342.1	427.2	322.1	250.7	226.9	183.3	251.2	224.0	181.3	399.5	475.4	3546.7
11	319.7	360.3	448.4	334.0	257.0	227.6	200.6	297.4	196.3	168.1	236.2	466.5	3511.9
12	350.8	368.3	449.8	358.2	262.4	227.7	244.5	306.0	321.7	220.7	304.7	386.9	3801.1
13	299.0	362.2	451.8	341.8	260.9	227.8	221.4	273.6	378.9	384.5	694.2	486.0	4381.9
14	335.2	371.4	419.8	330.6	258.5	228.8	187.3	331.3	304.9	336.0	571.8	411.8	4117.5
15	320.5	344.4	430.2	313.6	245.2	228.5	186.4	193.6	279.6	379.7	354.6	285.9	3663.2
16	303.7	366.1	425.5	314.0	214.9	229.1	199.1	267.4	273.4	241.8	262.1	618.7	3745.9
17	321.9	336.0	430.6	321.4	251.9	226.7	211.5	233.4	257.2	169.1	231.6	213.1	3244.3
18	245.2	322.3	427.5	322.9	253.4	226.7	191.3	289.7	341.9	259.8	633.5	521.4	4035.7
19	274.7	349.8	449.6	342.1	270.8	235.9	231.2	293.7	359.1	271.1	228.9	229.1	3536.1
20	240.0	328.1	413.5	304.9	239.4	226.6	196.2	244.4	200.9	157.1	365.7	203.2	3121.9
21	234.8	265.6	323.7	281.1	202.8	228.4	186.4	158.1	116.9	164.7	296.9	162.1	2641.5
22	225.6	258.1	319.1	279.7	202.2	228.0	185.0	165.6	105.1	240.0	260.9	159.7	2646.0
23	239.6	270.6	428.5	344.1	268.6	228.9	271.9	341.0	378.7	284.0	335.2	417.6	3758.9
24	285.7	351.5	432.2	320.3	252.4	228.7	191.0	250.4	262.6	186.3	258.0	208.8	3227.9
25	241.8	273.9	361.3	311.2	242.1	234.6	191.2	290.5	194.1	140.2	312.6	150.2	2943.7
26	240.8	271.9	331.2	288.8	208.1	235.2	191.4	290.2	344.4	277.3	249.5	483.4	3402.3
27	339.9	337.3	418.1	310.1	243.9	227.8	190.3	236.6	236.6	185.5	290.5	200.6	3217.2
28	238.6	267.5	328.2	308.2	259.1	232.0	206.1	242.2	377.3	269.0	282.5	404.7	3415.4
29	344.4	376.5	431.1	349.7	261.2	226.5	224.0	272.8	220.2	178.6	209.6	188.5	3302.9
30	236.2	269.0	331.8	293.9	254.2	236.1	205.5	292.9	311.6	284.6	307.3	346.9	3370.0
31	357.4	410.6	453.6	345.1	260.1	227.8	219.6	255.8	298.6	304.0	396.4	419.5	3948.4
32	356.8	414.8	437.5	324.6	251.4	228.3	198.4	259.5	212.4	271.1	756.0	458.6	4169.3
AVE	286.9	336.0	414.5	321.6	247.7	229.2	199.8	262.7	276.2	234.8	342.1	355.4	3507.0

Table B.5 Devil Canyon Power Flows - Case C Operation

POWERHOUSE FLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	6714.6	8795.5	11456.9	8526.1	7388.9	6461.1	7456.8	6562.3	7436.2	8363.4	10940.6	6149.8
2	6587.4	7447.9	8923.1	7913.3	6437.6	6528.5	5756.6	5581.7	8304.7	8585.9	10860.0	11307.8
3	8203.6	9918.0	11873.9	9060.5	7596.4	6460.1	7410.6	8845.9	8026.9	8470.5	10727.2	10293.7
4	10113.7	11010.3	11666.8	8576.4	7398.8	6461.6	7674.9	10138.6	12704.7	8564.0	10597.0	8149.3
5	6996.7	9300.3	11503.5	8800.9	7582.9	6459.0	7470.7	9540.0	10980.6	8374.1	9971.6	8219.9
6	7812.3	9885.8	11984.4	9225.9	7928.4	6483.4	7693.4	6475.1	11134.2	9117.2	13763.2	13763.2
7	7629.8	9167.6	11323.0	8498.5	7546.3	6494.2	7449.6	9466.8	13763.2	12225.1	13763.2	13763.2
8	8217.2	10152.8	12103.0	9160.0	8042.1	6500.8	7761.6	7682.3	12493.1	8379.6	10849.2	13763.2
9	10205.5	11187.3	12378.0	10012.1	7865.4	6470.1	8101.3	7211.8	10264.9	8463.1	10679.8	5938.8
10	6630.1	7603.1	11487.3	8891.7	7832.3	6507.9	7510.0	9055.7	9627.9	7970.4	13763.2	13763.2
11	9042.6	10001.7	12127.9	9263.0	7993.4	6490.9	7888.2	8343.2	7108.6	8339.3	10476.1	11848.1
12	10053.3	10241.8	12279.2	10062.6	8246.8	6646.7	9458.5	9217.5	13427.7	8879.8	11061.4	10623.9
13	8441.3	9923.1	12095.1	9372.6	8066.6	6486.6	8502.7	6732.5	13763.2	11506.2	13763.2	13763.2
14	9289.6	10075.0	12012.4	9072.7	8040.6	6450.4	7389.3	9925.7	12094.4	12483.3	13763.2	11777.2
15	8960.2	9464.4	11503.5	8554.7	7553.4	6457.7	7418.6	7670.5	12132.6	11706.9	11145.8	8265.1
16	8725.9	10024.1	11277.2	8502.1	7482.0	6442.4	7780.9	7053.5	10708.2	9380.0	10669.3	13763.2
17	9478.4	9286.8	11594.8	8855.5	7840.6	6517.8	8338.6	6457.9	13022.3	8256.2	10414.6	5594.3
18	6489.9	7809.7	11481.3	8934.7	7921.5	6516.2	7673.5	8252.0	12801.1	9962.0	13763.2	13763.2
19	7567.2	9582.5	12046.1	9428.0	8431.9	6786.5	8844.1	8637.8	13763.2	9944.9	10920.5	5909.9
20	6444.5	7253.0	10704.7	8263.4	7335.0	6455.0	7774.2	6225.8	6788.8	9714.3	11604.6	6202.5
21	6849.0	7703.1	9237.6	8258.5	6757.9	7016.4	6021.9	6078.1	6351.3	8062.2	10672.8	5802.5
22	7175.2	7988.3	9409.3	8312.1	6782.2	7033.4	6069.9	5751.2	6680.9	8571.6	10405.9	5596.0
23	6721.1	7565.7	9040.0	7932.2	6909.1	6667.6	8618.6	11597.8	13763.2	9360.4	11364.1	10206.1
24	7620.5	9513.8	11503.4	8716.6	7781.8	6453.7	7532.5	5913.4	10074.8	6901.8	11188.1	6152.0
25	6631.1	7437.5	6885.4	7868.1	6399.1	6601.6	5672.9	6786.2	7551.7	10230.6	11037.0	5620.1
26	6661.9	7506.3	9023.4	8024.3	6583.7	6815.1	5866.1	4914.7	13152.2	10084.9	10941.6	12038.9
27	9985.2	9232.0	11124.3	8473.6	7529.4	6481.9	7643.8	7258.4	9604.1	8892.6	11497.7	6082.3
28	6736.0	7667.2	9133.1	8054.9	6547.8	6712.1	5798.5	6296.2	13763.2	9117.9	11131.2	9519.0
29	9918.2	10589.8	12240.5	9692.0	8178.2	6529.0	8608.2	6364.3	7451.0	8639.0	10916.5	5973.4
30	6825.1	7615.8	9004.2	7977.8	6563.6	6642.3	5707.7	5464.0	9787.5	10078.6	10646.7	9828.7
31	9849.8	11367.2	12162.4	9458.7	8036.2	6486.9	8464.7	6665.3	11379.9	11298.5	12347.7	12342.0
32	9870.6	11447.3	11670.4	8863.7	7742.2	6467.9	7812.6	6801.7	8205.8	10608.3	13763.2	13493.0
AVE	8077.1	9180.8	11070.6	8769.1	7508.8	6565.2	7480.3	7467.7	10566.0	9454.2	11544.8	9668.6

Table ?.6 Devil Canyon Monthly Spills

SPILLS (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	949.2	226.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	914.2	0.0	2447.2	2732.6
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	970.7
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	963.2	1566.4
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1555.6	0.0	6253.7	1004.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2564.2	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2679.9
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6685.3	1965.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	188.4	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1416.5	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1216.2	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12217.9	0.0
AVE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	165.3	0.0	1002.2	354.5

Table K-[illegible] Devil Canyon [illegible] Energy Potential

ENERGY FROM RESERVOIR 2 (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	217.8	276.1	371.7	276.6	216.5	209.7	230.5	210.2	233.4	268.3	337.9	177.9	3026.5
2	196.0	214.4	266.1	237.7	176.7	203.9	170.5	175.9	260.7	274.7	336.9	344.3	2856.9
3	266.1	311.3	385.1	293.9	222.5	209.5	229.7	276.2	245.7	274.8	342.4	316.0	3375.2
4	328.1	345.6	378.4	278.2	216.8	209.6	244.1	324.8	398.6	274.5	331.1	247.7	3577.6
5	225.4	291.9	373.1	285.5	222.1	209.5	231.6	305.6	344.7	268.7	315.4	254.4	3327.8
6	253.4	310.3	388.7	299.2	232.3	210.3	236.5	207.4	349.5	295.7	445.4	432.0	3663.8
7	247.5	287.8	367.3	275.6	221.1	210.6	230.9	303.3	432.0	396.5	446.4	432.0	3851.1
8	266.5	318.7	392.6	297.1	235.6	210.6	240.6	246.1	392.2	271.5	344.9	423.9	3640.5
9	331.0	351.2	401.5	324.7	230.4	209.9	251.1	231.0	322.2	272.5	336.5	179.3	3441.4
10	206.8	235.9	372.6	288.5	229.5	211.1	233.4	290.1	302.2	256.2	445.8	432.0	3508.1
11	293.3	313.9	393.4	300.4	234.2	210.5	244.5	267.3	223.1	267.6	328.6	363.5	3440.4
12	326.1	321.5	398.3	326.4	241.6	215.6	293.2	295.3	421.5	288.0	355.2	330.0	3812.7
13	273.8	311.5	392.3	304.0	246.3	210.4	263.6	215.7	432.0	373.3	446.4	432.0	3891.3
14	301.3	316.2	389.6	294.3	235.6	209.2	229.0	318.0	379.6	404.9	446.4	369.7	3893.9
15	291.3	297.1	373.1	277.5	221.3	209.4	230.0	239.5	371.4	379.7	360.4	258.6	3509.3
16	283.0	314.6	365.8	275.8	219.2	209.0	241.2	225.9	336.1	304.3	342.5	427.6	3545.0
17	307.4	291.5	376.1	287.2	229.7	211.4	258.5	206.9	408.8	265.4	327.8	170.4	3341.1
18	207.3	243.6	372.4	289.8	232.1	211.3	237.9	264.3	401.8	323.1	446.4	432.0	3662.2
19	245.4	300.8	390.7	305.8	247.0	226.1	274.2	276.7	432.0	322.6	346.5	178.9	3540.7
20	203.6	224.4	346.7	268.0	214.9	209.4	241.0	199.4	213.1	304.6	348.3	176.6	2951.9
21	203.8	221.8	274.8	245.7	181.6	208.8	173.4	180.8	182.9	239.9	317.5	167.6	2598.7
22	213.5	230.0	280.0	247.3	182.3	209.3	174.8	171.1	192.4	255.0	309.6	164.0	2629.2
23	200.0	217.8	274.6	249.2	200.5	216.3	267.2	371.5	432.0	303.6	364.6	316.9	3414.2
24	247.2	299.2	373.1	282.7	228.0	209.3	233.5	189.4	316.3	283.3	341.0	177.1	3180.2
25	197.3	214.2	265.9	237.8	176.7	203.3	169.1	214.5	237.1	320.6	331.2	161.8	2729.6
26	198.2	216.1	268.5	238.7	176.9	202.8	168.9	152.8	412.9	327.1	348.4	370.9	3082.2
27	323.9	289.6	360.8	274.8	220.6	210.2	236.9	232.5	301.5	283.0	350.5	175.1	3259.7
28	200.4	220.8	271.7	240.7	179.6	206.1	173.0	199.6	432.0	295.8	355.2	294.0	3066.8
29	321.7	332.4	397.0	314.4	239.6	211.8	266.8	203.9	233.9	276.0	334.8	172.0	3304.3
30	203.1	219.3	267.9	237.5	176.8	201.9	168.4	171.9	306.8	326.9	344.7	307.9	2933.1
31	319.5	356.8	394.5	306.8	235.4	210.4	262.4	213.5	357.2	366.5	400.5	387.4	3811.0
32	320.2	359.3	378.5	287.5	226.8	209.8	242.2	217.9	257.6	344.1	446.4	423.6	3713.8
AVE	256.9	283.0	353.2	279.7	216.9	209.7	229.7	237.5	330.1	303.5	364.9	296.9	3361.9

Table B.2 Total Monthly Energy Potential
Watana + Devil Canyon

TOTAL ENERGY PRODUCED (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	439.7	594.0	800.9	588.8	457.0	438.0	416.4	440.7	420.9	437.3	551.1	363.0	5947.8
2	439.1	488.0	611.6	549.7	418.3	447.8	360.4	457.0	499.9	455.6	590.7	839.7	6147.6
3	563.3	670.0	827.0	623.2	469.7	438.0	416.4	500.5	501.9	489.5	580.6	729.5	6809.5
4	677.0	741.2	811.9	590.5	456.3	438.0	444.1	652.2	713.7	462.2	575.6	559.5	7122.4
5	507.9	629.2	802.9	607.8	468.0	438.0	416.4	580.2	599.1	439.9	544.1	555.3	6588.8
6	521.8	664.5	832.4	632.8	486.3	438.1	431.8	440.2	625.9	547.9	964.0	944.8	7530.5
7	525.4	624.6	791.6	587.9	465.4	438.0	416.4	595.4	809.9	733.2	944.9	935.2	7867.7
8	548.6	681.4	842.3	630.1	494.2	438.1	436.3	500.4	720.3	497.9	590.8	969.0	7349.3
9	676.9	746.6	848.3	685.7	484.2	438.1	438.2	483.0	600.3	472.2	586.5	387.8	6867.8
10	469.7	578.0	799.8	610.6	480.1	438.0	418.8	541.2	576.2	439.5	845.4	907.4	7054.8
11	613.0	674.2	841.8	634.4	491.1	438.1	445.1	564.6	419.4	435.7	564.8	830.0	6952.3
12	676.9	689.7	848.1	684.6	504.0	443.3	537.7	601.3	743.2	508.2	659.9	716.9	7613.7
13	572.8	673.7	844.1	645.8	497.2	438.2	485.0	489.3	810.9	757.8	1140.6	918.1	8273.2
14	636.5	687.6	839.4	624.9	494.0	438.1	416.4	649.3	684.6	740.9	1018.2	781.5	8011.4
15	611.8	641.4	803.3	591.1	466.4	438.0	416.3	443.2	750.9	759.4	715.0	545.5	7172.5
16	586.8	680.8	791.3	589.8	464.1	438.0	440.3	493.4	609.6	546.0	604.6	1046.3	7290.9
17	629.3	627.5	806.6	608.6	481.6	438.1	470.0	440.3	706.0	434.4	559.4	[illegible]	6585.4
18	452.6	565.9	799.8	612.7	485.5	438.1	429.2	554.1	743.7	582.9	1079.9	953.4	7697.9
19	520.1	650.6	840.3	647.9	517.9	456.0	505.3	570.4	791.1	593.7	575.4	408.0	7076.8
20	443.5	552.5	760.2	573.0	454.3	438.0	437.2	443.6	414.0	461.6	713.9	381.8	6073.8
21	436.6	487.4	598.5	526.8	384.4	437.2	359.8	338.9	299.7	424.6	614.4	329.8	5240.1
22	439.1	486.1	599.1	527.0	384.5	437.3	359.8	336.7	297.4	495.1	590.5	322.7	5277.2
23	439.6	488.5	703.2	593.2	469.1	445.2	469.1	712.5	810.7	587.6	699.0	734.6	7173.1
24	532.9	650.7	805.3	603.0	480.3	438.1	424.5	439.8	576.8	469.6	599.1	385.9	6408.0
25	439.1	488.0	627.2	549.0	418.9	437.9	360.1	505.1	431.2	461.0	643.9	312.1	5673.3
26	439.0	488.1	599.6	527.6	385.0	438.0	360.3	443.1	747.2	604.4	597.9	654.3	6464.5
27	663.7	627.1	778.9	584.9	464.5	438.0	427.3	469.1	538.1	468.5	641.0	375.7	6476.9
28	439.0	488.3	599.9	548.9	438.6	438.1	379.1	441.7	809.3	564.8	637.7	698.7	6484.3
29	666.1	708.9	848.1	664.0	500.8	438.2	490.8	476.6	454.1	454.6	544.4	360.5	6607.2
30	439.3	488.4	599.7	531.4	441.0	438.0	373.9	464.8	618.4	611.5	652.0	654.8	6303.1
31	676.9	767.4	848.1	651.9	495.5	438.2	482.0	469.3	655.8	670.5	796.9	806.9	7759.4
32	677.0	774.1	816.0	612.1	478.2	438.1	440.6	477.4	470.0	615.2	1202.4	882.1	7883.2
AVE	543.8	618.9	767.7	601.2	464.6	438.9	429.5	500.2	606.3	538.2	707.0	652.3	6868.9

Table K.7 Total Usable Energy in Year 2010
Watana + Devil Canyon

TOTAL USABLE ENERGY (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	439.7	594.0	800.9	588.8	457.0	438.0	416.4	440.7	420.9	437.3	550.6	363.0	5947.2
2	439.1	488.0	611.6	549.7	416.3	437.6	360.4	457.0	499.9	455.6	550.6	576.0	5843.8
3	563.3	670.0	827.0	623.2	469.7	438.0	416.4	500.5	501.9	489.5	550.6	576.0	6626.0
4	677.0	741.2	811.9	590.5	456.3	438.0	444.1	543.1	532.8	462.2	550.6	559.5	6807.3
5	507.9	629.2	802.9	607.8	466.0	438.0	416.4	543.1	532.8	439.9	544.1	555.3	6485.4
6	521.8	664.5	832.4	632.8	486.3	438.1	431.6	440.2	532.8	520.8	550.6	576.0	6628.0
7	525.4	624.6	791.6	587.9	465.4	438.0	416.4	543.1	532.8	520.8	550.6	576.0	6572.5
8	548.6	681.4	842.3	630.1	494.2	438.1	436.3	500.4	532.8	497.9	550.6	576.0	6728.6
9	676.9	746.6	848.2	685.7	484.2	438.1	458.2	483.0	532.8	472.2	550.6	367.8	6764.2
10	469.7	578.0	799.8	610.6	480.1	438.0	418.8	541.2	526.2	439.5	550.6	576.0	6428.5
11	613.0	674.2	841.8	634.4	491.1	438.1	445.1	543.1	419.4	435.7	550.6	576.0	6662.6
12	676.9	689.7	848.1	684.6	504.0	443.3	537.7	543.1	532.8	508.2	550.6	576.0	7094.9
13	572.8	673.7	844.1	645.8	497.2	438.2	485.0	489.3	532.8	520.8	550.6	576.0	6826.0
14	636.5	687.6	839.4	624.9	494.0	438.1	416.4	543.1	532.8	520.8	550.6	576.0	6860.1
15	611.8	641.4	803.3	591.1	466.4	438.0	416.3	433.2	532.8	520.8	550.6	545.5	6551.3
16	586.8	680.8	791.3	589.8	464.1	438.0	440.3	493.4	532.8	520.8	550.6	576.0	6664.5
17	629.3	627.5	806.6	608.6	481.6	438.1	470.0	440.3	532.8	434.4	550.6	383.6	6403.3
18	452.6	565.9	799.8	612.7	485.5	438.1	429.2	543.1	532.8	520.8	550.6	576.0	6507.1
19	520.1	650.6	840.3	647.9	517.9	456.0	505.3	543.1	532.8	520.8	550.6	408.0	6693.5
20	443.5	552.5	760.2	573.0	454.3	438.0	437.2	443.8	414.0	461.6	550.6	381.8	5910.5
21	438.6	487.4	598.5	526.8	384.4	437.2	359.8	338.9	299.7	424.6	550.6	329.8	5176.3
22	439.1	488.1	599.1	527.0	384.5	437.3	359.8	336.7	297.4	495.1	550.6	322.7	5237.3
23	439.6	488.5	703.2	593.2	469.1	445.2	489.1	543.1	532.8	520.8	550.6	576.0	6351.1
24	532.9	650.7	805.3	603.0	480.3	438.1	424.5	449.8	532.8	469.6	550.6	385.9	6313.5
25	439.1	488.0	627.2	549.0	418.9	437.9	360.3	505.1	431.2	461.0	550.6	312.1	5580.0
26	439.0	488.1	599.6	527.6	385.0	438.0	360.3	443.1	532.8	520.8	550.6	576.0	5860.8
27	663.7	627.1	778.9	584.9	464.5	438.0	427.3	469.1	532.8	468.5	550.6	375.7	6381.2
28	439.0	488.3	599.9	548.9	438.6	438.1	379.1	441.7	532.8	520.8	550.6	576.0	5953.9
29	666.1	708.9	848.1	664.0	500.8	438.2	490.8	476.6	454.1	454.6	544.4	360.5	6607.2
30	439.3	488.3	599.7	531.4	431.0	438.0	373.9	464.8	532.8	520.8	550.6	576.0	5946.5
31	676.9	767.4	848.1	651.9	495.5	438.2	482.0	469.3	532.8	520.8	550.6	576.0	7009.4
32	677.0	774.1	816.0	612.1	478.2	438.1	440.6	477.4	470.0	520.8	550.6	576.0	6830.8
AVE	543.8	618.9	767.7	601.2	464.6	438.9	429.5	481.7	497.6	487.5	550.2	501.2	6382.9

FORECAST DEMAND ENERGY (GWH)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
677.0	777.6	848.2	773.8	732.5	662.2	590.4	543.1	532.8	520.8	550.6	576.0	7784.9

Table B.10 Potential Spill from Devil Canyon in August

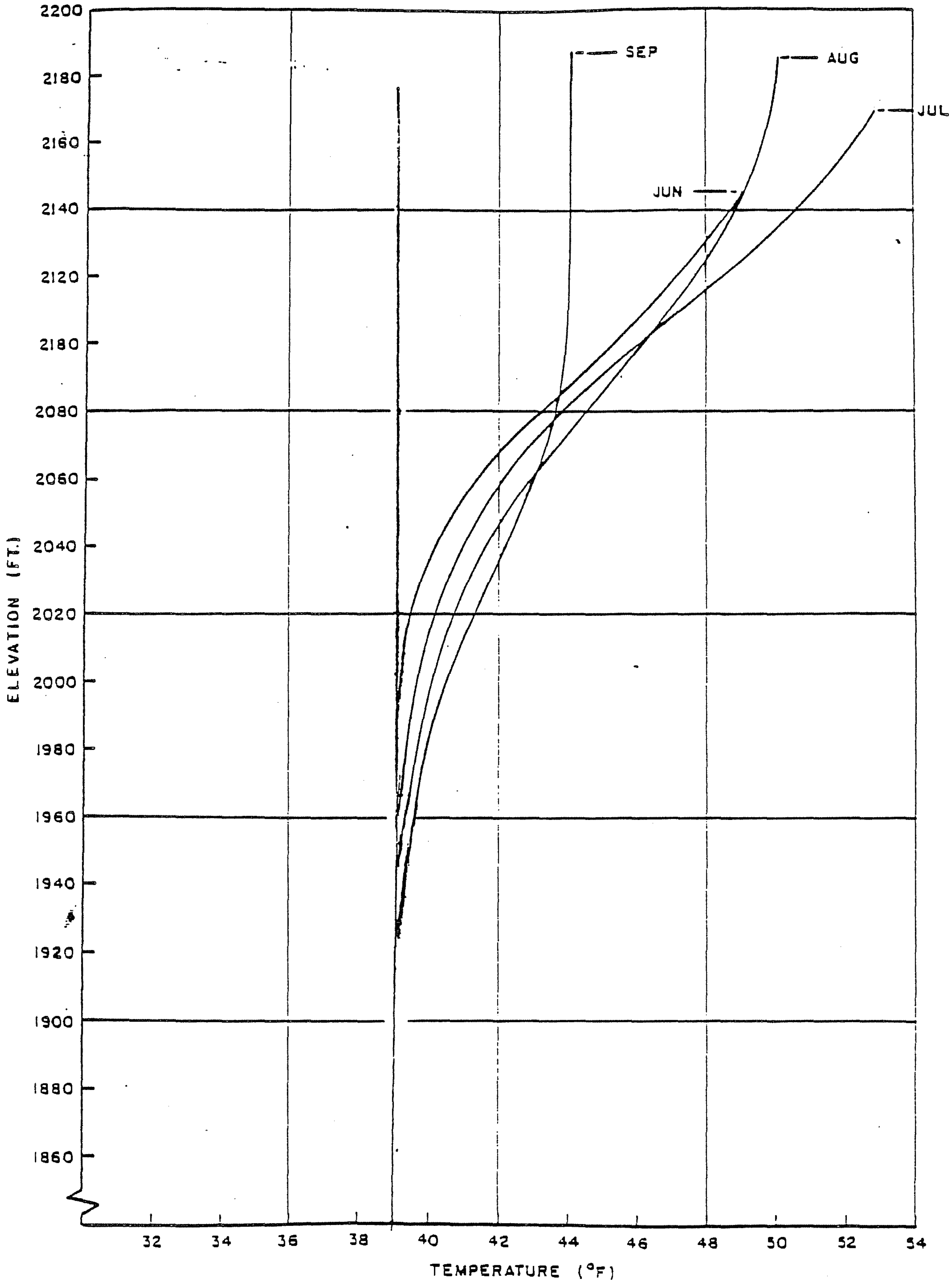
Year Simulated	Energy Potential GWh	Reservoir Operation A: Usable energy at [illegible], proportional to [illegible] — Usable energy yr 2010 - GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B: Maximum possible generation of usable energy at Devil Canyon — Usable energy yr 2010 - GWh	Turbine Q cfs	Spill cfs
1	337.9	337.4	10225	16	337.9	10[illegible]	0
2	336.9	296.8	9567	1293	336.9	10860	0
3	342.4	312.4	[illegible]	[illegible]	342.4	10727	0
4	331.1	306.1	9797	800	331.1	10577	0
5	315.4	315.4	9972	0	315.4	9772	0
6	446.4	253.3	7716	6992	446.4	13763	947
7	446.4	249.7	7678	6502	446.4	13763	2437
8	344.9	304.7	9534	1265	344.9	10547	0
9	336.5	300.7	9555	1135	336.5	10380	0
10	445.8	251.0	7738	6438	445.8	13763	953
11	328.6	314.4	10025	453	328.6	10476	0
12	355.2	249.1	7760	3306	355.2	11062	0
13	446.4	249.0	7678	12327	446.4	13763	6050
14	446.4	249.7	7698	8627	446.4	13763	[illegible]
15	360.4	247.0	7702	3444	360.4	[illegible]	0
16	342.5	262.1	8165	2834	342.5	[illegible]	0
17	327.8	319.0	10135	279	327.8	[illegible]	0
18	446.4	253.2	7715	12733	446.4	13763	6[illegible]
19	346.5	321.7	10139	782	346.5	10730	0
20	348.3	245.8	8191	3414	348.3	[illegible]	0
21	317.5	253.7	8528	2144	317.5	10675	0
22	301.6	269.7	9065	1341	301.6	10406	0
23	364.6	246.6	7748	3616	364.6	[illegible]	0
24	341.0	292.6	9600	1522	341.0	[illegible]	0
25	331.2	243.1	8102	2935	331.2	11027	0
26	348.4	301.1	9456	1426	348.4	[illegible]	0
27	350.5	260.1	8532	2966	350.5	114[illegible]	0
28	355.2	268.1	8402	2727	355.2	11131	0
29	334.8	334.8	10936	0	334.8	10927	0
30	344.7	247.3	7716	2431	344.7	10647	0
31	400.5	247.7	7705	4642	400.5	12[illegible]	0
32	446.4	250.1	7712	13269	446.4	13763	12[illegible]

Table 5.11 Potential Spill from Watana in August

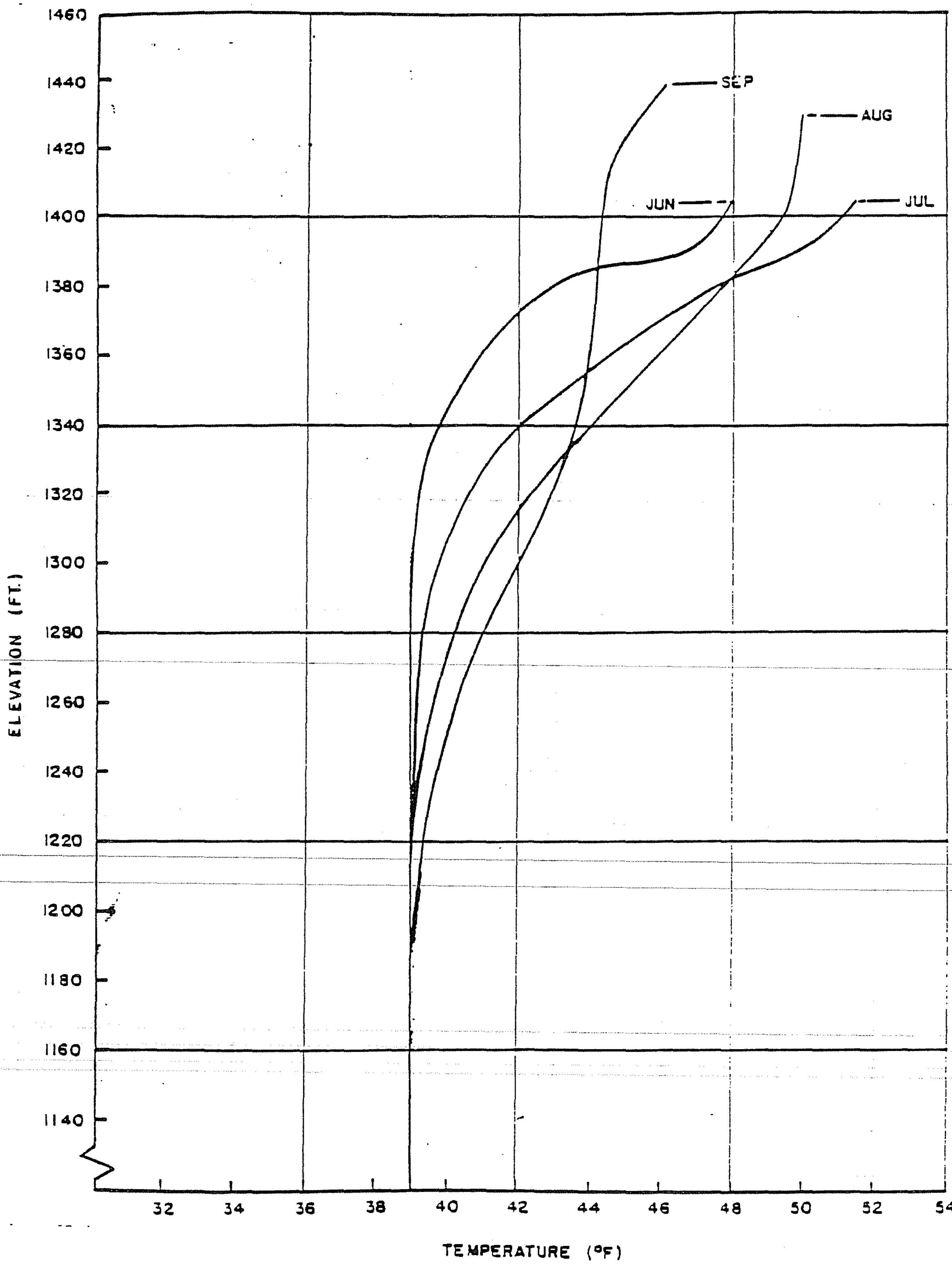
Year simulated	Energy Potential GWh	Reservoir Operation A: Usable energy at Watana and Devil Canyon proportional to average heads — Usable Energy Yr. 2010 – GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B: Maximum possible generation of usable energy at Devil Canyon — Usable energy Yr. 2010 GWh	Turbine Q cfs	Spill cfs
1	213.2	213.2	[illegible]	0	[illegible]	5520	13
2	258.8	258.8	6576	0	[illegible]	5537	1039
3	238.2	232.2	6135	0	208.2	[illegible]	773
4	244.5	244.5	[illegible]	0	[illegible]	5677	567
5	228.7	228.7	[illegible]	0	228.7	5712	0
6	517.5	300.3	7715	5575	[illegible]	2677	10313
7	498.5	300.9	7692	5072	[illegible]	[illegible]	10100
8	245.9	245.9	[illegible]	0	205.7	5214	1035
9	249.9	249.9	[illegible]	0	[illegible]	5519	423
10	379.5	279.6	7724	2576	104.3	2702	7578
11	236.2	236.2	[illegible]	0	222.0	[illegible]	[illegible]
12	304.7	301.5	7755	82	195.4	[illegible]	2311
13	694.2	301.6	7673	9989	[illegible]	2551	15311
14	571.8	300.4	7692	6926	[illegible]	2664	11954
15	350.6	301.6	[illegible]	1352	190.2	4355	4117
16	262.1	262.1	6734	0	206.1	[illegible]	1387
17	231.6	231.6	[illegible]	0	[illegible]	5775	[illegible]
18	633.5	300.4	7710	8550	104.2	2133	14117
19	228.9	228.9	[illegible]	0	221.1	5243	637
20	365.7	304.8	8136	1636	[illegible]	5433	[illegible]
21	296.9	[illegible]	[illegible]4	0	233.1	6334	[illegible]
[illegible]	280.9	280.9	[illegible]	0	[illegible]	6466	1071
[illegible]	335.2	302.0	7745	351	[illegible]	4770	3475
[illegible]	252.0	252.0	6715	0	214.6	5455	1230
[illegible]	312.5	307.5	8101	132	211.2	5775	[illegible]
[illegible]	249.5	249.5	[illegible]	0	202.2	5192	1214
[illegible]	290.5	[illegible]	7569	[illegible]	[illegible]	5214	[illegible]
[illegible]	282.5	[illegible]	[illegible]	0	195.4	5015	[illegible]
[illegible]	229.6	229.6	[illegible]	0	207.6	5471	0
[illegible]	307.3	300.8	7711	157	205.9	5272	[illegible]
[illegible]	346.4	300.7	7701	2451	[illegible]	[illegible]	[illegible]
[illegible]	756.0	300.5	7708	14438	104.2	2373	19473

Table B.12 Potential Spills from Devil Canyon [illegible]

Year simulated	Energy Potential GWh	Reservoir Operation A: Usable energy at Watana & Devil Canyon proportional to average heads — Usable energy in 2010 GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B: Maximum possible generation of usable energy at Devil Canyon — Usable energy 2010 GWh	Turbine Q cfs	Spill [illegible]
1	177.9	177.9	6150	0	177.9	6150	0
2	344.3	245.0	8047	3231	344.3	11308	0
3	318.0	246.5	7979	2215	318.0	10214	0
4	247.7	247.7	8149	0	247.7	8149	0
5	254.4	254.4	8220	0	254.4	8220	0
6	432.0	248.6	7920	6069	432.0	13763	[illegible]
7	432.0	248.6	7920	8576	432.0	13763	[illegible]
8	423.9	246.1	7990	6742	423.9	13763	471
9	179.3	179.3	5929	0	179.3	5929	0
10	432.0	248.6	7920	7409	432.0	13763	[illegible]
11	363.5	246.1	8021	3327	363.5	[illegible]	0
12	330.0	247.2	[illegible]	2575	[illegible]	[illegible]	0
13	432.0	248.6	7920	6347	[illegible]	13763	1564
14	369.7	248.6	7919	3858	[illegible]	11777	0
15	258.6	258.6	8265	0	258.6	[illegible]	0
16	427.6	247.2	[illegible]	[illegible]	427.6	13763	[illegible]
17	178.4	[illegible]	5594	0	178.4	[illegible]	0
18	432.0	248.6	7920	[illegible]	[illegible]	13763	1965
19	178.9	178.9	5710	0	178.9	5710	0
20	178.6	178.6	5202	0	178.6	5202	0
21	167.6	167.6	5322	0	167.6	[illegible]	0
22	164.0	164.0	5076	0	[illegible]	5076	0
23	316.9	247.1	7752	[illegible]	316.9	10206	0
24	177.1	177.1	6152	0	177.1	6152	0
25	161.8	[illegible]	5620	0	161.8	5620	0
26	370.9	246.1	7732	4051	370.9	[illegible]	0
27	175.1	175.1	6082	0	175.1	6082	0
28	294.0	246.4	[illegible]	1541	[illegible]	9519	0
29	172.0	172.0	5973	0	172.0	5973	0
30	307.9	248.3	7926	1902	307.9	9829	0
31	387.4	248.6	7920	4422	387.4	12342	0
32	423.6	[illegible]	[illegible]	5574	423.6	13472	0



WATANA RESERVOIR TEMPERATURE PROFILE



DEVIL CANYON RESERVOIR TEMPERATURE PROFILE

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): B. 34, I. 60

ACRES

OFFICE MEMORANDUM

TO: J.W. Hayden

Date: September 13, 1982

FROM: G. Krishnan

File: P5700.14.53

SUBJECT: Susitna Hydroelectric Project
Nitrogen Supersaturation Studies

Enclosed is a copy of the final draft of the report on Gas Concentration and Temperature of Spill Discharges Below Watana and Devil Canyon Dams.

Please note that no graphics efforts have been spent on getting the figures in the Acres standard format. This has been postponed until after your review of the material and advice on the inclusion of any field measurements of natural supersaturation in the river. Messers M. Bell and J. Douma had expressed an interest to receive copies of this report. Please advise if this can be done at this time.

G. Krishnan

GK:ccv
Enclosure

cc: J.D. Lawrence
A.F. Coniglio
K.R. Young
W. Dyok/D. Crawford

GAS CONCENTRATION AND TEMPERATURE OF SPILL DISCHARGES BELOW WATANA AND DEVIL CANYON DAMS

1 - INTRODUCTION

Supersaturation of atmospheric gases (especially nitrogen) in hatchery and aquarium facilities was first noted in the 1900's (1) and was ascribed as causing the condition in fish known as gas bubble disease. Supersaturation caused by entrainment of air in waters spilled over dams on the Columbia River was recognized as a problem for anadromous fisheries in the river in 1965. A comprehensive study (2) of dissolved gas levels in the Columbia River showed that waters plunging below spillways was the main cause of supersaturation in the river waters. Several later studies have confirmed the harmful effects of nitrogen supersaturation to fisheries. The tolerence of fish to levels of nitrogen supersaturation depends on the time of exposure, age, and species of the fish; dissolved nitrogen levels referenced to surface pressure above 110 percent are generally considered harmful (3). The state of Alaska water quality criterion is set of 110% for total gas saturation in its waters.

With this background, the potential problem of supersaturation of spill waters from the proposed Watana and Devil Canyon developments on the Susitna River was recognized early during the feasibility studies. Alternative spillway facilities were studied to minimize such a potential problem, and a scheme comprising fixed cone valves and overflow spillway was selected for each development based on detailed discussions with environmental study groups.

This report describes the selected spillway schemes briefly and presents the analyses and field investigations carried out to assess the performance of the proposed schemes with respect to gas supersaturation in spill waters. A related concern on temperature of spill waters is also discussed.

A summary of the studies undertaken and the important conclusions are presented in Section 2. A short description of the proposed schemes is given in Section 3. Section 4 details the engineering analyses carried out. Results of these analyses, field investigations, and their interpretation are presented in Section 5. The next section presents the major conclusions drawn from these studies. Appendix A comprises the field study report and Appendix B deals with the temperature of spill waters, its impacts downstream, and possible reservoir operation scenarios to minimize such impacts.

2 - SUMMARY

Relatively little information is available in the literature on the performance of fixed-cone valves to reduce gas supersaturation in their discharges. Published studies (4) on the aeration efficiency of Howell Bunger valves (the more commonly known type of fixed-cone valves) were reviewed, and a theoretical assessment of the performance of the proposed valve layouts was made based on the physical and geometric characteristics of diffused jets discharging freely into the atmosphere. Results of a companion study on assessment of scour hole development below high-head spillways (5) were used to estimate the potential plunging of the valve discharges into tailwater pools at the proposed developments, and the resulting supersaturation in the releases was calculated. Specific field tests were conducted at the Lake Comanche Dam on the Mokelumne River in California (6) to study jet characteristics and the efficiency of the existing Howell Bunger valves in reducing supersaturation level in the reservoir releases.

The analyses indicate that no serious supersaturation of nitrogen is likely to occur in the releases from the proposed Watana and Devil Canyon developments for spills up to 1:50 year recurrence interval. Field test results tend to confirm some of the assumptions made in the theoretical analysis with respect to jet shape, diffusion, and gas concentration in the valve discharges. Several assumptions and approximations, albeit conservative, have been made in the analyses which should be confirmed in later study phases, perhaps in a physical model. For the purpose of feasibility studies, however, it is felt that the analyses adequately support the proposed schemes for their intended purpose.

A related question of the temperature of spill waters and its effects on the downstream water temperature has been analyzed and detailed in Appendix B. Simulation studies of the two-reservoir operations indicate that continuous (24 hour) spills would occur in the month of August in 30 out of 32 years of simulation and in 18 out of 32 years in September for the Case "C" operation which maintains a minimum instantaneous flow of 12,000 cfs in August at Gold Creek. This spill frequency is simulated for a system energy demand in the year 2010 (Bettelle forecast) and assumes that the entire demand is met by

Watana and Devil Canyon developments where possible. The spills will be greater and more frequent in the years between 2002 (Devil Canyon commissioning) and 2010. When Watana alone is operational (between 1993 and 2002), less frequent spills are simulated to occur. Reservoir operation studies are currently being refined to finalize acceptable downstream flows.

Temperature of spill waters at Watana is expected to be close to that of power flow, and hence, it is not expected to create temperature problems downstream when Watana is operating alone (1993-2002) or when it spills into Devil Canyon. At Devil Canyon, however, spill temperature is expected to be close to 39°F compared to a power flow temperature of 48-49°F in August and 45°F in September. This is based on the conservative assumption that the temperature of spill water does not increase significantly while in contact with the atmosphere despite the highly diffused valve discharge. It is, therefore, considered necessary to keep the spill from Devil Canyon to a minimum to avoid unacceptably low downstream temperatures. The analyses indicate that by operating Devil Canyon to meet most or all of the base load demand and with Watana generating essentially to meet peak demands and spilling continuously when necessary, it would be possible to maintain downstream flow temperatures below Devil Canyon close to that of power flow while reducing spill frequency considerably.

During major floods (1:10 year or rarer), there will be significant spills from Devil Canyon in addition to the power flow resulting in cold slugs of water downstream for a few days. It will be necessary to establish criteria for acceptability of lower temperatures for short durations in August and September in consultation with fisheries study groups and concerned agencies. Currently, downstream water temperature analyses are being refined, and when the results are available, the above spill temperatures and duration should be reviewed to confirm downstream temperatures during normal power operation as well as flood events. If the projected temperature regime downstream is unacceptable, alternative means to remedy the situation should be considered. These may include provision of higher level intakes to several or all fixed-cone valve discharges at Devil Canyon, multilevel power intake at Devil Canyon, limited operation of main overflow spillway (for floods 1:50 year or more frequent) to improve temperature without serious increase in nitrogen super-saturation, etc.

3 - SCOPE OF ANALYSES

The objective of the analyses presented in the following sections is to provide an assessment of the performance of the fixed-cone valves in their proposed configuration with respect to their potential in reducing gas concentration in spill waters from the Watana and Devil Canyon developments. The analysis is a theoretical study supplemented by available field information on performance of these valves for aeration. Field measurements were conducted on the Howell Bunger valves at the Lake Comanche dam on the Mokelumne River in California. Results of the tests are interpreted to confirm some of the study assumptions.

A related question of temperature of spill waters is analyzed in Appendix B. The data for the analyses has been drawn from the Feasibility Report (7).

4 - SCHEME DESCRIPTION

This section presents a short description of the selected spillway and outlet facilities for the proposed Watana and Devil Canyon developments.

4.1 - Scheme Description

Selection of the discharge capacity and the type of spillway and outlet facilities has been based on project safety, environmental, and economic considerations. At each development, a set of fixed-cone valves is provided in the outlet works to discharge spills up to 1:50 year recurrence interval. The main spillway comprises a gated control structure and a chute with a flip bucket at its end. This facility has a capacity to discharge, in combination with the outlet works, the routed design flood which has a return period of 1:10,000 years. A fuse plug with an associated rock-cut channel is provided to discharge flows above the design flood and up to the estimated probable maximum flood at the dam. Detailed descriptions of the facilities are presented in the Feasibility Report (7).

The primary purpose of the outlet facility is to discharge the spill waters up to 1:50 year recurrence in such a manner as to reduce potential supersaturation of the spill with atmospheric gases, particularly nitrogen. This frequency was adopted after discussions with environmental study groups as an acceptable level of protection of the downstream fisheries against the gas bubble disease. A set of fixed-cone valves were selected to discharge the spills in highly diffused jets to achieve significant energy dissipation without provision of a stilling basin or a plunge pool where potentially large supersaturation develops. The valves have been selected to be within current world experience with respect to their size and operating heads. At Watana, six 78 inch diameter valves are provided and are located about 125 ft above average tailwater level in the river. The design capacity of each valve is 6,000 cfs. At Devil Canyon, seven fixed cone valves with a total design capacity of 38,500 cfs are provided at two levels within the arch dam, four 102 inch valves at the high level some 170 ft above average tailwater level, and three 90 inch valves about 50 ft above average tailwater level. The lower valves have a capacity of 5,100 cfs each and the higher ones 5,800 cfs each. In sizing these valves, it has been assumed that the valve gate opening will be restricted to 80% of full stroke to reduce vibration.

5 - ENGINEERING ANALYSES

This section details the analyses carried out to estimate potential supersaturation in the releases from the Watana and Devil Canyon developments when the reservoirs spill.

5.1 - Available Data

Fixed cone valves have been used in several water resource projects for water control, energy dissipation, and aeration of discharge waters, and data on their performance for such operations is readily available. However, no precedence has been reported on the use of such valves for reducing or eliminating gas supersaturation in spill waters. Manufacturer's catalog information on Howell Bunger valves and Boving Sleeve type discharge regulators (both particular types of fixed cone valves) and the Tennessee Valley Authority Study (4) on aeration efficiency of Howell Bunger valves form the specific data available. Theoretical analyses are carried out based on the geometric and physical characteristics of diffused jets discharging freely into the atmosphere.

5.2 - Field Data Collection

A review of existing facilities where a potential for spilling during the spring of 1982 existed was made, and the Lake Comanche dam, on the Mokelumne River in California, was selected as a feasible site for specific testing.

The Comanche Lake dam is of the rockfill type with outlet facilities fitted with four Howell Bunger valves. These valves are located at the toe of the dam and spray the discharge into confined concrete conduits before releasing the water to the stream.

Outflow through the valves was around 4,000 cfs during the test on May 28, 1982. Water samples were collected at several depths in the reservoir near the valves and at downstream locations and analyzed for nitrogen and oxygen concentrations. Details of the test procedure and results are presented in Appendix 1.

5.3 - Method of Analysis

(a) Flow from the fixed cone valves leaves the structure as a free-discharging jet diffusing radially at the cone angle. The path of the jet depends on the energy of flow available at the valve and the angle at which the jet leaves the valve (assumed as 45°). Referring to Figure 5.1, the path of the trajectory is given by the following equation (8):

$$y = x \tan \theta - \frac{x^2}{k(4 H_n \text{Cos}^2 \theta)} \tag{1}$$

where:

θ = angle of the jet to the horizontal;

k = a factor to take account of loss of energy and velocity reduction due to the effect of air resistance, internal turbulences, and disintegration of the jet (assumed at 0.9);

H_n = net energy of the jet, ft.

The proposed valve operation restricts the opening of the valve gate to 80% of full stroke. This may be interpreted as equivalent to producing an additional head loss in the system, thereby reducing the discharge to 80% of the theoretical capacity. The general discharge equation for the valve:

$$Q_T = CA \sqrt{2g\ h_n} \tag{2}$$

may then be written as:

$$Q_D = 0.8\ Q_T = CA \sqrt{2g\ (\cdot 8)^2\ h_n} \tag{2a}$$

$$= CA \sqrt{2g \times \cdot 64 \times h_n} \tag{3}$$

where:

Q_T = theoretical capacity of valve, cfs;
A = area of valve, ft;
C = coefficient of discharge ($\sim$ · 85 for fixed-cone valves);
h_n = net head upstream of valve, cfs;
Q_D = design capacity of valve, cfs.

Equation (1) may be rewritten now as:

$$y = x \tan \theta - \frac{x^2}{k \quad 4 \times (0.64 \times h_n) \times \cos^2 \theta} \qquad (4)$$

Referring to Figure 5.1, the longitudinal throw of the jet is calculated with θ=45° and -45° while its laterial throw calculated when θ=0°.

Vertical rise of the jet above the valve is calculated as a simple projectile subject to gravity and neglecting air friction to yield a conservative value.

(b) Potential Plunging Depth of Jet(s) Into Tailwater Pool

As part of the feasibility studies of the Watana and Devil Canyon developments, a study was made by Acres on the scour hole development below high head spillways, and the results therefrom have been used to estimate the potential plunging of the jets from the fixed cone valves into tailwater. Figure 5.2 presents a definition sketch for the study carried out for a typical flip bucket spillway configuration. It may be readily observed that significant differences exist between a "solid" jet leaving a flip bucket and the diffused discharge jet from the fixed-cone valves in the available energy and its concentration in the jet for scouring downstream or plunging into the tailwater pool. Equation (5) was developed in the above mentioned studies to estimate scour depth for a solid jet:

$$y = 0.24\, q^{0.65}\, H^{0.32} \qquad (5)$$

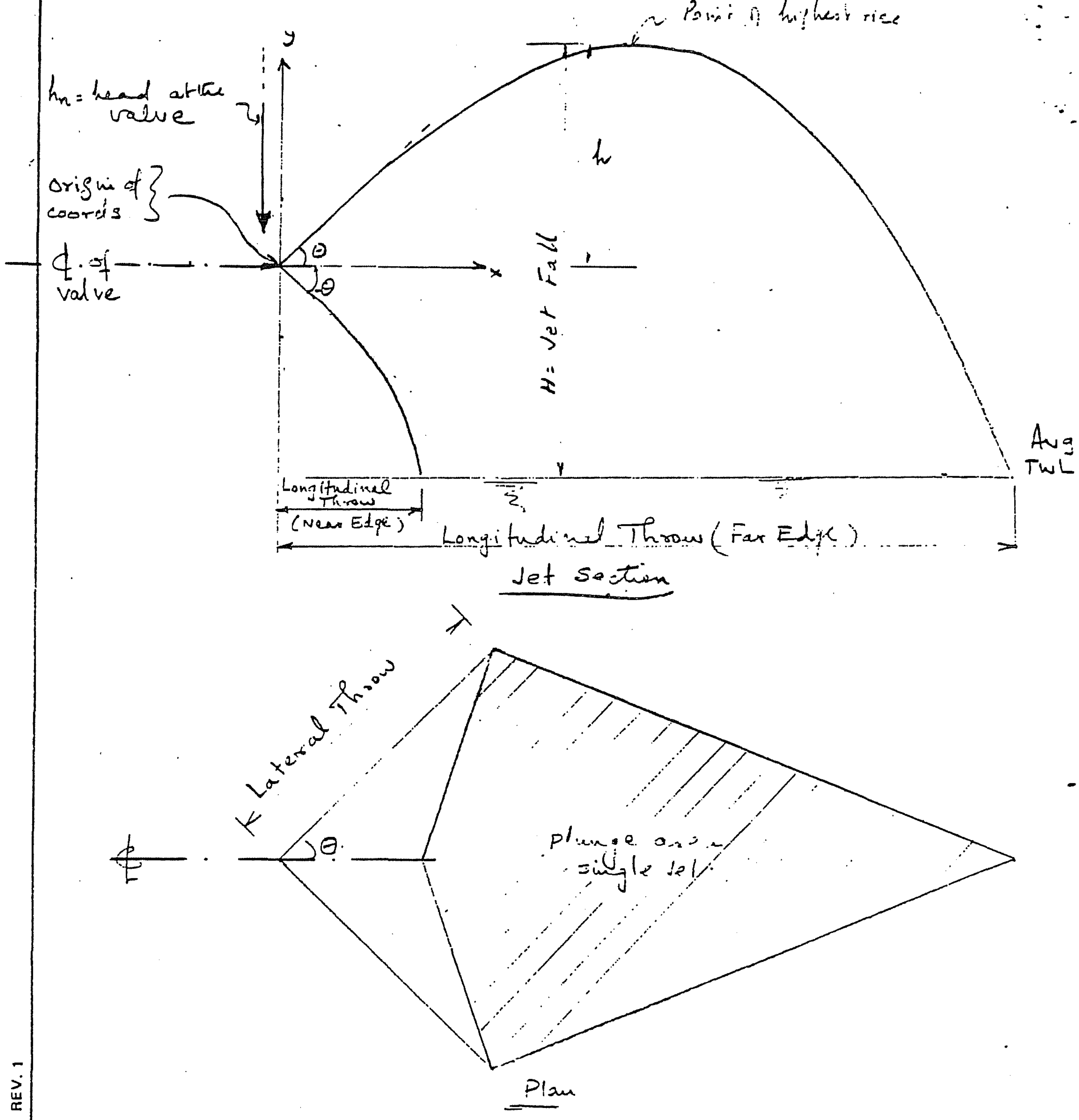
It is assumed that spills from Watana will get completely mixed in the Devil Canyon storage during their passage through 26 miles of reservoir and that no supersaturation would build up in the reservoir due to Watana spills.

ACRES

Calculations

SUBJECT:

JOB NUMBER ______
FILE NUMBER ______
SHEET ______ OF ______
BY ______ DATE ______
APP ______ DATE ______



DEFINITION SKETCH FOR DISPERSED JET

FIGURE 5.1

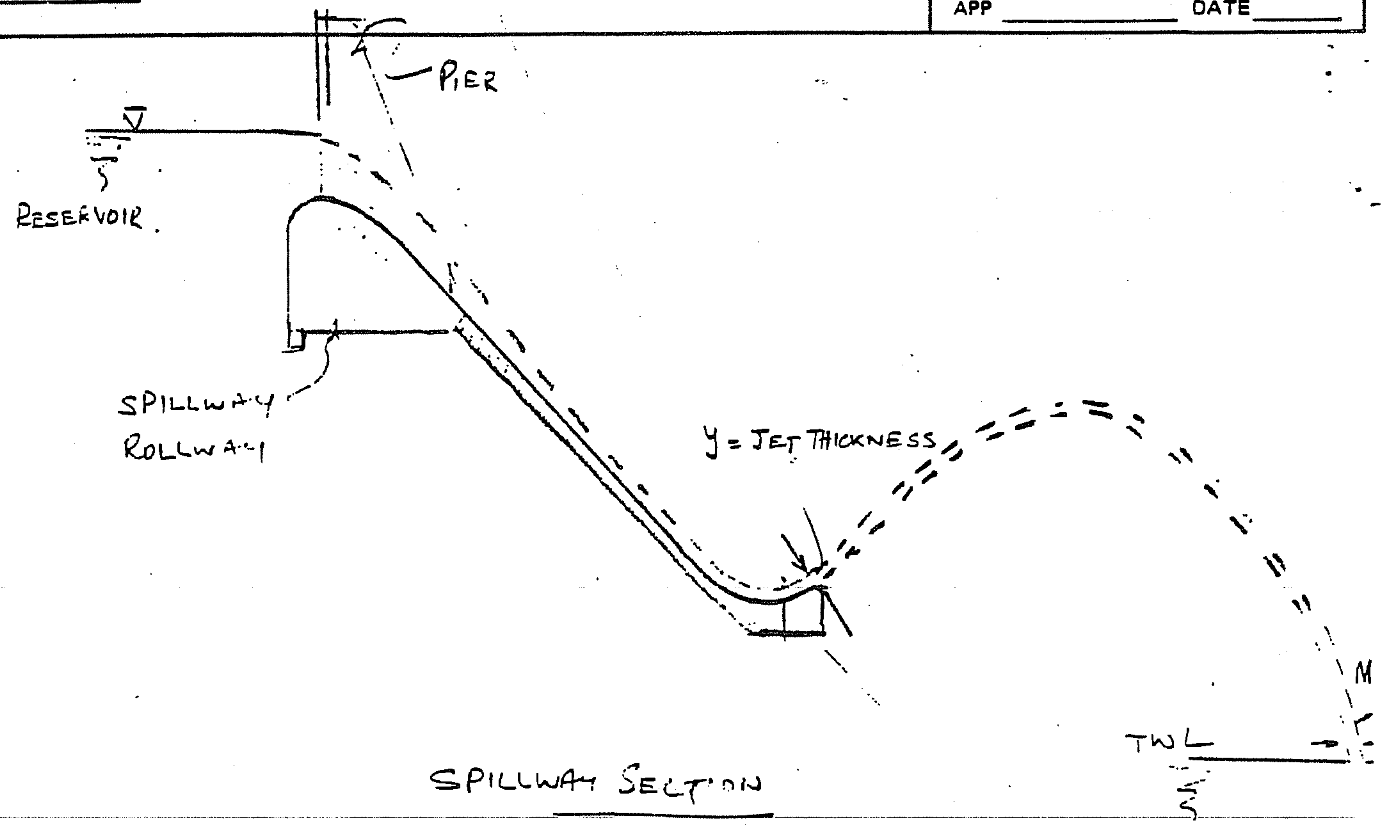
FORM NO. 152 REV. 1

ACRES

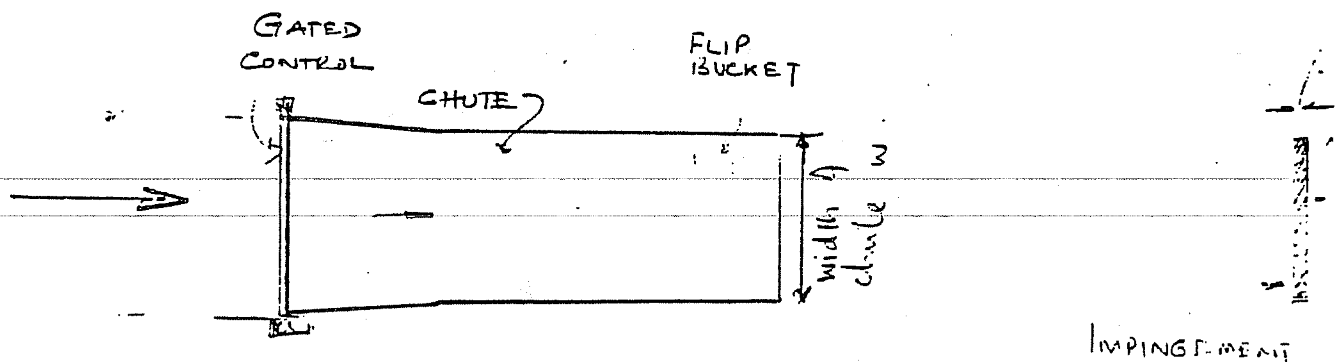
Calculations

SUBJECT:

JOB NUMBER ______
FILE NUMBER ______
SHEET ______ OF ______
BY ______ DATE ______
APP ______ DATE ______



SPILLWAY SECTION



PLAN

DEFINITION SKETCH FOR A 'SOLID JET FROM CHUTE - FLIP BUCKET SPILLWAY

FORM NO. 152 REV. 1

FIGURE S.2

6 - RESULTS

Table 6.1 presents the results of the analyses carried out to assess the performance of the fixed cone valves at the proposed Watana and Devil Canyon developments in relation to the potential gas supersaturation of spill waters. Figures 6.1 and 6.2 present the jet interference pattern and the areas of impingement.

Estimated supersaturation in the spill discharges with a recurrence interval of 1 in 50 years is 101% at Watana and 102% at Devil Canyon. For more frequent spills, these concentrations are expected to be somewhat lower due to lower intensity of spill discharge and consequent lower plunge in the tailwater pool. For spills of rarer frequency, the main chute spillway will operate leading to potentially greater supersaturation in the downstream discharges.

Results of spill temperature analysis is presented in Appendix B.

TABLE 6.1 - RESULTS OF ANALYSES

Description	Watana Valves	Devil Canyon Valves Upper Level	Devil Canyon Valves Lower Level
1. Valve Parameters			
Diameter of fixed cone valves-inches	78	102	90
Number of valves	6	4	3
Design capacity-cfs	4,000	5,800	5,100
Elevation of valve centerline-ft	1,560	1,050	930
Elevation above average tailwater-ft	105	170	50
Net head (h_n) at the valve-ft	508	365	450
Angle of valve discharge with horizontal-degrees (assumed)	45	45	45
2. Jet Geometry			
Longitudinal throw-near edge-ft	91	130	46
Longitudinal throw-far edge-ft	676	550	564
Lateral throw-ft	351	378	228
Impingement area of single jet-ft^2	145,200	112,250	83,400
Impingement area of all jets-ft^2	221,300	173,250	
Maximum fall of jet (H)-ft	359	353	275
3. Jet Characteristics			
Average intensity of discharge of single jet cfs/ft^2	0.028	0.052	0.061
Maximum intensity (q^1) when all jets are operating cfs/ft^2	6 x 0.028 = 0.168	4 x ·052 + 3 x ·061 = 0.391	
Estimated plunge depth-ft	0.3	0.62 (H=353')	
4. Supersaturation Estimates (1:50 year flood)			
Design valve discharge-cfs	24,000	38,500	
Assumed simultaneous power flow-cfs	7,000	3,500	
Total downstream discharge-cfs	31,000	42,000	
Assumed gas concentration in power flow-percent and valve discharge at valve-%	100.0	100.0	
Maximum gas concentration in valve discharge below dam-%	100.9	101.9	
Maximum gas concentration in total downstream discharge-%	100.7	101.7	

7 - CONCLUSIONS

1. The analyses described above indicate that the proposed fixed-cone valves would adequately prevent serious gas supersaturation in spill waters up to a recurrence interval of 1:50 years.

2. Several assumptions have had to be made in the analyses with respect to jet characteristics and its potential plunge into tailwater pool. Field test results available are only indicative of the valve performance. In particular, the configuration of the proposed valves set high above the tailwater pool and their free discharge with the atmosphere differ significantly from the Lake Comanche dam arrangement and the TVA test facility. In view of the nature of analyses and lack of precedence for the proposed valve arrangement, it is recommended that a physical model study be carried out to confirm the performance of the valves.

Calculations

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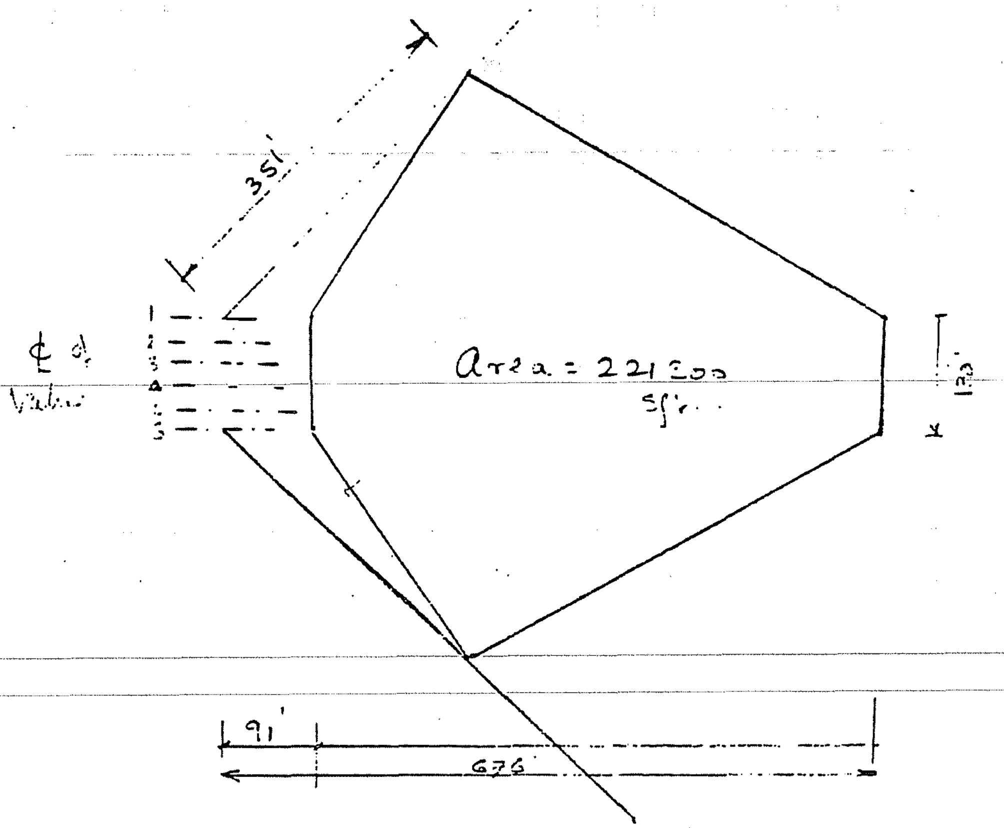
SUBJECT:

JOB NUMBER
FILE NUMBER
SHEET OF
BY DATE
APP DATE



VALVE DISCHARGE PATTERN AND IMPINGEMENT AREA FOR [illegible]

FIGURE 6.1

FORM NO. 152 REV. 1

Calculations

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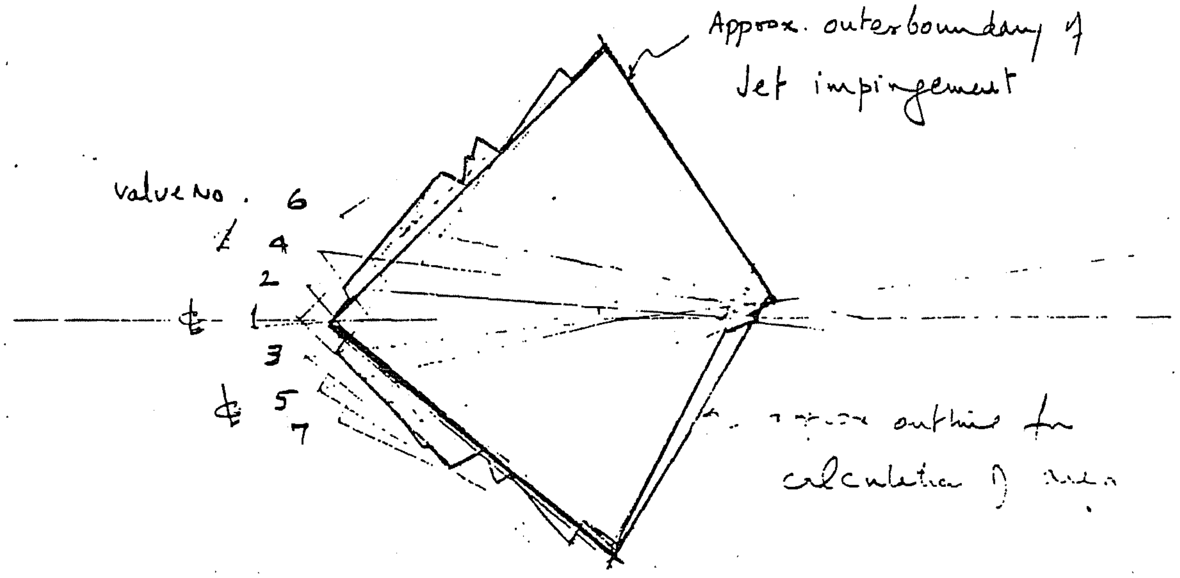

Ref. Plate 52
vol. 3. Feasibility Report

0 100' 200'
scale.

When all 7 valves are operating -
total area of impingement ~ $\frac{550 \times 630}{2}$ = 173250 s/f.

VALVE DISCHARGE PATTERN
IMPINGEMENT AREA FOR
DEVIL CANYON

FIGURE 6·2

FORM NO. 152 REV. 1

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ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): C. 62, I. 373

SUSITNA HYDROELECTRIC PROJECT

HYPOTHETICAL DAM-BREAK ANALYSES

TASK 3 – HYDROLOGY

MARCH 1982

Prepared by:

ACRES

ALASKA POWER AUTHORITY

ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT

TASK 3.05 - FLOOD STUDIES

SUBTASK 3.05(iv)
HYPOTHETICAL DAM BREAK ANALYSES - CLOSEOUT REPORT

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3 - SCOPE OF WORK

The objectives of this study are to analyze extreme cases of flood waves produced by hypothetical failures of the proposed dams of the Susitna Hydroelectric Project. The analyses are carried out over the reach of the Susitna River from the most upstream point in the reservoir of the dam being considered to the confluence of Trapper Creek, approximately 5 miles downstream from Talkeetna (see Figure 3.1).

To satisfy the study objectives, the work was organized and carried out in the following manner:

- Scenarios of worst case hypothetical dam failures were postulated for the Watana dam, the Devil Canyon dam, the Watana upstream cofferdam, and a domino type failure of both the Watana and Devil Canyon dams.

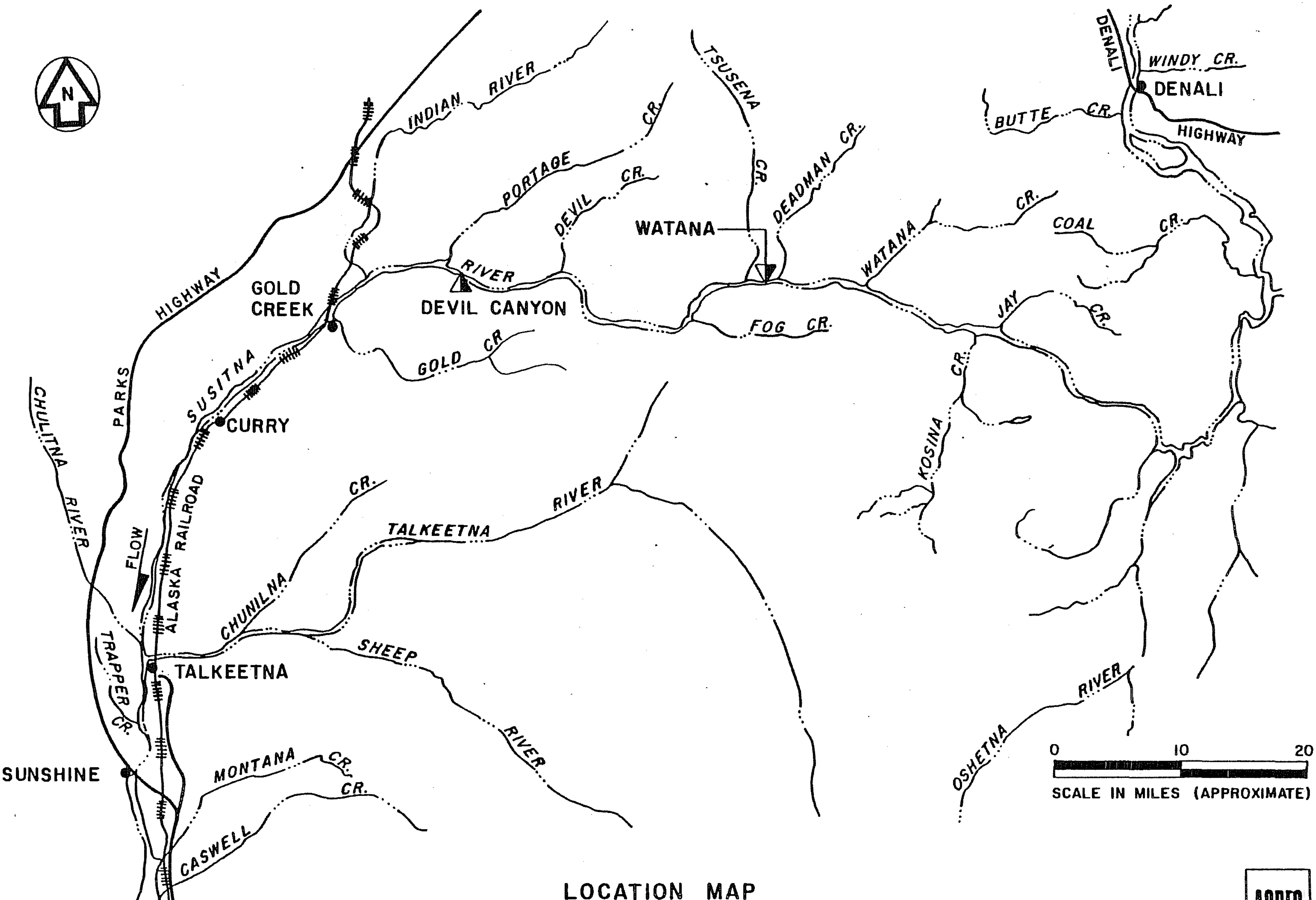
- A dam break computer program was selected to assist in analyses.

- Final dam breach dimensions and time of breach formation were estimated for each scenario.

- Downstream valley topographical and vegetative information were assembled and the geometric models were prepared.

- Dam break hydrographs were developed and routed downstream. Peak flood elevations, time to peak, and peak discharges were determined at various downstream locations for each of the postulated failures.

- The study was completed with analyses of the routed hydrographs and a comparison of flood wave crest levels in the river reach under dam break and probable maximum flood conditions together with the 50 year flood conditions.



LOCATION MAP

FIGURE 3.1

4 - HYPOTHETICAL DAM FAILURE SCENARIOS

Earth/rockfill dams are extremely safe structures capable of safely withstanding severe seismic shaking. The structure is normally designed to slump during a severe earthquake without being overtopped. As with all major water retaining structures, the safety of the development is also dependent on the performance of properly designed spillway facilities to safely discharge severe floods. Should spillway facilities not perform satisfactorily during a major seismic event (they are normally very conservatively designed to do so), there is a risk of overtopping of the earth/rockfill dam which could lead to a breach and subsequent failure.

Concrete dams are also extremely safe structures capable of safely withstanding severe seismic shaking and flood conditions. However, there is a very remote possibility of a flood of unforeseen magnitude occurring simultaneously with severe seismic shaking which together with spillway malfunction might lead to overtopping of the dam and under extremely adverse conditions, breaching of the structure.

Four hypothetical dam failure scenarios which create extreme conditions in the river reach have been postulated. The probability of any of these scenarios actually occuring is considered to be extremely small, but still not equal to zero. The hypothetical dam failure scenarios are described below.

4.1 - Hypothetical Watana Dam Failure

The remote possibility of a failure at Watana would have to be based on a combination of unlikely events. For study purposes these events are assumed as follows: Prior to the construction of the Devil Canyon dam, a major earthquake and a Probable Maximum Flood (PMF) simultaneously occur at Watana. All normal outflow facilities are inoperable and only the emergency spillway is left to discharge flows from the reservoir. Seismic activity causes the Watana dam to slump to a crest elevation of 2205. The rockfill dam catastrophic failure is initiated when the reservoir level is three above over the crest level (El. 2208).

4.2 - Hypothetical Devil Canyon Dam Failure

Similarly, at Devil Canyon the following combination of unlikely events is assumed: The Devil Canyon arch dam fails during a PMF routed through the Watana reservoir. All of the Devil Canyon dam normal outflow facilities are inoperable and only the emergency spillway discharges flows downstream. The Devil Canyon arch dam failure is initiated when the Devil Canyon reservoir reaches the maximum level or when thirty feet of water is flowing over the arch dam, whichever occurs first. Failure of the saddle dam is not considered since this case would produce lower discharges and water levels below the dam compared to the failure of the arch dam.

4.3 - Hypothetical Domino Type Failures

In this case, the following combination of unlikely events is assumed: This scenario is a combination of the Watana and Devil Canyon failure scenarios. The Watana dam failure triggers a failure of the Devil Canyon arch dam. The Watana dam failure is the same as that postulated in Section 4.1 followed by Devil Canyon arch dam failure as postulated in Section 4.2. The Devil Canyon reservoir level at which catastrophic failure begins is that level which is determined during the analysis of the hypothetical Devil Canyon dam failure.

4.4 - Hypothetical Watana Cofferdam Failure

In this case, the following scenario is assumed: The upstream Watana cofferdam fails during a fifty year flood. The diversion tunnels are sufficiently obstructed to raise the pool level three feet over the dam crest. The cofferdam crest elevation is 1545 and catastrophic failure is initiated at a pool level of 1548.

5 - TECHNICAL METHODOLOGY

The technical methodology employed yields the most accurate results reasonably achievable given the constraints of the problem. This methodology employs state-or-the-art analysis of the problem and is described in the following sections.

5.1 - Dam Break Computer Program Selection

The National Weather Service (NWS) dam break flood forecasting model, "DAMBRK," by Dr. Danny Fread (2) was selected to model the hypothetical dam failures. McMahon (4), United States Geological Survey (5), and others have judged this model to be the best dam break model currently available. The NWS DAMBRK model includes an extremely versatile dynamic flood routing program which solves the Saint Venant equations by implicit finite difference techniques.

The dam break hydrograph is developed internally by the Fread method. The hydrograph is dependent on the final breach shape and the time over which the breach develops. Specific breach input parameters are bottom width, bottom elevation, side slopes, and time of failure (see Figure 5.1).

The program requires minimal river cross section data. Of major importance is river slope, roughness, and valley geometry. DAMBRK interpolates cross sections at intervals as needed and specified by the user. This capability is nearly essential for numerical stability requires that the distance between cross sections be approximately equal to the product of the wave speed and the time step used in the analysis.

To determine the hypothetical failure pool level of the Devil Canyon arch dam discussed in Section 4.2, the Modified Puls method, a storage routing technique based on the continuity principle, was employed to rout the PMF through the Watana and the Devil Canyon reservoirs. This method was also used to determine the point on the PMF hydrograph at which the hypothetical Watana dam failure commences. The Modified Puls routing was accomplished with an Acres' in-house computer program.

5.2 - Breach Dimensions and Time of Failure

The final breach geometry is specified in DAMBRK by bottom width, bottom elevation, and side slopes which must be equal on both sides. The natural channel width and elevation at the sites have been used as breach dimensions. Breach side slopes are assumed to be one horizontal to one vertical for an earth/rockfill dam and the average valley slope for the arch dam.

Development of the breach commences when the pool level is equal to or greater than the assumed failure elevation. Breach progression is directly related to the ratio of the time passed since start of failure to the total duration of failure, or "time of failure". The time of failure pertains to only the catastrophic event and not to the relatively lower antecedant discharges. Dam break hydrographs can be very sensitive to the time of failure. Unfortunately, there is no method available to accurately determine time of failures. Time of failures may be either crudely estimated based on erosion characteristics of the dam and/or determined as that time which would produce a hydraulically instantaneous failure. The unreliability of time of failure prediction necessitated a sensitivity analysis. Watana dam time of failures of 2.5 hours and 3.0 hours were analyzed. These times are based on a conservative estimate of time required to erode approximately 49 million cubic yards of material. Devil Canyon time of failures of 0.4 hours and 0.5 hours were analyzed. A Watana cofferdam time of failure of 0.5 hours was assumed. The domino failure scenario is based on a Watana time of failure of 2.5 hours and a Devil Canyon time of failure of 0.5 hours.

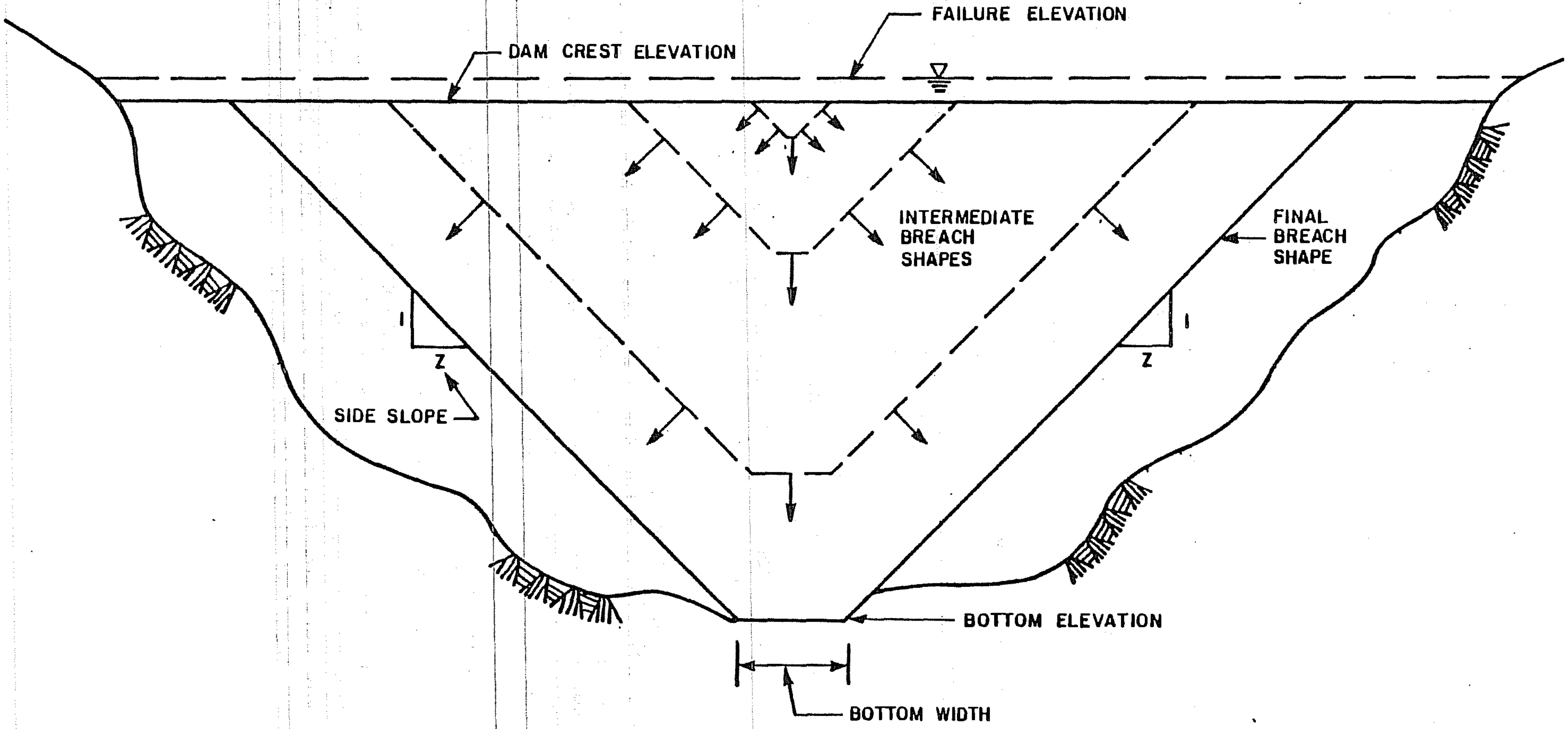
5.3 - Geometric Model

A simplified geometric model representative of the river valley is input into DAMBRK. Cross sections are required only at significant changes in river slope or valley cross section. Eight elevations and corresponding valley widths are input to define each river cross section. Additional sections are created in the model by interpolation. Surface roughness is expressed as the Manning coefficient "n" and input for each reach defined by the original sections.

The majority of cross section information was taken from United States Geological Survey quadrangle maps with a horizontal scale of 1:63360 and 100 foot contour intervals upstream of the Town of Chase and 50 foot intervals downstream of Chase. More detailed river valley topographical information is available only in the vicinity of Devil Canyon and Watana.

To define the downstream cross section geometry it is desirable to have more detailed information than currently available. This is especially true in the vicinity of Talkeetna where the river valley width is in the range of two to three miles and only 50 foot contour intervals are available. Nevertheless, the available topographical information is sufficient to analyze flood waves with reasonable accuracy.

The Manning coefficients were predicted for the reaches of the Susitna River. Manning's coefficient calculations for the over bank area are based on bottom friction and drag from partially submerged obstructions (6). Composite "n" values were determined using the assumption of equal velocity across the section (1). Preliminary DAMBRK runs showed that in a few reaches the flow regime changed with time from subcritical to supercritical and back to subcritical as the dam break flood wave passed through a reach. At numerous sections, the Froude number became so large that mathematical nonconvergence occurred in the computer run or the computed flow area at a cross section became zero. To eliminate modeling problems due to supercritical flow in a subcritical run, it is common practice to either alter the cross section geometry or increase the "n" value (3). Thus, in a number of reaches, the "n" values were increased to values above the predicted "n" value. The artifically high "n" values tend to reduce the speed of the wave and increase the depth of flow in the reach. The DAMBRK output has been adjusted slightly in an attempt to smooth errors created by computer modeling limitations.



BREACH DEFINITION SKETCH

FIGURE 5.1

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6 - ANALYSES OF DAM BREAK FLOOD WAVES

Dam break hydrographs have been dynamically routed down the Susitna River to the confluence of Trapper Creek which is approximately 5 miles downstream from Talkeetna. Peak flood levels, peak discharges, and time to peak were determined along the river. The following sections summarize the study results and discuss sensitivity of the analysis to time of failure assumed.

Peak dam break flood levels are compared to the PMF and 50 year flood levels at selected cross sections and shown graphically in Figures 6.1, 6.2 and 6.3.

6.1 - Watana Failure Analyses

The hypothetical Watana dam break was analyzed for failure times of 3.0 hours and 2.5 hours. The Watana dam break hydrograph superposed on the PMF hydrograph is shown in Figure 6.4. The Watana dam break hydrograph at Watana and Talkeetna is shown in Figure 6.5. Maximum stage, flow rate, velocity, and time to peak stage are given in Table 6.1 at six locations along the Susitna River.

6.2 - Devil Canyon Failure Analyses

The hypothetical Devil Canyon dam break was analyzed for failure times of 0.5 hours and 0.4 hours. The Devil Canyon dam break hydrograph at Devil Canyon and Talkeetna is shown in Figure 6.6. Maximum stage, flow rates, velocities, and times to peak stage are given in Table 6.2.

6.3 - Domino Failure Analyses

The hypothetical domino type failure analysis is based on failure times of 2.5 hours and 0.5 hours at Watana and Devil Canyon, respectively. The dam break hydrograph at the Devil Canyon dam and Talkeetna is shown in Figure 6.7. Maximum stage, flow rates, velocities, and times to peak stage are given in Table 6.3.

6.4 - Watana Cofferdam Failure Analysis

The hypothetical Watana cofferdam failure analysis is based on a failure time of 0.5 hours. The Watana cofferdam hydrograph at Watana and Talkeetna is shown in Figure 6.8. Maximum stage, flow rates, velocities, and times to peak stage are given in Table 6.4.

6.5 - Sensitivity Analysis Discussion

The sensitivity analysis conducted revealed that the failure times chosen give results not significantly different from those for hydraulically instantanous failure times. Both the Devil Canyon and Watana peak discharges increased only slightly with reduced failure times. Differences in downstream effects are not discernible over the range of failure times tested. However, since much longer failure times would be outside of the hydraulically instantanous failure range, they should significantly reduce the downstream affects of dam failure.

TABLE 6.1: WATANA DAM BREAK ANALYSES SUMMARY TABLE

Location	Maximum Stage (ft)		Maximum Flow (cfs)		Maximum Velocity (fps)		Time to Peak Stage (hr)		PMF Stage (ft)
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	
Watana	N.A.	N.A.	42,624,000	40,464,000	76	73	N.A.	N.A.	N.A.
Indian River	126	125	30,121,000	29,390,000	63	63	3.9	4.3	22
Gold Creek	179	177	29,980,000	29,239,000	40	39	4.2	4.6	31
Curry	205	203	27,939,000	27,439,000	62	62	4.5	4.9	53
Talkeetna	77	77	26,331,000	25,992,000	16	17	5.4	5.7	25
Trapper Creek	85	85	26,175,000	25,910,000	21	21	5.9	6.2	15

(1) 2.5 hour time of failure
(2) 3.0 hour time of failure

TABLE 6.2: DEVIL CANYON DAM BREAK ANALYSES SUMMARY TABLE

Location	Maximum Stage (ft)		Maximum Flow (cfs)		Maximum Velocity (fps)		Time to Peak Stage (hr)		PMF Stage (ft)
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	
Devil Canyon	N.A.	N.A.	11,453,000	10,963,000	60	59	N.A.	N.A.	N.A.
Indian River	73	73	9,054,000	9,116,000	43	43	0.8	0.9	22
Gold Creek	103	103	8,512,000	8,598,000	31	31	0.8	1.0	31
Curry	112	112	6,391,000	6,408,000	37	37	1.9	1.9	53
Talkeetna	42	42	5,271,000	5,274,000	9	9	3.3	3.3	25
Trapper Creek	56	56	4,608,000	4,609,000	8	8	4.1	4.2	15

(1) 0.4 hour time of failure
(2) 0.5 hour time of failure

N.A. - Not Applicable

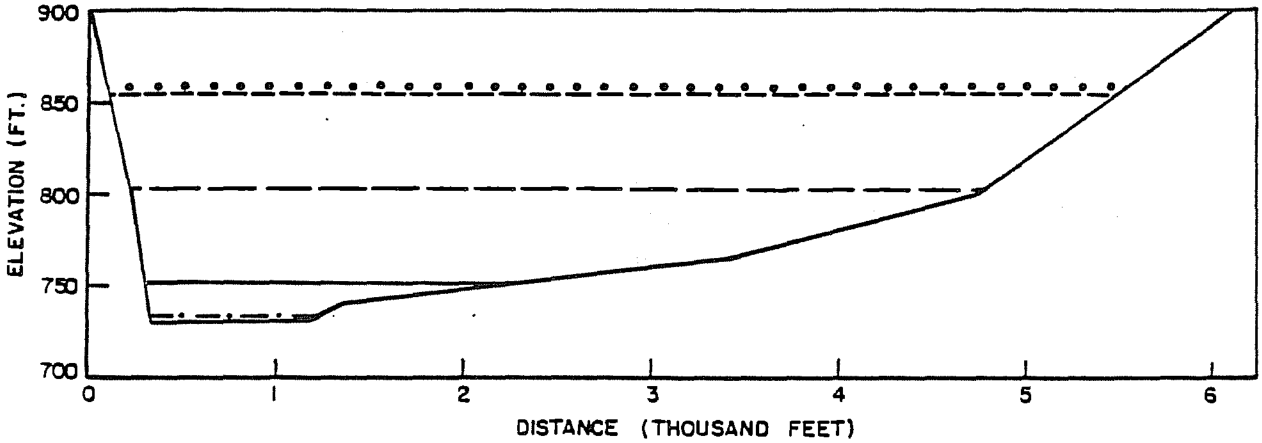
TABLE 6.3: DOMINO FAILURE ANALYSES SUMMARY TABLE

Location	Maximum Stage (ft)	Maximum Flow (cfs)	Maximum Velocity (fps)	Time to Peak Stage (hr)	PMF Stage (ft)
Watana	N.A.	42,587,000	75	N.A.	N.A.
Devil Canyon	579	31,112,000	90	3.6	N.A.
Indian River	128	31,036,000	64	3.8	22
Gold Creek	183	30,853,000	39	4.1	31
Curry	208	28,991,000	63	4.3	53
Talkeetna	79	27,553,000	17	5.2	25
Trapper Creek	86	27,457,000	21	5.7	15

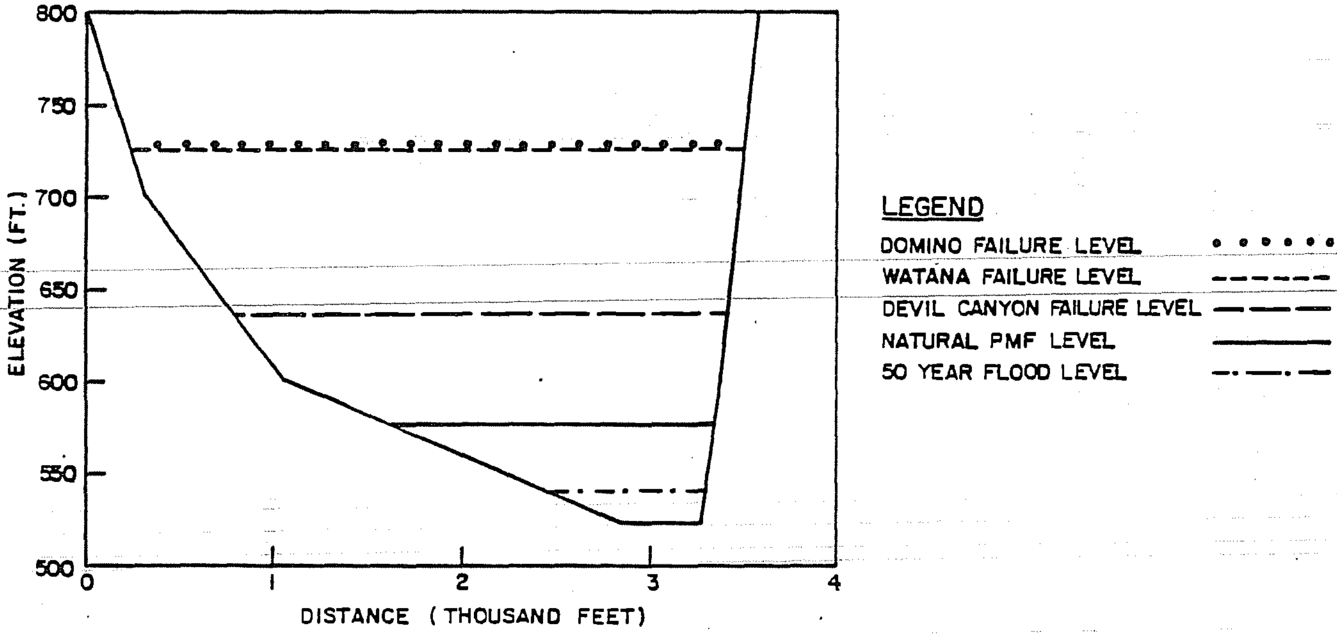
TABLE 6.4: WATANA COFFERDAM FAILURE ANALYSE SUMMARY TABLE

Location	Maximum State (ft)	Maximum Flow (cfs)	Maximum Velocity (fps)	Time to Peak Stage (hr)	50 Yr Flood Stage (ft)
Watana	N.A.	469,800	19	N.A.	N.A.
Indian River	18	321,400	15	5.0	3
Gold Creek	27	323,700	12	5.3	9
Curry	30	298,400	21	7.2	18
Talkeetna	11	290,000	6	10.1	7
Trapper Creek	11	354,900	6	10.8	5

N.A. - Not Applicable



INDIAN RIVER CROSS SECTION



CURRY CROSS SECTION

FIGURE 6.1

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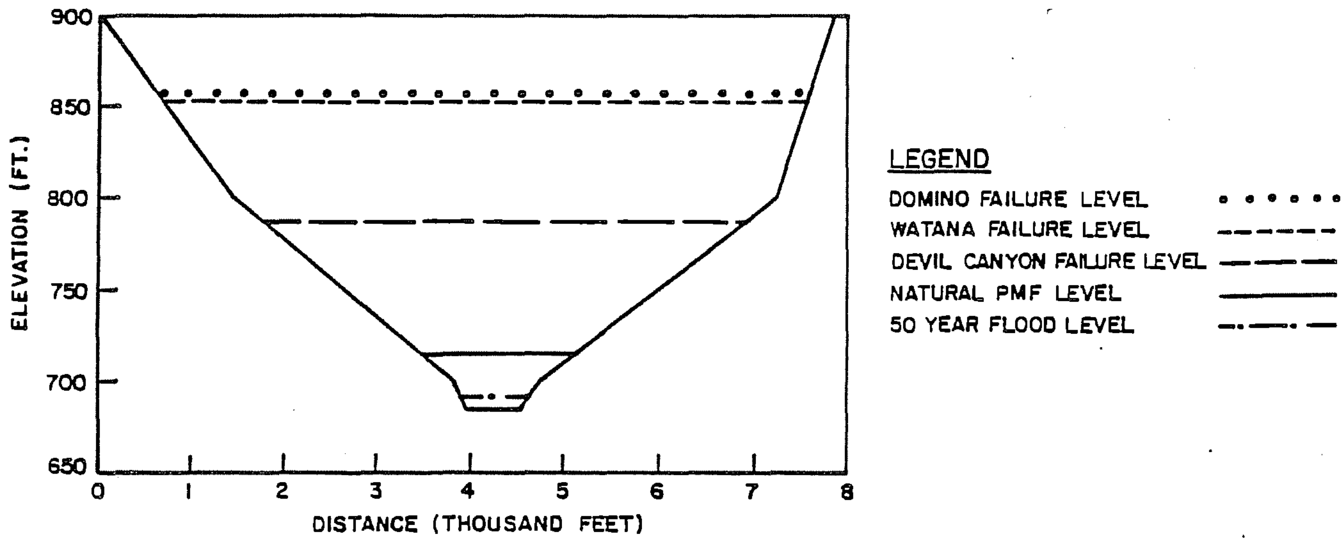
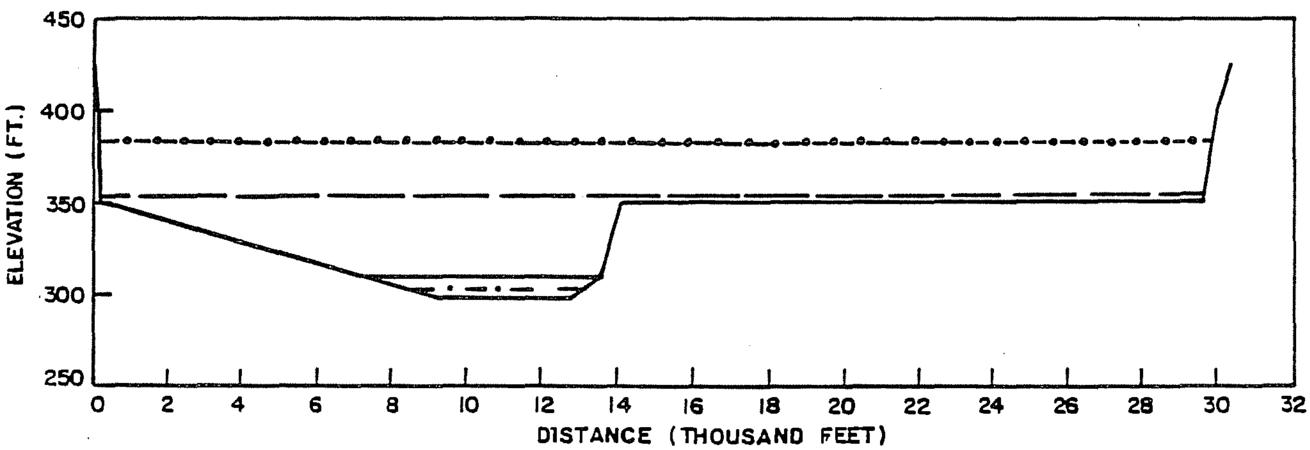


GOLD CREEK CROSS SECTION



TRAPPER CREEK CROSS SECTION

FIGURE 6.2

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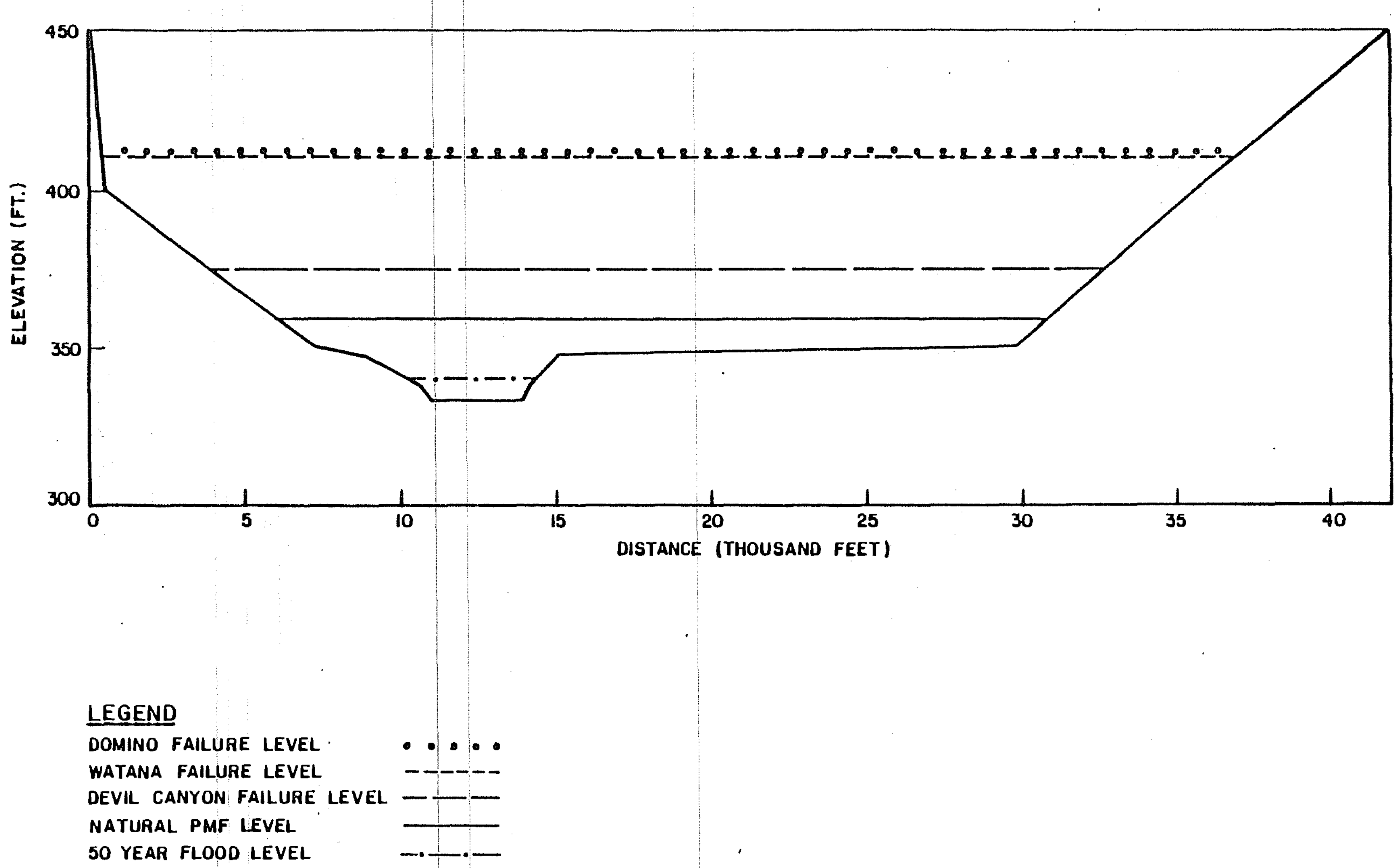

TALKEETNA CROSS SECTION

FIGURE 6.3

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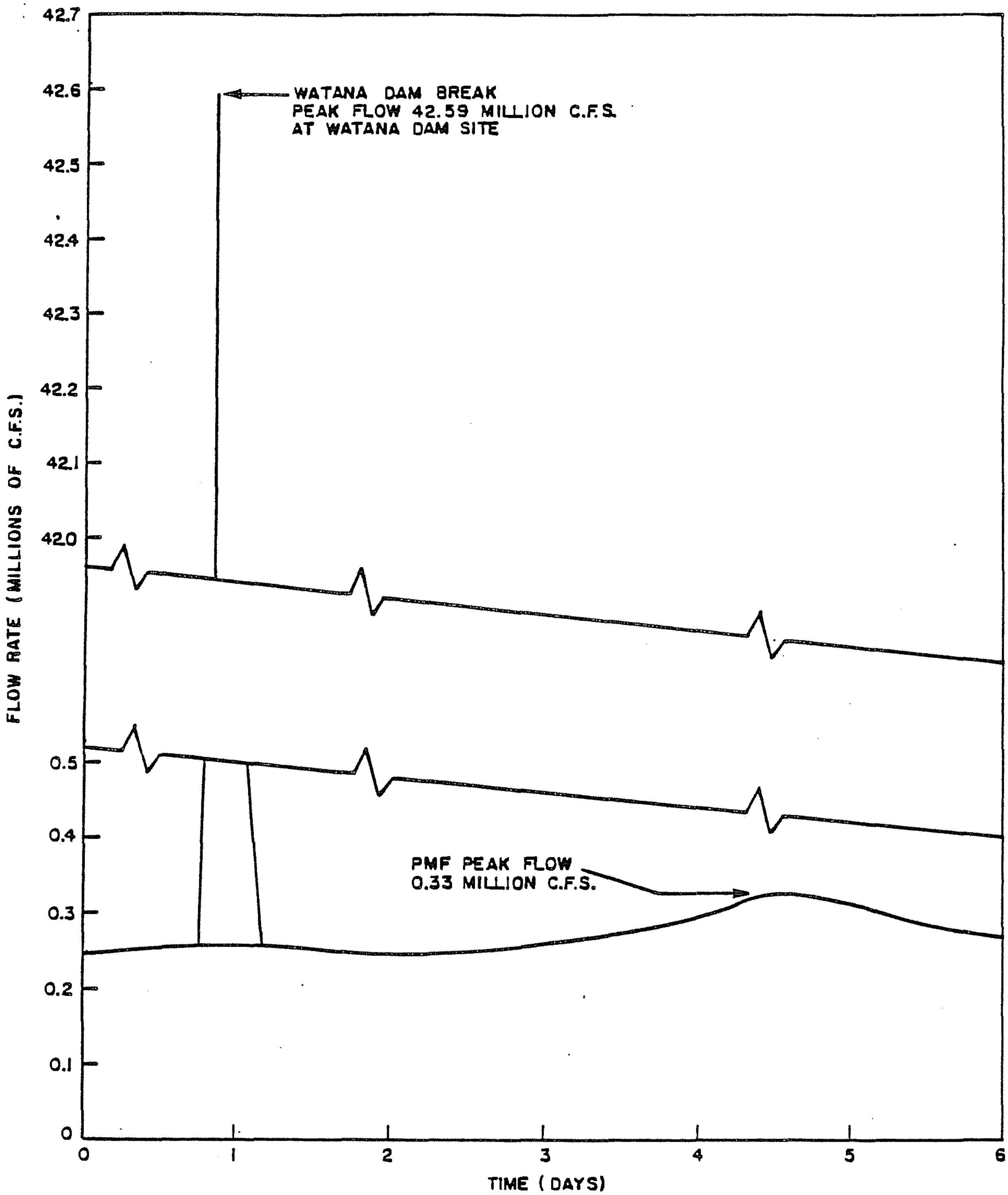

WATANA DAM BREAK HYDROGRAPH
SUPERPOSED ON THE PMF HYDROGRAPH

FIGURE 6.4

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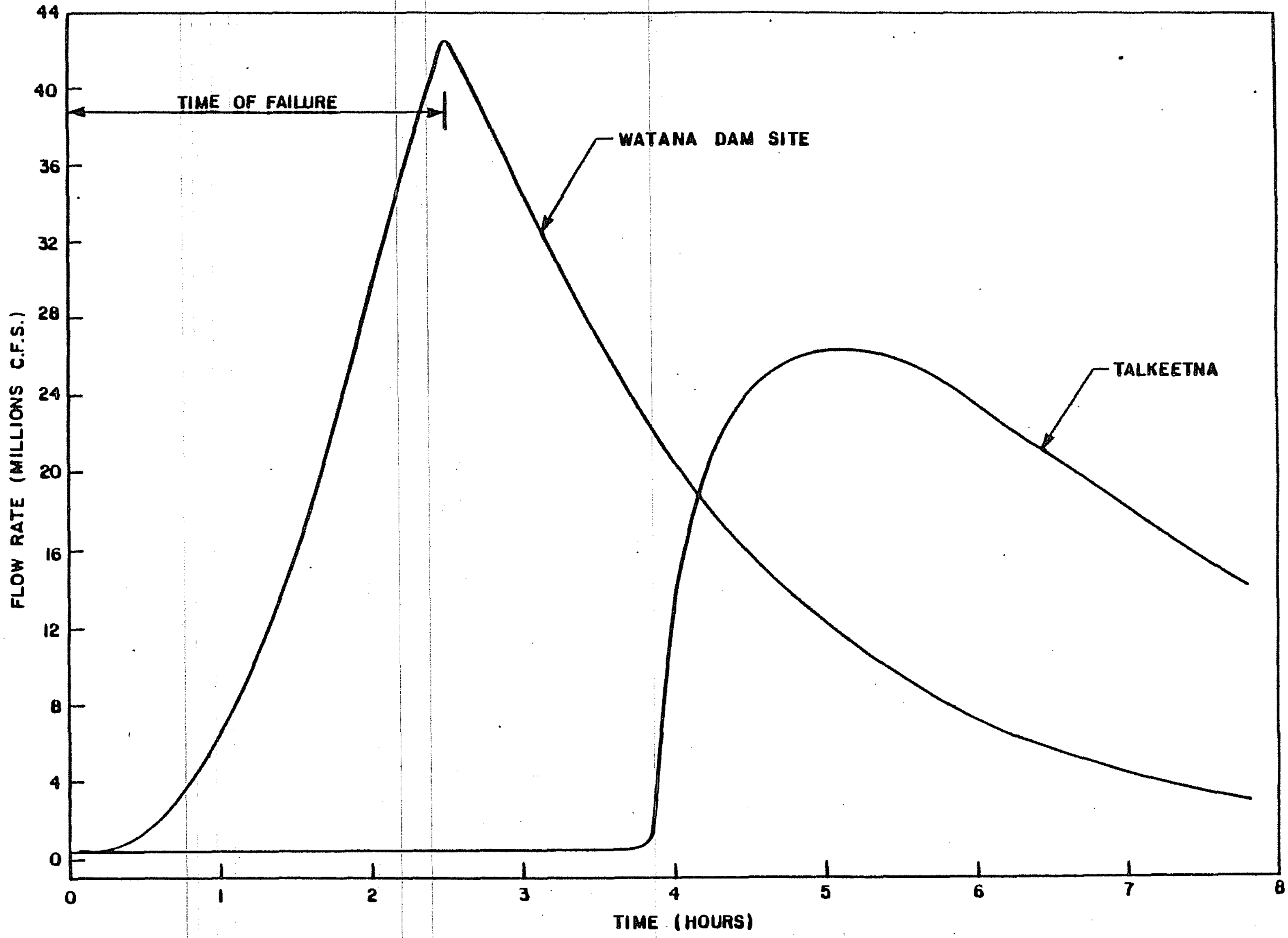
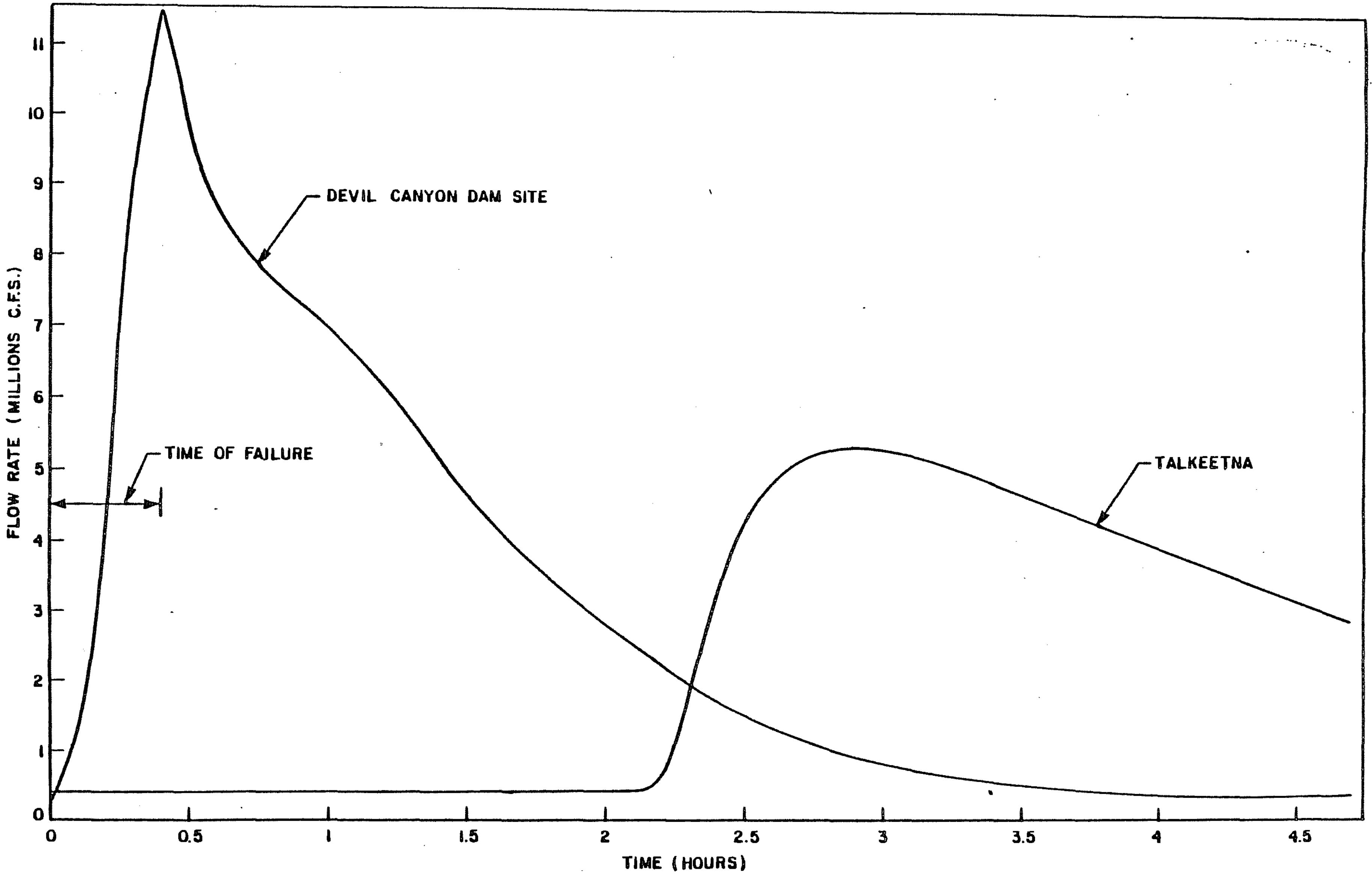


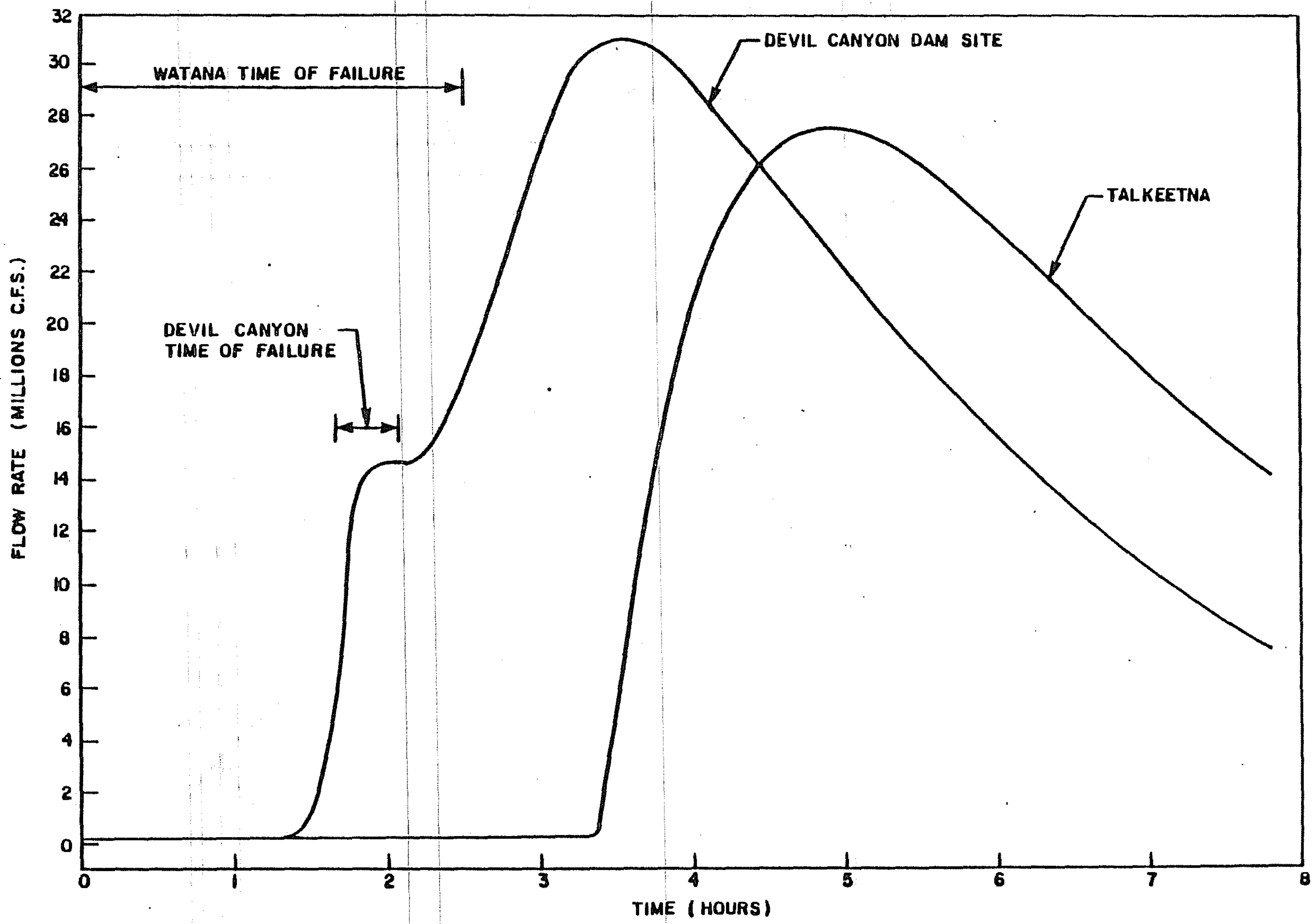
WATANA DAM BREAK HYDROGRAPH

FIGURE 6.5



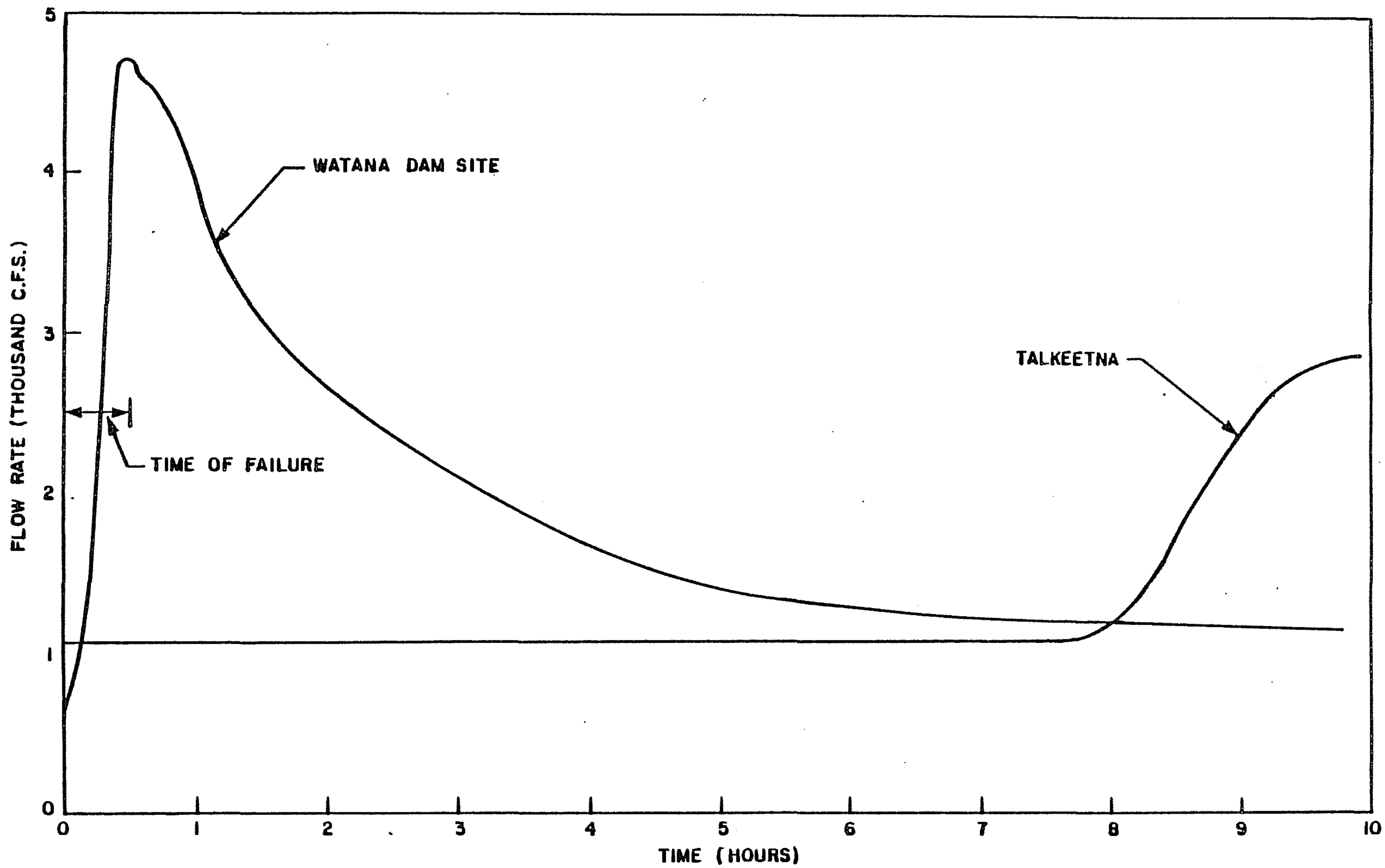
DEVIL CANYON DAM BREAK HYDROGRAPH

FIGURE 6.6



DOMINO DAM BREAK HYDROGRAPH

FIGURE 6.7



WATANA COFFERDAM DAM BREAK HYDROGRAPH

FIGURE 6.8

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7 - CONCLUSIONS

7.1 - Conclusions

The conclusions of this study are:

- The hypothetical dam failure at Watana produces a peak flood level at Talkeetna 52 feet above the level which would be produced by the PMF.

- The hypothetical dam failure at Devil Canyon produces a peak flood level at Talkeetna 17 feet above the level which would be produced by the PMF.

- The hypothetical domino failure downstream effects are not significantly different from those of the Watana dam failing prior to the construction of the Devil Canyon dam.

- The hypothetical failure effects of Devil Canyon dam failing singly are less devastating than those of the failure of Watana singly.

- The Devil Canyon dam will fail if the Watana dam fails.

- Peak discharges and elevations produced by the hypothetical Watana cofferdam failure are less than those which would be produced by the PMF but approximately 4 feet higher than the 50 year flood at Talkeetna.

- A period of approximately 5 hours would elapse between initiation of a failure at Watana and the arrival of the flood peak at Talkeetna. Additional time might be available prior to the failure with appropriate flood and other event warning systems.

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APPENDIX A

EXCERPT FROM DAMBRK: THE NWS DAM-BREAK FLOOD FORECASTING MODEL (2)

DAMBRK: THE NWS DAM-BREAK FLOOD FORECASTING MODEL

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February 10, 1981

1. INTRODUCTION

Catastrophic flash flooding occurs when a dam is breached and the impounded water escapes through the breach into the downstream valley. Usually the response time available for warning is much shorter than for precipitation-runoff floods. Dam failures are often caused by overtopping of the dam due to inadequate spillway capacity during large inflows to the reservoir from heavy precipitation runoff. Dam failures may also be caused by seepage or piping through the dam or along internal conduits, slope embankment slides, earthquake damage and liquefaction of earthen dams from earthquakes, and landslide-generated waves within the reservoir. Middlebrooks (1952) describes earthen dam failures occurring within the U.S. prior to 1951. Johnson and Illes (1976) summarize 300 dam failures throughout the world.

The potential for catastrophic flooding due to dam failures has recently been brought to the Nation's attention by several dam failures such as the Buffalo Creek coal-waste dam, the Toccoa Dam, the Teton Dam, and the Laurel Run Dam. A report by the U.S. Army (1975) gives an inventory of the Nation's approximately 50,000 dams with heights greater than 25 ft. or storage volumes in excess of 50 acre-ft. The report also classifies some 20,000 of these as being "so located that failure of the dam could result in loss of human life and appreciable property damage...."

The National Weather Service (NWS) has the responsibility to advise the public of downstream flooding when there is a failure of a dam. Although this type of flood has many similarities to floods produced by precipitation runoff, the dam-break flood has some very important differences which make it difficult to analyze with the common techniques which have worked so well for the precipitation-runoff floods. To aid NWS flash flood hydrologists who are called upon to forecast the downstream flooding (flood inundation information and warning times) resulting from dam-failures, a numerical model (DAMBRK) has been recently developed. Herein is presented an outline of the model's theoretical basis, its predictive capabilities, and ways of utilizing the model for forecasting of dam-break floods. The DAMBRK model may also be used for a multitude of purposes by planners, designers, and analysts who are concerned with possible future or historical flood inundation mapping due to dam-break floods and/or reservoir spillway floods, or any specified flood hydrograph.

2. MODEL DEVELOPMENT

The DAMBRK model attempts to represent the current state-of-the-art in understanding of dam failures and the utilization of hydrodynamic theory to predict the dam-break wave formation and downstream progression. The model has wide applicability; it can function with various levels of input data ranging from rough estimates to complete data specification; the required data is readily accessible; and it is economically feasible to use, i.e., it requires a minimal computation effort on large computing facilities.

The model consists of three functional parts, namely: (1) description of the dam failure mode, i.e., the temporal and geometrical description of the breach; (2) computation of the time history (hydrograph) of the outflow through the breach as affected by the breach description, reservoir inflow, reservoir storage characteristics, spillway outflows, and downstream tailwater elevations; and (3) routing of the outflow hydrograph through the downstream valley in order to determine the changes in the hydrograph due to valley storage, frictional resistance, downstream bridges or dams, and to determine the resulting water surface elevations (stages) and flood-wave travel times.

DAMBRK is an expanded version of a practical operational model first presented in 1977 by the author (Fread, 1977). That model was based on previous work by the author on modeling breached dams (Fread and Harbaugh, 1973) and routing of flood waves (Fread, 1974, 1976). There have been a number of other operational dam-break models that have appeared recently in the literature, e.g., Price, et al. (1977), Gundlach and Thomas (1977), Thomas (1977), Keefer and Simons (1977), Chen and Druffel (1977), Balloffet, et al. (1974), Balloffet (1977), Brown and Rogers (1977), Rajar (1978), Brevard and Theurer (1979). DAMBRK differs from each of these models in the treatment of the breach formation, the outflow hydrograph generation, and the downstream flood routing.

6. SUMMARY AND CONCLUSIONS

A dam-break flood forecasting model (DAMBRK) is described and applied to some actual dam-break flood waves. The model consists of a breach component which utilizes simple parameters to provide a temporal and geometrical description of the breach. A second component computes the reservoir outflow hydrograph resulting from the breach via a broad-crested weir-flow approximation, which includes effects of submergence from downstream tailwater depths and corrections for approach velocities. Also, the effects of storage depletion and upstream inflows on the computed outflow hydrograph are accounted for through storage routing within the reservoir. The third component consists of a dynamic routing technique for determining the modifications to the dam-break flood wave as it advances through the downstream valley, including its travel time and resulting water surface elevations. The dynamic routing component is based on a weighted, four-point non-linear finite difference solution of the one-dimensional equations of unsteady flow which allows variable time and distance steps to be used in the solution procedure. Provisions are included for routing supercritical flows as well as subcritical flows, and incorporating the effects of downstream obstructions such as road-bridge embankments and/or other dams.

Model data requirements are flexible, allowing minimal data input when it is not available while permitting extensive data to be used when appropriate.

The model was tested on the Teton Dam failure and the Buffalo Creek coal-waste dam collapse. Computed outflow volumes through the breaches coincided with the observed values in magnitude and timing. Observed peak discharges along the downstream valleys were satisfactorily reproduced by the model even though the flood waves were severely attenuated as they advanced downstream. The computed peak flood elevations were within an average of 1.5 ft and 1.8 ft of the observed maximum elevations for Teton and Buffalo Creek, respectively. Both the Teton and Buffalo Creek simulations indicated an important lack of sensitivity of downstream discharge to errors in the forecast of the breach size and timing. Such errors produced significant differences in the peak discharge in the vicinity of the dams; however, the differences were rapidly reduced as the waves advanced downstream. Computational requirements of the model are quite feasible; CPU time (IBM 360/195) was 0.005 second per hr per mile of prototype dimensions for the Teton Dam simulation, and 0.095 second per hr per mile for the Buffalo Creek simulation. The more rapidly rising Buffalo Creek wave (τ = 0.008 hr as compared to Teton where τ = 1.25 hr) required smaller Δt and Δx computational steps; however, total computation times (Buffalo: 19 sec and Teton: 18 sec) were similar since the Buffalo Creek wave attenuated to insignificant values in a shorter distance downstream and in less time than the Teton flood wave.

Suggested ways for using the DAMBRK model in preparation of pre-computed flood information and in real-time forecasting were presented.

APPENDIX B

SAMPLE DAMBRK OUTPUT

TY COSOUT.OUT

1/23/83 RJW

Watana & Devil Canyon Failure

COSOUT.OUT

Watana TF = 2.5

D.C. TF = 0.5

PROGRAM DAMBRK---VERSION-A-09/10/80

ANALYSIS OF THE DOWNSTREAM FLOOD HYDROGRAPH

PRODUCED BY THE DAM BREAK OF

MULTIPLE FAILURES

ON

SUSITNA RIVER

ANALYSIS BY

ACRES AMERICAN INC.
LIBERTY BANK BLD., MAIN AT COURT ST.
BUFFALO, NEW YORK 14202

BASED ON PROCEDURE DEVELOPED BY

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SILVER SPRING, MARYLAND 20910

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*********************************
*********************************
***                           ***
***   SUMMARY OF INPUT DATA   ***
***                           ***
*********************************
*********************************
```

INPUT CONTROL PARAMETERS FOR MULTIPLE FAILURES

PARAMETER	VARIABLE	VALUE
NUMBER OF DYNAMIC ROUTING REACHES	KKN	1
TYPE OF RESERVOIR ROUTING	KUI	1
MULTIPLE DAM INDICATOR	MULDAM	2
PRINTING INSTRUCTIONS FOR INPUT SUMMARY	KDMP	3
NO. OF RESERVOIR INFLOW HYDROGRAPH POINTS	ITEH	5
INTERVAL OF CROSS-SECTION INFO PRINTED OUT WHEN JNK=9	NPRT	0
FLOOD-PLAIN MODEL PARAMETER	KFLP	0
LANDSLIDE PARAMETER	KSL	0

IDAM= 5

IDAM= 12

DAM NUMBER 1

MULTIPLE FAILURES   RESERVOIR AND BREACH PARAMETERS

PARAMETER	UNITS	VARIABLE	VALUE
ELEVATION OF WATER SURFACE	FT	YO	2208.01
SIDE SLOPE OF BREACH		Z	1.00
ELEVATION OF BOTTOM OF BREACH	FT	YBMIN	1460.00
WIDTH OF BASE OF BREACH	FT	BB	420.00
TIME TO MAXIMUM BREACH SIZE	HR	TFH	2.50
ELEVATION OF WATER WHEN BREACHED	FT	HF	2208.00
ELEVATION OF TOP OF DAM	FT	HD	2205.00
ELEVATION OF UNCONTROLLED SPILLWAY CREST	FT	HSP	0.00
ELEVATION OF CENTER OF GATE OPENINGS	FT	HGT	0.00
DISCHARGE COEF. FOR UNCONTROLLED SPILLWAY		CS	0.00
DISCHARGE COEF. FOR GATE FLOW		CG	0.00
DISCHARGE COEF. FOR UNCONTROLLED WEIR FLOW		CDO	6720.00
DISCHARGE THRU TURBINES	CFS	QT	326000.00

DAM NUMBER 2

MULTIPLE FAILURES   RESERVOIR AND BREACH PARAMETERS

PARAMETER	UNITS	VARIABLE	VALUE
ELEVATION OF WATER SURFACE	FT	YO	1455.00
SIDE SLOPE OF BREACH		Z	1.34
ELEVATION OF BOTTOM OF BREACH	FT	YBMIN	907.00
WIDTH OF BASE OF BREACH	FT	BB	120.00
TIME TO MAXIMUM BREACH SIZE	HR	TFH	0.50

ELEVATION OF WATER WHEN BREACHED	FT	HF	1475.90
ELEVATION OF TOP OF DAM	FT	HD	1465.00
ELEVATION OF UNCONTROLLED SPILLWAY CREST	FT	HSP	1470.00
ELEVATION OF CENTER OF GATE OPENINGS	FT	HGT	0.00
DISCHARGE COEF. FOR UNCONTROLLED SPILLWAY		CS	2900.00
DISCHARGE COEF. FOR GATE FLOW		CG	0.00
DISCHARGE COEF. FOR UNCONTROLLED WEIR FLOW		CDO	4277.50
DISCHARGE THRU TURBINES	CFS	QT	160500.00

DHF(INTERVAL BETWEEN INPUT HYDROGRAPH ORDINATES) = 0.00 HRS.

TEH(TIME AT WHICH COMPUTATIONS TERMINATE) = 8.00 HRS.

INFLOW HYDROGRAPH TO MULTIPLE FAILURES
****

252743. 255000. 257000. 257500. 258000.

TIME OF INFLOW HYDROGRAPH ORDINATES

0.00 2.00 4.00 6.00 15.00

CROSS-SECTIONAL PARAMETERS FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	VARIABLE	VALUE
NUMBER OF CROSS-SECTIONS	NS	24
MAXIMUM NUMBER OF TOP WIDTHS	NCS	8
NUMBER OF CROSS-SECTIONAL HYDROGRAPHS TO PLOT	NTT	5
TYPE OF OUTPUT OTHER THAN HYDROGRAPH PLOTS	JNK	4
CROSS-SECTIONAL SMOOTHING PARAMETER	KSA	0
DOWNSTREAM SUPERCRITICAL OR NOT	KSUPC	0
NO. OF LATERAL INFLOW HYDROGRAPHS	LQ	7

NUMBER OF CROSS-SECTION WHERE HYDROGRAPH DESIRED
(MAX NUMBER OF HYDROGRAPHS = 6)
****

6 12 16 18 23

CROSS-SECTIONAL VARIABLES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	UNITS	VARIABLE
LOCATION OF CROSS-SECTION	MI	XS(I)
ELEVATION (MSL) OF FLOODING AT CROSS-SECTION	FT	FSTG(I)
ELEV CORRESPONDING TO EACH TOP WIDTH	FT	HS(K,I)
TOP WIDTH CORRESPONDING TO EACH ELEV (ACTIVE FLOW PORTION)	FT	BS(K,I)
TOP WIDTH CORRESPONDING TO EACH ELEV	FT	BSS(K,I)

```
SURFACE AREA CORRESPONDING TO EACH ELEV     ACRES    DSA(K,I)
        (ACTIVE FLOW PORTION)
SURFACE AREA CORRESPONDING TO EACH ELEV     ACRES    SSA(K,I)
        (OFF-CHANNEL PORTION)

NUMBER OF CROSS-SECTION                               I
NUMBER OF ELEVATION LEVEL                             K
```

```
CROSS-SECTION NUMBER  1
*************************

XS(I) =   0.000   FSTG(I) =     0.00          XSL(I) =     0.0          XSR(I) =      0.0

HS  ...   2200.0  2230.0  2380.0  2585.0  2643.0  2765.0  2862.0  3060.0

BS  ...    792.8   987.9  1963.5  3296.8  3674.0  4467.5  5098.4  6386.2

BSS ...      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER  2
*************************

XS(I) =   3.784   FSTG(I) =     0.00          XSL(I) =     0.0          XSR(I) =      0.0

HS  ...   2160.0  2190.0  2340.0  2545.0  2603.0  2725.0  2822.0  3020.0

BS  ...    792.8   987.9  1963.5  3296.8  3674.0  4467.5  5098.4  6386.2

BSS ...      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER  3
*************************

XS(I) =  35.000   FSTG(I) =     0.00          XSL(I) =     0.0          XSR(I) =      0.0

HS  ...   1830.0  1860.0  2010.0  2215.0  2273.0  2395.0  2492.0  2690.0

BS  ...    792.8   987.9  1963.5  3296.8  3674.0  4467.5  5098.4  6386.2

BSS ...      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
```

CROSS-SECTION NUMBER 4
****

XS(I) = 63.000 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1465.0	1495.0	1645.0	1850.0	1908.0	2030.0	2127.0	2325.0
BS ...	792.8	1114.0	2723.0	4921.0	5543.0	6852.0	7892.0	10015.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 5
****

XS(I) = 70.500 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1460.0	1490.0	1640.0	1845.0	1903.0	2025.0	2122.0	2320.0
BS ...	250.0	350.0	825.0	1340.0	1830.0	2300.0	2920.0	4800.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 6
****

XS(I) = 71.000 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1455.0	1500.0	1600.0	1700.0	1800.0	2000.0	2100.0	2200.0
BS ...	370.0	725.0	980.0	1550.0	1720.0	2560.0	3200.0	5680.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 7
****

XS(I) = 73.300 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1450.0	1500.0	1550.0	1600.0	1700.0	1800.0	1900.0	2000.0
BS ...	260.0	1680.0	2130.0	2785.0	3700.0	4440.0	5325.0	6430.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 8
****

XS(I) = 78.200 FSTO(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1379.0	1400.0	1500.0	1600.0	1700.0	1800.0	1900.0	2000.0
BS ...	475.0	2120.0	3395.0	4175.0	5010.0	5800.0	6940.0	8175.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 9
****

XS(I) = 85.900 FSTO(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1265.0	1300.0	1400.0	1500.0	1600.0	1700.0	1800.0	1900.0
BS ...	785.0	990.0	1115.0	1590.0	1960.0	2850.0	3375.0	4225.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 10
****

XS(I) = 91.500 FSTO(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1122.0	1200.0	1300.0	1400.0	1500.0	1600.0	1700.0	1900.0
BS ...	325.0	520.0	890.0	1150.0	1590.0	2640.0	3275.0	4545.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 11
****

XS(I) = 97.700 FSTO(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	995.0	1100.0	1200.0	1300.0	1400.0	1500.0	1800.0	1900.0
BS ...	310.0	535.0	845.0	1125.0	1530.0	1900.0	4165.0	5210.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 12
****

XS(I) = 101.800   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	907.0	1100.0	1200.0	1300.0	1400.0	1500.0	1600.0	1700.0
BS ...	265.0	565.0	765.0	960.0	1400.0	2650.0	3240.0	4120.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 13
****

XS(I) = 102.200   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	902.0	1100.0	1200.0	1300.0	1400.0	1500.0	1600.0	1700.0
BS ...	265.0	565.0	765.0	960.0	1400.0	2650.0	3240.0	4120.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 14
****

XS(I) = 103.800   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	880.0	950.0	1000.0	1050.0	1100.0	1200.0	1300.0	1400.0
BS ...	370.0	530.0	630.0	1100.0	1570.0	1900.0	2210.0	2550.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 15
****

XS(I) = 109.000   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	800.0	825.0	850.0	875.0	900.0	1000.0	1100.0	1200.0
BS ...	1575.0	1865.0	2110.0	2600.0	3060.0	3540.0	4865.0	5385.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 16
****

XS(I) = 112.900 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	730.0	745.0	800.0	850.0	900.0	950.0	1000.0	1100.0
BS ...	1695.0	3100.0	4550.0	5350.0	6125.0	6425.0	6750.0	7470.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 17
****

XS(I) = 119.900 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	635.0	650.0	675.0	700.0	750.0	800.0	850.0	900.0
BS ...	2220.0	2770.0	3720.0	4650.0	4800.0	4950.0	5225.0	5500.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 18
****

XS(I) = 130.800 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	523.0	540.0	550.0	575.0	600.0	650.0	700.0	750.0
BS ...	400.0	490.0	550.0	1465.0	2315.0	2735.0	3165.0	3380.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 19
****

XS(I) = 135.200 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	480.0	490.0	500.0	525.0	550.0	600.0	650.0	700.0
BS ...	660.0	825.0	970.0	1340.0	1675.0	2365.0	2915.0	3455.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 20
****

XS(I) = 141.300 FSTB(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	440.0	445.0	450.0	475.0	500.0	525.0	550.0	600.0
BS ...	1155.0	1250.0	1400.0	2445.0	3475.0	3600.0	3700.0	4005.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 21
****

XS(I) = 144.000 FSTB(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	412.0	416.0	420.0	432.0	448.0	457.0	482.0	557.0
BS ...	720.0	760.0	800.0	3150.0	3260.0	3370.0	3600.0	4665.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 22
****

XS(I) = 148.600 FSTB(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	365.0	372.0	380.0	390.0	400.0	415.0	430.0	450.0
BS ...	1010.0	1500.0	2100.0	6000.0	10000.0	15900.0	17200.0	19000.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 23
****

XS(I) = 152.800 FSTB(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	333.0	338.0	345.0	355.0	365.0	375.0	385.0	400.0
BS ...	2950.0	3600.0	8000.0	13700.0	19000.0	24500.0	29500.0	33200.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

```
CROSS-SECTION NUMBER 24
************************

XS(I) = 157.700   FSTG(I) =     0.00          XSL(I) =      0.0          XSR(I) =      0.0

HS  ...     298.0    308.0    320.0    335.0    350.0    365.0    380.0    400.0

BS  ...    3500.0   6000.0   8200.0  11000.0  17000.0  23000.0  29000.0  29750.0

BSS ...       0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0



MANNING N ROUGHNESS COEFFICIENTS FOR THE GIVEN REACHES
      (CM(K,I),K=1,NCS) WHERE I = REACH NUMBER
**********************************************************

REACH  1 ... 0.045   0.045   0.045   0.045   0.045   0.045   0.045   0.045

REACH  2 ... 0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.035

REACH  3 ... 0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.035

REACH  4 ... 0.035   0.035   0.035   0.035   0.035   0.035   0.035   0.035

REACH  5 ... 0.045   0.045   0.045   0.045   0.045   0.045   0.045   0.045

REACH  6 ... 0.095   0.095   0.095   0.095   0.095   0.095   0.095   0.095

REACH  7 ... 0.089   0.089   0.089   0.089   0.089   0.089   0.089   0.089

REACH  8 ... 0.075   0.075   0.075   0.075   0.075   0.075   0.075   0.075

REACH  9 ... 0.075   0.075   0.075   0.075   0.075   0.075   0.075   0.075

REACH 10 ... 0.075   0.075   0.075   0.075   0.075   0.075   0.075   0.075

REACH 11 ... 0.070   0.070   0.070   0.070   0.070   0.070   0.070   0.070
```

REACH 12 ...	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
REACH 13 ...	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
REACH 14 ...	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
REACH 15 ...	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
REACH 16 ...	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
REACH 17 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 18 ...	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
REACH 19 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 20 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 21 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 22 ...	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
REACH 23 ...	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060

CROSS-SECTIONAL VARIABLES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	UNITS	VARIABLE
MINIMUM COMPUTATIONAL DISTANCE USED BETWEEN CROSS-SECTIONS	MI	DXM(I)
CONTRACTION - EXPANSION COEFFICIENTS BETWEEN CROSS-SECTIONS		FKC(I)

REACH NUMBER	DXM(I)	FKC(I)
1	3.000	0.000
2	4.000	0.000
3	7.000	0.000
4	8.000	0.200
5	0.500	-0.700
6	0.500	-0.700
7	0.900	0.000
8	1.500	0.000
9	1.500	0.000
10	1.500	0.000
11	1.500	0.000
12	1.500	0.000
13	0.500	0.000
14	1.300	-0.500

15	0.700	0.000
16	0.350	0.000
17	0.520	0.000
18	0.880	0.000
19	0.870	0.000
20	1.350	0.000
21	0.420	-0.700
22	0.250	0.000
23	0.320	0.000

DOWNSTREAM FLOW PARAMETERS FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	UNITS	VARIABLE	VALUE
**	*******	******	*************
MAX DISCHARGE AT DOWNSTREAM EXTREMITY	CFS	QMAXD	0.0
MAX LATERAL OUTFLOW PRODUCING LOSSES	CFS/FT	QLL	0.000
INITIAL SIZE OF TIME STEP	HR	DTHM	0.040
INITIAL WATER SURFACE ELEVATION DOWNSTREAM	FT	YDN	0.00
SLOPE OF CHANNEL DOWNSTREAM OF DAM	FT/MI	SOM	0.00
THETA WEIGHTING FACTOR		THETA	0.00
CONVERGENCE CRITERION FOR STAGE	FT	EPSY	0.100
TIME AT WHICH DAM STARTS TO FAIL	HR	TFI	0.00

LATERAL INFLOW REACH NUMBER

LQX(I)

7

10

14

16

18

20

23

(QL(L, 1),L=1,ITEM)

27000. 27000. 27000. 27000. 27000.

```
        (QL(L, 2),L=1,ITEM)
  27000.    27000.    27000.    27000.    27000.

        (QL(L, 3),L=1,ITEM)
  14000.    14000.    14000.    14000.    14000.

        (QL(L, 4),L=1,ITEM)
  14000.    14000.    14000.    14000.    14000.

        (QL(L, 5),L=1,ITEM)
   6000.     6000.     6000.     6000.     6000.

        (QL(L, 6),L=1,ITEM)
   6000.     6000.     6000.     6000.     6000.

        (QL(L, 7),L=1,ITEM)
 228000.   228000.   228000.   228000.   228000.
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************************************
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***                              ***
***   SUMMARY OF OUTPUT DATA     ***
***                              ***
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CROSS-SECTION NO.	MILE	BOTTOM ELEVATION FEET	REACHNO.	REACH LENGTH MILES	SLOPE FT/MI	MESAGE
1	0.00	2200.00				
2	3.78	2160.00	1	3.78	10.57	
3	35.00	1830.00	2	31.22	10.57	
4	63.00	1465.00	3	28.00	13.04	
5	70.50	1460.00	4	7.50	0.67	
6	71.00	1455.00	5	0.50	10.00	
7	73.30	1450.00	6	2.30	2.17	
8	78.20	1379.00	7	4.90	14.49	
9	85.90	1265.00	8	7.70	14.81	
10	91.50	1122.00	9	5.60	25.54	
11	97.70	995.00	10	6.20	20.48	
12	101.80	907.00	11	4.10	21.46	
13	102.20	902.00	12	0.40	12.50	
14	103.80	880.00	13	1.60	13.75	
15	109.00	800.00	14	5.20	15.38	
16	112.90	730.00	15	3.90	17.95	
17	119.90	635.00	16	7.00	13.57	
18	130.80	523.00	17	10.90	10.28	
19	135.20	480.00	18	4.40	9.77	
20	141.30	440.00	19	6.10	6.56	
21	144.00	412.00	20	2.70	10.37	
22	148.60	365.00	21	4.60	10.22	
23	152.80	333.00	22	4.20	7.62	
24	157.70	298.00	23	4.90	7.14	

NUMBER OF INTERMEDIATE STATIONS (N) = 146 (MAXIMUM ALLOWABLE = 200

RE-NUMBERED VALUES FOR IDAM

IDAM(1) = 14

IDAM(2) = 38

1 252743.00
2 252743.00
3 252743.00
4 252743.00

5	252743.00
6	252743.00
7	252743.00
8	252743.00
9	252743.00
10	252743.00
11	252743.00
12	252743.00
13	252743.00
14	361093.06
15	361093.06
16	361093.06
17	361093.06
18	361093.06
19	361093.06
20	388093.06
21	388093.06
22	388093.06
23	388093.06
24	388093.06
25	388093.06
26	388093.06
27	388093.06
28	388093.06
29	388093.06
30	388093.06
31	388093.06
32	388093.06
33	415093.06
34	415093.06
35	415093.06
36	415093.06
37	415093.06
38	160500.00
39	160500.00
40	160500.00
41	160500.00
42	160500.00
43	174500.00
44	174500.00
45	174500.00
46	174500.00
47	174500.00
48	174500.00
49	174500.00
50	174500.00
51	174500.00
52	188500.00
53	188500.00
54	188500.00
55	188500.00
56	188500.00
57	188500.00
58	188500.00
59	188500.00
60	188500.00
61	188500.00
62	188500.00
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65	188500.00
66	188500.00
67	188500.00
68	188500.00
69	188500.00
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71	188500.00
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78	188500.00
79	188500.00
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83	188500.00
84	188500.00
85	188500.00
86	188500.00
87	188500.00
88	188500.00
89	188500.00
90	188500.00
91	188500.00
92	194500.00
93	194500.00
94	194500.00
95	194500.00
96	194500.00
97	194500.00
98	194500.00
99	194500.00
100	194500.00
101	194500.00
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103	194500.00
104	200500.00
105	200500.00
106	200500.00
107	200500.00
108	200500.00
109	200500.00
110	200500.00
111	200500.00
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127	200500.00
128	200500.00
129	200500.00
130	200500.00
131	200500.00
132	428500.00
133	428500.00
134	428500.00
135	428500.00
136	428500.00

137 428500.00
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140 428500.00
141 428500.00
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143 428500.00
144 428500.00
145 428500.00
146 428500.00

L=146	X(L)=	157.700	YD(L)=	314.18	HO=	316.51	K= 0
L=145	X(L)=	157.373	YD(L)=	316.54	HO=	316.51	K= 2
L=144	X(L)=	157.047	YD(L)=	318.95	HO=	318.86	K= 2
L=143	X(L)=	156.720	YD(L)=	321.40	HO=	321.24	K= 2
L=142	X(L)=	156.393	YD(L)=	323.86	HO=	323.67	K= 3
L=141	X(L)=	156.067	YD(L)=	326.33	HO=	326.13	K= 3
L=140	X(L)=	155.740	YD(L)=	328.80	HO=	328.60	K= 3
L=139	X(L)=	155.413	YD(L)=	331.27	HO=	331.07	K= 3
L=138	X(L)=	155.087	YD(L)=	333.72	HO=	333.53	K= 3
L=137	X(L)=	154.760	YD(L)=	336.16	HO=	335.99	K= 3
L=136	X(L)=	154.433	YD(L)=	338.57	HO=	338.44	K= 2
L=135	X(L)=	154.107	YD(L)=	340.96	HO=	340.87	K= 2
L=134	X(L)=	153.780	YD(L)=	343.32	HO=	343.27	K= 2
L=133	X(L)=	153.453	YD(L)=	345.64	HO=	345.64	K= 2
L=132	X(L)=	153.127	YD(L)=	347.93	HO=	347.98	K= 2
L=131	X(L)=	152.800	YD(L)=	349.65	HO=	350.29	K= 3
L=130	X(L)=	152.538	YD(L)=	349.77	HO=	351.96	K= 4
L=129	X(L)=	152.275	YD(L)=	350.02	HO=	352.71	K= 4
L=128	X(L)=	152.013	YD(L)=	350.52	HO=	352.89	K= 4
L=127	X(L)=	151.750	YD(L)=	351.48	HO=	353.27	K= 4
L=126	X(L)=	151.488	YD(L)=	353.00	HO=	354.00	K= 3
L=125	X(L)=	151.225	YD(L)=	354.96	HO=	355.24	K= 3
L=124	X(L)=	150.963	YD(L)=	357.13	HO=	356.98	K= 3
L=123	X(L)=	150.700	YD(L)=	359.39	HO=	359.05	K= 3
L=122	X(L)=	150.438	YD(L)=	361.68	HO=	361.26	K= 3
L=121	X(L)=	150.175	YD(L)=	364.00	HO=	363.53	K= 3
L=120	X(L)=	149.913	YD(L)=	366.34	HO=	365.84	K= 3
L=119	X(L)=	149.650	YD(L)=	368.71	HO=	368.17	K= 3
L=118	X(L)=	149.388	YD(L)=	371.11	HO=	370.52	K= 3
L=117	X(L)=	149.125	YD(L)=	373.54	HO=	372.91	K= 3
L=116	X(L)=	148.863	YD(L)=	376.00	HO=	375.32	K= 3
L=115	X(L)=	148.600	YD(L)=	378.50	HO=	377.77	K= 3
L=114	X(L)=	148.140	YD(L)=	384.29	HO=	382.95	K= 3
L=113	X(L)=	147.680	YD(L)=	389.73	HO=	388.45	K= 4
L=112	X(L)=	147.220	YD(L)=	395.21	HO=	394.06	K= 4
L=111	X(L)=	146.760	YD(L)=	400.39	HO=	399.52	K= 3
L=110	X(L)=	146.300	YD(L)=	405.41	HO=	404.85	K= 3
L=109	X(L)=	145.840	YD(L)=	410.35	HO=	409.95	K= 3
L=108	X(L)=	145.380	YD(L)=	415.28	HO=	414.93	K= 3
L=107	X(L)=	144.920	YD(L)=	420.22	HO=	419.87	K= 3
L=106	X(L)=	144.460	YD(L)=	425.18	HO=	424.80	K= 3
L=105	X(L)=	144.000	YD(L)=	430.18	HO=	429.75	K= 3
L=104	X(L)=	142.650	YD(L)=	443.72	HO=	444.03	K= 3
L=103	X(L)=	141.300	YD(L)=	455.49	HO=	457.95	K= 3
L=102	X(L)=	140.429	YD(L)=	462.38	HO=	462.32	K= 2
L=101	X(L)=	139.557	YD(L)=	468.74	HO=	467.51	K= 3
L=100	X(L)=	138.686	YD(L)=	475.10	HO=	474.13	K= 3
L= 99	X(L)=	137.814	YD(L)=	481.50	HO=	480.50	K= 3
L= 98	X(L)=	136.943	YD(L)=	487.96	HO=	486.88	K= 3
L= 97	X(L)=	136.071	YD(L)=	494.49	HO=	493.30	K= 3
L= 96	X(L)=	135.200	YD(L)=	501.12	HO=	499.80	K= 3
L= 95	X(L)=	134.320	YD(L)=	508.98	HO=	509.26	K= 3
L= 94	X(L)=	133.440	YD(L)=	518.85	HO=	517.95	K= 3
L= 93	X(L)=	132.560	YD(L)=	528.71	HO=	526.81	K= 3
L= 92	X(L)=	131.680	YD(L)=	538.76	HO=	536.68	K= 3
L= 91	X(L)=	130.800	YD(L)=	549.10	HO=	516.64	K= 3

L= 90	X(L)= 130.255	YD(L)= 555.11	HO= 553.65	K= 3
L= 89	X(L)= 129.710	YD(L)= 559.09	HO= 560.51	K= 3
L= 88	X(L)= 129.165	YD(L)= 562.63	HO= 565.50	K= 4
L= 87	X(L)= 128.620	YD(L)= 566.19	HO= 569.26	K= 4
L= 86	X(L)= 128.075	YD(L)= 569.98	HO= 572.81	K= 4
L= 85	X(L)= 127.530	YD(L)= 574.06	HO= 576.40	K= 3
L= 84	X(L)= 126.985	YD(L)= 578.42	HO= 580.42	K= 4
L= 83	X(L)= 126.440	YD(L)= 583.03	HO= 584.64	K= 3
L= 82	X(L)= 125.895	YD(L)= 587.83	HO= 589.13	K= 3
L= 81	X(L)= 125.350	YD(L)= 592.74	HO= 593.83	K= 3
L= 80	X(L)= 124.805	YD(L)= 597.75	HO= 598.68	K= 3
L= 79	X(L)= 124.260	YD(L)= 602.82	HO= 603.65	K= 3
L= 78	X(L)= 123.715	YD(L)= 607.95	HO= 608.69	K= 3
L= 77	X(L)= 123.170	YD(L)= 613.13	HO= 613.79	K= 3
L= 76	X(L)= 122.625	YD(L)= 618.34	HO= 618.94	K= 3
L= 75	X(L)= 122.080	YD(L)= 623.59	HO= 624.14	K= 3
L= 74	X(L)= 121.535	YD(L)= 628.87	HO= 629.37	K= 3
L= 73	X(L)= 120.990	YD(L)= 634.17	HO= 634.63	K= 3
L= 72	X(L)= 120.445	YD(L)= 639.49	HO= 639.92	K= 3
L= 71	X(L)= 119.900	YD(L)= 644.83	HO= 645.23	K= 3
L= 70	X(L)= 119.550	YD(L)= 649.42	HO= 649.71	K= 3
L= 69	X(L)= 119.200	YD(L)= 654.24	HO= 654.25	K= 2
L= 68	X(L)= 118.850	YD(L)= 659.05	HO= 658.95	K= 2
L= 67	X(L)= 118.500	YD(L)= 663.87	HO= 663.77	K= 2
L= 66	X(L)= 118.150	YD(L)= 668.69	HO= 668.59	K= 2
L= 65	X(L)= 117.800	YD(L)= 673.51	HO= 673.41	K= 2
L= 64	X(L)= 117.450	YD(L)= 678.33	HO= 678.22	K= 2
L= 63	X(L)= 117.100	YD(L)= 683.15	HO= 683.04	K= 2
L= 62	X(L)= 116.750	YD(L)= 687.97	HO= 687.86	K= 2
L= 61	X(L)= 116.400	YD(L)= 692.80	HO= 692.69	K= 2
L= 60	X(L)= 116.050	YD(L)= 697.63	HO= 697.51	K= 2
L= 59	X(L)= 115.700	YD(L)= 702.45	HO= 702.34	K= 2
L= 58	X(L)= 115.350	YD(L)= 707.28	HO= 707.16	K= 2
L= 57	X(L)= 115.000	YD(L)= 712.11	HO= 711.99	K= 2
L= 56	X(L)= 114.650	YD(L)= 716.95	HO= 716.82	K= 2
L= 55	X(L)= 114.300	YD(L)= 721.78	HO= 721.65	K= 2
L= 54	X(L)= 113.950	YD(L)= 726.62	HO= 726.49	K= 2
L= 53	X(L)= 113.600	YD(L)= 731.45	HO= 731.32	K= 2
L= 52	X(L)= 113.250	YD(L)= 736.29	HO= 736.16	K= 2
L= 51	X(L)= 112.900	YD(L)= 741.13	HO= 741.00	K= 2
L= 50	X(L)= 112.120	YD(L)= 756.31	HO= 755.09	K= 3
L= 49	X(L)= 111.340	YD(L)= 769.99	HO= 769.72	K= 2
L= 48	X(L)= 110.560	YD(L)= 784.34	HO= 784.15	K= 2
L= 47	X(L)= 109.780	YD(L)= 798.42	HO= 798.16	K= 2
L= 46	X(L)= 109.000	YD(L)= 812.65	HO= 812.38	K= 2
L= 45	X(L)= 107.700	YD(L)= 841.30	HO= 832.54	K= 4
L= 44	X(L)= 106.400	YD(L)= 860.86	HO= 856.97	K= 3
L= 43	X(L)= 105.100	YD(L)= 887.07	HO= 881.08	K= 3
L= 42	X(L)= 103.800	YD(L)= 913.94	HO= 903.97	K= 3
L= 41	X(L)= 103.267	YD(L)= 928.34	HO= 917.84	K= 4
L= 40	X(L)= 102.733	YD(L)= 939.23	HO= 932.14	K= 4
L= 39	X(L)= 102.200	YD(L)= 949.73	HO= 914.79	K= 3
L= 38	X(L)= 101.800	YD(L)= 949.73	HO= 993.73	K= 0
L= 37	X(L)= 99.750	YD(L)= 999.41	HO= 993.73	K= 3
L= 36	X(L)= 97.700	YD(L)= 1060.12	HO= 1040.57	K= 4
L= 35	X(L)= 96.150	YD(L)= 1089.43	HO= 1083.52	K= 3
L= 34	X(L)= 94.600	YD(L)= 1120.69	HO= 1122.40	K= 3
L= 33	X(L)= 93.050	YD(L)= 1151.93	HO= 1152.68	K= 3
L= 32	X(L)= 91.500	YD(L)= 1182.66	HO= 1183.94	K= 3
L= 31	X(L)= 89.633	YD(L)= 1218.14	HO= 1230.84	K= 3
L= 30	X(L)= 87.767	YD(L)= 1256.77	HO= 1271.90	K= 3
L= 29	X(L)= 85.900	YD(L)= 1299.27	HO= 1308.96	K= 3
L= 28	X(L)= 84.360	YD(L)= 1326.48	HO= 1324.65	K= 3
L= 27	X(L)= 82.820	YD(L)= 1347.38	HO= 1347.08	K= 2
L= 26	X(L)= 81.280	YD(L)= 1368.46	HO= 1371.13	K= 2
L= 25	X(L)= 79.740	YD(L)= 1389.35	HO= 1392.12	K= 3

L= 24	X(L)=	78.200	YD(L)=	1410.17	HO=	1413.11	K= 3
L= 23	X(L)=	77.220	YD(L)=	1427.97	HO=	1425.36	K= 3
L= 22	X(L)=	76.240	YD(L)=	1445.14	HO=	1410.37	K= 3
L= 21	X(L)=	75.260	YD(L)=	1462.49	HO=	1457.85	K= 3
L= 20	X(L)=	74.280	YD(L)=	1479.92	HO=	1475.11	K= 4
L= 19	X(L)=	73.300	YD(L)=	1496.80	HO=	1492.51	K= 3
L= 18	X(L)=	72.725	YD(L)=	1505.02	HO=	1496.71	K= 4
L= 17	X(L)=	72.150	YD(L)=	1510.59	HO=	1502.78	K= 4
L= 16	X(L)=	71.575	YD(L)=	1515.46	HO=	1509.68	K= 3
L= 15	X(L)=	71.000	YD(L)=	1520.30	HO=	1514.90	K= 3
L= 14	X(L)=	70.500	YD(L)=	1520.30	HO=	1525.30	K= 0
L= 13	X(L)=	63.000	YD(L)=	1529.09	HO=	1525.30	K= 3
L= 12	X(L)=	56.000	YD(L)=	1531.88	HO=	1618.45	K= 7
L= 11	X(L)=	49.000	YD(L)=	1659.46	HO=	1667.36	K= 4
L= 10	X(L)=	42.000	YD(L)=	1765.17	HO=	1732.55	K= 7
L= 9	X(L)=	35.000	YD(L)=	1844.03	HO=	1849.19	K= 3
L= 8	X(L)=	30.541	YD(L)=	1903.44	HO=	1897.37	K= 4
L= 7	X(L)=	26.081	YD(L)=	1942.04	HO=	1944.45	K= 3
L= 6	X(L)=	21.622	YD(L)=	1995.04	HO=	1993.46	K= 3
L= 5	X(L)=	17.162	YD(L)=	2038.14	HO=	2039.25	K= 3
L= 4	X(L)=	12.703	YD(L)=	2088.06	HO=	2087.30	K= 3
L= 3	X(L)=	8.243	YD(L)=	2133.28	HO=	2133.81	K= 3
L= 2	X(L)=	3.784	YD(L)=	2181.74	HO=	2181.38	K= 3
L= 1	X(L)=	0.000	YD(L)=	2226.18	HO=	2221.08	K= 3
L=146	X(L)=	157.700	YD(L)=	314.18	HO=	316.51	K= 0
L=145	X(L)=	157.373	YD(L)=	316.54	HO=	316.51	K= 2
L=144	X(L)=	157.047	YD(L)=	318.95	HO=	318.86	K= 2
L=143	X(L)=	156.720	YD(L)=	321.40	HO=	321.24	K= 2
L=142	X(L)=	156.393	YD(L)=	323.86	HO=	323.67	K= 3
L=141	X(L)=	156.067	YD(L)=	326.33	HO=	326.13	K= 3
L=140	X(L)=	155.740	YD(L)=	328.80	HO=	328.60	K= 3
L=139	X(L)=	155.413	YD(L)=	331.27	HO=	331.07	K= 3
L=138	X(L)=	155.087	YD(L)=	333.72	HO=	333.53	K= 3
L=137	X(L)=	154.760	YD(L)=	336.16	HO=	335.99	K= 3
L=136	X(L)=	154.433	YD(L)=	338.57	HO=	338.44	K= 2
L=135	X(L)=	154.107	YD(L)=	340.96	HO=	340.87	K= 2
L=134	X(L)=	153.780	YD(L)=	343.32	HO=	343.27	K= 2
L=133	X(L)=	153.453	YD(L)=	345.64	HO=	345.64	K= 2
L=132	X(L)=	153.127	YD(L)=	347.93	HO=	347.98	K= 2
L=131	X(L)=	152.800	YD(L)=	349.65	HO=	350.29	K= 3
L=130	X(L)=	152.538	YD(L)=	349.77	HO=	351.96	K= 4
L=129	X(L)=	152.275	YD(L)=	350.02	HO=	352.71	K= 4
L=128	X(L)=	152.013	YD(L)=	350.52	HO=	352.89	K= 4
L=127	X(L)=	151.750	YD(L)=	351.48	HO=	353.27	K= 4
L=126	X(L)=	151.488	YD(L)=	353.00	HO=	354.00	K= 3
L=125	X(L)=	151.225	YD(L)=	354.96	HO=	355.24	K= 3
L=124	X(L)=	150.963	YD(L)=	357.13	HO=	356.98	K= 3
L=123	X(L)=	150.700	YD(L)=	359.39	HO=	359.05	K= 3
L=122	X(L)=	150.438	YD(L)=	361.68	HO=	361.26	K= 3
L=121	X(L)=	150.175	YD(L)=	364.00	HO=	363.53	K= 3
L=120	X(L)=	149.913	YD(L)=	366.34	HO=	365.84	K= 3
L=119	X(L)=	149.650	YD(L)=	368.71	HO=	368.17	K= 3
L=118	X(L)=	149.388	YD(L)=	371.11	HO=	370.52	K= 3
L=117	X(L)=	149.125	YD(L)=	373.54	HO=	372.91	K= 3
L=116	X(L)=	148.863	YD(L)=	376.00	HO=	375.32	K= 3
L=115	X(L)=	148.600	YD(L)=	378.50	HO=	377.77	K= 3
L=114	X(L)=	148.140	YD(L)=	384.29	HO=	382.95	K= 3
L=113	X(L)=	147.680	YD(L)=	389.73	HO=	388.45	K= 4
L=112	X(L)=	147.220	YD(L)=	395.21	HO=	394.06	K= 4
L=111	X(L)=	146.760	YD(L)=	400.39	HO=	399.52	K= 3
L=110	X(L)=	146.300	YD(L)=	405.41	HO=	404.85	K= 3
L=109	X(L)=	145.840	YD(L)=	410.35	HO=	409.95	K= 3
L=108	X(L)=	145.380	YD(L)=	415.28	HO=	414.93	K= 3
L=107	X(L)=	144.920	YD(L)=	420.22	HO=	419.87	K= 3
L=106	X(L)=	144.460	YD(L)=	425.18	HO=	424.80	K= 3
L=105	X(L)=	144.000	YD(L)=	430.18	HO=	429.75	K= 3

L	X(L)	YD(L)	HO	K
L=104	X(L)= 142.65	YD(L)= 44[illegible].12	HO= [illegible].93	K=3
L=103	X(L)= 141.300	YD(L)= 455.49	HO= 457.95	K= 3
L=102	X(L)= 140.429	YD(L)= 462.38	HO= 462.32	K= 2
L=101	X(L)= 139.557	YD(L)= 468.74	HO= 467.51	K= 3
L=100	X(L)= 138.686	YD(L)= 475.10	HO= 474.13	K= 3
L= 99	X(L)= 137.814	YD(L)= 481.50	HO= 480.50	K= 3
L= 98	X(L)= 136.943	YD(L)= 487.96	HO= 486.00	K= 3
L= 97	X(L)= 136.071	YD(L)= 494.49	HO= 493.30	K= 3
L= 96	X(L)= 135.200	YD(L)= 501.12	HO= 499.00	K= 3
L= 95	X(L)= 134.320	YD(L)= 508.98	HO= 509.26	K= 3
L= 94	X(L)= 133.440	YD(L)= 518.85	HO= 517.95	K= 3
L= 93	X(L)= 132.560	YD(L)= 528.71	HO= 526.81	K= 3
L= 92	X(L)= 131.680	YD(L)= 538.76	HO= 536.60	K= 3
L= 91	X(L)= 130.800	YD(L)= 549.10	HO= 546.64	K= 3
L= 90	X(L)= 130.255	YD(L)= 555.11	HO= 553.83	K= 3
L= 89	X(L)= 129.710	YD(L)= 559.09	HO= 560.51	K= 3
L= 88	X(L)= 129.165	YD(L)= 562.63	HO= 565.50	K= 4
L= 87	X(L)= 128.620	YD(L)= 566.19	HO= 569.26	K= 4
L= 86	X(L)= 128.075	YD(L)= 569.98	HO= 572.81	K= 4
L= 85	X(L)= 127.530	YD(L)= 574.06	HO= 576.48	K= 3
L= 84	X(L)= 126.985	YD(L)= 578.42	HO= 580.42	K= 4
L= 83	X(L)= 126.440	YD(L)= 583.03	HO= 584.64	K= 3
L= 82	X(L)= 125.895	YD(L)= 587.83	HO= 589.13	K= 3
L= 81	X(L)= 125.350	YD(L)= 592.74	HO= 593.83	K= 3
L= 80	X(L)= 124.805	YD(L)= 597.75	HO= 598.68	K= 3
L= 79	X(L)= 124.260	YD(L)= 602.82	HO= 603.65	K= 3
L= 78	X(L)= 123.715	YD(L)= 607.95	HO= 608.69	K= 3
L= 77	X(L)= 123.170	YD(L)= 613.13	HO= 613.79	K= 3
L= 76	X(L)= 122.625	YD(L)= 618.34	HO= 618.94	K= 3
L= 75	X(L)= 122.080	YD(L)= 623.59	HO= 624.14	K= 3
L= 74	X(L)= 121.535	YD(L)= 628.87	HO= 629.37	K= 3
L= 73	X(L)= 120.990	YD(L)= 634.17	HO= 634.63	K= 3
L= 72	X(L)= 120.445	YD(L)= 639.49	HO= 639.92	K= 3
L= 71	X(L)= 119.900	YD(L)= 644.83	HO= 645.23	K= 3
L= 70	X(L)= 119.550	YD(L)= 649.42	HO= 649.71	K= 3
L= 69	X(L)= 119.200	YD(L)= 654.24	HO= 654.25	K= 2
L= 68	X(L)= 118.850	YD(L)= 659.05	HO= 658.95	K= 2
L= 67	X(L)= 118.500	YD(L)= 663.87	HO= 663.77	K= 2
L= 66	X(L)= 118.150	YD(L)= 668.69	HO= 668.59	K= 2
L= 65	X(L)= 117.800	YD(L)= 673.51	HO= 673.41	K= 2
L= 64	X(L)= 117.450	YD(L)= 678.33	HO= 678.22	K= 2
L= 63	X(L)= 117.100	YD(L)= 683.15	HO= 683.04	K= 2
L= 62	X(L)= 116.750	YD(L)= 687.97	HO= 687.86	K= 2
L= 61	X(L)= 116.400	YD(L)= 692.80	HO= 692.69	K= 2
L= 60	X(L)= 116.050	YD(L)= 697.63	HO= 697.51	K= 2
L= 59	X(L)= 115.700	YD(L)= 702.45	HO= 702.34	K= 2
L= 58	X(L)= 115.350	YD(L)= 707.28	HO= 707.16	K= 2
L= 57	X(L)= 115.000	YD(L)= 712.11	HO= 711.99	K= 2
L= 56	X(L)= 114.650	YD(L)= 716.95	HO= 716.82	K= 2
L= 55	X(L)= 114.300	YD(L)= 721.78	HO= 721.65	K= 2
L= 54	X(L)= 113.950	YD(L)= 726.62	HO= 726.49	K= 2
L= 53	X(L)= 113.600	YD(L)= 731.45	HO= 731.32	K= 2
L= 52	X(L)= 113.250	YD(L)= 736.29	HO= 736.16	K= 2
L= 51	X(L)= 112.900	YD(L)= 741.13	HO= 741.00	K= 2
L= 50	X(L)= 112.120	YD(L)= 756.31	HO= 755.09	K= 3
L= 49	X(L)= 111.340	YD(L)= 769.99	HO= 769.72	K= 2
L= 48	X(L)= 110.560	YD(L)= 784.34	HO= 784.15	K= 2
L= 47	X(L)= 109.780	YD(L)= 798.42	HO= 798.16	K= 2
L= 46	X(L)= 109.000	YD(L)= 812.65	HO= 812.38	K= 2
L= 45	X(L)= 107.700	YD(L)= 841.30	HO= 832.54	K= 4
L= 44	X(L)= 106.400	YD(L)= 860.86	HO= 856.97	K= 3
L= 43	X(L)= 105.100	YD(L)= 887.07	HO= 881.08	K= 3
L= 42	X(L)= 103.800	YD(L)= 913.94	HO= 903.97	K= 3
L= 41	X(L)= 103.267	YD(L)= 928.34	HO= 917.04	K= 4
L= 40	X(L)= 102.733	YD(L)= 939.23	HO= 932.84	K= 4
L= 39	X(L)= 102.200	YD(L)= 949.73	HO= 944.79	K= 3

L	X(L)	YD(L)	HO	K
L= 38	X(L)= 101.800	YD(L)= 1453.00	HO= 1444.00	K= 0
L= 37	X(L)= 99.750	YD(L)= 1454.98	HO= 1499.00	K= 4
L= 36	X(L)= 97.700	YD(L)= 1455.00	HO= 1520.99	K= 4
L= 35	X(L)= 96.150	YD(L)= 1455.01	HO= 1508.74	K= 4
L= 34	X(L)= 94.600	YD(L)= 1455.02	HO= 1502.63	K= 4
L= 33	X(L)= 93.050	YD(L)= 1455.04	HO= 1502.64	K= 4
L= 32	X(L)= 91.500	YD(L)= 1455.08	HO= 1502.66	K= 4
L= 31	X(L)= 89.633	YD(L)= 1455.12	HO= 1518.60	K= 4
L= 30	X(L)= 87.767	YD(L)= 1455.17	HO= 1526.60	K= 4
L= 29	X(L)= 85.900	YD(L)= 1455.25	HO= 1526.65	K= 4
L= 28	X(L)= 84.360	YD(L)= 1455.35	HO= 1501.84	K= 4
L= 27	X(L)= 82.820	YD(L)= 1455.45	HO= 1489.50	K= 4
L= 26	X(L)= 81.280	YD(L)= 1455.57	HO= 1489.60	K= 4
L= 25	X(L)= 79.740	YD(L)= 1455.74	HO= 1489.71	K= 4
L= 24	X(L)= 78.200	YD(L)= 1456.05	HO= 1489.86	K= 4
L= 23	X(L)= 77.220	YD(L)= 1456.67	HO= 1481.50	K= 4
L= 22	X(L)= 76.240	YD(L)= 1458.58	HO= 1477.66	K= 4
L= 21	X(L)= 75.260	YD(L)= 1465.02	HO= 1478.93	K= 4
L= 20	X(L)= 74.280	YD(L)= 1479.79	HO= 1483.10	K= 3
L= 19	X(L)= 73.300	YD(L)= 1496.79	HO= 1493.71	K= 3
L= 18	X(L)= 72.725	YD(L)= 1505.02	HO= 1496.64	K= 4
L= 17	X(L)= 72.150	YD(L)= 1510.59	HO= 1502.78	K= 4
L= 16	X(L)= 71.575	YD(L)= 1515.46	HO= 1509.68	K= 3
L= 15	X(L)= 71.000	YD(L)= 1520.30	HO= 1514.90	K= 3
L= 14	X(L)= 70.500	YD(L)= 2208.01	HO= 2213.01	K= 0
L= 13	X(L)= 63.000	YD(L)= 2208.01	HO= 2213.01	K= 3
L= 12	X(L)= 56.000	YD(L)= 2208.01	HO= 2301.76	K= 4
L= 11	X(L)= 49.000	YD(L)= 2208.01	HO= 2344.89	K= 4
L= 10	X(L)= 42.000	YD(L)= 2208.01	HO= 2344.89	K= 4
L= 9	X(L)= 35.000	YD(L)= 2208.01	HO= 2344.89	K= 5
L= 8	X(L)= 30.541	YD(L)= 2208.01	HO= 2300.78	K= 4
L= 7	X(L)= 26.081	YD(L)= 2208.01	HO= 2278.73	K= 4
L= 6	X(L)= 21.622	YD(L)= 2208.01	HO= 2278.73	K= 4
L= 5	X(L)= 17.162	YD(L)= 2208.02	HO= 2278.73	K= 4
L= 4	X(L)= 12.703	YD(L)= 2208.03	HO= 2278.73	K= 5
L= 3	X(L)= 8.243	YD(L)= 2208.08	HO= 2278.74	K= 5
L= 2	X(L)= 3.784	YD(L)= 2208.38	HO= 2278.77	K= 5
L= 1	X(L)= 0.000	YD(L)= 2218.54	HO= 2271.80	K= 5

I	X(I)	YD(I)	YNORM(I)
1	0.00	2218.54	2226.18
2	3.78	2208.38	2181.74
3	8.24	2208.08	2133.28
4	12.70	2208.03	2088.06
5	17.16	2208.02	2038.14
6	21.62	2208.01	1995.04
7	26.08	2208.01	1942.04
8	30.54	2208.01	1903.44
9	35.00	2208.01	1844.03
10	42.00	2208.01	1765.17
11	49.00	2208.01	1659.46
12	56.00	2208.01	1531.08
13	63.00	2208.01	1529.09
14	70.50	2208.01	1520.30
15	71.00	1520.30	1520.30
16	71.58	1515.46	1515.46
17	72.15	1510.59	1510.59
18	72.73	1505.02	1505.02
19	73.30	1496.79	1496.80
20	74.28	1479.79	1479.92
21	75.26	1465.02	1462.49
22	76.24	1458.58	1445.14
23	77.22	1456.67	1427.97
24	78.20	1456.05	1410.17
25	79.74	1455.74	1389.35
26	81.20	1455.57	1368.46
27	82.82	1455.45	1347.38

28	84.36	1455.3[illegible]	1326.78
29	85.90	1455.25	1299.27
30	87.77	1455.17	1256.77
31	89.63	1455.12	1218.14
32	91.50	1455.08	1182.66
33	93.05	1455.04	1151.93
34	94.60	1455.02	1120.69
35	96.15	1455.01	1089.43
36	97.70	1455.00	1060.12
37	99.75	1454.98	999.41
38	101.80	1455.00	949.73
39	102.20	949.73	949.73
40	102.73	939.23	939.23
41	103.27	928.34	928.34
42	103.80	913.94	913.94
43	105.10	887.07	887.07
44	106.40	860.86	860.86
45	107.70	841.30	841.30
46	109.00	812.65	812.65
47	109.78	798.42	798.42
48	110.56	784.34	784.34
49	111.34	769.99	769.99
50	112.12	756.31	756.31
51	112.90	741.13	741.13
52	113.25	736.29	736.29
53	113.60	731.45	731.45
54	113.95	726.62	726.62
55	114.30	721.78	721.78
56	114.65	716.95	716.95
57	115.00	712.11	712.11
58	115.35	707.28	707.28
59	115.70	702.45	702.45
60	116.05	697.63	697.63
61	116.40	692.80	692.80
62	116.75	687.97	687.97
63	117.10	683.15	683.15
64	117.45	678.33	678.33
65	117.80	673.51	673.51
66	118.15	668.69	668.69
67	118.50	663.87	663.87
68	118.85	659.05	659.05
69	119.20	654.24	654.24
70	119.55	649.42	649.42
71	119.90	644.83	644.83
72	120.44	639.49	639.49
73	120.99	634.17	634.17
74	121.53	628.87	628.87
75	122.08	623.59	623.59
76	122.62	618.34	618.34
77	123.17	613.13	613.13
78	123.71	607.95	607.95
79	124.26	602.82	602.82
80	124.80	597.75	597.75
81	125.35	592.74	592.74
82	125.89	587.83	587.83
83	126.44	583.03	583.03
84	126.98	578.42	578.42
85	127.53	574.06	574.06
86	128.07	569.98	569.98
87	128.62	566.19	566.19
88	129.16	562.63	562.63
89	129.71	559.09	559.09
90	130.25	555.11	555.11
91	130.80	549.10	549.10
92	131.68	538.76	538.76
93	132.56	528.71	528.71

94	133.44	516.85	510.05
95	134.32	508.98	508.98
96	135.20	501.12	501.12
97	136.07	494.49	494.49
98	136.94	487.96	487.96
99	137.81	481.50	481.50
100	138.69	475.10	475.10
101	139.56	468.74	468.74
102	140.43	462.38	462.38
103	141.30	455.49	455.49
104	142.65	443.72	443.72
105	144.00	430.18	430.18
106	144.46	425.18	425.18
107	144.92	420.22	420.22
108	145.38	415.28	415.28
109	145.84	410.35	410.35
110	146.30	405.41	405.41
111	146.76	400.39	400.39
112	147.22	395.21	395.21
113	147.68	389.73	389.73
114	148.14	384.29	384.29
115	148.60	378.50	378.50
116	148.86	376.00	376.00
117	149.13	373.54	373.54
118	149.39	371.11	371.11
119	149.65	368.71	368.71
120	149.91	366.34	366.34
121	150.18	364.00	364.00
122	150.44	361.68	361.68
123	150.70	359.39	359.39
124	150.96	357.13	357.13
125	151.23	354.96	354.96
126	151.49	353.00	353.00
127	151.75	351.48	351.48
128	152.01	350.52	350.52
129	152.28	350.02	350.02
130	152.54	349.77	349.77
131	152.80	349.65	349.65
142	153.13	347.93	347.93
133	153.45	345.64	345.64
134	153.78	343.32	343.32
135	154.11	340.96	340.96
136	154.43	338.57	338.57
137	154.76	336.16	336.16
138	155.09	333.72	333.72
139	155.41	331.27	331.27
140	155.74	328.80	328.80
141	156.07	326.33	326.33
142	156.39	323.86	323.86
143	156.72	321.40	321.40
144	157.05	318.95	318.95
145	157.37	316.54	316.54
146	157.70	314.18	314.18

```
TT =    0.0000        DTH =  0.0400        ITERR =   0
QU(1) =   252743.0    YU(1) =     2218.5  QU(N) =   428500.0  YU(N) =     314.18  FRDM=0.68 IFR=  1 FRM=0.00 IFM= 13

TT =    0.0000        DTH =  0.0400        ITERR =   1
QU(1) =   252743.0    YU(1) =     2218.5  QU(N) =   429697.0  YU(N) =     314.18  FRDM=0.68 IFR=  1 FRM=0.00 IFM= 13

TT =    0.0000        DTH =  0.0400        ITERR =   1
QU(1) =   252743.0    YU(1) =     2218.5  QU(N) =   429601.2  YU(N) =     314.18  FRDM=0.68 IFR=  1 FRM=0.00 IFM= 13

TT =    0.0400        DTH =  0.0400        ITERR =   1
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TT = 8.0000 DTH = 0.0400 ITERR = 2
QU(1) = 257611.1 YU(1) = 2225.9 QU(N) = 15266066.0 YU(N) = 377.92 FRDM=2.56 IFR= 11 FRM=0.10 IFM= 13

KTIME=203 ALLOWABLE KTIME= 698 TT= 8.0

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
0.000	2228.27	257611	2.800	11.33	7.72	0.00	0.00
3.784	2208.40	317065	0.480	9.56	6.52	0.00	0.00
8.243	2208.09	621556	0.400	8.69	5.92	0.00	0.00
12.703	2208.03	1147668	0.600	9.99	6.81	0.00	0.00
17.162	2208.02	1910650	0.240	11.17	7.62	0.00	0.00
21.622	2208.02	2928112	0.200	12.53	8.54	0.00	0.00
26.081	2208.01	4234858	0.120	14.96	10.20	0.00	0.00
30.541	2208.02	5901427	0.280	17.47	11.91	0.00	0.00
35.000	2208.02	7958014	0.200	17.35	11.83	0.00	0.00
42.000	2208.03	12458996	0.120	18.88	12.87	0.00	0.00
49.000	2208.03	18725304	0.040	16.99	11.58	0.00	0.00
56.000	2208.02	26391248	0.000	15.35	10.46	0.00	0.00
63.000	2208.01	35471588	0.000	13.96	9.52	0.00	0.00
70.500	2208.01	42587424	0.000	62.18	42.40	0.00	0.00
1 71.000	1887.49	42587424	2.520	75.18	51.26	0.00	0.00
71.575	1862.08	42547012	2.640	62.87	42.86	0.00	0.00
72.150	1845.43	42417684	2.880	53.73	36.64	0.00	0.00
72.725	1834.87	42181500	2.960	46.34	31.59	0.00	0.00
2 73.300	1827.47	41820912	3.000	39.98	27.26	0.00	0.00
74.280	1819.31	41234012	3.040	37.01	25.23	0.00	0.00
75.260	1813.16	40452496	3.080	34.17	23.30	0.00	0.00
76.240	1808.46	39507136	3.080	30.46	20.77	0.00	0.00
77.220	1804.92	38556228	3.120	27.45	18.72	0.00	0.00
3 78.200	1802.18	37447756	3.120	24.53	16.72	0.00	0.00
79.740	1797.23	35882208	3.120	24.93	17.00	0.00	0.00
81.280	1791.10	34552812	3.160	25.66	17.50	0.00	0.00
82.820	1782.83	33866440	3.200	27.42	18.69	0.00	0.00
84.360	1770.60	33424858	3.200	31.75	21.64	0.00	0.00
4 85.900	1748.72	33102712	3.280	40.48	27.60	0.00	0.00
87.767	1727.13	32738712	3.320	40.28	27.46	0.00	0.00
89.633	1704.16	32370350	3.400	40.77	27.80	0.00	0.00
5 91.500	1678.24	31986412	3.440	41.73	28.45	0.00	0.00
93.050	1655.93	31726170	3.440	42.10	28.70	0.00	0.00
94.600	1633.45	31497282	3.480	42.38	28.89	0.00	0.00
96.150	1610.53	31329138	3.520	43.11	29.40	0.00	0.00
6 97.700	1587.09	31221118	3.520	44.03	30.02	0.00	0.00
99.750	1554.84	31140230	3.520	46.48	31.69	0.00	0.00
101.800	1486.38	31111910	3.520	60.02	40.92	0.00	0.00
102.200	1395.66	31111910	3.560	89.69	61.15	0.00	0.00

102.[illegible]	[illegible].3	[illegible]	3.[illegible]	[illegible]	[illegible].60	0.[illegible]	[illegible]
103.267	1287.94	31106228	3.560	79.59	54.27	0.00	0.00
103.800	1252.43	31104928	3.560	69.45	47.35	0.00	0.00
105.100	1187.22	31107104	3.600	60.15	41.01	0.00	0.00
106.400	1130.05	31095154	3.600	54.05	36.85	0.00	0.00
107.700	1075.58	31082102	3.640	50.53	34.45	0.00	0.00
109.000	976.75	31084596	3.640	65.95	44.97	0.00	0.00
109.780	960.00	31082242	3.640	58.40	39.87	0.00	0.00
110.560	942.65	31074844	3.680	53.34	36.36	0.00	0.00

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	********	**********	*********	********	*********
111.340	925.22	31071896	3.680	49.60	33.82	0.00	0.00
112.120	907.18	31060380	3.720	47.09	32.11	0.00	0.00
112.900	887.83	31036336	3.760	45.75	31.20	0.00	0.00
113.250	882.69	31039204	3.800	45.86	31.26	0.00	0.00
113.600	877.71	31025584	3.840	45.88	31.28	0.00	0.00
113.950	872.84	31008818	3.840	45.90	31.29	0.00	0.00
114.300	868.19	30987972	3.920	45.88	31.28	0.00	0.00
114.650	863.87	30961824	4.000	45.82	31.24	0.00	0.00
115.000	859.98	30934044	4.040	45.52	31.04	0.00	0.00
115.350	856.53	30898216	4.120	45.26	30.86	0.00	0.00
115.700	853.47	30853374	4.120	44.88	30.60	0.00	0.00
116.050	850.76	30799250	4.160	44.39	30.27	0.00	0.00
116.400	848.33	30736224	4.200	43.79	29.86	0.00	0.00
116.750	846.19	30665176	4.200	43.09	29.38	0.00	0.00
117.100	844.26	30593378	4.200	41.99	28.63	0.00	0.00
117.450	842.51	30517732	4.200	41.18	28.08	0.00	0.00
117.800	840.94	30437978	4.240	40.35	27.51	0.00	0.00
118.150	839.51	30355102	4.240	39.52	26.94	0.00	0.00
118.500	838.20	30278678	4.240	38.40	26.18	0.00	0.00
118.850	837.00	30201376	4.240	37.61	25.64	0.00	0.00
119.200	835.88	30123054	4.240	36.85	25.13	0.00	0.00
119.550	834.84	30051962	4.240	35.89	24.47	0.00	0.00
119.900	833.86	29982134	4.240	35.21	24.00	0.00	0.00
120.445	831.86	29876980	4.240	35.12	23.95	0.00	0.00
120.990	829.83	29780804	4.240	35.29	24.06	0.00	0.00
121.535	827.75	29690360	4.240	35.29	24.06	0.00	0.00
122.080	825.61	29606382	4.240	35.52	24.22	0.00	0.00
122.625	823.41	29530492	4.240	35.63	24.29	0.00	0.00
123.170	821.14	29458908	4.280	35.95	24.51	0.00	0.00
123.715	818.78	29396984	4.280	36.17	24.66	0.00	0.00
124.260	816.33	29337450	4.280	36.58	24.94	0.00	0.00
124.805	813.76	29287806	4.280	36.94	25.19	0.00	0.00
125.350	811.05	29239658	4.280	37.40	25.55	0.00	0.00
125.895	808.19	29200138	4.280	37.99	25.90	0.00	0.00
126.440	805.13	29162536	4.280	38.69	26.38	0.00	0.00
126.985	801.84	29130766	4.280	39.40	26.86	0.00	0.00
127.530	798.28	29102700	4.280	40.31	27.48	0.00	0.00
128.075	794.38	29076104	4.280	41.30	28.16	0.00	0.00
128.620	790.05	29056406	4.320	42.53	28.99	0.00	0.00

129.165	786.15	29036486	4.320	45.78	24.99	0.00	0.00
129.710	779.40	29019456	4.320	45.69	31.15	0.00	0.00
130.255	772.67	29005960	4.320	47.92	32.67	0.00	0.00
12 130.800	763.96	28991268	4.320	50.92	34.72	0.00	0.00
131.680	755.87	28976520	4.360	51.05	34.80	0.00	0.00
132.560	747.25	28958814	4.360	51.39	35.04	0.00	0.00
133.440	737.67	28943216	4.360	52.02	35.47	0.00	0.00
134.320	726.25	28934120	4.360	53.37	36.39	0.00	0.00
13 135.200	683.12	28928538	4.320	69.14	47.14	0.00	0.00

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	********	**********	*********	*********	*********
136.071	669.67	28926830	4.400	66.87	45.59	0.00	0.00
136.943	656.67	28919314	4.400	64.88	44.24	0.00	0.00
137.814	644.88	28910270	4.400	62.74	42.78	0.00	0.00
138.686	633.24	28906220	4.440	60.97	41.57	0.00	0.00
139.557	623.08	28892542	4.520	59.01	40.23	0.00	0.00
140.429	615.84	28863044	4.560	55.99	38.17	0.00	0.00
14 141.300	610.74	28831564	4.560	52.52	35.81	0.00	0.00
142.650	608.88	28801742	4.520	44.87	30.59	0.00	0.00
15 144.000	524.68	28794788	4.480	78.99	53.86	0.00	0.00
144.460	516.52	28796170	4.520	63.18	43.07	0.00	0.00
144.920	507.73	28796878	4.520	54.09	36.88	0.00	0.00
145.380	499.24	28796654	4.520	48.03	32.75	0.00	0.00
145.840	491.16	28795200	4.520	43.65	29.76	0.00	0.00
146.300	483.44	28793432	4.560	40.33	27.50	0.00	0.00
146.760	475.98	28793992	4.560	37.76	25.75	0.00	0.00
147.220	468.65	28793024	4.560	35.78	24.39	0.00	0.00
147.680	461.27	28790268	4.600	34.34	23.41	0.00	0.00
148.140	453.49	28788042	4.600	33.57	22.89	0.00	0.00
16 148.600	444.43	28786938	4.600	34.12	23.26	0.00	0.00
148.863	441.21	28784756	4.640	33.16	22.61	0.00	0.00
149.125	438.11	28779588	4.760	32.25	21.99	0.00	0.00
149.388	435.71	28765746	5.000	31.28	21.33	0.00	0.00
149.650	434.07	28733768	5.120	30.10	20.52	0.00	0.00
149.913	432.89	28675600	5.120	28.59	19.49	0.00	0.00
150.175	432.04	28593888	5.160	26.59	18.13	0.00	0.00
150.438	431.42	28492502	5.160	24.71	16.85	0.00	0.00
150.700	430.96	28377526	5.160	22.63	15.43	0.00	0.00
150.963	430.61	28259338	5.160	20.88	14.24	0.00	0.00
151.225	430.35	28142144	5.160	19.09	13.02	0.00	0.00
151.488	430.15	28027826	5.160	17.49	11.92	0.00	0.00
151.750	430.00	27917800	5.160	16.05	10.94	0.00	0.00
152.013	429.88	27812836	5.160	14.76	10.06	0.00	0.00
152.275	429.79	27717316	5.160	13.67	9.32	0.00	0.00
152.538	429.72	27630332	5.160	12.62	8.60	0.00	0.00
17 152.800	429.66	27553452	5.160	11.68	7.96	0.00	0.00
153.127	427.85	27699442	5.160	11.98	8.17	0.00	0.00
153.453	426.03	27632398	5.160	12.19	8.31	0.00	0.00
153.780	424.14	27578476	5.200	12.42	8.47	0.00	0.00
154.107	422.19	27535142	5.200	12.66	8.63	0.00	0.00

154.[illegible]	[illegible].15	[illegible]	5.[illegible]	[illegible]	[illegible].81	0.[illegible]	[illegible]
154.760	418.01	27474650	5.200	13.21	9.01	0.00	0.00
155.087	415.76	27457812	5.200	13.52	9.22	0.00	0.00
155.413	413.38	27444142	5.200	13.87	9.46	0.00	0.00
155.740	410.83	27438440	5.240	14.27	9.73	0.00	0.00
156.067	408.06	27435156	5.240	14.72	10.04	0.00	0.00
156.393	405.02	27439010	5.200	15.27	10.41	0.00	0.00
156.720	401.58	27444002	5.200	15.95	10.87	0.00	0.00
157.047	397.53	27456694	5.200	16.87	11.50	0.00	0.00

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	********	**********	*********	*********	*********
157.373	392.45	27475192	5.120	18.25	12.45	0.00	0.00
157.700	385.06	27507370	4.960	21.11	14.39	0.00	0.00

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 15

BELOW MULTIPLE FAILURES AT MILE 71.00

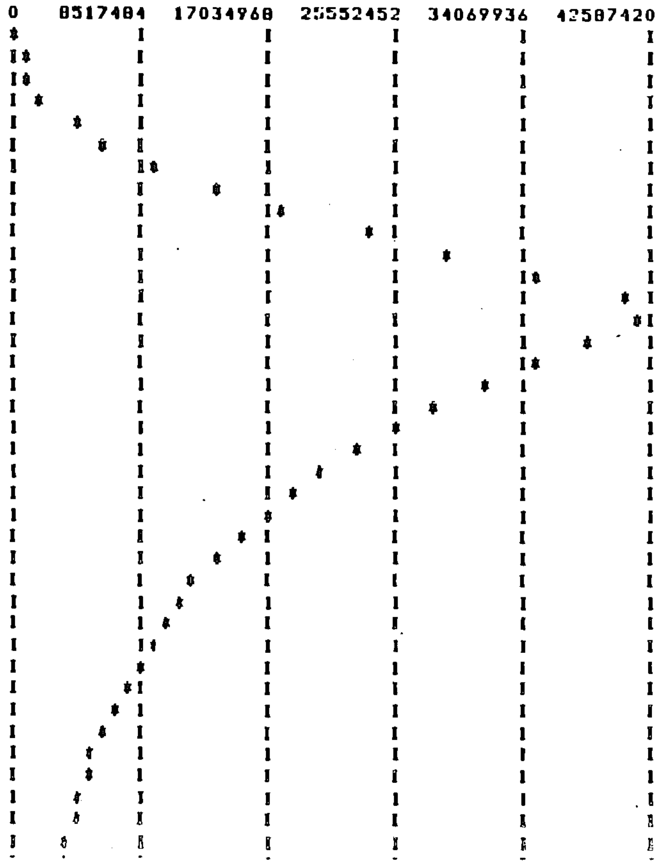
GAGE ZERO = 1455.00 MAX ELEVATION REACHED BY FLOOD WAVE = 1887.49

FLOOD STAGE NOT AVAILABLE

MAX STAGE = 432.49 AT TIME = 2.52 HOURS

MAX FLOW = 42587424 AT TIME = 2.52 HOURS

HR	STAGE	FLOW
0.0	65.3	361093
0.2	70.3	479953
0.4	91.2	1014876
0.6	124.3	2129368
0.8	161.5	3849966
1.0	200.9	6297127
1.2	238.9	9499439
1.4	273.5	13504259
1.6	306.5	18198556
1.8	337.9	23442124
2.0	368.0	29068926
2.2	396.2	34866756
2.4	421.9	40518904
2.6	431.5	41523176
2.8	427.0	38338640
3.0	420.7	34890164
3.2	411.8	31496268
3.4	400.9	28290108
3.6	388.5	25361062
3.8	375.4	22753804
4.0	361.9	20458612
4.2	348.2	18448220
4.4	334.6	16669837
4.6	321.3	15074528
4.8	308.1	13624444
5.0	295.1	12305652
5.2	282.3	11107820
5.4	269.8	10021558
5.6	257.7	9041072
5.8	246.0	8153188
6.0	234.8	7358992
6.2	223.6	6625690
6.4	212.8	5958229
6.6	203.5	5437003
6.8	194.9	4974215
7.0	186.3	4509882
7.2	177.7	4061652
7.4	169.4	3653440
7.6	161.6	3293037



$V_{hydrograph} \approx 4.369 \times 10^{11}$ ft^3

$V_{[illegible]} \simeq 4.517 \times 10^{11}$ ft^3

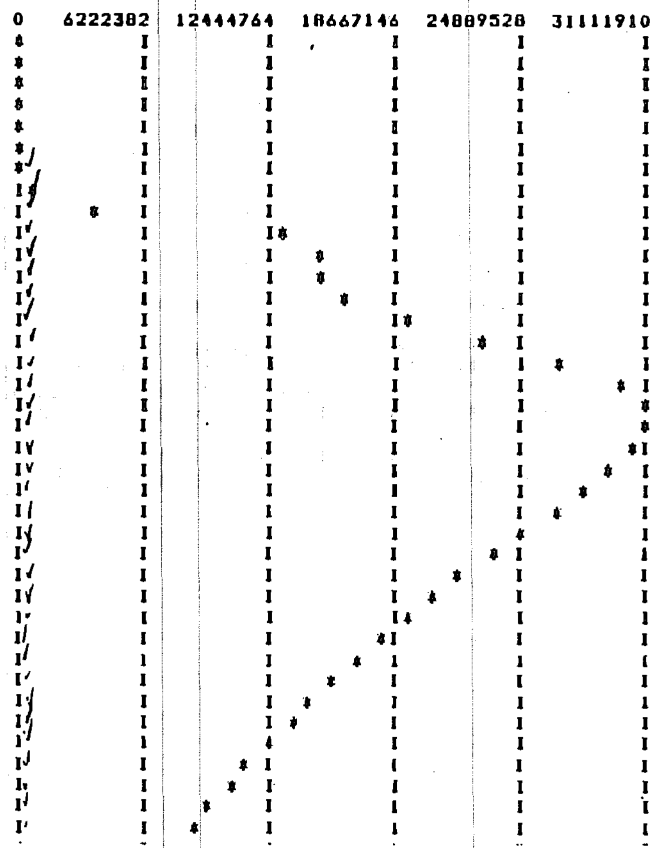
7.8 154.3 2968915

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 38 *DEVIL CANYON*
BELOW MULTIPLE FAILURES AT MILE 101.80

GAGE ZERO = 907.00 MAX ELEVATION REACHED BY FLOOD WAVE = 1486.38
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 579.38 AT TIME = 3.52 HOURS
MAX FLOW = 31111912 AT TIME = 3.52 HOURS

D.C. failure @ 568.9

HR	STAGE	FLOW
0.0	548.0	160500
0.2	553.0	160500
0.4	554.9	160500
0.6	556.6	160500
0.8	558.1	160567
1.0	559.4	167277
1.2	560.7	179916
1.4	567.9	325063
1.6	571.0	3607777
1.8	504.1	13280243
2.0	440.8	14664711
2.2	440.6	14701547
2.4	457.8	16307810
2.6	486.7	19167628
2.8	522.1	23000854
3.0	553.8	26976634
3.2	571.2	29638658
3.4	578.3	30913356
3.6	579.1	31058122
3.8	576.0	30433892
4.0	570.0	29337148
4.2	561.7	27978732
4.4	551.6	26490338
4.6	540.3	24958996
4.8	528.2	23452606
5.0	515.5	22018078
5.2	502.6	20672402
5.4	489.7	19329332
5.6	476.8	18009714
5.8	464.2	16791272
6.0	451.8	15658334
6.2	439.6	14561401
6.4	427.0	13491602
6.6	413.5	12424975
6.8	399.7	11423067
7.0	386.0	10408404
7.2	373.0	9620321
7.4	360.4	8831875
7.6	*347.9*	*8099503*



7.8 335.6 7423592

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 51 *INDIAN CREEK*
BELOW MULTIPLE FAILURES AT MILE 112.90

GAGE ZERO = 730.00 MAX ELEVATION REACHED BY FLOOD WAVE = 887.83
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 157.83 AT TIME = 3.76 HOURS
MAX FLOW = 31036338 AT TIME = 3.72 HOURS

HR	STAGE	FLOW
0.0	11.1	174500
0.2	11.1	174501
0.4	11.2	175231
0.6	11.2	175589
0.8	11.2	175686
1.0	11.2	175706
1.2	11.2	175707
1.4	11.2	175728
1.6	11.2	175595
1.8	11.1	175501
2.0	68.4	7558429
2.2	103.7	14112761
2.4	108.6	14704284
2.6	114.2	16309481
2.8	123.2	19299470
3.0	134.8	23357660
3.2	145.6	27204840
3.4	153.1	29777102
3.6	156.9	30909888
3.8	157.0	30944184
4.0	156.8	30258800
4.2	154.7	29143764
4.4	151.9	27799204
4.6	148.4	26352440
4.8	144.5	24861506
5.0	140.2	23362042
5.2	136.0	21962082
5.4	131.8	20650026
5.6	127.5	19331254
5.8	123.1	18054620
6.0	119.0	16866352
6.2	115.0	15757381
6.4	111.1	14695907
6.6	107.2	13655168
6.8	103.3	12627906
7.0	99.3	11651947
7.2	95.5	10742678
7.4	91.8	9892706
7.6	88.3	9113359

Plot scale (FLOW): 0 6207267 12414534 18621801 24829068 31036335

7.8	85.0	8392901

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 91 *CURRY*
BELOW MULTIPLE FAILURES AT MILE 130.80

GAGE ZERO = 523.00 MAX ELEVATION REACHED BY FLOOD WAVE = 763.96
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 240.96 AT TIME = 4.32 HOURS
MAX FLOW = 28991270 AT TIME = 4.24 HOURS

Plot scale (FLOW): 0 5798254 11596508 17394762 23193016 28991270

HR	STAGE	FLOW
0.0	26.1	188500
0.2	26.1	188500
0.4	26.1	188500
0.6	26.1	188500
0.8	26.1	188500
1.0	26.1	188500
1.2	26.1	188500
1.4	26.1	188500
1.6	26.1	188500
1.8	26.1	188500
2.0	26.1	188685
2.2	26.1	188949
2.4	26.2	189275
2.6	88.4	4348701
2.8	140.1	10439139
3.0	163.4	13660586
3.2	184.3	17227870
3.4	203.7	21317502
3.6	219.7	24800390
3.8	230.8	27177342
4.0	237.4	28489240
4.2	240.4	28973620
4.4	240.9	28849276
4.6	239.5	28291464
4.8	236.7	27438192
5.0	233.0	26384570
5.2	228.6	25197396
5.4	223.7	23968042
5.6	218.7	22740702
5.8	213.5	21511230
6.0	208.1	20276976
6.2	202.7	19081808
6.4	197.3	17938606
6.6	191.9	16846116
6.8	186.6	15788913
7.0	181.2	14763081
7.2	175.9	13769617
7.4	170.5	12826947

7.6	160.1	11.555/7
7.8	159.7	11088517

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 131 *Talkeetna*

BELOW MULTIPLE FAILURES AT MILE 152.80

GAGE ZERO = 333.00 MAX ELEVATION REACHED BY FLOOD WAVE = 429.66

FLOOD STAGE NOT AVAILABLE

MAX STAGE = 96.66 AT TIME = 5.16 HOURS

MAX FLOW = 27553454 AT TIME = 4.92 HOURS

Plot scale (FLOW): 0 5510690 11021380 16532070 22042760 27553450

HR	STAGE	FLOW
0.0	16.6	200500
0.2	16.6	200500
0.4	16.7	201047
0.6	16.7	201657
0.8	16.7	202016
1.0	16.7	202222
1.2	16.7	202338
1.4	16.7	202407
1.6	16.7	202450
1.8	16.7	202479
2.0	16.7	202497
2.2	16.7	202508
2.4	16.7	202517
2.6	16.7	202521
2.8	16.7	202524
3.0	16.7	202526
3.2	16.7	202528
3.4	17.1	259199
3.6	48.3	8905987
3.8	66.2	16016373
4.0	76.9	20701010
4.2	84.4	23844176
4.4	89.6	25797432
4.6	93.2	26919654
4.8	95.4	27466200
5.0	96.5	27526438
5.2	96.6	27195462
5.4	96.2	26552622
5.6	95.3	25684132
5.8	94.0	24685478
6.0	92.6	23616612
6.2	91.0	22503688
6.4	89.4	21368664
6.6	87.6	20243614
6.8	85.9	19145956
7.0	84.1	18083444
7.2	82.4	17053882
7.4	80.6	16055884
7.6	78.9	15090451

COMMENT I.375:

"Page E-3-251: Item 8: We are concerned that illustrations of mitigative design features are minimal and generally limited to road construction without specific data on the extent to which area materials will allow implementation of the side-borrow or balanced cut-and-fill techniques. Location maps should also be included for all mitigative design features."

RESPONSE:

This suggestion regarding the inclusion of more illustrations and location maps of mitigative design features will be carried out in more refined versions of the Mitigation Plan, especially as detailed engineering design proceeds. Please refer to the Response to Comment I.378 for additional discussion regarding the side borrow technique.

COMMENT I.376:

"Page E-3-251: (b): The FWS supports funding and implementation of mitigation concurrently with project planning and construction. We are concerned that outlined mitigation studies are generally limited to planning studies with some follow-up monitoring (Table E-3-177). Provisions are lacking for implementing measures that will be recommended through these study efforts. Please also see our comments on Table E.3.177."

RESPONSE:

The Mitigation Plan presented in FERC License Application Section 3.4 is specific where detailed design and construction planning have proceeded sufficiently and conceptual where they have not. As stated on FERC License Application page E-3-252, "as engineering design and construction planning proceed, features of this mitigation plan will be correspondingly refined with respect to specific locations, procedures and costs." The Power Authority cannot locate the referenced comments on FERC License Application Table E.3.177.

COMMENT I.377:

"Page E-3-252: Paragraph 1 to 4: We recommend that the Biological Stipulations included with our comments as Attachment A be made conditions of the FERC license and incorporated in any project contracts and bid specifications.

"With the exception of wetlands mitigation planning, we concur with the mitigation objectives and framework outlined here. As stated previously in Sections 3.2.3 and 3.3.5, inadequate identification of wetlands means that higher priority mitigation options to avoid and minimize impacts may now be more difficult to incorporate in project planning.

"We believe that a mechanism and responsible parties should be identified for ensuring that, 'features of this mitigation plan will be correspondingly refined with respect to specific locations, procedures, and costs' as project design and planning proceeds."

RESPONSE:

A. The Power Authority does not concur with the DOI recommendation that all Biological Stipulations included in DOI Attachment A be made conditions of the FERC License. It is the Power Authority's opinion that many of these conditions, or similar conditions, will be stipulated in state, Federal and local permits required for construction and operation of the Project. That being the case, it is unnecessary that they become FERC License conditions.

   Also, many of the proposed stipulations are either contradictory or untenable.

   See also Response to Comment I.425.

B. The Power Authority believes that several formal mechanisms already exist which may result in the refinement of the Mitigation Plan. These mechanisms are described below:

   Application Process

   Agency and public comments addressing the Mitigation Plan in the License Application may be used to refine the Mitigation Plan.

RESPONSE TO COMMENT I.377 (cont.):

NEPA Process

The Draft EIS will provide for agency and public comment on project features and alternatives as well as mitigation proposed for each. The Power Authority may use those comments to further refine its Mitigation Plan.

Settlement Process

The Power Authority has embarked upon an ambitious settlement process the main emphasis of which is to coordinate with agencies, local governments and intervenors and arrive at a mutually agreeable Mitigation Plan (see Response to Comment I.81).

FERC Hearing Process

If the NEPA process and the Settlement Process do not result in a mutually acceptable Mitigation Plan, the FERC may order hearings to address this issue. It is the Power Authority's intention, however, to avoid hearings to the maximum extent possible.

COMMENT I.378:

"Page E-3-252: (a) Direct Loss of Vegetation: We question the estimated area for access borrow areas. According to the following Section, (i), (page E-3-265, paragraphs 2 and 4) borrow needs could run from 90 to 180 acres the Denali Highway-to-Watana road segment and from 50 to 100 acres for the road between the Watana and Devil Canyon Dams. Potential borrow needs for the railroad link, work pads, airstrips, and camps/villages are not clearly identified, and the size of potential spoil disposal areas are not quantified. Our specific comments on the five mitigation options follow under Sections (i) through (v)."

RESPONSE:

The preliminary investigations performed in siting the access roads to both Watana and Devil Canyon and the railhead-railway for Devil Canyon established potential borrow sites to be used in case sufficient material from side borrow was not available. The definition of these sites was to indicate the potential resources available along the access routes. The upper limit on borrow areas indicated in the Comment does not reflect the area that will

RESPONSE TO COMMENT I.378 (cont.):

be required. Similarly, the lower limit would also indicate that each of the borrow sites identified would be utilized, which may or may not be the case. Optimum access siting requires a balance between the length of access (volume of material moved and placed) and the material haul lengths. The siting of an access maximizing the utilization of material adjacent to the access can justify an increased length and still be the most economical alternative. In FERC License Application Figure E.3.37 potential borrow sites are indicated along the alignments for the Watana access road, the Devil Canyon access road and the railhead-railway for Devil Canyon. The area requirements in hectares for these three accesses including borrow sites are presented in FERC License Application Table E.3.144 (see revised Table E.3.144 referenced in the Response to Comment I.370). Site material not suitable for use in access construction will be stockpiled until the borrow operation is advanced well enough at the site so that the spoil material can be placed in the used borrow area. This spoil material will be shaped and graded so as not to affect drainage and impact runoff water quality.

Borrow for construction camps and villages will be minimal, the permanent village requirements principally for landscaping can be obtained from borrow area D and quarry site B. Spoil from the construction camps that cannot be incorporated in grading or landscaping can be spoiled in designated areas that lie within the impoundment zone. Two specific areas are designated on each of FERC License Application Exhibits F 35 and F 71.

COMMENT I.379:

"Pages E-3-254 through E-3-275: (i) Minimization: The discussion is limited by the: (1) inadequacy of wetlands mapping (see our comments on Sections 3.2.3 and 3.3.5), and (2) vegetation classification which cannot be usefully integrated with the wildlife impact analyses and mitigation determinations. Without these items, it is impossible to assess the adequacy of minimizing impacts through siting."

RESPONSE:

The Power Authority anticipates that the DEIS will reasonably describe wetlands in the project area, classify vegetation as necessary and assess various mitigation options and that the DEIS will summarize and incorporate prior studies of these topics.

COMMENT I.380 (underlined text):

"Page E-3-254 Last Paragraph through Page E-3-256: Paragraph 2: We recommend that the proposed temporary airstrip be sited so that it can later be expanded to become the permanent airstrip. This suggestion is compatible with the applicant's recent request to fund a 2500-foot temporary airfield at the Watana base camp which would subsequently be expanded to the 6000-foot airfield necessary during project construction 3B-5/.

"We also recommend consolidation of the Watana constuction camp, village, and townsite. We note these facilities (Exhibit F, Plate F35) are spread out com pared to the Devil Canyon camp and village (Exibit F, Plate F70). We also note the Watana facilities are close to the environmentally sensitive Deadman Creek area. Following remapping of wetlands, the siting of Watana facilities should be reviewed.

"The purpose and scheduled use of the circular road system outlined in Exhibit F, Plate F35, between the emergency spillway, Susitna River, and Tsusena Creek should be explained. As we commented on the draft license application, we have not had input into the decisions regarding the type, administration or siting of the construction camp, village, and townsite (Chapter 11, W-3-046). We concur with the concept of common corridor routing for the Watana-to-Gold Greek access and transmission corridors although the map scale represented in Figures E.3.39 and E.3.40 makes it difficult to evaluate those project features. Consultation with resource agencies during the on-ground planning of detailed project design may indicate areas where winter movement of construction equipment and materials is preferable to prevent impacts in biologically sensitive areas. Please refer to our previous comments on access for line maintenance, Section 3.3.4(b)."

"3B-5/ Construction of Temporary Airfield at Watana. Appendix 4 to Agenda Item IV, Action Item No. 1, prepared for the APA Board of Directors."

RESPONSE:

Refer to the Response to Comment I.92.

COMMENT I.381 (underlined text):

"Page E-3-254 Last Paragraph through Page E-3-256: Paragraph 2: We recommend that the proposed temporary airstrip be sited so that it can later be expanded to become the permanent airstrip. This suggestion is compatible with the applicant's recent request to fund a 2500-foot temporary airfield at the Watana base camp which would subsequently be expanded to the 6000-foot airfield necessary during project construction 3B-5/.

"We also recommend consolidation of the Watana constuction camp, village, and townsite. We note these facilities (Exhibit F, Plate F35) are spread out compared to the Devil Canyon camp and village (Exibit F, Plate F70). We also note the Watana facilities are close to the environmentally sensitive Deadman Creek area. Following remapping of wetlands, the siting of Watana facilities should be reviewed.

"The purpose and scheduled use of the circular road system outlined in Exhibit F, Plate F35, between the emergency spillway, Susitna River, and Tsusena Creek should be explained. As we commented on the draft license application, we have not had input into the decisions regarding the type, administration or siting of the construction camp, village, and townsite (Chapter 11, W-3-046). We concur with the concept of common corridor routing for the Watana-to-Gold Greek access and transmission corridors although the map scale represented in Figures E.3.39 and E.3.40 makes it difficult to evaluate those project features. Consultation with resource agencies during the on-ground planning of detailed project design may indicate areas where winter movement of construction equipment and materials is preferable to prevent impacts in biologically sensitive areas. Please refer to our previous comments on access for line maintenance, Section 3.3.4(b)."

"3B-5/ Construction of Temporary Airfield at Watana. Appendix 4 to Agenda Item IV, Action Item No. 1, prepared for the APA Board of Directors."

RESPONSE:

Refer to Response to Comment I.91 relative to combining the Construction Camp, Village and Permanent Village. During final layout of facilities, impacts on wetlands will be

RESPONSE TO COMMENT I.381 (cont.):

minimized to the extent practical.

COMMENT I.382 (underlined text):

"Page E-3-254 Last Paragraph through Page E-3-256: Paragraph 2: We recommend that the proposed temporary airstrip be sited so that it can later be expanded to become the permanent airstrip. This suggestion is compatible with the applicant's recent request to fund a 2500-foot temporary airfield at the Watana base camp which would subsequently be expanded to the 6000-foot airfield necessary during project construction 3B-5/.

"We also recommend consolidation of the Watana constuction camp, village, and townsite. We note these facilities (Exhibit F, Plate F35) are spread out compared to the Devil Canyon camp and village (Exibit F, Plate F70). We also note the Watana facilities are close to the environmentally sensitive Deadman Creek area. Following remapping of wetlands, the siting of Watana facilities should be reviewed.

"The purpose and scheduled use of the circular road system outlined in Exhibit F, Plate F35, between the emergency spillway, Susitna River, and Tsusena Creek should be explained. As we commented on the draft license application, we have not had input into the decisions regarding the type, administration or siting of the construction camp, village, and townsite (Chapter 11, W-3-046). We concur with the concept of common corridor routing for the Watana-to-Gold Greek access and transmission corridors although the map scale represented in Figures E.3.39 and E.3.40 makes it difficult to evaluate those project features. Consultation with resource agencies during the on-ground planning of detailed project design may indicate areas where winter movement of construction equipment and materials is preferable to prevent impacts in biologically sensitive areas. Please refer to our previous comments on access for line maintenance, Section 3.3.4(b)."

"3B-5/ Construction of Temporary Airfield at Watana. Appendix 4 to Agenda Item IV, Action Item No. 1, prepared for the APA Board of Directors."

RESPONSE TO COMMENT I.382:

Please refer to the Responses to Comments I.92 and I.543 concerning airstrips. See the Responses to Comments I.380 and I.543 for Response to Comments on Construction Camp, village and townsite. We also confirm that final siting of these installations will take into consideration any wetlands (see Response to Comment I.330). The "circular road system outlined in Exhibit F, Plate F35" is for moving material excavated for project features to spoil areas and moving materials excavated in borrow and quarry areas for use in the project features. Given the scale of the drawing, the alignment shown is schematic. Detailed design will consider site specific topography and foundation conditions in selecting an alignment that will minimize environmental impacts during and after project construction and meet design and safety standards established in the design criteria and construction specifications. Please refer to the Response to Comment I.367 regarding access for transmission line maintenance.

The scheduled use of these temporary construction roads can be determined from the Watana Construction Schedule in FERC License Application Exhibit C (Figure C.1). For example, main dam excavation begins after mid-1986, fill operations begin in mid-1987 and continue intermittently until late 1993. Emergency spillway work begins early in the second quarter of 1991 and continues for approximately six months with the same schedule repeated in 1992.

COMMENT I.383:

"Page E-3-256: Paragraph 3: and Page E-3-258: Paragraph 2: Facility sitings presently are located in low biomass areas. It is important that these areas be not only economically advantageous to clear, but that such areas be of low value to wildlife, as acknowledged on page E-3-260, paragraph 2. For example, a low birch/mixed shrub area may be more important in providing moose forage, particularly if cover is available nearby, than the higher biomass of a tall alder area which provides cover but no food."

RESPONSE:

Comment noted.

COMMENT I.384:

"<u>Paragraph 3 through Page E-3-258, and Pages E-3-260: Paragraph 4 through 262</u>: We reiterate our recommendation to drop the Denali Highway-to-Watana access segment because of big game resource values described here, as well as area furbearer, raptor, and wetland values. Moreover, significant secondary impacts of increased disturbance will result from the increased access allowed by that route. Please refer to our letters dated August 17, 1982 and January 14, 1983 to Eric P. Yould, APA. Eliminating the Denali Highway-to-Watana access road is the design change with the greatest potential for mitigating access road impacts to wildlife."

RESPONSE:

The issues surrounding the selection of a preferred access route are complex from an environmental perspective (see Responses to Comments A.1, A.3 and F.7). It is recognized that the Denali route traverses a relatively inaccessible area considered to be of a relatively high quality for wildlife and other resources. From a purely wildlife standpoint, impacts could be greater for the Denali plan than for a plan involving access from the west. Impacts to large raptors, furbearers, brown bear and caribou could be higher under the Denali plan, while impacts to black bear and moose would likely be higher under the other alternative plans. Wetland impacts and the total amount of habitat lost could also be higher under the Denali plan. Probably of greatest concern from a wildlife standpoint, however, is the potential for increased accessibility to sensitive areas from road traffic along the Denali access road. With careful management and use restriction (see Responses to Comments I.289 and I.364), it will be possible to reduce nonconstruction-related secondary impacts.

Although wildlife-related impacts could be judged greater with the Denali access plan, the Denali access plan is preferred when all factors are considered. Thus, although it is recognized that wildlife impacts could likely be greater for the Denali plan, the other benefits of the Denali alternative outweigh the disadvantages.

Reasons supporting the Denali access route include the fact that the proposed Denali to Watana access road crosses fewer major streams than other routes along the Susitna River, and would not cross any anadromous fish streams. The Denali route generally traverses flatter terrain, with better drained soils than the other routes, and would be the least

RESPONSE TO COMMENT I.384 (cont.):

difficult to construct of the aternatives considered. These conditions result in the Denali plan having a lower initial cost, and its being favored from a construction standpoint. The Denali plan provides the best access for support of field forces since under the Denali plan the early stages of project construction can be completed more readily. These and many other factors were evaluated in several reports, including the Access Recommendation Report (Acres American, Inc. March 1983), which summarizes the major issues.

REFERENCES

Acres American, Inc., Supplement to the Feasibility Report (March 1983).

COMMENT I.385:

"Page E-3-258: Paragraph 1: Although the Watana-to-Devil Canyon transmission and access routes share a common corridor, it does not appear that they have adjacent or combined rights-of-way. Higher resolution mapping and field verification should be used to evaluate the viability of combining rights-of-way to minimize adverse impacts."

RESPONSE:

Sharing or combining rights-of-way generally results in less overall environmental impact and reduced construction and operating costs. The viability of combining more of the transmission and access road rights-of-way will be explored as tower siting and route refinement take place during the detailed engineering phase of the Project. At that time, up-to-date aerial photography will be utilized in conjunction with field investigation and construction site drawings. However, transmission right-of-way generally is point to point to minimize length. Road right-of-way must take advantage of contours to maintain acceptable grade, horizontal and vertical curves.

COMMENT I.386:

"Page E-3-256: Paragraphs 1 and 2 and Pages E-3-261 through 266: We concur with the objective of siting borrow areas adjacent to the access road and with the recommended side-

COMMENT I.386 (cont.):

borrow or balanced cut-and-fill techniques. These methods will work only where suitable materials exist within the proposed access corridor or when it is stipulated in project licensing requirements and contractor specifications and then monitored throughout project development.

"For side-borrow construction, we recommend that the project engineers work with interagency monitoring team in the selection of temporary overburden and topsoil stockpile locations. Schedules should be provided for use and reclamation of access borrow and spoil areas. Borrow areas which would remain open for maintenance of roads, workpads, or other facilities should also be indicated. Necessary reclamation, whether simply recontouring, scarification, and fertilization to promote reestablishment of native species, or seeding and possibly sprigging of willows in more erodable areas, should be detailed in project reclamation plans and receive concurrence of the monitoring team. Site preparation should be undertaken as soon as construction use of an area is completed; seeding should be done by the first growing season after site disturbance has been completed. Please refer to the Biological Stipulations we have included as Attachment A and our comments on Section 3.4.2(a)(ii) Rectification."

RESPONSE:

The adoption of certain construction practices, including the sideborrow concept, can limit the impact of access road construction. Since the development of large borrow areas has the potential of disturbing more area than the access roads themselves, special attention will be given to designing the access road to take advantage of opportunities to employ the sideborrow technique. In addition, Alaska Power Authority intends to have its engineers work with environmental scientists in selecting temporary overburden and topsoil stockpile locations. Other suggestions in the Comment will also be considered for incorporation into the access road design and construction specifications.

It is the Power Authority's intention to identify more potential borrow areas and stockpile sites than will actually be needed, so that the contractors will have a number of options for completing the access road construction. Resource agencies will have an opportunity to review design criteria and alignments.

COMMENT I.387:

"Page E-3-263: Paragraph 4: This section should explain how the transmission corridor in the Jack Long Creek area will be maintained since 'temporary' bridging of the creek will be accomplished for construction. We recommend transportation of construction materials and equipment via helicopter in this area to minimize potential disturbance, erosion, and loss of fish and wildlife habitats.

"Please refer to Attachment C, for additional recommendations."

RESPONSE:

The transmission line right-of-way in the Jack Creek area will be maintained by ground access. East of the Jack Creek crossing, the transmission line right-of-way will be maintained by access from the Devil Canyon access road. The line and right-of-way west of the crossing will be maintained via access along the Intertie route to the Gold Creek substation.

It is the intention of the Power Authority that ground access be used for construction and maintenance of the transmission line (FERC License Application page E-3-271). The many limitations of helicopter use (FERC License Application page E-3-271) make it impractical to specify helicopter use as the sole means of access except in very limited locations where rugged terrain or severe environmental impact make their use imperative. In addition, being forced to depend solely on helicopters as the means of transport for service restoration presents an unnecessary risk in terms of delay and safety.

Prudent planning for maintenance and restoration of the transmission line necessitates provisions for ground access to the line.

COMMENT I.388:

"Page E-3-264: Paragraph 1: We concur with realignments and improved siting of the railhead facility to further minimize project impacts to furbearers, eagles, and wetlands. The discussion should include how such siting will minimize disturbances to big game. Until additional assessment data can be incorporated into moose, black bear, and brown bear

COMMENT I.388 (cont.):

models, it is not possible to compare habitat values of alternative locations.

"Paragraph 3: A road crown of 2 to 3 feet above original ground level may not provide an adequate thermal blanket in areas of permafrost."

RESPONSE:

The railhead facility site, while necessary to be placed on the south side of Jack Long Creek due to a beaver pond and other wildlife concerns, is sited close to the construction camp and village to reduce disturbance effects on surrounding big game. It is also in fairly wet forested habitats containing some black spruce--habitats not highly productive for either browse species used by moose, or spring forage or berry plants utilized by bears.

FERC License Application Figure E.3.83 contains a typical cross-section of the side-borrow roadway. The feasibility design as shown indicates a variable sub-base thickness. The reference to a two-to-three-foot road crown on FERC License Application page E-3-264 is a generality for allowing the reader to compare a finished road section using side borrow with the conventional roadway section. The actual thickness of the roadway crown will be established prior to completing the construction specifications by design-related investigations of the sub-base material conditions in the field including permafrost.

Roads susceptible to deterioration by permafrost usually lie on silt-covered lower hillslopes or organic-rich soils in lowlands which contain a high percentage of ice and ice wedges. Thawing of such ground results in noticeable differential subsidence.

Because permafrost containing large amounts of ice has not been encountered along the proposed alignment, the roadway is expected to be subjected to only that subsidence caused by thawing of the so-called "warm" permafrost prevalent in the area. Some slough and swale deposits may contain segregated ice, but these deposits are restricted and easily removable. For these reasons, the feasibility design using two to three feet of road crown is considered to be appropriate. See also Response to Comment A.4.

COMMENT I.389:

"Page 266: Paragraph 3 through Page 268: We recommend that resource agency concurrence be obtained during detailed engineering design for final site selection and procedures for spoil disposal. Spoil should be armored with rock and/or gravel to stabilize the soils against wave action and prevent sedimentation during reservoir drawdown. Spoil which may be unsuitable for disposal because of cost, composition, or proposed construction schedules should be identified. Settling ponds may be necessary in conjunction with temporary construction berms or borrow pits. No spoil should be placed upon snow, even for temporary disposal, and overburden should not be pushed onto areas adjacent to roadways which cross tundra vegetation.

"Additional recommendations for settling ponds, should they be used in spoil disposal, follow:

1. Settling ponds should be sized for gravel processing quantities, and fines. 3B-6/.

2. Generally, when half the capacity of settling ponds are filled with silt, they should be cleaned out.

3. If the settleable fines are to be deposited between the flood pool's high and low water marks, they should be covered with a rock blanket for stabilization.

"The length of time and potential areas to be covered by any 'temporary' spoils disposals should be designated."

"3B-6/ U.S. Forest Service. Guidelines for Reducing Sediment in Placer Mining Wastewater. No date, available from Alaska Resources Library, Anchorage, Alaska. 31 pp."

RESPONSE:

Spoil sites are to be located within the impoundment or within the borrow pits themselves (see Plates F 34 and F 71 of FERC License Application).

During the detailed engineering design of spoil operations, technical specifications will be developed and incorporated into the earthwork contract packages concerning final spoil site selection and procedures for spoil disposal. See the Response to Comment I.425.

RESPONSE TO COMMENT I.389 (cont.):

The contents of these specifications will comply with Federal and State regulatory statutes and will include:

1. Classification of spoil materials;

2. Types of spoil sites (exterior to impoundment, interior impoundment, permanent - temporary);

3. Permit and code requirements;

4. Site preparation (stripping, grubbing, stockpiling organics);

5. Grading and drainage (excavation, construction berms, dikes);

6. Erosion control and spoil stabilization (slopes, surface treatment);

7. Sedimentation control (settling ponds, treatment);

8. Discharge requirements;

9. Quality control, sampling and testing procedures; and

10. Documentation.

By incorporating these specifications into all earthwork contracts, continuing long-term earthwork operations will be accomplished in compliance with applicable regulations through application of contract administration techniques and quality control testing and inspection.

COMMENT I.390:

"Page E-3-267 Last Paragraph through Page E-3-268: Paragraph 1: This section should explain the proposal to deposit spoil above the 50-year flood level for the Devil Canyon Reservoir. We recommend that all disposal be within the impoundment area and that vegetation slash be burned to preclude debris accumulations in water entrainment systems."

RESPONSE:

As stated on FERC License Application page E-3-253, generally spoil will be deposited within the impoundments or in the excavated borrow areas. Spoil disposal, siltation

RESPONSE TO COMMENT I.390 (cont.):

control and site rehabilitation will be addressed in detail in the Project Erosion Control, Waste Management, Revegetation/Rehabilitation Plans, to be developed by the Power Authority and reviewed by the appropriate agencies.

COMMENT I.391:

"Page E-3-268: Paragraph 3: Accurate wetlands maps should be used in geotechnical alignment studies so that wetlands and ice-rich soils can be avoided. Involvement of the environmental monitors should help further minimize sitings or drainage crossings potentially detrimental to fish and wildlife."

RESPONSE:

During detailed design, wetland maps at 1:63,360 of the project area as well as site specific studies along portions of the access road alignment will be completed prior to and in conjunction with geotechnical exploration. All wetland activities will comply with COE, ADEC and ADF&G regulations.

State-of-the-art practices in ice-rich soils and ADOT road design criteria will be used in the design and construction of the access road.

Please also refer to the Response to Comment I.147. In addition, the Power Authority and the U.S. Fish and Wildlife Service, Region Seven are currently negotiating an MOU that will support a joint wetland mapping program. Draft wetland maps are expected during the winter of 1984-85.

COMMENT I.392:

"Page E-3-269: Paragraph 3: It is unclear what portion of the Anchorage to Fairbanks transmission corridor to 'be widened to accomodate an additional single-tower right-of-way 190 feet (58 m) wide' has been included in the previous vegetation assessment (Section 3.3.4(a) and Tables E.3.79, E.3.80 and E.3.86). The statement that this alignment 'may depart from the previously established corridor' substantiates our previous concerns that by not evaluating the Intertie as an integral part of the Susitna project, further impacts could result from later needs to upgrade the line."

RESPONSE TO COMMENT I.392:

The additional single-tower right-of-way referenced in paragraph 3, FERC License Application page E-3-269 of Exhibit E, refers to the addition of the Devil Canyon transmission line from Gold Creek to Anchorage. This results in two lines existing between Gold Creek and Willow (not including the Intertie) and three lines existing between Willow and Cook Inlet (Knik Arm). FERC License Application Tables E.3.79 and E.3.86 did not include a calculation of the area of vegetation to be cleared for the additional line to Anchorage associated with Devil Canyon. These have been corrected and are referenced in the Response to Comment I.370. FERC License Application Table E.3.80 represents impacts associated with the transmission lines between Watana and Gold Creek and is not relevant to the Anchorage-to-Fairbanks corridor.

The statement that the alignment "may depart from the previously established corridor in locations" was intended to reflect the possibility that constraints identified during construction of the Intertie often may be avoided through route refinement. Major corridor deviations are not intended. Typical impacts associated with construction of transmission lines, such as change of vegetation, will occur when the later (Devil Canyon) line is constructed. However, since it will be adjacent and parallel to the other Susitna River and the Intertie line, the types, locations and significance of impacts within this corridor can be anticipated as a result of previous construction.

COMMENT I.393:

"Page E-3-269: Paragraph 4: The referenced 69 kilovolt (kv) service transmission line has not been previously mentioned and appears inconsistent the statement that diesel generators will be used to maintain the camp and village and construction activities (Exhibit A, Section 1.13(d)(i), page A-1-27). Please clarify the purpose of this line, proposed right-of-way, height of utility poles, distance of the centerline from the access road, and connections at the Denali Highway end. According to the APA, three alternatives are under consideration for supplying power during project construction; (1) a 69kv service transmission line from Cantwell along the Denali Highway-to-Watana access route; (2) a transmission line from the Intertie near Gold Creek along the railroad and access road which follow the Susitna River; and (3) use of diesel generators (Thomas A.

COMMENT I.393 (cont.):

Arminski, APA Deputy Project Manager, personal communications of September 30, 1983). The existence of those three alternatives should be described in detail in the license application. We recommend that alternative (3), diesel generation, be used to avoid impacts of an additional transmission line."

RESPONSE:

The type of power supplied for project construction and camp purposes has not yet been finalized. Issues that will be addressed in reaching a final decision include contractor preference and flexibility, construction scheduling, power availability and reserve from the Intertie, and agreements with utilities to tap Intertie power.

The three alternatives referenced in the Response to Comment I.393 are still under consideration. While a final decision has not been made, a combination of diesel and transmission line is considered most likely. Presently, the preferred option for supplying transmission line power is construction of a line from Gold Creek to Watana as shown in Exhibit G of the License Application (reference Response to Comment A.7). This line would be energized at 138 kV and then stepped down to the necessary power requirement at the construction site. Upon completion of Watana construction the line would then be upgraded to 345 kV for incorporation into the Susitna power system.

The 69 kV transmission line option, if selected, would run from Cantwell along the Denali Highway to the access road, and then parallel the access road to the construction site. Placement of this line would be within the right-of-way of the access road. Typical design characteristics for such a line include the following:

- Tower Type - Single Circuit wood pole
- Height - 42-45 feet
- Right-of-way - Approximately 50 feet
- Proximity to access road - Outside edge of drainage swale
- Connection at Cantwell - Transformer at Cantwell Substation

COMMENT I.394:

"Pages E-3-269 through E-3-274: The mitigative practices that are described here should be part of Biological Stipulations included in project licensing and contract bid specifications. Once the moose carrying capacity model and more detailed vegetation mapping is completed, an analysis should be undertaken of the potential to optimize browse production by additional transmission line clearing or varying vegetation heights by changing maintenance schedules within constraints of safe line operation. Follow-up studies should be initiated to confirm the value of expected browse enhancement and aid planning and implementation of such vegetation manipulations."

RESPONSE:

A. As mentioned in more detail elsewhere (I.425), the Power Authority does not concur with the U.S. Fish and Wildlife Service's recommendation that all biological stipulations be adopted as articles of license or (as presented) contract specifications.

B. The Power Authority will investigate the feasibility of enhancing moose browse within the transmission line right-of-way. If an enhancement program appears warranted and is embarked upon, an appropriate monitoring program will be initiated. Please refer to the Response to Comment I.277.

COMMENT I.395:

"Page E-3-273: Paragraph 4: Potential policy conflicts should be identified in conjunction with access road and transmission line siting studies. Agreements with public and private landowners which provide for the mitigation determined necessary by the applicant should be confirmed prior to project licensing. Unless such agreements are incorporated into the license, there is no guarantee that mitigative management policies will be adopted. The record on negotiation settlement proceedings for the Terror Lake hydroelective project now under construction by the applicant on Kodiak Island supports such careful planning."

RESPONSE TO COMMENT I.395:

The Power Authority is presently discussing policy issues with agencies and landowners including issues dealing with access and transmission lines. It is the Power Authority's intent to continue consulting with resource management agencies, land managers and owners to identify all relevant issues and resolve conflicts, if any.

As required by FERC regulations, measures and facilities recommended for mitigation by agencies have been described in the FERC License Application. When feasible and necessary, agreements with public and private landowners regarding mitigation may be obtained prior to project licensing. It is anticipated, however, that not all agreements regarding mitigation will be confirmed prior to the license. Refinements to mitigation plans are a continuous process based on information received from ongoing studies, site specific information gathered during field investigation and information based on detailed design. All of these will continue after granting of the FERC license.

In addition, given the length of time to completion of the Project and the dynamic arena of Alaska land use planning, it is prudent to reexamine policy issues and agreements prior to, during and after construction.

The Power Authority anticipates that the FERC license issued for this Project will include FERC's customary and appropriate conditions and will not include unnecessary conditions. For example, any mitigation agreements may be enforced in accordance with their terms and need not be duplicatively and wastefully enforced through FERC license conditions.

COMMENT I.396:

"<u>Page E-3-274: Paragraph 4 and Page E-3-275: Paragraph 1</u>: The text should explain: (1) inconsistencies between these figures and those in Section 3.4.2(a); and (2) calculations of areas where vegetation removal will be minimized."

RESPONSE:

Inconsistencies between figures on FERC License Application pages E-3-274 and E-3-275, and calculations of areas where vegetation removal will be minimized have been corrected in

RESPONSE TO COMMENT I.396 (cont.):

Supplemental Information Request Response 3B-7 provided to the FERC on July 11, 1983. The revised tables and relevant portions of the text that subsequently required modification is included in Reference I.370.2 (see February 15, 1984 APA Response Document, Reference Volume). Additional cross-sections to FERC License Application page E-3-252 have been included in Reference I.370.2 as well.

COMMENT I.397:

"Pages E-3-275 through E-3-281(ii) Rectification: A preliminary assessment should be made of vegetation cover type losses from the standpoint of how long each area will be disturbed. As reclamation and revegetation take effect and disturbance by construction activities decreases, some habitat values would be expected to slowly increase. We agree that predictions of how plant succession will proceed on these lands over time are difficult to justify. However, we suggest that the information presented here, coupled with the successional information presented earlier (Section 3.3.1(b)[i] and in Table E.3.144) will allow an assessment of the range of possible vegetation restoration over time. The typical 10-year time frames within which each area will be completely out of production must be coupled with the up to 150 year time spans necessary for revegetation in order to thoroughly assess project impacts. Although these losses may be 'temporary,' they are significant within the average life-spans of area wildlife."

RESPONSE:

The statement in the FERC License Application which discusses the rate of revegetation and states that 150 years may be required for revegetation refers to development of mature plant communities on harsh sites. The intervening successional phases provide productive habitat. Additional evaluation will be made during the Mitigation Plan refinement. Assessments of the rate and direction of revegetation can be made part of the site-specific restoration plans.

COMMENT I.398:

"Page E-3-276: Construction Camp: The text should clarify the double listing for dismantling and redraining the 78 acres involved here."

RESPONSE TO COMMENT I.398:

The FERC License Application text cites the rehabilitation action as "dismantling" of the temporary facilities such as the construction camp and "reclaiming" the area by preparing the acreage for re-establishment of vegetation. It is anticipated that the camp will be dismantled in phases and therefore will likely occur over a two-year period. This is why the 156 acres required for the construction camp is split into two parts.

COMMENT I.399:

"Page E-3-277: Borrow Area D: It appears that an additional 70 acres should be listed under the excavation and reclamation category for 1986."

RESPONSE:

Under Borrow Area D, on the listing of rehabilitated lands at Watana, an additional 70 acres should be added under excavation and reclaiming, for 1986. The revised list should read as follows:

RESPONSE TO COMMENT I.399 (cont.):

License Application Page E-3-277 - Revised

3.4 - Mitigation Plan

WATANA (CONT.)

Facility & Vegetation	Action	Year	Area (acres)
Borrow Area D	Excavate	1985	70
- Woodland Black Spruce	Excavate & Reclaim	1986	70 & 70
- Closed Birch Forest	Excavate & Reclaim	1987	70 & 70
- Open Mixed Forest	Excavate & Reclaim	1988	100 & 70
- Wet Sedge-Grass Tundra	Excavate & Reclaim	1989	100 & 100
- Closed Tall Shrub	Excavate & Reclaim	1990	100 & 100
- Birch Shrub	Excavate & Reclaim	1991	100 & 100
- Mixed Low	Excavate & Reclaim	1992	100 & 100
Shrub	Reclaim	1993	100

DEVIL CANYON

Facility & Vegetation	Action	Year	Area (acres)
Construction Camp	Start Const.	1994	45
- Closed Mixed Forest	Complete Const.	1995	45
	Dismantle & Reclaim	2002	89
Village	Start Const.	1995	48
- Closed Mixed Forest	Complete Const.	1996	48
	Dismantle & Reclaim	2002	96
Construction Roads	Start Const.	1994	75
- Open Black Spruce Forest	Complete Const.	1995	25
- Closed Birch Forest	Grade & Reclaim	2003	100
- Open Mixed Forest			
- Closed Mixed Forest			

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S):
B. 19

R&M CONSULTANTS, INC. 5024 CORDOVA • BOX 6087 • ANCHORAGE ALASKA 9950? • PH 907-561-1733

ENGINEERS
GEOLOGISTS
PLANNERS
SURVEYORS

November 9, 1983 R&M No. 352333

Envirosphere Company
1617 Cole Boulevard, Suite 250
Golden, CO 80401

Attention: Mr. Don Beaver

Re: Susitna Hydroelectric Project, Slough Groundwater Studies

Dear Don:

I recently reviewed your report, September 1983 Site Visit and FY 1984 Plan of Study. In this report you requested the following 1983 data:

- Water levels and temperatures from wells.
- Slough and mainstem stage and discharge measurements.
- Seepage meter and piezometer data.
- Slough temperature and water quality data.

1. Water levels and temperatures from wells.

   This data is not yet complete and will be forwarded when possible. We are awaiting reduction of Datapod chips.

2. Slough and mainstem stage and discharge measurements. Enclosed are:

   a. Water discharge records for the Susitna River at Gold Creek for water year 1982 and provisional 1983.

   b. Water discharge records for 1983 for Sloughs 8A, 9, and 11 (provisional).

3. Seepage meter and piezometer data. Enclosed are:

   a. Seepage meter program summary.

   b. Seepage meter field data collected this summer in Sloughs 8A, 9, 11, and 21.

   c. Plots of data in "b" above.

   d. Comments on seepage meter data.

4. Slough temperature and water quality data.

   a. Selected portions of ADF&G report "Winter Aquatic Studies (October 1983 - May 1983). Covered in this report are intragravel and surface water temperatures for Sloughs 8A, 9, 11 and 21 for the period August 1982 to May 1983, and results of an incubation study which measured various water quality parameters of upwelling groundwater.

   b. A short review of ADF&G Preliminary Intergravel Temperature data for Sloughs 8A, 9, 11 and 21 covering the period June 1983 to August 1983.

Data that needed for groundwater analysis, but not yet reduced includes:

- Precipitation for 1983 at Sherman.
- Specific mainstem water surface elevations at various discharges in the areas of Sloughs 8A, 9, 11, and 21 (ADF&G data).
- Results of further ADF&G incubation studies.
- Water levels and temperatures from wells.

The above will be forwarded as available. Please call if you have questions or desire additional data.

Very truly yours,

R&M CONSULTANTS, INC.

Robert Butera
Staff Civil Engineer

RB/kys

cc: Dr. John Bizer
Mr. Wayne Dyok

RJB 5/17/83

Slough Seepage meter Program

Objective: To define the relationship between mainstem water surface elevation and upwelling rates in selected side-sloughs between Talkeetna and Devil Canyon.

Methods: Seepage meters to be set permanently into substrate in areas of sloughs which are main sources of water to the slough throughout the year. Measurement of seepage rates to be made at various mainstem water surface elevations.

The data to be obtained include:

- Date and time of sampling.
- mainstem Flow in Susitna River at Gold Creek,
- Water surface elevation in slough at seepage meter.
- water surface elevation in mainstem nearby to seepage meter.
- Temperature of upwelling water.
- seepage rate in ml./minute
- piezometric head in selected locations.

Locations: Determined from ADF+G mapping of observed upwelling locations and from slough surveys. As shown on attached maps

Report: Comparison of Q Susitna River at Gold Creek vs seepage rate.

Seepage meter 8-1

	Date	Mean Daily Qcc	Average Vol/min (ml.)	w.s.e of slough (ft. msl.)	Temp °C	Piezomet Head (ft.)	comments
	5/20/83						Installed
1	5/22	19,000	169	573.64	3.1		
2	6/10	21,600	121	573.60	3.7		
3	7/14	19,800	28	573.57	5.5		
4	8/10	31,900	158	573.66	4.3		
5	8/11	27,700	152	573.64	–	0.14	piez. installed. Screen is 1' below substrate
6	8/24	24,700	–	–	–	0.09	
7	9/21	11,000	(1 sample) 12	573.57	–	–	sampled by W. Dioche
8	9/23	17,500	20	573.64	–	0.03	
9	10/11	9,300	18	573.65	–	0.02	
10	10/27	5,300	-7	573.33	3.1	-0.14	channel is now effluent

Comments:

- Seepage meter was located in gravel bed in area of a few small visible upwellings.
- Staff gage 0 elevation = 572.69' msl.

SEEPAGE METER 8-2

Date	Mean Daily Q Gold Creek	Average Vol/min (ml.)	wse of slough (Ft. msl.)	Temp (°C)	Piezometer Head (Ft.)	Comments
5/20/83						installed
5/22	19,000	122	574.76	3.4		
6/10	21,000	102	574.69	5.0		
7/14	19,800	60	574.37	7.0		
8/10	31,900	104	574.82	4.5		
9/21	11,000	–	–	–		channel dewatered
9/23	17,500	71	574.45	–		
10/11	9300	45	574.31	2.0		water held in pool by snow and ice control downstream
10/27	5300	–	–	–		channel dewatered

Comments:

- Seepage meter located 300' downstream of berm. 1-4" cobbles in channel.
- staff gage 0 elevation = 573.81' msl.

Seepage meter 9-1

location: Slough 9 at downstream end near area of large bank seepage and upwelling about 100' downstream of streamgage on RB.

staff gage 0 elevation =

Date	Q_{ac}	Average Volume/min (ml.)	WSE of slough (Ft. msl.)	temp (oC)	piezometer head (Ft.)	Comments
5/20/83						Installed
5/21/83	20,000	169	592.70	—		
5/24/83	17,000	169	592.60	3.4		
6/8/83	22,000	75	593.00	3.0		Can overtopped meter silted over
7/13/83	19,100	255	592.65	3.4	0.15	
10/11/83	9300	138	592.79	3.5	0.09	
10/27/83	5300	107	592.65	3.5	0.11	Good flow of water from banks

Comments:

- Seepage meter located at downstream end of slough 9 on right bank in area of large bank seepage.
- Staff gage 0 elevation = 591.15

SEEPAGE METER 9-2

location: Slough 9 in marshy area which feeds tributary at corner near RR tracks. Most downstream meter of two

Date	Mean Daily Discharge @ Gold Creek	Average Volume/min (ml)	Staff gage	temp (°C)	Piezometer head (Ft.)	Comments
5/20/83						Installed
5/24/83	17,000	44	0.69	4.1	–	Q in stream = 11.9 cfs
6/10/83	21,000	25	0.70	4.0	–	Q in stream = 1.8 cfs
7/13/83	19,100	38	0.82	5.0	0.77	Q in stream = 1.1 cfs
8/10/83	31,900	66	1.11	5.5	1.17	Q in stream = 5c = 1.5
9/23/83	17,500	51	0.95	7.0	0.88	recent rains
10/11/83	9300	85	0.98	6.4	0.28	recent 21" snow creek high
10/27/83	5300	36	0.87	4.8	0.73	Q in stream = 0.9 cfs

Comments:

Staff gage '0' elevation = (not surveyed to date)

Seepage meter 9-3

Location: Slough 9 in marshy area which feeds tributary at rear of slough 9 near RR tracks. Upstream meter of two. Set 6" into silt on upwelling.

Date	Q cc	Average Volume (ml)	Staff gage	temp. (°C)	midi Piez.	Comments
5/10/83						Installed
5/24/83	17,000	180	0.69	4.1	> 0.4	Q in stream = 11.9 cfs
6/10/83	21,000	110	0.70	4.0		Q in stream = 1.8 cfs
7/13/83	19,100	53	0.82	5.0	0.72	Q in stream = 1.1 cfs

although flow in trib stream is down the flow from marshy area has continued unabated. Rise in stage is due to retardation of flow by dense growth of grass.

Date	Q cc	Average Volume (ml)	Staff gage	temp. (°C)	midi Piez.	Comments
8/10/83	31,900	149	1.11	5.5	1.15	Q in stream at SG = 1.5
9/23/83	17,500	84	0.95	7.0	0.90	recent rains
10/11/83	9300	71	0.98	6.4	0.92	recently [illegible] snow creek high from rainfall
10/27/83	5300	90	0.87	4.8	0.81	Q in stream = 0.9 cfs.

Comments:

staff gage '0' elevation - (not surveyed to date)

Seepage Meter 11-1

location: Slough 11 at streamgage site. No visible upwelling at time of installation

Date	Qoc	Average Volume/min (ml)	Staff gage	Temp (°C)	mini Piez	Comments
8/12/83	27,500	138	671.16	5.5	0.04	Installed
9/21/83	11,000	—	671.07	—	0.065	No other measurements
9/22/83	13,600	77	671.08	—	0.015	Don Beaver
10/7/83	8300	70	671.08	3.0	0.04 (?)	[illegible] measured
10/11/83	9500	63	671.08	2.9	0.08	
10/27/83	5300	59	671.66	7.4	0.09	

Comments:

Staff gage "0" elevation = 670.18

Seepage meter 11-2.

location : 100' upstream of staff gage 20' downstream of NOF16.
thermograph in left bank in area of visible upwelling

Date	Q cr	Average Vol./min (ml.)	Staff gage	Temp. (°C)	Comments
8/12/83	24,500	60	1.11	5.2	Installed
9/22/83	13,600	41	1.04	–	w/Don Tanner
10/7/83	8300	41	1.04	3.6	Wayne Doyle (1 inch ice cover)
10/11/83	9300	45	1.05	2.4	
10/27/83	5300	40	1.01	2.4	4" ice cover on pool

Comments:

Staff gage '0' elevation = (not surveyed to date)

SEEPAGE METER 21-1

Location: Slough 21, 200' downstream of staff gage 142.056B on right bank at staff gage 142.057C

staff gage zero elevation = 744.29

Date	Q	Avg. Valve Volume/min (flow)	Slough WSE (MSL)	Mainstem Susitna WSE	Δhead	Temp	Comments
6-9-83	21,000	95	744.84	748.07	3.23	4.0	Installed today
7-12-83	19,700	132	744.79	748.18	3.39	4.5	
8-10-83	31,900	104	746.29	749.44	3.15	6.5	slough overtopped
8-12-83	24,500	147	744.91	748.60	3.69	4.1	
8-25-83	27,400	117	745.35	748.89	3.54	–	
9/7/83	15,200	166	744.79	747.25	2.46	3.5	recent rains
10/7/83	8200	158	744.79	746.66 (calculated)	1.87	3.8	measured by W.D.
10/11/83	9200	139	744.78	746.86 (calculated)	2.08	3.8	
10/27/83	5300	172	744.79	746.11	1.32	3.5	lot of upwelling

Seepage meter 21-2

	Date	Mean Daily Q Gold Creek (CFs)	Average Vol/min (ml.)	Temp (°C)	Piezometer head (Ft)	wse Slough (msl)	wse mainstem (msl)	ΔH Ft	Comments
1	5/22/83	19,000	168	3.7	–	744.94	747.61	2.67	Installed
2	6/9/83	21,000	258	4.0	0.29	745.03	748.07	3.04	
3	7/12/83	19,700	390	4.5	0.31	745.03	748.18	3.15	
4	8/10/83	31,900	289	5.2	0.24	746.35	749.44	1.65	slough overtopped
5	8/12/83	24,500	435	4.0	0.39	745.12	748.60	3.48	
6	8/25/83	27,400	382	–	0.39	745.36	748.89	3.53	slough not overtopped
7	9/24/83	15,200	310	3.3	0.35	745.04	747.25	2.21	
8	10/7/83	8300	327	3.6	0.19(?)	745.01	(calculated) 746.66	1.65	measured by Wayne Dieck
9	10/11/83	9300	356	3.6	0.35	745.03	(calculated) 746.86	1.83	
10	10/27/83	5300	337	3.5	0.38	745.03	746.11	1.08	lots of upwelling all over slough

Comments :

Location : In slough 21 nr. staff gage 142.056B along left bank
staff gage zero elevation = 744.15 Ft msl.

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): B. 34, I. 60

LAKE COMANCHE
DISSOLVED NITROGEN STUDY

Prepared for

Milo Bell
P.O. Box 23
Mukilteo, Washington 98275

Prepared by

Ecological Analysts, Inc.
2150 John Glenn Drive
Concord, California 94520

June 1982

Nitrogen gas in the deep water of a reservoir may be slightly super-saturated due to the hydro-static pressure of the overlying water (Wetzel, 1975). Therefore water flowing from a dam with a deep intake may contain a super-saturated concentration of nitrogen. If this excess nitrogen gas is not rapidly released into the atmosphere, it may cause nitrogen gas bubble disease in fish residing below the dam outfall (Conroy and Herman, 1970).

A study was conducted at Lake Comanche Dam, Mokelumne River, California, to determine the efficiency of the Howell-Bunger Valve in removing super-saturated dissolved nitrogen (N_2) from the dam's tailwater.

The valves spray outfall water into concrete conduits before releasing the water to the stream. This was observed and photographed at Lake Comanche Dam on 28 May, 1982 ~~1981~~, at a flow of 4000 cfs into the Mokelumne River (see accompanying photos). This creates a turbulent and aerated flow with the purpose of facilitating nitrogen gas release to the atmosphere.

By sampling nitrogen gas in the reservoir near the intake, and at several locations below the outfall valves, the efficiency of the valve was obtained.

METHODS

In order to determine nitrogen gas concentrations at various depths in the reservoir, water samples were collected in Lake Comanche approximately 50 m from the dam directly over the river channel on 28 May 1982. A Van Dorn Bottle was lowered from a boat to collect water samples at depths of 0, 10, 20, 30, and 38.4 m. As reported by East Bay Municipal Utility District the dam intake was at a depth of 38.4 m (126 ft) at the time of the sampling.

Once taken aboard, each sample was poured with minimum turbulence into an airtight bottle and capped in a manner that left no air bubbles in the bottle. Bottles were placed in a cooler for transportation to the lab. Studies conducted by Steve Wilhelms of the Hydraulic Laboratory, U.S. Army Waterway Experiment Station, Vicksburg, Mississippi (personal communication) indicate that brief exposure of deep water samples to atmospheric conditions has little effect on nitrogen gas concentrations. However, he has found that periods of exposure to atmospheric air bubbles during transportation can cause significant changes in nitrogen gas concentrations, hence the need for removing all air bubbles before transportation. Excess water remaining in the Van Dorn Bottles was measured for temperature. The atmospheric pressure measured on site at the time of sampling was 753 mm.

At the tailwater below the dam, water was collected by immersing the sample bottles under the water and capping them in a manner that left no air bubbles in the bottles. Samples were taken at the outfall, 100 m below the outfall, and 200 m below the outfall. Water temperatures were taken at each of these locations. Bottles were placed in a cooler for transportation to the lab. At the time of sampling, the outfall flow was 4,000 cfs. The atmospheric pressure was 753 mm.

The water collected was analyzed for nitrogen gas (N_2) and oxygen (O_2) in a California State Certified Water lab using a Carle Model 8700 Basic Gas Chromatogram with a thermal conductivity conductor several hours after collection.

RESULTS

Location	Depth (m)	Temperature (°C)	N_2 (mg/l)	N_2 % Saturation	O_2 (mg/l)	O_2 % Saturat
Reservoir	0	22.0	14.9	101	9.2	105
	10	14.5	17.0	100	9.3	90
	20	13.2	17.3	99	10.0	94
	30	11.0	17.9	99	10.2	93
	38.4	10.0	18.5	101	9.3	82
Dam Tailwater						
At Valve	0	10.2	17.7	97	11.1	94
100 m downstream	0	10.5	17.3	95	11.2	98
200 m downstream	0	11.5	17.9	97	10.9	98

References

Conroy, D.A., and R. L. Herman. Textbook of Fish Diseases. 1970. T.F.H. Publications, Jersey City, New Jersey. 302 pp.

Wetzel, R. G. 1975. Limnology. W.B. Saunders Company, Philadelphia. 743 pp.

APPENDIX B

SPILLS AT WATANA AND DEVIL CANYON DEVELOPMENTS

B.1 - OPERATION OF WATANA AND DEVIL CANYON COMBINED (Beyond Year 2002)

(a) Spill Quantities and Frequency

The monthly reservoir simulation studies calculate spill volumes as the flow required to be discharged from the dam to satisfy downstream requirements less the maximum turbine capacity, and does not restrict the turbine flow in relation to the actual energy demand of the system. Total energy production, as calculated, is the energy potential of the schemes. Usable energy is then calculated as the potential or the maximum energy demand, whichever is smaller. The turbine flows are not readjusted to the level of usable energy production. Tables B.1 to B.9 present selected results of the reservoir simulation studies which indicate this.

Tables B.10 to B.12 are developed from the reservoir simulation studies for adjusted turbine flows for two alternative generation patterns at Watana and Devil Canyon for the months of August and September when spills are most likely to occur. Alternative A assumes that whenever the potential energy generation from Watana and Devil Canyon developments is greater than the usable energy level, each development will share the usable energy generation in proportion to their average heads. However, in the months when Watana outflow, as simulated, is not sufficient to generate energy in proportion to its average head, Devil Canyon will make up this difference. This operation is required in such years when Devil Canyon is being drawn down to meet the minimum downstream flow requirements (years 1, 2, for example). Alternative B assumes that Devil Canyon would generate all the energy possible consistent with downstream flow requirements, and Watana would only operate to make up the difference in years when energy potential is greater than usable. This assumes that all the energy from Devil Canyon is useable as base load on a daily basis. Battelle load forecast (1981) tends to confirm this assumption for the year 2010. However, during earlier years, such operation may not be fully possible.

It may be readily seen from Tables B.10 to B.12 that frequency of continuous spills (24 hours) from the reservoirs in the months of August and September is significantly greater than presented by the reservoir simulation (Tables B.3 and B.6).

The analyses summarized in Tables B.10 to B.12 indicate that Devil Canyon would spill in 30 out of 32 years in August and 16 out of 32 years in September for the Case "C" operation which maintains a minimum instantaneous flow of 12,000 cfs in August at Gold Creek. For downstream discharge requirements greater than 12,000 cfs at Gold Creek, it is estimated that the frequency of spills may not be increased significantly. However, the volume of spills will be larger to make up for increased flow requirement. The above spill frequency is simulated for a system energy demand in the year 2010 (Battelle Forecast) and assumes that the entire demand is met by Watana and Devil Canyon developments where possible. The spills will be greater and more frequent in the years between 2002 (Devil Canyon commissioning) and 2010.

It may be seen that operation Alternative 2, which provides for maximum possible energy generation from Devil Canyon while Watana is allowed to spill, results in significantly reduced spill frequency from Devil Canyon. This type of operation is expected to be advantageous with regard to downstream water quality (see Section B.2).

Several intermediate distributions of generation between Watana and Devil Canyon is also possible. A recommended operation will be derived after finalizing the downstream flow requirements and the refined temperature modeling studies which are currently in progress.

(b) Spill Quality

(i) Spill Temperature

Figures B.1 and B.2 are extracts from the project Feasibility Report (7) and present simulated temperature profiles in the Watana and Devil Canyon reservoirs for the months June to September. Refinement of reservoir temperature modeling is currently in progress, but the differences between the revised profiles are not expected to be very significant from the ones presented here for these months.

Temperature of spill waters at Watana is expected to be close to that of power flow, and hence, it is not expected to create temperature problems downstream when Watana is operating alone (1993-2002) or when it spills into Devil Canyon. At Devil Canyon, however, spill temperature is expected to be close to 39°F compared to a power flow temperature of 48-49°F in August and 45°F in September. This is based on the conservative assumption that the temperature of spill water does not increase significantly while in contact with the atmosphere despite the highly diffused valve discharge. It is, therefore, considered prudent to keep the spill from Devil Canyon to a minimum to maintain as high a downstream temperature as possible during spills.

The operation Alternative 2 indicates that by operating Devil Canyon to generate as much as possible during these months and with Watana generating essentially to meet peak demands and spilling continuously when necessary, it would be possible to maintain downstream flow temperatures below Devil Canyon close to that of power flow.

During major floods (1:10 year or rarer frequency), there will be significant spills from Devil Canyon (see Tables B.10 and B.11) in addition to the power flow resulting in cold slugs of water downstream for a few to several days. It will be necessary to establish criteria for acceptability of lower temperatures for short durations in August and September in consultation with fisheries study groups and concerned Agencies. Currently, downstream water temperature analyses are being refined, and when the results are available, the above spill temperatures and duration should be reviewed to confirm downstream temperatures during normal power operation as well as flood events. If the projected temperature regime downstream is unacceptable, alternative means to remedy the situation should be considered. These may include provision of higher level intakes to several or all fixed-cone value discharges at Devil Canyon, multilevel power intake at Devil Canyon, limited operation of main overflow spillway (for floods 1:50 year or more frequent) to improve downstream water temperature without serious increase in nitrogen supersaturation, etc.

(ii) Gas Supersaturation

It does not appear (from Table 6.1) that there would be significant advantage in spilling from Watana as compared to spills from Devil Canyon in terms of gas concentration.

B.2 - OPERATION OF WATANA ALONE (1993-2002)

Before Devil Canyon is commissioned, Watana would operate alone, and spills required to maintain downstream flows will have to be made through the fixed-cone valves. Reservoir simulations indicate that, generally, spills would be of lower magnitude during this operation due to greater percentage of flow being used to generate usable energy.

It is believed that the river reach of some 30 miles between Watana dam and Devil Canyon would lessen the impact of spill temperature and gas concentration below Devil Canyon and would pose less problems, if any, compared to the case when Devil Canyon development is also commissioned.

Table B.1 [illegible] monthly inflow

RESERVOIR 1

INFLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4719.9	2083.6	1168.9	815.1	611.7	559.1	680.1	8665.9	16432.1	15193.4	[illegible]	1320.4
2	3299.1	1107.3	906.2	808.0	673.0	619.8	1302.2	11649.8	16517.9	19756.6	16478.0	17265.5
3	4592.9	2170.1	1501.0	1274.5	841.0	735.0	803.9	4216.5	25773.4	22110.9	17356.3	11571.0
4	6285.7	2756.8	1281.2	818.9	611.7	670.7	1382.0	15037.2	21469.8	17355.3	16681.6	11513.5
5	4218.9	1599.6	1183.8	1087.6	803.1	638.2	942.6	11696.8	19476.7	16983.6	20420.6	9165.5
6	3859.2	2051.1	1549.5	1386.3	1050.5	866.1	940.6	6716.1	24851.4	23787.9	23537.0	[illegible]
7	4102.3	1588.1	1038.6	816.9	754.6	694.4	716.3	12953.3	27171.8	25831.3	19153.4	13194.4
8	4208.0	2276.6	1707.0	1373.0	1189.0	935.0	945.1	10176.2	25275.0	19948.9	17317.7	14841.1
9	6034.9	2935.9	2258.5	1480.6	1041.7	974.5	1265.4	9957.8	22097.8	19752.7	18844.4	5978.2
10	3668.0	1729.5	1115.1	1081.0	949.0	694.0	865.7	10140.6	18329.6	20453.1	23940.4	12465.9
11	5165.5	2213.5	1672.3	1400.4	1138.9	961.1	1069.9	13044.3	13233.4	19506.1	19334.1	16065.6
12	6049.3	2327.8	1973.2	1779.9	1304.8	1331.0	1965.0	13637.9	22264.1	19839.8	19480.2	10146.2
13	4637.6	2263.4	1760.4	1608.9	1257.4	1176.8	1457.4	11343.5	36017.1	23443.7	19987.1	[illegible]
14	5560.1	2508.9	1706.9	1308.9	1164.7	883.6	776.6	15299.2	20663.4	26767.4	21011.4	10600.0
15	5187.1	1789.1	1194.7	852.0	781.6	575.2	609.2	3578.8	42841.9	20082.6	[illegible]	7574.2
16	4759.4	2368.2	1070.3	863.0	772.7	807.3	1232.4	10966.0	21213.0	23235.9	17393.1	12225.6
17	5221.2	1565.3	1203.6	1060.4	984.7	984.7	1338.4	7094.1	25935.6	16153.5	17350.9	9214.1
18	3269.6	1202.2	1121.6	1102.2	1031.3	689.5	849.7	12535.5	24711.9	21987.3	[illegible]	13372.9
19	4019.0	1934.3	1704.2	1617.6	1560.4	1560.4	1576.7	12838.7	25764.0	22082.8	14147.5	7162.6
20	3135.0	1354.9	753.9	619.2	607.5	686.0	1261.6	9313.7	13960.1	14843.5	7771.9	4160.0
21	2403.1	1026.9	709.3	536.2	602.1	624.1	986.4	9536.4	14399.0	16410.1	[illegible]	7224.1
22	3768.0	2496.4	1687.4	1097.1	777.4	717.1	813.7	7857.2	27612.8	21136.4	27446.6	12188.9
23	4979.1	2587.0	1957.4	1670.9	1491.4	1366.0	1305.4	15973.1	27429.3	19820.3	17509.5	10955.7
24	4301.2	1977.9	1246.5	1031.5	1000.2	873.9	914.1	7267.0	26859.3	16351.1	18016.7	8099.7
25	3056.5	1354.7	931.6	786.4	689.9	627.3	871.9	13889.0	14780.6	15971.9	13521.7	9766.2
26	3088.8	1474.4	1276.7	1215.8	1110.3	1041.4	1211.2	11672.2	26689.2	23430.4	15126.6	13075.3
27	5679.1	1601.1	876.2	757.8	743.2	690.7	1059.8	8938.8	19994.0	17015.3	18393.5	5711.5
28	2973.5	1926.7	1687.5	1348.7	1202.9	1110.8	1203.4	8569.4	31352.8	19707.3	14807.3	10613.1
29	5793.9	2645.3	1979.7	1577.9	1267.7	1256.7	1408.4	11231.5	17277.2	18385.2	13412.1	7132.6
30	3773.9	1944.9	1312.6	1136.8	1055.4	1101.2	1317.9	12369.3	22904.8	24911.7	16670.7	9096.7
31	6150.0	3525.0	2032.0	1470.0	1233.0	1177.0	1404.0	10140.0	23400.0	26740.0	18000.0	11000.0
32	6458.0	3297.0	1385.0	1147.0	971.0	889.0	1103.0	10406.0	17323.0	27840.0	31435.0	12026.0
AVE	4513.1	2052.4	1404.8	1137.3	978.9	898.3	1112.6	10397.6	22922.4	20778.0	18431.4	10676.4

Table B.2 [illegible] Power Flows . Case 'C' Operation

POWERHOUSE FLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5276.3	8474.4	11285.3	8391.5	7254.9	[illegible]	[illegible]	6551.7	[illegible]	4546.5	[illegible]	4900.4
2	6234.5	7324.0	9102.0	8464.7	7326.2	6551.2	5554.2	7559.3 [illegible]				
[illegible]	6844.1	1630.2	6576.5	13051.6								
3	7568.3	9549.1	11617.4	8851.3	7494.2	6366.9	5457.6	6409.6	7389.9	5719.7	6135.3	10601.3
4	8881.8	10527.8	11397.6	8395.7	7264.9	6365.6	5846.8	9241.8	8943.6	4991.8	6626.2	8206.5
5	7194.3	8976.6	11300.2	8864.5	7456.3	6567.8	5404.4	7775.0	7265.2	4579.7	5917.9	7900.3
6	6834.6	9430.1	11565.9	8965.1	7703.7	6345.9	5648.4	6627.3	7933.7	6692.3	13289.8	13447.8
7	7077.7	8967.1	11155.0	8393.7	7408.0	6336.3	5422.2	8265.3	10712.1	8844.4	12744.0	13194.4
8	7183.4	9655.6	11823.4	8949.8	7842.2	6330.4	5719.3	7209.1	9352.7	6501.2	6328.7	14301.6
9	8805.9	10526.1	11738.1	9694.2	7694.9	6357.9	6051.0	7144.7	7949.2	5316.5	6441.1	5471.6
10	6643.4	9108.5	11231.5	8657.8	7602.2	6324.0	5417.5	7119.7	6419.8	4845.6	10300.0	12466.9
11	8140.9	9592.5	11788.7	8977.2	7792.1	6239.2	5861.9	8406.6	[illegible]	4505.4	6138.6	13284.9
12	8931.7	9803.0	11622.3	9624.0	7958.0	6736.6	7139.7	6649.6	[illegible]	5659.0	7837.0	10146.2
13	7613.0	9642.4	11676.8	9185.7	7910.6	6343.1	6468.3	7719.1	[illegible]	9961.3	[illegible]	[illegible]
14	6535.5	9887.9	11825.3	8885.6	7637.9	6375.6	5475.6	9351.6	[illegible]	[illegible]	[illegible]	[illegible]
15	8162.5	9166.1	11311.1	8428.7	7434.8	6369.1	5452.9	5539.1	10761.9	9863.2	9051.8	7524.2
16	7734.6	9747.2	11166.7	8439.8	7425.9	6382.6	5820.5	7576.7	7810.9	6420.2	6734.3	16225.6
17	8196.6	8944.3	11320.0	8637.2	7637.9	6315.1	6179.7	6642.3	8515.5	4506.3	[illegible]	5613.0
18	6245.2	8581.2	11238.0	8679.0	7684.5	6316.6	5591.2	8196.3	9716.6	6866.1	16260.0	13672.9
19	6994.4	9313.3	11820.6	9194.4	8213.6	6568.2	6751.4	8406.3	10193.5	[illegible]	5880.7	6015.5
20	6110.4	8733.9	10870.3	8196.0	7260.7	6371.4	5736.1	6933.8	5600.2	4270.8	9821.8	5657.0
21	6385.6	7578.3	9136.9	8137.8	6651.3	6918.7	5961.7	4892.9	3631.4	5330.1	8263.8	4663.1
22	6198.0	7402.9	9021.9	8090.4	6016.0	6883.7	5897.4	5160.5	3262.7	6756.4	7536.6	4248.9
23	6153.2	7240.4	11277.0	9247.7	8144.6	6373.8	6480.1	9618.4	10679.2	7464.2	8595.5	10955.7
24	7276.6	9356.9	11362.9	8608.3	7653.4	6372.6	5581.6	7128.3	7541.5	4985.5	6715.3	5525.7
25	6196.2	7329.3	9516.4	8363.1	7343.1	6549.4	5595.7	8226.2	5565.6	3776.7	8332.6	4036.2
26	6243.9	7361.3	8813.6	7631.3	6351.8	6584.6	5620.6	8257.3	9538.8	7327.3	6402.3	12681.6
27	8654.5	8980.1	10992.6	8334.6	7396.4	6447.4	5564.0	6716.2	6784.5	4972.5	7569.4	5330.5
28	6157.1	7202.2	8673.1	8290.9	7856.1	6461.9	6023.4	6879.2	10725.5	7064.7	7247.5	10613.1
29	8769.3	10024.3	11855.3	9395.5	7920.9	6305.1	6541.2	7726.7	6311.4	4769.6	5470.6	5025.6
30	6096.7	7236.4	8767.4	7906.2	7708.6	6578.8	6007.2	8289.4	8874.4	7522.5	7678.1	9096.7
31	9099.8	10930.5	11921.9	9273.2	7886.2	6342.9	6415.4	7252.5	8524.9	8036.5	10151.7	11000.0
32	9082.6	11038.5	11501.4	8723.7	7624.2	6359.9	5799.2	7356.0	6092.8	7212.3	19491.0	12026.0
AVE	7346.5	8988.6	10944.3	8681.2	7543.7	6421.8	5872.6	7474.4	7895.0	6247.0	8846.7	9361.9

Table [illegible].2 [illegible] Monthly Spills

SPILLS (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2755.0	0.0
AVE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.1	0.0

Table E.1 [illegible] Monthly Energy Potential

ENERGY FROM RESERVOIR 1 (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	221.9	318.0	429.3	312.2	240.6	228.3	185.8	230.5	187.4	169.0	213.2	185.0	2921.2
2	243.1	273.5	345.4	312.0	241.6	235.0	189.9	281.0	239.2	180.8	253.6	495.4	3290.8
3	297.2	358.7	441.9	329.3	247.1	228.5	186.7	224.2	256.2	214.8	238.[illegible]	411.5	3434.3
4	348.9	395.6	433.5	312.4	239.6	228.4	200.0	327.4	314.9	187.7	244.5	311.9	3544.8
5	282.5	337.3	429.8	322.4	245.9	228.5	184.8	274.6	254.4	171.2	228.[illegible]	300.6	3260.9
6	268.4	354.2	443.7	333.6	254.0	227.8	193.3	232.8	276.4	252.2	517.5	411.8	3666.7
7	277.9	336.8	424.3	312.3	244.3	227.4	185.4	292.2	377.8	336.6	498.5	503.1	4016.7
8	282.1	362.7	449.7	333.0	258.6	227.3	195.7	254.3	328.2	226.4	245.9	545.0	3708.9
9	345.9	395.5	446.8	361.0	253.7	228.2	207.1	252.0	278.1	199.7	249.9	208.5	3426.4
10	260.9	342.1	427.2	322.1	230.7	226.9	183.3	251.2	224.0	181.3	399.5	475.4	3546.7
11	319.7	360.3	448.4	334.0	257.0	227.6	200.6	297.4	196.3	168.1	236.2	466.5	3511.9
12	350.8	368.4	449.8	358.2	262.4	227.7	214.5	306.0	321.7	220.2	304.7	386.9	3801.1
13	299.0	362.2	451.8	341.8	260.9	227.8	221.4	273.6	378.9	384.5	694.2	486.0	4381.9
14	335.2	371.4	449.8	330.6	258.5	228.8	187.3	331.3	304.9	336.0	571.8	411.8	4117.5
15	320.5	344.4	430.2	313.6	245.2	228.5	186.4	193.6	379.6	379.7	354.6	285.9	3663.2
16	303.7	366.1	435.5	314.0	214.9	229.1	199.1	267.4	273.4	241.8	262.1	618.7	3745.9
17	321.9	336.0	430.6	321.4	251.9	226.7	211.5	233.4	257.2	169.1	231.6	213.1	3244.3
18	245.2	322.3	427.5	322.9	253.4	226.7	191.3	289.7	341.9	259.8	633.5	521.4	4035.7
19	274.7	349.8	449.6	342.1	270.8	235.9	231.2	293.7	359.1	271.1	228.9	229.1	3536.1
20	240.0	328.1	413.5	304.9	239.4	226.6	196.2	244.4	200.9	157.1	365.7	203.2	3121.9
21	234.8	265.6	323.7	281.1	202.8	228.4	186.4	158.1	116.9	164.7	296.9	162.1	2641.5
22	225.6	258.1	319.1	279.7	202.2	228.0	185.0	165.6	105.1	240.6	260.9	159.7	2646.0
23	239.6	270.6	428.5	344.1	268.6	228.9	271.9	341.0	378.7	284.0	335.2	417.6	3758.9
24	285.7	351.5	432.2	320.3	252.4	228.7	191.0	250.4	262.6	186.3	258.0	208.8	3227.9
25	241.8	273.9	361.3	311.2	242.1	234.6	191.2	290.5	194.1	140.2	312.6	150.2	2943.7
26	240.8	271.9	331.2	288.8	208.1	235.2	191.4	290.2	344.4	277.3	249.5	483.4	3402.3
27	339.9	337.3	418.1	310.1	243.9	227.8	190.3	236.6	236.6	185.5	290.5	200.6	3217.2
28	238.6	267.5	328.2	308.2	259.1	232.0	206.1	242.2	377.3	269.0	282.5	404.7	3415.4
29	344.4	376.5	431.1	349.7	261.2	226.5	224.0	272.8	220.2	178.6	209.6	188.5	3302.9
30	236.2	269.0	331.8	293.9	254.2	236.1	205.5	292.9	311.6	284.6	307.3	346.9	3370.0
31	357.4	410.6	453.6	345.1	260.1	227.8	219.6	255.8	298.6	304.0	396.4	419.5	3948.4
32	356.8	414.8	437.5	324.6	251.4	228.3	198.4	259.5	212.4	271.1	756.0	458.6	4169.3
AVE	286.9	336.0	414.5	321.6	247.7	229.2	199.8	262.7	276.2	234.8	342.1	355.4	3507.0

Table B.5 Devil Canyon Power Flows - Case C Operation

POWERHOUSE FLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	6714.6	8795.5	11456.9	8526.1	7386.9	6464.1	7456.8	6562.3	7436.2	8363.4	10940.6	6149.8
2	6587.4	7447.9	6923.1	7913.3	6437.6	6628.5	5756.6	5581.7	8304.7	8585.9	10860.0	11307.8
3	8203.6	9918.0	11873.9	9060.5	7596.4	6460.1	7410.6	8845.9	8026.9	8470.5	10727.2	10293.7
4	10113.7	11010.3	11666.8	8576.4	7398.8	6461.6	7674.9	10138.6	12704.7	8564.0	10597.0	8149.3
5	6996.7	9300.3	11503.5	8800.9	7582.9	6459.0	7470.7	9540.0	10980.6	8374.1	9971.6	8219.9
6	7812.3	9885.8	11984.4	9225.9	7928.4	6483.4	7693.4	6475.1	11134.2	9117.2	13763.2	13763.2
7	7629.8	9167.6	11323.0	8498.5	7546.3	6494.2	7449.6	9466.8	13763.2	12225.1	13763.2	13763.2
8	8217.2	10152.8	12103.0	9160.0	8042.1	6500.8	7761.6	7682.3	12493.1	8379.6	10849.2	13763.2
9	10205.5	11187.3	12378.0	10012.1	7865.4	6470.1	8101.3	7211.8	10264.9	8463.1	10679.8	5938.8
10	6630.1	7603.1	11487.3	8891.7	7832.3	6507.9	7510.0	9055.7	9627.9	7970.4	13763.2	13763.2
11	9042.6	10001.7	12127.9	9263.0	7993.4	6490.9	7888.2	8343.2	7106.6	8339.3	10476.1	11848.1
12	10053.3	10241.8	12279.2	10062.6	8246.8	6646.7	9458.5	9217.5	13427.7	8879.8	11061.4	10623.9
13	8441.3	9923.1	12095.1	9372.6	8066.6	6486.6	8502.7	6732.5	13763.2	11506.2	13763.2	13763.2
14	9289.6	10075.0	12012.4	9072.7	8040.6	6450.4	7385.3	9925.7	12094.4	12483.3	13763.2	11777.2
15	8960.2	9464.4	11503.5	8554.7	7553.4	6457.7	7418.6	7670.5	12132.6	11706.9	11145.8	8265.1
16	8725.9	10024.1	11277.2	8502.1	7482.0	6442.4	7780.9	7053.5	10708.2	9380.0	10669.3	13763.2
17	9478.4	9286.8	11594.8	8855.5	7840.6	6517.8	8338.6	6457.9	13022.3	8256.2	10414.6	5594.3
18	6489.9	7809.7	11481.3	8934.7	7921.5	6516.2	7673.5	8252.0	12801.1	9962.0	13763.2	13763.2
19	7567.2	9582.5	12046.1	9428.0	8431.9	6786.5	8844.1	8637.8	13763.2	9944.9	10920.5	5909.9
20	6444.5	7253.0	10704.7	8263.4	7335.0	6455.0	7774.2	6225.8	6788.8	9714.3	11604.6	6202.5
21	6849.0	7703.1	9237.6	8258.5	6757.9	7016.4	6021.9	6078.1	6351.3	8062.2	10672.8	5802.5
22	7175.2	7988.3	9409.3	8312.1	6782.2	7033.4	6069.9	5751.2	6680.9	8571.6	10405.9	5596.0
23	6721.1	7565.7	9040.0	7932.2	6909.1	6667.6	8618.6	11597.8	13763.2	9356.4	11364.1	10206.1
24	7626.5	9513.8	11503.4	8716.6	7781.8	6453.7	7532.5	5913.4	10074.8	6901.8	11188.1	6152.0
25	6631.1	7437.5	6885.4	7868.1	6399.1	6601.6	5672.9	6786.2	7551.7	10230.6	11037.0	5620.1
26	6661.9	7506.3	9023.4	8024.3	6583.7	6815.1	5866.1	4914.7	13152.2	10084.9	10941.6	12038.9
27	9985.2	9232.0	11124.3	8473.6	7529.4	6481.9	7643.8	7258.4	9604.1	8892.6	11497.7	6082.3
28	6736.0	7667.2	9133.1	8054.9	6547.8	6712.1	5798.5	6296.2	13763.2	9117.9	11131.2	9519.0
29	9918.2	10589.8	12240.5	9692.0	8178.2	6529.0	8608.2	6364.3	7451.0	8639.0	10916.5	5973.4
30	6825.1	7615.8	9004.2	7977.8	6563.6	6642.3	5707.7	5464.0	9787.5	10078.6	10646.7	9828.7
31	9849.8	11367.2	12162.4	9458.7	8036.2	6486.9	8464.7	6665.3	11379.9	11298.5	12347.7	12342.0
32	9870.6	11447.3	11670.4	8863.7	7742.2	6467.9	7812.6	6801.7	8205.8	10608.3	13763.2	13493.0
AVE	8077.1	9180.8	11070.6	8769.1	7508.8	6565.2	7480.3	7467.7	10566.0	9454.2	11544.8	9668.6

Table 8.6 Devil Canyon Monthly Spills

SPILLS (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	949.2	226.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	914.2	0.0	2447.2	2732.6
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	970.7
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	963.2	1566.4
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1555.6	0.0	6253.7	1004.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2564.2	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2679.9
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6685.3	1965.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	188.4	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1416.5	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1216.2	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12217.9	0.0
AVE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	165.3	0.0	1002.2	354.5

Table [illegible] Devil Canyon Monthly Energy Potential

ENERGY FROM RESERVOIR 2 (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	217.8	276.1	371.7	276.6	216.5	209.7	230.5	210.2	233.4	268.3	337.9	177.9	3026.5
2	196.0	214.4	266.1	237.7	176.7	202.9	170.5	175.9	260.7	274.7	336.9	344.3	2856.9
3	266.1	311.3	385.1	293.9	222.5	209.5	229.7	276.2	245.7	274.8	342.4	316.0	3375.2
4	328.1	345.6	378.4	278.2	216.8	209.6	244.1	324.8	398.6	274.5	331.1	247.7	3577.6
5	225.4	291.9	373.1	285.5	222.1	209.5	231.6	305.6	344.7	268.7	315.4	254.4	3327.8
6	253.4	310.3	388.7	299.2	232.3	210.3	236.5	207.4	349.5	295.7	445.4	432.0	3663.8
7	247.5	287.8	367.3	275.6	221.1	210.6	230.9	303.3	432.0	396.5	446.4	432.0	3851.1
8	266.5	318.7	392.6	297.1	235.6	210.6	240.6	246.1	392.2	271.5	344.9	423.9	3640.5
9	331.0	351.2	401.5	324.7	230.4	209.9	251.1	231.0	322.2	272.5	336.5	179.3	3441.4
10	206.8	235.9	372.6	288.5	229.5	211.1	233.4	290.1	302.2	256.2	445.8	432.0	3508.1
11	293.3	313.9	393.4	300.4	234.2	210.5	244.5	267.3	223.1	267.6	328.6	363.5	3440.4
12	326.1	321.5	398.3	326.4	241.6	215.6	293.2	295.3	421.5	288.0	355.2	330.0	3812.7
13	273.8	311.5	392.3	304.0	246.3	210.4	263.6	215.7	432.0	373.3	446.4	432.0	3891.3
14	301.3	316.2	389.6	294.3	235.6	209.2	229.0	318.0	379.6	404.9	446.4	369.7	3893.9
15	291.3	297.1	373.1	277.5	221.3	209.4	230.0	239.5	371.4	379.7	360.4	258.6	3509.3
16	283.0	314.6	365.8	275.8	219.2	209.0	241.2	225.9	336.1	304.3	342.5	427.6	3545.0
17	307.4	291.5	376.1	287.2	229.7	211.4	258.5	206.9	408.8	265.4	327.8	170.4	3341.1
18	207.3	243.6	372.4	289.8	232.1	211.3	237.9	264.3	401.8	323.1	446.4	432.0	3662.2
19	245.4	300.8	390.7	305.8	247.0	226.1	274.2	276.7	432.0	322.6	346.5	178.9	3540.7
20	203.6	224.4	346.7	268.0	214.9	209.4	241.0	199.4	213.1	304.6	348.3	176.6	2951.9
21	203.8	221.8	274.8	245.7	181.6	208.8	173.4	180.8	182.9	239.9	317.5	167.6	2598.7
22	213.5	230.0	280.0	247.3	182.3	209.3	174.8	171.1	192.4	255.0	309.6	164.0	2629.2
23	200.0	217.8	274.6	249.2	200.5	216.3	267.2	371.5	432.0	363.6	364.6	316.9	3414.2
24	247.2	299.2	373.1	282.7	228.0	209.3	233.5	189.4	316.3	283.3	341.0	177.1	3180.2
25	197.3	214.2	265.9	237.8	176.7	203.3	169.1	214.5	237.1	320.6	331.2	161.8	2729.6
26	198.2	216.1	268.5	238.7	176.9	202.8	168.9	152.8	412.9	327.1	348.4	370.9	3082.2
27	323.9	289.6	360.8	274.8	220.6	210.2	236.9	232.5	301.5	283.0	350.5	175.1	3259.7
28	200.4	220.8	271.7	240.7	179.6	206.1	173.0	199.6	432.0	295.8	355.2	294.0	3066.8
29	321.7	332.4	397.0	314.4	239.6	211.8	266.8	203.9	233.9	276.0	334.8	172.0	3304.3
30	203.1	219.3	267.9	237.5	176.8	201.9	168.4	171.9	306.8	326.9	344.7	307.9	2933.1
31	319.5	356.8	394.5	306.8	235.4	210.4	262.4	213.5	357.2	366.5	400.5	387.4	3811.0
32	320.2	359.3	378.5	287.5	226.8	209.8	242.2	217.9	257.6	344.1	446.4	423.6	3713.8
AVE	256.9	283.0	353.2	279.7	216.9	209.7	229.7	237.5	330.1	303.5	364.9	296.9	3361.9

Table 8.2 Total Monthly Energy Potential
Watana + Devil Canyon

TOTAL ENERGY PRODUCED (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	439.7	594.0	800.9	588.8	457.0	438.0	416.4	440.7	420.9	437.3	551.1	363.0	5947.8
2	439.1	488.0	611.6	549.7	418.3	437.8	360.4	457.0	499.9	455.6	590.7	839.7	6147.6
3	563.3	670.0	827.0	623.2	469.7	438.0	416.4	500.5	501.9	489.5	580.6	729.5	6809.5
4	677.0	741.2	811.9	590.5	456.3	438.0	444.1	652.2	713.7	462.2	575.6	559.5	7122.4
5	507.9	629.2	802.9	607.8	468.0	438.0	416.4	580.2	599.1	439.9	544.1	555.3	6588.8
6	521.8	664.5	832.4	632.8	486.3	438.1	431.8	440.2	625.9	547.9	964.0	944.8	7530.5
7	525.4	624.6	791.6	587.9	465.4	438.0	416.4	595.4	809.9	733.2	944.9	935.2	7867.7
8	548.6	681.4	842.3	630.1	494.2	438.1	436.3	500.4	720.3	497.9	590.8	969.0	7349.3
9	676.9	746.6	848.3	685.7	484.2	438.1	438.2	463.0	600.3	472.2	586.5	387.8	6867.8
10	469.7	578.0	799.8	610.6	480.1	438.0	418.8	541.2	576.2	439.5	845.4	907.4	7054.8
11	613.0	674.2	841.8	634.4	491.1	438.1	445.1	564.6	419.4	435.7	564.8	840.0	6952.3
12	676.9	689.7	848.1	684.6	504.0	443.3	537.7	601.3	743.2	508.2	659.9	716.9	7613.7
13	572.8	673.7	844.1	645.8	497.2	438.2	485.0	489.3	810.9	757.8	1140.6	918.1	8273.2
14	636.5	687.6	839.4	624.9	494.0	438.1	416.4	649.3	684.6	740.9	1018.2	781.5	8011.4
15	611.8	641.4	803.3	591.1	466.4	438.0	416.3	443.2	750.9	759.4	715.0	545.5	7172.5
16	586.8	680.8	791.3	589.8	464.1	438.0	440.3	453.4	609.6	546.0	604.6	1046.3	7290.9
17	629.3	627.5	806.6	608.6	481.6	438.1	470.0	440.3	706.0	434.4	559.4	[illegible]	6585.4
18	452.6	565.9	799.8	612.7	485.5	438.1	429.2	554.1	743.7	582.9	1079.9	953.4	7697.9
19	520.1	650.6	840.3	647.9	517.9	456.0	505.3	570.4	791.1	593.7	575.4	408.0	7076.8
20	443.5	552.5	760.2	573.0	454.3	438.0	437.2	443.6	414.0	461.6	713.9	381.8	6073.8
21	436.6	487.4	598.5	526.8	384.4	437.2	359.8	338.9	299.7	424.6	614.4	329.8	5240.1
22	439.1	486.1	599.1	527.0	384.5	437.3	359.8	336.7	297.4	495.1	590.5	322.7	5277.2
23	439.2	488.5	703.2	593.2	469.1	445.2	489.1	712.5	810.7	587.6	699.0	734.6	7173.1
24	532.9	650.7	805.3	603.0	480.3	438.1	424.5	439.8	576.8	469.6	599.1	385.9	6408.0
25	439.1	488.0	627.2	549.0	418.9	437.9	360.1	505.1	431.2	461.0	643.9	312.1	5673.1
26	439.0	488.1	599.6	527.6	385.0	438.0	360.3	443.1	747.2	604.4	597.9	654.3	6464.5
27	663.7	627.1	778.9	584.9	464.5	438.0	427.3	469.1	538.1	468.5	641.0	375.7	6476.9
28	439.0	488.3	599.9	548.9	438.6	438.1	379.1	441.7	809.3	564.8	637.7	698.7	6484.3
29	666.1	708.9	848.1	664.0	500.8	438.2	490.8	476.6	454.1	454.6	544.4	360.5	6607.2
30	439.3	488.4	599.7	531.4	431.0	438.0	373.9	464.8	618.4	611.5	652.0	654.8	6303.1
31	676.9	767.4	848.1	651.9	495.5	438.2	482.0	469.3	655.8	670.5	796.9	806.9	7759.4
32	677.0	774.1	816.0	612.1	478.2	438.1	440.6	477.4	470.0	615.2	1202.4	882.1	7883.2
AVE	543.8	618.9	767.7	601.2	464.6	438.9	429.5	500.2	606.3	538.2	707.0	652.3	6868.9

Table K.7 Total Usable Energy in Year 2010
Watana + Devil Canyon

TOTAL USABLE ENERGY (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	439.7	594.0	800.9	566.8	457.0	438.0	416.4	440.7	420.9	437.3	550.6	363.0	5947.2
2	439.1	488.0	611.6	549.7	416.3	437.6	360.4	457.0	499.9	455.6	550.6	576.0	5843.8
3	563.3	670.0	827.0	623.2	469.7	438.0	416.4	500.5	501.9	489.5	550.6	576.0	6626.0
4	677.0	741.2	811.9	590.5	456.3	438.0	444.1	543.1	532.8	462.2	550.6	559.5	6807.3
5	507.9	629.2	802.9	607.8	466.0	438.0	416.4	543.1	532.8	439.9	544.1	555.3	6485.4
6	521.8	664.5	832.4	632.8	486.3	438.1	431.6	440.2	532.8	520.8	550.6	576.0	6628.0
7	525.4	624.6	791.6	587.9	465.4	438.0	416.4	543.1	532.8	520.8	550.6	576.0	6572.5
8	548.6	681.4	842.3	630.1	494.2	438.1	436.3	500.4	532.8	497.9	550.6	576.0	6728.6
9	676.9	746.6	848.2	685.7	484.2	438.1	458.2	483.0	532.8	472.2	550.6	387.8	6764.2
10	469.7	578.0	799.8	610.6	480.1	438.0	418.8	541.2	526.2	439.5	550.6	576.0	6428.5
11	613.0	674.2	841.8	634.4	491.1	438.1	445.1	543.1	419.4	435.7	550.6	576.0	6662.6
12	676.9	689.7	848.1	684.6	504.0	443.3	537.7	543.1	532.8	508.2	550.6	576.0	7094.9
13	572.8	673.7	844.1	645.8	497.2	438.2	485.0	489.3	532.8	520.8	550.6	576.0	6826.0
14	636.5	687.6	839.4	624.9	494.0	438.1	416.4	543.1	532.8	520.8	550.6	576.0	6860.1
15	611.8	641.4	803.3	591.1	466.4	438.0	416.3	433.2	532.8	520.8	550.6	545.5	6551.3
16	586.8	680.8	791.3	589.8	464.1	438.0	440.3	493.4	532.8	520.8	550.6	576.0	6664.5
17	629.3	627.5	806.6	608.6	481.6	438.1	470.0	440.3	532.8	434.4	550.6	383.6	6403.3
18	452.6	565.9	799.8	612.7	485.5	438.1	429.2	543.1	532.8	520.8	550.6	576.0	6507.1
19	520.1	650.6	840.3	647.9	517.9	456.0	505.3	543.1	532.8	520.8	550.6	408.0	6693.5
20	443.5	552.5	760.2	573.0	454.3	438.0	437.2	443.8	414.0	461.6	550.6	381.8	5910.5
21	438.6	487.4	598.5	526.8	384.4	437.2	359.8	338.9	299.7	424.6	550.6	329.8	5176.3
22	439.1	488.1	599.1	527.0	384.5	437.3	359.8	336.7	297.4	495.1	550.6	322.7	5237.3
23	439.6	488.3	703.2	593.2	469.1	445.2	489.1	543.1	532.8	520.8	550.6	576.0	6351.1
24	532.9	650.7	805.3	603.0	480.3	438.1	424.5	449.8	532.8	469.6	550.6	385.9	6313.5
25	439.1	488.0	627.2	549.0	418.9	437.9	360.3	505.1	431.2	461.0	550.6	312.1	5580.0
26	439.0	488.1	599.6	527.6	385.0	438.0	360.3	443.1	532.8	520.8	550.6	576.0	5860.8
27	663.7	627.1	778.9	584.9	464.5	438.0	427.3	469.1	532.8	468.5	550.6	375.7	6381.2
28	439.0	488.3	599.9	548.9	438.6	438.1	379.1	441.7	532.8	520.8	550.6	576.0	5953.9
29	666.1	708.9	848.1	664.0	500.8	438.2	490.8	476.6	454.1	454.6	544.4	360.5	6607.2
30	439.3	488.3	599.7	531.4	431.0	438.0	373.9	464.8	532.8	520.8	550.6	576.0	5946.5
31	676.9	767.4	848.1	651.9	495.5	438.2	482.0	469.3	532.8	520.8	550.6	576.0	7009.4
32	677.0	774.1	816.0	612.1	478.2	438.1	440.6	477.4	470.0	520.8	550.6	576.0	6830.8
AVE	543.8	618.9	767.7	601.2	464.6	438.9	429.5	481.7	497.6	487.5	550.2	501.2	6382.9

FORECAST DEMAND ENERGY (GWH)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
677.0	777.6	848.2	773.8	732.5	662.2	590.4	543.1	532.8	520.8	550.6	576.0	7784.9

Table B.10 Potential Spill from Devil Canyon in August

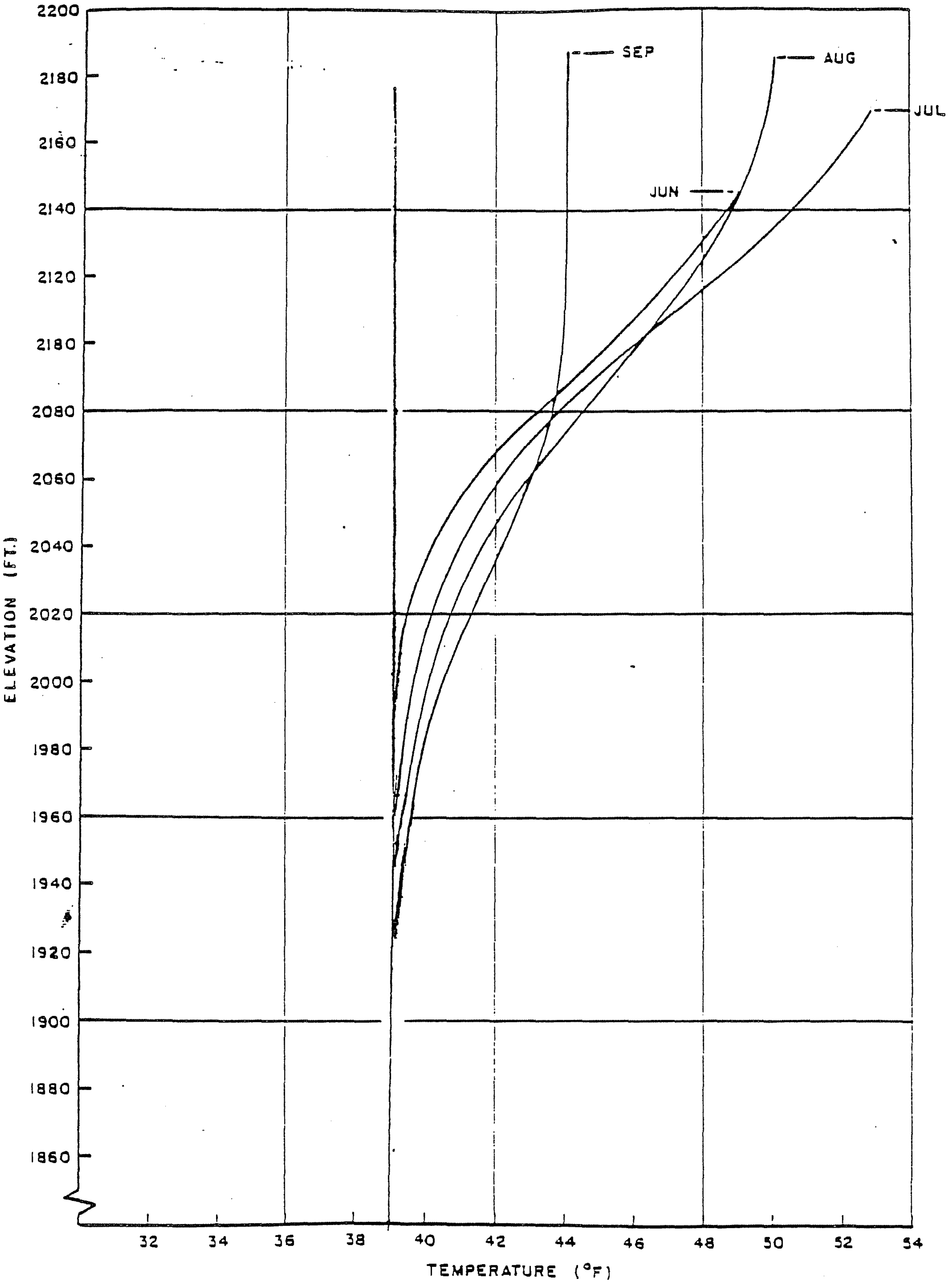
Year Simulated	Energy Potential GWh	Reservoir Operation A: Usable energy at Watana and Devil Canyon proportional to present levels — Usable energy 1/12 2010 GWh	Reservoir Operation A: Turbined cfs	Reservoir Operation A: Spill cfs	Reservoir Operation B: Maximum possible generation of usable energy at Devil Canyon — Usable energy 1/12 2010 GWh	Reservoir Operation B: Turbined cfs	Reservoir Operation B: Spill cfs
1	337.9	337.4	10225	16	337.9	1024[illegible]	0
2	336.9	296.3	9567	1293	336.9	10860	0
3	342.4	312.4	[illegible]	[illegible]	342.4	10727	0
4	331.1	306.1	9797	300	331.1	10597	0
5	315.4	315.4	9972	0	315.4	9972	0
6	446.4	253.3	7716	6002	446.4	13763	947
7	446.4	249.7	7698	6502	446.4	13763	2467
8	344.9	304.7	9534	1265	344.9	10549	0
9	336.5	300.7	9555	1135	336.5	10380	0
10	445.8	251.0	7738	5438	445.8	13763	253
11	328.6	314.4	10025	453	328.6	10276	0
12	355.2	249.1	7760	3306	355.2	11062	0
13	446.4	249.0	7678	12327	446.4	13763	6059
14	446.4	249.7	7698	8327	446.4	13763	[illegible]
15	360.4	247.0	7702	3444	360.4	[illegible]	0
16	342.5	262.1	8165	2834	342.5	[illegible]	0
17	327.8	319.0	10135	279	327.8	[illegible]	0
18	446.4	253.2	7715	12733	446.4	13763	6885
19	346.5	321.7	10139	782	346.5	10730	0
20	348.3	245.3	8191	3414	348.3	[illegible]	0
21	317.5	253.7	8528	2144	317.5	[illegible]	0
22	301.6	269.7	9065	1341	301.6	[illegible]	0
23	364.6	246.6	7748	3616	364.6	[illegible]	0
24	341.0	292.6	9600	1522	341.0	[illegible]	0
25	331.2	243.1	8102	2935	331.2	[illegible]	0
26	348.4	301.1	9456	1425	348.4	[illegible]	0
27	350.5	260.1	8532	2966	350.5	114[illegible]	0
28	355.2	268.1	8402	2721	355.2	11131	0
29	334.8	334.8	10936	0	334.8	10937	0
30	344.7	247.3	7716	2421	344.7	10647	0
31	400.5	247.7	7725	4642	400.5	123[illegible]	0
32	446.4	250.1	7712	18259	446.4	13763	12[illegible]

Table 5.11 Potential Spill from Watana in August

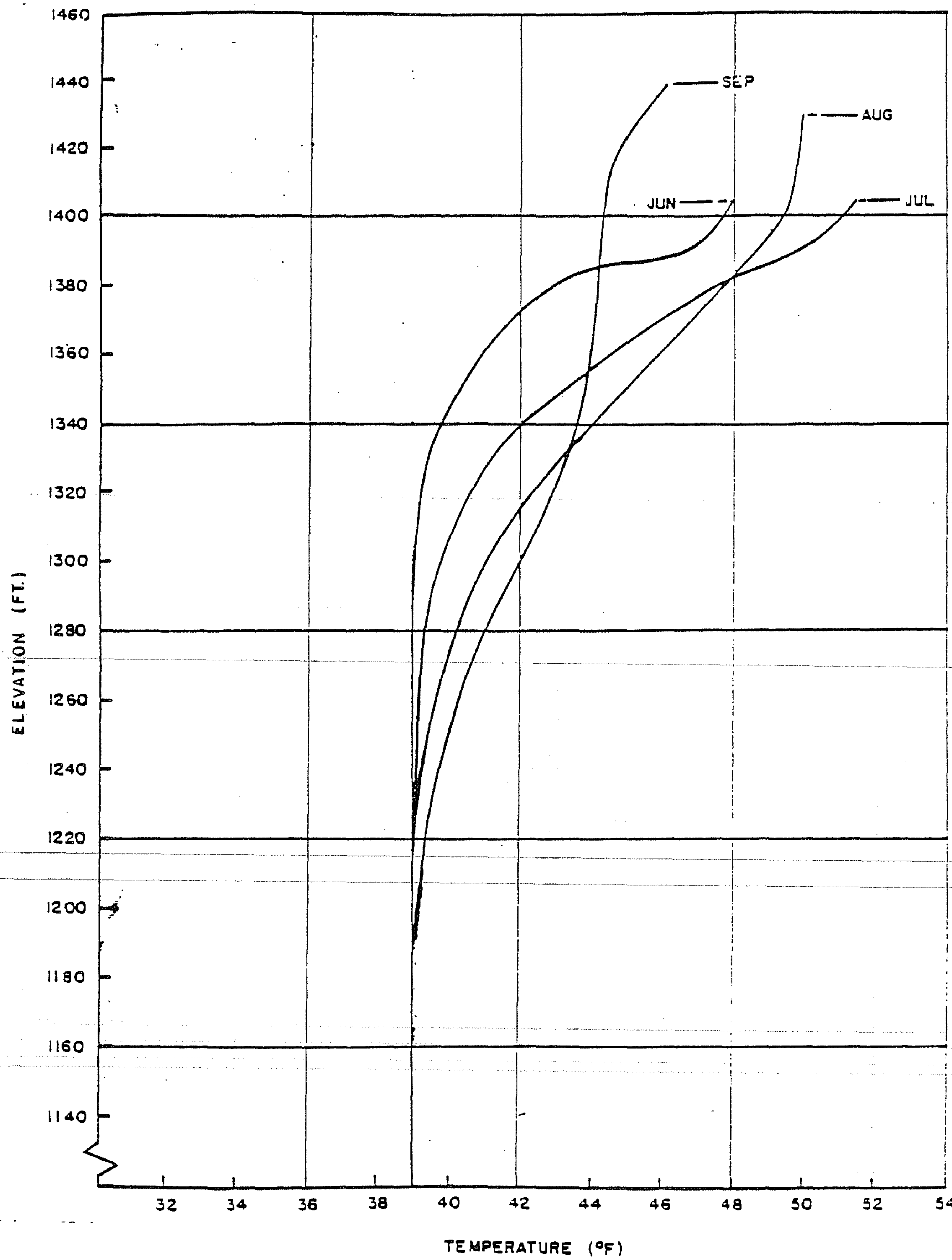
Year simulated	Energy Potential GWh	Reservoir Operation A — Usable energy at Watana and Devil Canyon proportional to average heads: Usable Energy Yr. 2010 – GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B — Maximum possible generation of usable energy at Devil Canyon: Usable energy Yr. 2010 GWh	Turbine Q cfs	Spill cfs
1	213.2	213.2	5532	0	212.7	5540	13
2	253.8	253.8	6576	0	[illegible]	5537	1337
3	233.2	232.2	6135	0	208.2	5742	773
4	244.5	244.5	[illegible]	0	213.5	5677	627
5	228.7	228.7	[illegible]	0	228.7	5712	0
6	517.5	300.3	7715	5275	[illegible]	2677	10313
7	498.5	300.9	7692	5072	[illegible]	[illegible]	10100
8	245.9	245.9	[illegible]	0	205.7	5214	1935
9	249.9	249.9	[illegible]	0	[illegible]	5519	923
10	379.5	279.6	7724	2576	104.3	2702	7573
11	236.2	236.2	[illegible]	0	222.0	5770	337
12	304.7	301.5	7755	82	185.4	5003	2311
13	694.2	301.6	7673	9989	[illegible]	2651	15311
14	571.8	300.4	7692	6926	[illegible]	2664	11954
15	358.6	301.6	7647	1352	190.2	4255	4117
16	262.1	262.1	6734	0	208.1	5347	1387
17	231.6	231.6	[illegible]	0	222.5	5775	[illegible]
18	633.5	300.4	7710	8550	104.2	2733	14117
19	228.9	228.7	[illegible]	0	221.1	5243	637
20	365.7	304.8	8136	1636	[illegible]	5433	4331
21	296.9	[illegible]	[illegible]	0	233.1	6304	[illegible]
[illegible]	280.[illegible]	280.[illegible]	[illegible]	0	[illegible]	6466	1071
[illegible]	335.2	302.0	7745	251	[illegible]	4770	3475
[illegible]	252.0	252.0	6715	0	[illegible]	5455	[illegible]
[illegible]	312.5	307.5	8101	132	211.2	5775	2323
[illegible]	249.5	249.5	[illegible]	0	202.[illegible]	5192	1214
[illegible]	290.5	[illegible]	7569	[illegible]	207.1	5214	[illegible]
[illegible]	282.5	[illegible]	[illegible]	0	195.4	5015	2202
[illegible]	229.6	229.6	[illegible]	0	207.6	5471	0
[illegible]	307.3	300.8	7711	157	205.9	5272	[illegible]
[illegible]	346.4	300.7	7701	2451	[illegible]	[illegible]	[illegible]
[illegible]	756.0	300.5	7708	14438	104.2	2373	19473

Table B.12 Potential Spills from Devil Canyon at [illegible]

Year simulated	Energy Potential GWh	Reservoir Operation A — Usable energy at Watana & Devil Canyon proportional to average heads: Usable energy in 2010 GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B — Maximum possible generation of usable energy at Devil Canyon: Usable energy 2010 GWh	Turbine Q cfs	Spill cfs
1	177.9	177.9	6150	0	177.9	6150	0
2	344.3	245.0	8047	3231	344.3	11308	0
3	318.0	246.5	7979	2215	318.0	10214	0
4	247.7	247.7	8149	0	247.7	8149	0
5	254.4	254.4	8220	0	254.4	8220	0
6	432.0	248.6	7920	6069	432.0	13763	[illegible]
7	432.0	248.6	7920	8576	432.0	13763	2732
8	423.9	246.1	7990	6742	423.9	13763	271
9	179.3	179.3	5929	0	179.3	5929	0
10	432.0	248.6	7920	7409	432.0	13763	[illegible]
11	363.5	246.1	8021	3827	363.5	11828	0
12	330.0	247.2	[illegible]	2575	330.0	[illegible]	0
13	432.0	248.6	7920	6347	[illegible]	13763	1564
14	369.7	248.6	7919	3858	[illegible]	11777	0
15	258.6	258.6	8265	0	258.6	[illegible]	0
16	427.6	247.2	[illegible]	[illegible]	427.6	13763	[illegible]
17	170.4	323.6	5594	0	170.4	5574	0
18	432.0	248.6	7920	[illegible]	[illegible]	13763	1965
19	178.9	178.9	5710	0	178.9	5710	0
20	178.6	178.6	5202	0	178.6	5202	0
21	167.6	167.6	5322	0	167.6	[illegible]	0
22	164.0	164.0	5096	0	164.0	5076	0
23	316.9	247.1	7752	[illegible]	316.9	10206	0
24	177.1	177.1	6152	0	177.1	6152	0
25	161.8	312.1	5620	0	161.8	5620	0
26	370.9	246.1	7738	4051	370.9	[illegible]	0
27	175.1	175.1	6082	0	175.1	6082	0
28	294.0	246.4	7772	1541	[illegible]	9519	0
29	172.0	172.0	5973	0	172.0	5973	0
30	307.9	248.3	7726	1902	307.9	9829	0
31	337.4	248.6	7920	4422	337.4	12342	0
32	423.6	[illegible]	7919	5574	423.6	13473	0



WATANA RESERVOIR TEMPERATURE PROFILE



DEVIL CANYON RESERVOIR TEMPERATURE PROFILE

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): B. 34, I. 60

ACRES

OFFICE MEMORANDUM

TO:	J.W. Hayden	*Date:*	September 13, 1982
FROM:	G. Krishnan	*File:*	P5700.14.53
SUBJECT:	Susitna Hydroelectric Project Nitrogen Supersaturation Studies		

Enclosed is a copy of the final draft of the report on Gas Concentration and Temperature of Spill Discharges Below Watana and Devil Canyon Dams.

Please note that no graphics efforts have been spent on getting the figures in the Acres standard format. This has been postponed until after your review of the material and advice on the inclusion of any field measurements of natural supersaturation in the river. Messers M. Bell and J. Douma had expressed an interest to receive copies of this report. Please advise if this can be done at this time.

G. Krishnan

GK:ccv
Enclosure

cc: J.D. Lawrence
A.F. Coniglio
K.R. Young
W. Dyok/D. Crawford

GAS CONCENTRATION AND TEMPERATURE OF SPILL DISCHARGES BELOW WATANA AND DEVIL CANYON DAMS

1 - INTRODUCTION

Supersaturation of atmospheric gases (especially nitrogen) in hatchery and aquarium facilities was first noted in the 1900's (1) and was ascribed as causing the condition in fish known as gas bubble disease. Supersaturation caused by entrainment of air in waters spilled over dams on the Columbia River was recognized as a problem for anadromous fisheries in the river in 1965. A comprehensive study (2) of dissolved gas levels in the Columbia River showed that waters plunging below spillways was the main cause of supersaturation in the river waters. Several later studies have confirmed the harmful effects of nitrogen supersaturation to fisheries. The tolerence of fish to levels of nitrogen supersaturation depends on the time of exposure, age, and species of the fish; dissolved nitrogen levels referenced to surface pressure above 110 percent are generally considered harmful (3). The state of Alaska water quality criterion is set of 110% for total gas saturation in its waters.

With this background, the potential problem of supersaturation of spill waters from the proposed Watana and Devil Canyon developments on the Susitna River was recognized early during the feasibility studies. Alternative spillway facilities were studied to minimize such a potential problem, and a scheme comprising fixed cone valves and overflow spillway was selected for each development based on detailed discussions with environmental study groups.

This report describes the selected spillway schemes briefly and presents the analyses and field investigations carried out to assess the performance of the proposed schemes with respect to gas supersaturation in spill waters. A related concern on temperature of spill waters is also discussed.

A summary of the studies undertaken and the important conclusions are presented in Section 2. A short description of the proposed schemes is given in Section 3. Section 4 details the engineering analyses carried out. Results of these analyses, field investigations, and their interpretation are presented in Section 5. The next section presents the major conclusions drawn from these studies. Appendix A comprises the field study report and Appendix B deals with the temperature of spill waters, its impacts downstream, and possible reservoir operation scenarios to minimize such impacts.

2 - SUMMARY

Relatively little information is available in the literature on the performance of fixed-cone valves to reduce gas supersaturation in their discharges. Published studies (4) on the aeration efficiency of Howell Bunger valves (the more commonly known type of fixed-cone valves) were reviewed, and a theoretical assessment of the performance of the proposed valve layouts was made based on the physical and geometric characteristics of diffused jets discharging freely into the atmosphere. Results of a companion study on assessment of scour hole development below high-head spillways (5) were used to estimate the potential plunging of the valve discharges into tailwater pools at the proposed developments, and the resulting supersaturation in the releases was calculated. Specific field tests were conducted at the Lake Comanche Dam on the Mokelumne River in California (6) to study jet characteristics and the efficiency of the existing Howell Bunger valves in reducing supersaturation level in the reservoir releases.

The analyses indicate that no serious supersaturation of nitrogen is likely to occur in the releases from the proposed Watana and Devil Canyon developments for spills up to 1:50 year recurrence interval. Field test results tend to confirm some of the assumptions made in the theoretical analysis with respect to jet shape, diffusion, and gas concentration in the valve discharges. Several assumptions and approximations, albeit conservative, have been made in the analyses which should be confirmed in later study phases, perhaps in a physical model. For the purpose of feasibility studies, however, it is felt that the analyses adequately support the proposed schemes for their intended purpose.

A related question of the temperature of spill waters and its effects on the downstream water temperature has been analyzed and detailed in Appendix B. Simulation studies of the two-reservoir operations indicate that continuous (24 hour) spills would occur in the month of August in 30 out of 32 years of simulation and in 18 out of 32 years in September for the Case "C" operation which maintains a minimum instantaneous flow of 12,000 cfs in August at Gold Creek. This spill frequency is simulated for a system energy demand in the year 2010 (Bettelle forecast) and assumes that the entire demand is met by

Watana and Devil Canyon developments where possible. The spills will be greater and more frequent in the years between 2002 (Devil Canyon commissioning) and 2010. When Watana alone is operational (between 1993 and 2002), less frequent spills are simulated to occur. Reservoir operation studies are currently being refined to finalize acceptable downstream flows.

Temperature of spill waters at Watana is expected to be close to that of power flow, and hence, it is not expected to create temperature problems downstream when Watana is operating alone (1993-2002) or when it spills into Devil Canyon. At Devil Canyon, however, spill temperature is expected to be close to 39°F compared to a power flow temperature of 48-49°F in August and 45°F in September. This is based on the conservative assumption that the temperature of spill water does not increase significantly while in contact with the atmosphere despite the highly diffused valve discharge. It is, therefore, considered necessary to keep the spill from Devil Canyon to a minimum to avoid unacceptably low downstream temperatures. The analyses indicate that by operating Devil Canyon to meet most or all of the base load demand and with Watana generating essentially to meet peak demands and spilling continuously when necessary, it would be possible to maintain downstream flow temperatures below Devil Canyon close to that of power flow while reducing spill frequency considerably.

During major floods (1:10 year or rarer), there will be significant spills from Devil Canyon in addition to the power flow resulting in cold slugs of water downstream for a few days. It will be necessary to establish criteria for acceptability of lower temperatures for short durations in August and September in consultation with fisheries study groups and concerned agencies. Currently, downstream water temperature analyses are being refined, and when the results are available, the above spill temperatures and duration should be reviewed to confirm downstream temperatures during normal power operation as well as flood events. If the projected temperature regime downstream is unacceptable, alternative means to remedy the situation should be considered. These may include provision of higher level intakes to several or all fixed-cone valve discharges at Devil Canyon, multilevel power intake at Devil Canyon, limited operation of main overflow spillway (for floods 1:50 year or more frequent) to improve temperature without serious increase in nitrogen super-saturation, etc.

3 - SCOPE OF ANALYSES

The objective of the analyses presented in the following sections is to provide an assessment of the performance of the fixed-cone valves in their proposed configuration with respect to their potential in reducing gas concentration in spill waters from the Watana and Devil Canyon developments. The analysis is a theoretical study supplemented by available field information on performance of these valves for aeration. Field measurements were conducted on the Howell Bunger valves at the Lake Comanche dam on the Mokelumne River in California. Results of the tests are interpreted to confirm some of the study assumptions.

A related question of temperature of spill waters is analyzed in Appendix B. The data for the analyses has been drawn from the Feasibility Report (7).

4 - SCHEME DESCRIPTION

This section presents a short description of the selected spillway and outlet facilities for the proposed Watana and Devil Canyon developments.

4.1 - Scheme Description

Selection of the discharge capacity and the type of spillway and outlet facilities has been based on project safety, environmental, and economic considerations. At each development, a set of fixed-cone valves is provided in the outlet works to discharge spills up to 1:50 year recurrence interval. The main spillway comprises a gated control structure and a chute with a flip bucket at its end. This facility has a capacity to discharge, in combination with the outlet works, the routed design flood which has a return period of 1:10,000 years. A fuse plug with an associated rock-cut channel is provided to discharge flows above the design flood and up to the estimated probable maximum flood at the dam. Detailed descriptions of the facilities are presented in the Feasibility Report (7).

The primary purpose of the outlet facility is to discharge the spill waters up to 1:50 year recurrence in such a manner as to reduce potential supersaturation of the spill with atmospheric gases, particularly nitrogen. This frequency was adopted after discussions with environmental study groups as an acceptable level of protection of the downstream fisheries against the gas bubble disease. A set of fixed-cone valves were selected to discharge the spills in highly diffused jets to achieve significant energy dissipation without provision of a stilling basin or a plunge pool where potentially large supersaturation develops. The valves have been selected to be within current world experience with respect to their size and operating heads. At Watana, six 78 inch diameter valves are provided and are located about 125 ft above average tailwater level in the river. The design capacity of each valve is 6,000 cfs. At Devil Canyon, seven fixed cone valves with a total design capacity of 38,500 cfs are provided at two levels within the arch dam, four 102 inch valves at the high level some 170 ft above average tailwater level, and three 90 inch valves about 50 ft above average tailwater level. The lower valves have a capacity of 5,100 cfs each and the higher ones 5,800 cfs each. In sizing these valves, it has been assumed that the valve gate opening will be restricted to 80% of full stroke to reduce vibration.

5 - ENGINEERING ANALYSES

This section details the analyses carried out to estimate potential supersaturation in the releases from the Watana and Devil Canyon developments when the reservoirs spill.

5.1 - Available Data

Fixed cone valves have been used in several water resource projects for water control, energy dissipation, and aeration of discharge waters, and data on their performance for such operations is readily available. However, no precedence has been reported on the use of such valves for reducing or eliminating gas supersaturation in spill waters. Manufacturer's catalog information on Howell Bunger valves and Boving Sleeve type discharge regulators (both particular types of fixed cone valves) and the Tennessee Valley Authority Study (4) on aeration efficiency of Howell Bunger valves form the specific data available. Theoretical analyses are carried out based on the geometric and physical characteristics of diffused jets discharging freely into the atmosphere.

5.2 - Field Data Collection

A review of existing facilities where a potential for spilling during the spring of 1982 existed was made, and the Lake Comanche dam, on the Mokelumne River in California, was selected as a feasible site for specific testing.

The Comanche Lake dam is of the rockfill type with outlet facilities fitted with four Howell Bunger valves. These valves are located at the toe of the dam and spray the discharge into confined concrete conduits before releasing the water to the stream.

Outflow through the valves was around 4,000 cfs during the test on May 28, 1982. Water samples were collected at several depths in the reservoir near the valves and at downstream locations and analyzed for nitrogen and oxygen concentrations. Details of the test procedure and results are presented in Appendix 1.

5.3 - Method of Analysis

(a) Flow from the fixed cone valves leaves the structure as a free-discharging jet diffusing radially at the cone angle. The path of the jet depends on the energy of flow available at the valve and the angle at which the jet leaves the valve (assumed as 45°). Referring to Figure 5.1, the path of the trajectory is given by the following equation (8):

$$y = x \tan \theta - \frac{x^2}{k(4 H_n \cos^2 \theta)} \qquad (1)$$

where:

θ = angle of the jet to the horizontal;

k = a factor to take account of loss of energy and velocity reduction due to the effect of air resistance, internal turbulences, and disintegration of the jet (assumed at 0.9);

H_n = net energy of the jet, ft.

The proposed valve operation restricts the opening of the valve gate to 80% of full stroke. This may be interpreted as equivalent to producing an additional head loss in the system, thereby reducing the discharge to 80% of the theoretical capacity. The general discharge equation for the valve:

$$Q_T = CA \sqrt{2g\ h_n} \qquad (2)$$

may then be written as:

$$Q_D = 0.8\ Q_T = CA \sqrt{2g\ (\cdot 8)^2\ h_n} \qquad (2a)$$

$$= CA \sqrt{2g \times \cdot 64 \times h_n} \qquad (3)$$

where:

Q_T = theoretical capacity of valve, cfs;
A = area of valve, ft;
C = coefficient of discharge ($\sim$ .85 for fixed-cone valves);
h_n = net head upstream of valve, cfs;
Q_D = design capacity of valve, cfs.

Equation (1) may be rewritten now as:

$$y = x \tan \theta - \frac{x^2}{k \quad 4 \times (0.64 \times h_n) \times \cos^2 \theta} \qquad (4)$$

Referring to Figure 5.1, the longitudinal throw of the jet is calculated with θ=45° and -45° while its laterial throw calculated when θ=0°.

Vertical rise of the jet above the valve is calculated as a simple projectile subject to gravity and neglecting air friction to yield a conservative value.

(b) Potential Plunging Depth of Jet(s) Into Tailwater Pool

As part of the feasibility studies of the Watana and Devil Canyon developments, a study was made by Acres on the scour hole development below high head spillways, and the results therefrom have been used to estimate the potential plunging of the jets from the fixed cone valves into tailwater. Figure 5.2 presents a definition sketch for the study carried out for a typical flip bucket spillway configuration. It may be readily observed that significant differences exist between a "solid" jet leaving a flip bucket and the diffused discharge jet from the fixed-cone valves in the available energy and its concentration in the jet for scouring downstream or plunging into the tailwater pool. Equation (5) was developed in the above mentioned studies to estimate scour depth for a solid jet:

$$y = 0.24 \, q^{0.65} \, H^{0.32} \qquad (5)$$

It is assumed that spills from Watana will get completely mixed in the Devil Canyon storage during their passage through 26 miles of reservoir and that no supersaturation would build up in the reservoir due to Watana spills.

ACRES

Calculations

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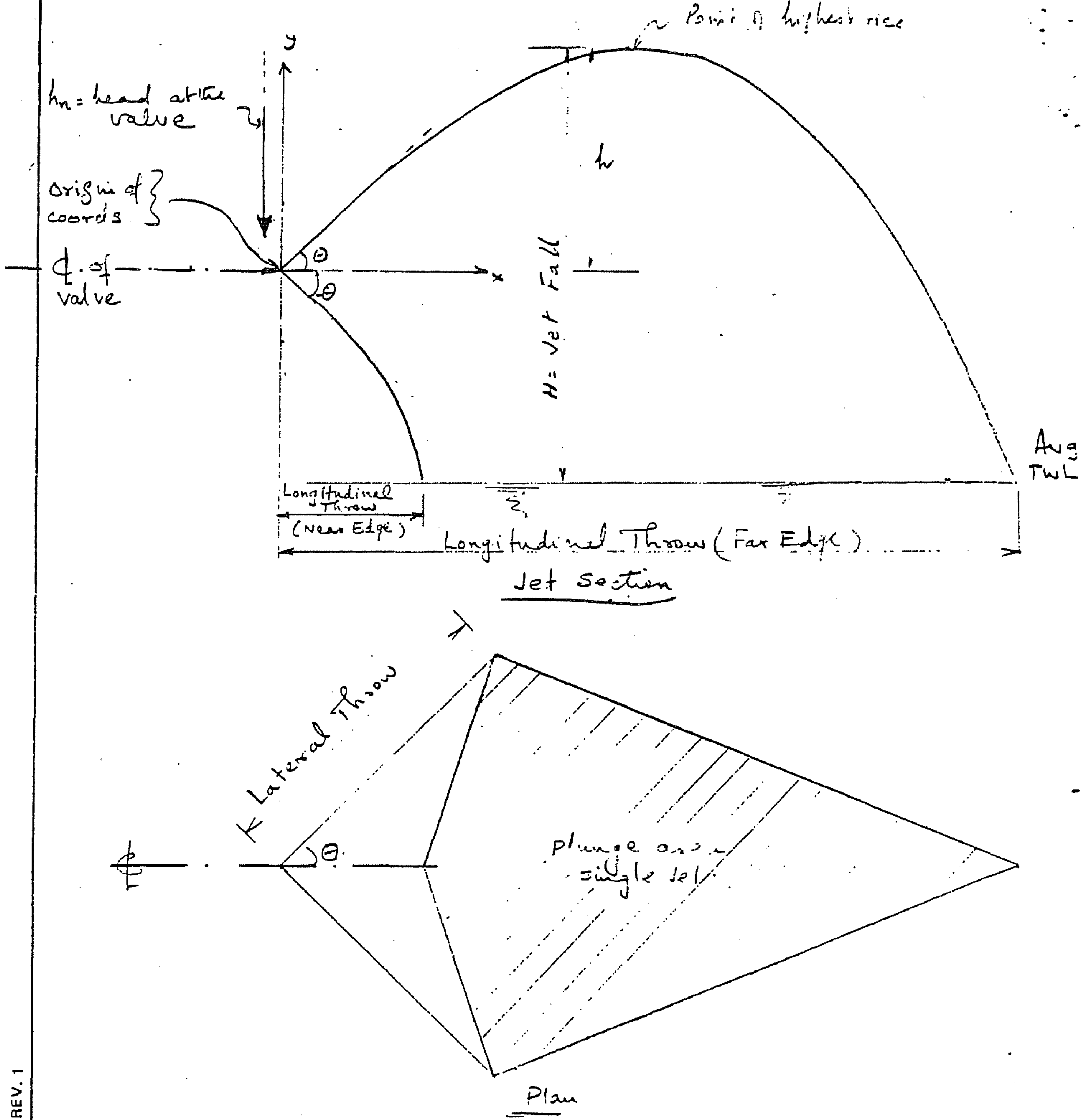

DEFINITION SKETCH FOR [illegible] JET

FIGURE 5.1

FORM NO. 152 REV. 1

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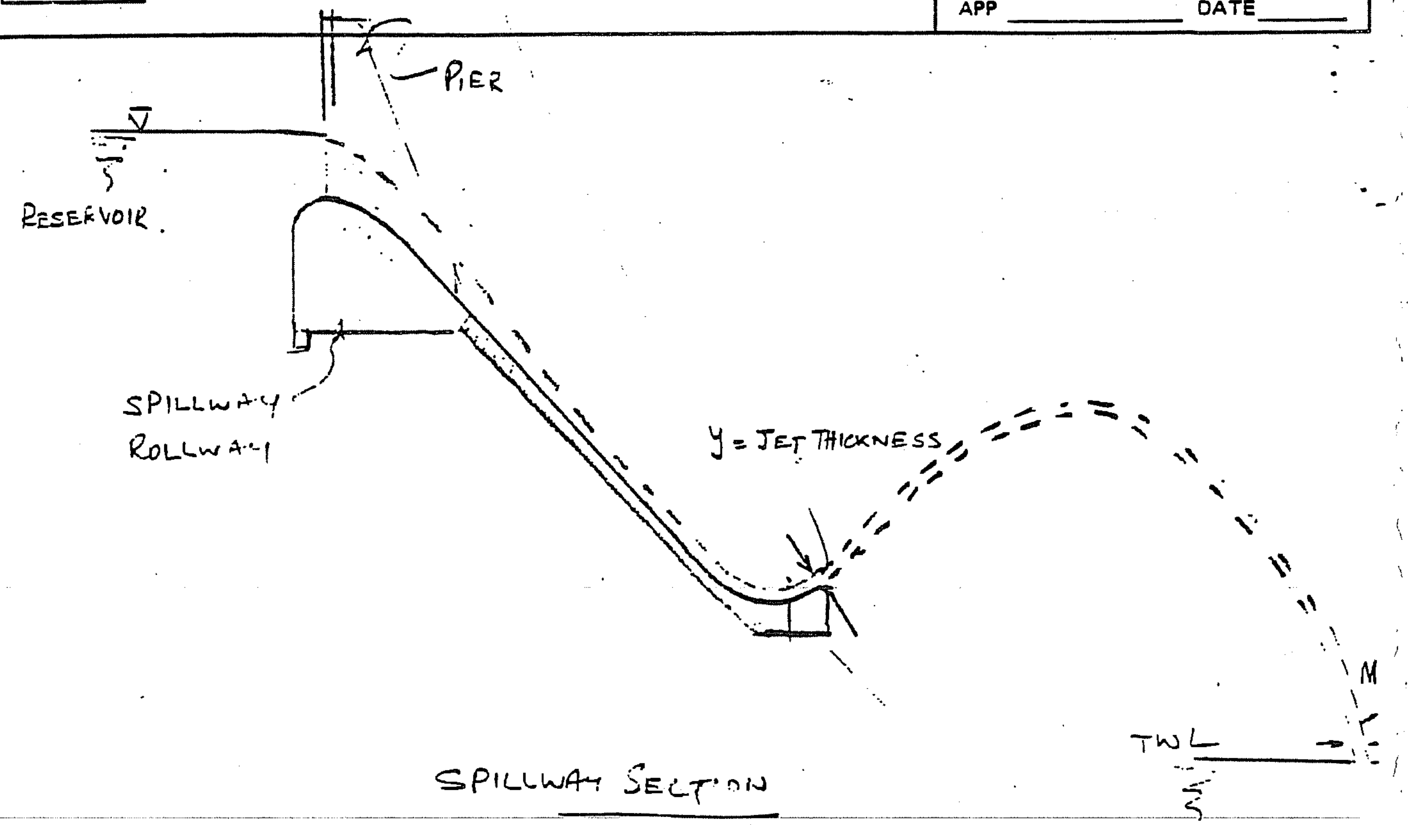
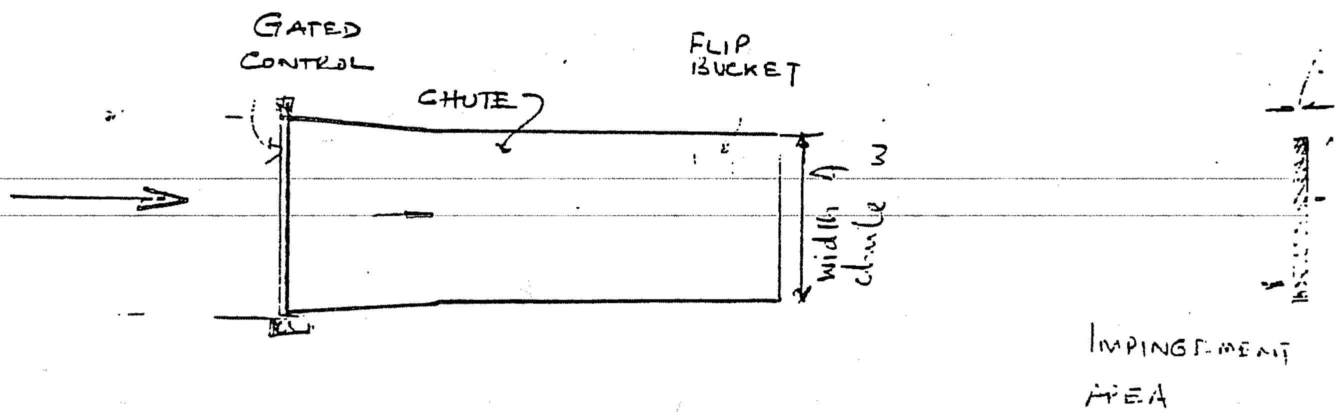


SPILLWAY SECTION



PLAN

DEFINITION SKETCH FOR 'SOLID JET FROM CHUTE-FLIP BUCKET SPILLWAY

FIGURE 5.2

FORM NO. 152 REV. 1

6 - RESULTS

Table 6.1 presents the results of the analyses carried out to assess the performance of the fixed cone valves at the proposed Watana and Devil Canyon developments in relation to the potential gas supersaturation of spill waters. Figures 6.1 and 6.2 present the jet interference pattern and the areas of impingement.

Estimated supersaturation in the spill discharges with a recurrence interval of 1 in 50 years is 101% at Watana and 102% at Devil Canyon. For more frequent spills, these concentrations are expected to be somewhat lower due to lower intensity of spill discharge and consequent lower plunge in the tailwater pool. For spills of rarer frequency, the main chute spillway will operate leading to potentially greater supersaturation in the downstream discharges.

Results of spill temperature analysis is presented in Appendix B.

TABLE 6.1 - RESULTS OF ANALYSES

Description	Watana Valves	Devil Canyon Valves Upper Level	Devil Canyon Valves Lower Level
1. Valve Parameters			
Diameter of fixed cone valves-inches	78	102	90
Number of valves	6	4	3
Design capacity-cfs	4,000	5,800	5,100
Elevation of valve centerline-ft	1,560	1,050	930
Elevation above average tailwater-ft	105	170	50
Net head (h_n) at the valve-ft	508	365	450
Angle of valve discharge with horizontal-degrees (assumed)	45	45	45
2. Jet Geometry			
Longitudinal throw-near edge-ft	91	130	46
Longitudinal throw-far edge-ft	676	550	564
Lateral throw-ft	351	378	228
Impingement area of single jet-ft^2	145,200	112,250	83,400
Impingement area of all jets-ft^2	221,300	173,250	
Maximum fall of jet (H)-ft	359	353	275
3. Jet Characteristics			
Average intensity of discharge of single jet cfs/ft^2	0.028	0.052	0.061
Maximum intensity (q^1) when all jets are operating cfs/ft^2	6 x 0.028 = 0.168	4 x ·052 + 3 x ·061 = 0.391	
Estimated plunge depth-ft	0.3	0.62 (H=353^1)	
4. Supersaturation Estimates (1:50 year flood)			
Design valve discharge-cfs	24,000	38,500	
Assumed simultaneous power flow-cfs	7,000	3,500	
Total downstream discharge-cfs	31,000	42,000	
Assumed gas concentration in power flow-percent and valve discharge at valve-%	100.0	100.0	
Maximum gas concentration in valve discharge below dam-%	100.9	101.9	
Maximum gas concentration in total downstream discharge-%	100.7	101.7	

7 - CONCLUSIONS

1. The analyses described above indicate that the proposed fixed-cone valves would adequately prevent serious gas supersaturation in spill waters up to a recurrence interval of 1:50 years.

2. Several assumptions have had to be made in the analyses with respect to jet characteristics and its potential plunge into tailwater pool. Field test results available are only indicative of the valve performance. In particular, the configuration of the proposed valves set high above the tailwater pool and their free discharge with the atmosphere differ significantly from the Lake Comanche dam arrangement and the TVA test facility. In view of the nature of analyses and lack of precedence for the proposed valve arrangement, it is recommended that a physical model study be carried out to confirm the performance of the valves.

Calculations

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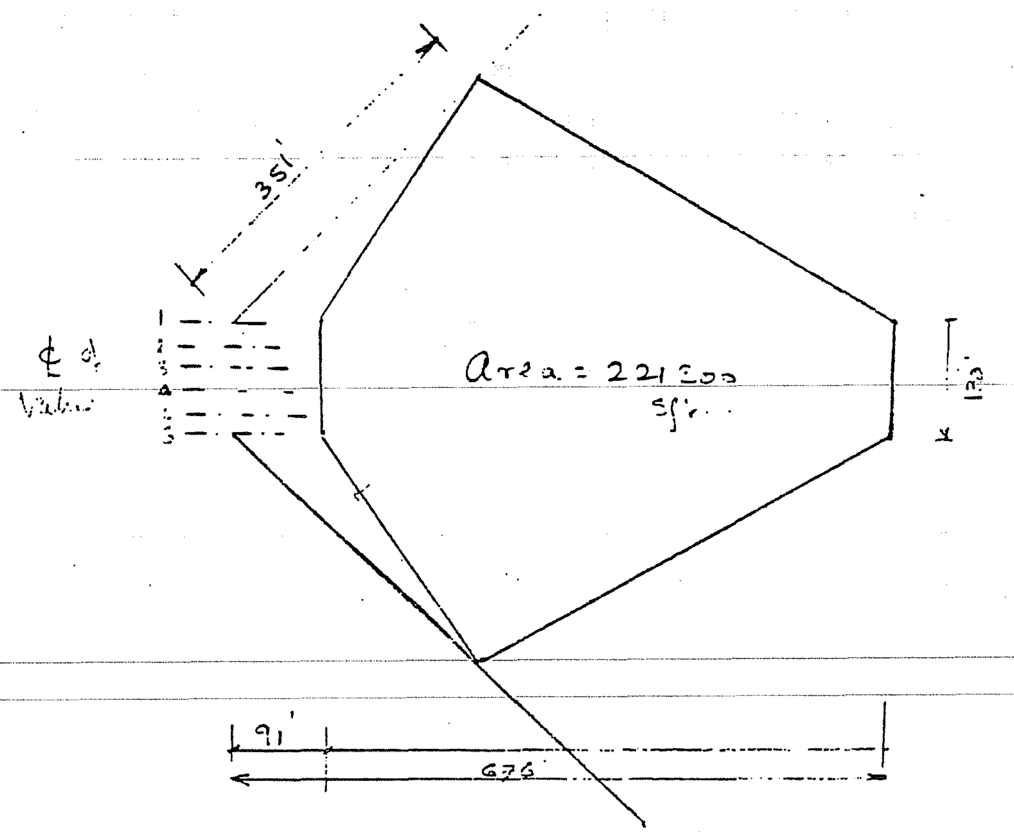

VALVE DISCHARGE PATTERN AND IMPINGEMENT AREA FOR [illegible]

FIGURE 6.1

FORM NO. 152 REV. 1

ACRES **Calculations**

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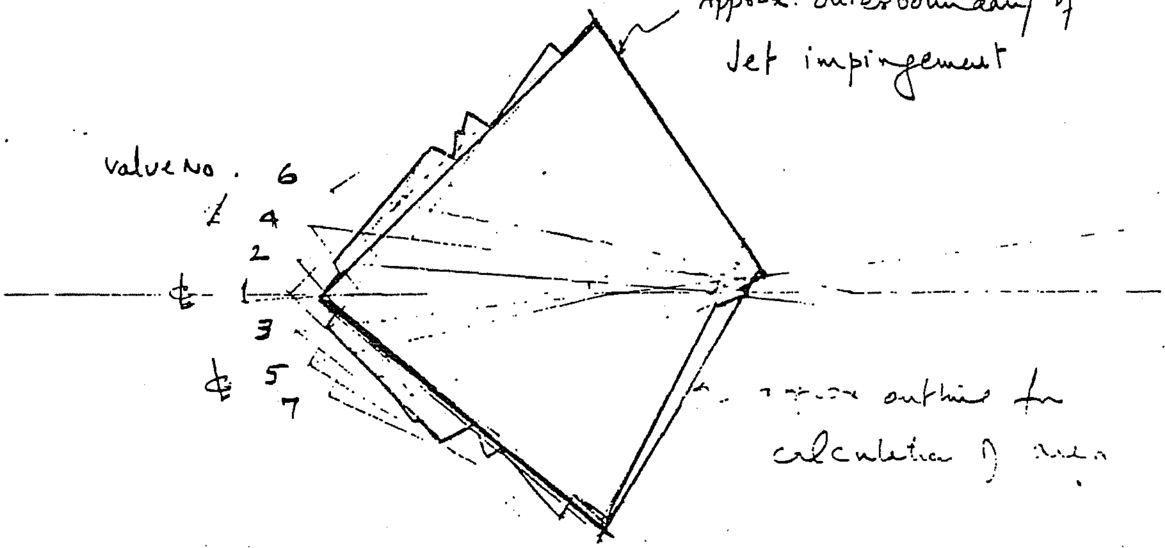

Ref. Plate 52
vol. 3. Feasibility Report

0 100' 200'
scale.

When all 7 valves are operating -
total area of impingement ≃ $\frac{550 \times 630}{2}$ = 173250 s/f.

VALVE DISCHARGE PATTERN
IMPINGEMENT AREA FOR
DEVIL CANYON

FIGURE 6·2

FORM NO. 152 REV. 1

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ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): C. 49

Erosion and Sedimentation in the Kenai River, Alaska

By KEVIN M. SCOTT

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ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Multiply inch-pound unit	*By*	*To obtain metric unit*
°F (degree Fahrenheit)	$^5/_9(F-32)$	°C (degree Celsius)
in. (inch)	2.540×10	mm (millimeter)
ft (foot)	3.048×10^{-1}	m (meter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
ft^3/s (cubic foot per second)	2.832×10^{-2}	m^3/s (cubic meter per second)

National Geodetic Vertical Datum of 1929 (NGVD of 1929), the reference surface to which relief features and altitude data are related, and formerly called "mean sea level," is herein called "sea level."

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EROSION AND SEDIMENTATION IN THE KENAI RIVER, ALASKA

By KEVIN M. SCOTT

ABSTRACT

The Kenai River system is the most important freshwater fishery in Alaska. The flow regime is characterized by high summer flow of glacial melt water and periodic flooding caused by sudden releases of glacier-dammed lakes in the headwaters. Throughout most of its 50-mi course across the Kenai Peninsula Lowlands to Cook Inlet, the river meanders within coarse bed material with a median diameter typically in the range 40-60 mm. Every nontidal section of the stream is a known or potential salmon-spawning site.

The stream is underfit, a condition attributed to regional glacial recession and hypothesized drainage changes, and locally is entrenched in response to geologically recent changes in base level. The coarseness of the bed material is explained by these characteristics, combined with the reservoirlike effects of two large morainally impounded lakes, Kenai and Skilak Lakes, that formed as lowland glaciers receded. Throughout the central section of the river the channel is effectively armored, a condition that may have important long-term implications for the ability of this section of channel to support the spawning and rearing of salmon.

The 3.8-river-mile channel below Skilak Lake contains submersed, crescentic gravel dunes with lengths of more than 500 ft and heights of more than 15 ft. Such bed forms are highly unusual in streams with coarse bed material. The dunes were entirely stable from 1950 to at least 1977, so much so that small details of shape were unmodified by a major glacial-outburst flood in 1974. The features are the product of a flood greatly in excess of any recorded discharge.

The entrenched section of the channel has been stable since 1950-51 or earlier; only negligible amounts of bank erosion are indicated by sequential aerial photographs. Bank erosion is active both upstream and downstream from the entrenched channel, however, and erosion rates in those reaches are locally comparable to rates in other streams of similar size. Although erosion rates have been generally constant since 1950-51, evidence suggests a possible recent decrease in bank stability and an increase in erosion that could be related to changes in river use.

The high sustained flow of summer encourages a variety of recreation-related modification to the bank and flood plain—canals, groins, boat ramps, slips, embankments, as well as commercial developments. As population and recreational use increase, development can pose a hazard to the productivity of the stream through increased suspended-sediment concentration resulting directly from construction and, with greater potential for long-term impact, indirectly from bank erosion. A short-term hazard to both stream and developments is the cutoff of meander loops, the risk of which is increased by canals and boat slips cut in the surface layer of cohesive, erosion-resistant sediment on the flood plain within nonentrenched meander loops. A significant long-term hazard is an increase in bank erosion rates resulting from the loss of stabilizing vegetation on the high (as high as 70 ft) cutbanks of entrenched and partly entrenched sections of channel. Potential causes of erosion and consequent vegetation loss are river-use practices, meander cutoffs, and groin construction.

INTRODUCTION

The Kenai River is a large proglacial stream draining the inland side of the Kenai Mountains and crossing the lowlands of the Kenai Peninsula to Cook Inlet. The most obvious feature of the river in the lowlands is the presence of coarse bed material in association with a meandering pattern; in the spectrum of bed-material sizes of meandering streams, the Kenai River is near the coarse end. Both the bed material and the channel pattern reflect previous geologic intervals when discharge was greater and glaciers were more widespread. Glaciers continue to influence the hydrology of the river, extending today within the watershed to altitudes below 500 ft. The major flood discharges have originated historically from outbursts of a glacier-dammed lake every 2 to 4 years.

The Kenai River system is the most heavily used freshwater fishery in Alaska (U.S. Army Corps of Engineers, 1978, p. 126). Salmon fishing attracts increasing numbers of visitors from the Anchorage area during the summer, particularly for the runs of king salmon. The development associated with this recreational use, though small in scale, is expanding rapidly along the downstream 45.5 river miles that lies mainly in a corridor of State-owned and private lands outside the Kenai National Moose Range (fig. 1). The potential for further development, evidenced by the demand for recreational property and the population increases in communities within the corridor, is large. For details on the environment of the river and the associated 197-mi^2 corridor, readers can refer to the comprehensive survey by the U.S. Army Corps of Engineers (1978).

The section of the river described in this report is the 50.3 mi of channel below Skilak Lake, a large moraine-impounded lake with influence on the flow regime of the river (fig. 1). The purpose of the study is to describe the recent history, geomorphic characteristics, and sedimentation system of the stream downstream from Skilak Lake and to indicate the types, locations, and timing of development that could prove harmful to the fluvial habitat in its ability to support the spawning and rearing of salmon. This report is concerned mainly with developments in the

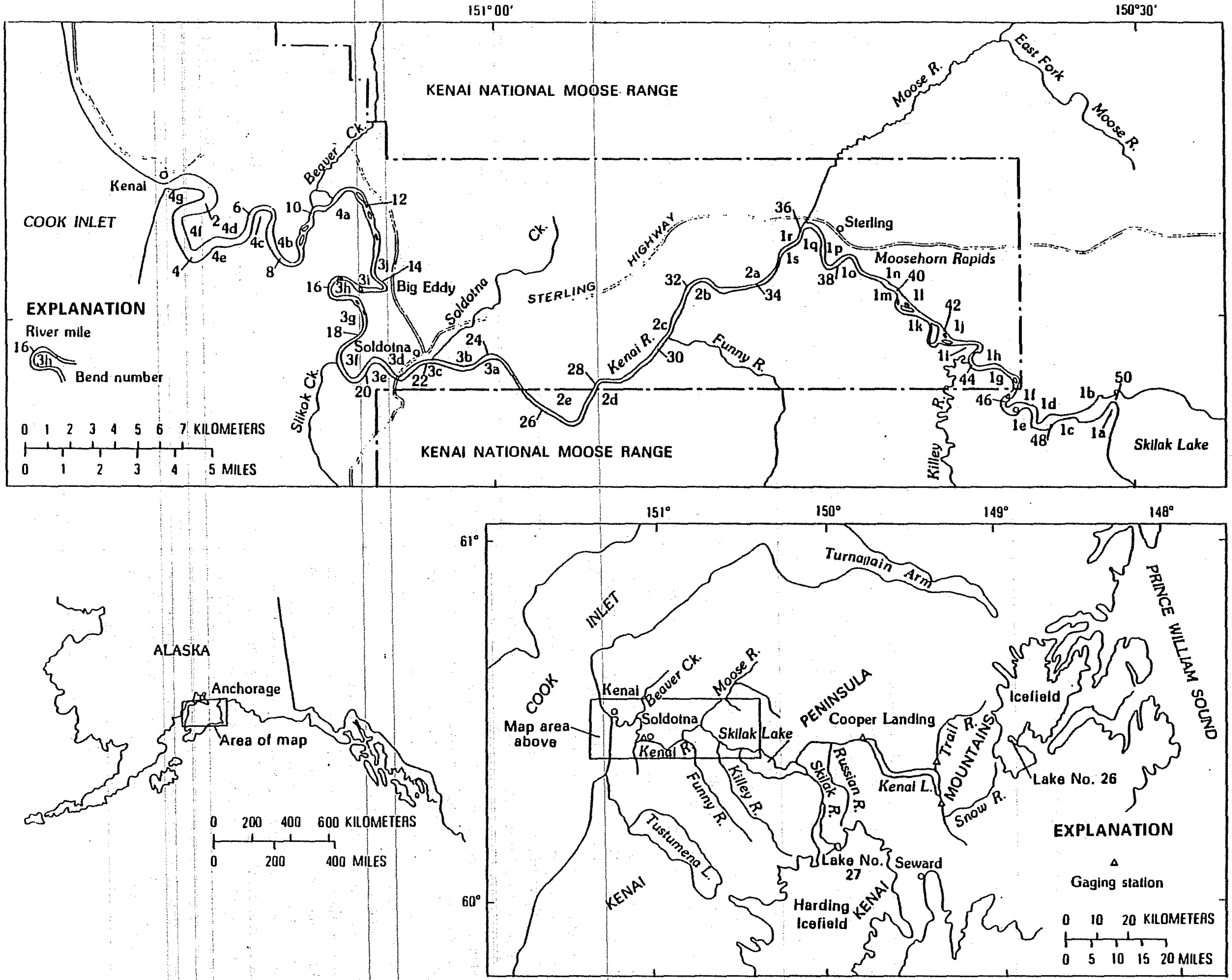


FIGURE 1.— Configuration of the Kenai River downstream from Skilak Lake. Glacial lakes capable of yielding potentially hazardous flood discharges are numbered in accordance with Post and Mayo (1971).

category of alterations to the navigable channel for which a permit from the Department of the Army is required. Upland development and land-use changes are not considered.

In a stream the size and type of the Kenai River, increased suspended-sediment transport will be the first general effect of development with the potential to be deleterious to the physical stream system, chiefly through deposition of fine sediment in the pores of the streambed gravel. Consequently, the present levels of suspended-sediment concentration and the possible causes of future increases are emphasized. Other changes in the sediment system are, of course, possible.

The most important feature of the environment to the economy of the area is the ability of the Kenai River to act as the freshwater habitat for salmon taken directly by sport fishing and indirectly by commercial fishing in Cook Inlet. Four species (king, sockeye, silver, and pink) use the river for spawning in runs from early spring to as late as December. The presence of chum salmon has also been reported. The young of three valuable species (king, sockeye, and silver) are found in the stream year round. Every nontidal part of the river is a known or potential spawning site for at least one species (U.S. Army Corps of Engineers, 1978, fig. 27).

Salmon-producing habitats are sensitive to many factors, but most importantly to sedimentation and water temperature (Meehan, 1974, p. 4). The deposition of fine sediment, with the consequent loss of permeability in streambed gravel during the time of egg and fry development, has been described by many studies as the most detrimental sedimentation effect (for example, Meehan and Swanston, 1977, p. 1). The deposited sediment reduces the flow of oxygen-bearing water within the gravel where eggs and alevins (preemergent fry) are incubating. It may also act as a physical barrier to the emergence of fry and may cause changes in the population of aquatic insects on which the young salmon depend for food.

Erosion and sedimentation have been described as the most insidious of civilization's effects on aquatic life, in that the processes may go unnoticed and the damage can be widespread, cumulative, and permanent (Cordone and Kelley, 1961, p. 189). Unlike most causes of degradation in water quality, erosion and the resulting increase in sediment transport may be triggered by a set of conditions and then may continue to increase or even accelerate after the triggering circumstances have ceased. The possible causes of such a response and why this form of response could occur along the sections of the Kenai River with high, presently stable cut banks are one focus of this report.

Acknowledgments.—This study was completed in cooperation with the U.S. Fish and Wildlife Service, to the personnel of which the writer is indebted for much helpful discussion and the supply of aerial photographs. Many local residents shared their knowledge of the past behavior of the Kenai River and helped form the writer's historical perspective on the stream.

THE KENAI RIVER WATERSHED

The Kenai River drains 2,200 mi² of the Kenai Peninsula, encompassing a watershed that extends from the icefields of the Kenai Mountains westward to Cook Inlet. Summer flow originating as melt water from ice- and snow-covered terrain dominates the hydrologic system of the river. Approximately 210 mi² of the drainage basin consists of glaciers or permanent snowfields, of which 130 mi² is part of the Harding Icefield and attached valley glaciers (fig. 1).

CLIMATE

The climate of the watershed is transitional between the wet and relatively mild marine climate of coastal areas and the colder and dryer continental environment of interior Alaska. The high sustained flow in the Kenai River in middle and late summer reflects the combination of melt water and superimposed storm runoff. More than half the annual precipitation falls in the 4-month period from July through October, with an average of almost 4 in. occurring in September, the wettest month.

Annual rainfall totals vary greatly within the drainage basin because of the orographic effect of the Kenai Mountains on storm systems moving northward from the Gulf of Alaska. In the lowlands downstream from Skilak Lake the annual precipitation is less than 20 in. Southeastward in the progressively higher parts of the basin, precipitation totals increase markedly and probably exceed 80 in. at the crest of the range. The regional distribution of precipitation is reflected in the altitudes to which glaciers descend—many outlet glaciers extend to the tidewater of the Gulf of Alaska; within the Kenai River drainage basin, however, valley glaciers reach no lower than 500 ft.

VEGETATION

The flood plain of the Kenai River and the surrounding terrain are covered by Alaskan taiga association of white spruce and hardwoods, locally with black spruce on north-facing slopes and poorly drained areas (Helmers and Cushwa, 1973, figs. 1, 2; U.S. Army Corps of Engineers, 1978, fig. 31). Evidence of stream behavior can be obtained from vegetation bordering streambanks and on flood plains. Areas of active bank erosion may be characterized by spruce trees leaning at angles into the river as their root support is progressively eroded. When nearly horizontal, the trees are known as "sweepers," named with good reason by early-day raftsmen and hazardous to modern river runners as well. Ice damage in spruce trees on flood plains is evidence of ice-jam flooding and, if datable by dendrochronology, can serve as evidence of flood frequency (Levashov, 1966). Several episodes of ice damage are detectable on trees of the flood plain within meander loop 3-H.

The interior meander loops of the Kenai River do not show the vegetational age succession that would be expected under conditions of rapid channel change. Some meanders do, however, show a variation in vegetation type within the point-bar deposits that corresponds to differences in sediment texture. As documented by Gill (1972) in the Mackenzie River delta, coarse-textured deposits with a lower water content and higher soil temperature encourage the growth of such hardwoods as balsam poplar. The finer textured deposits commonly support mature stands of spruce. The differences in texture mark the episodic accretion by which the meander loops develop—the coarser deposits correspond to the more rapid periods of accretion.

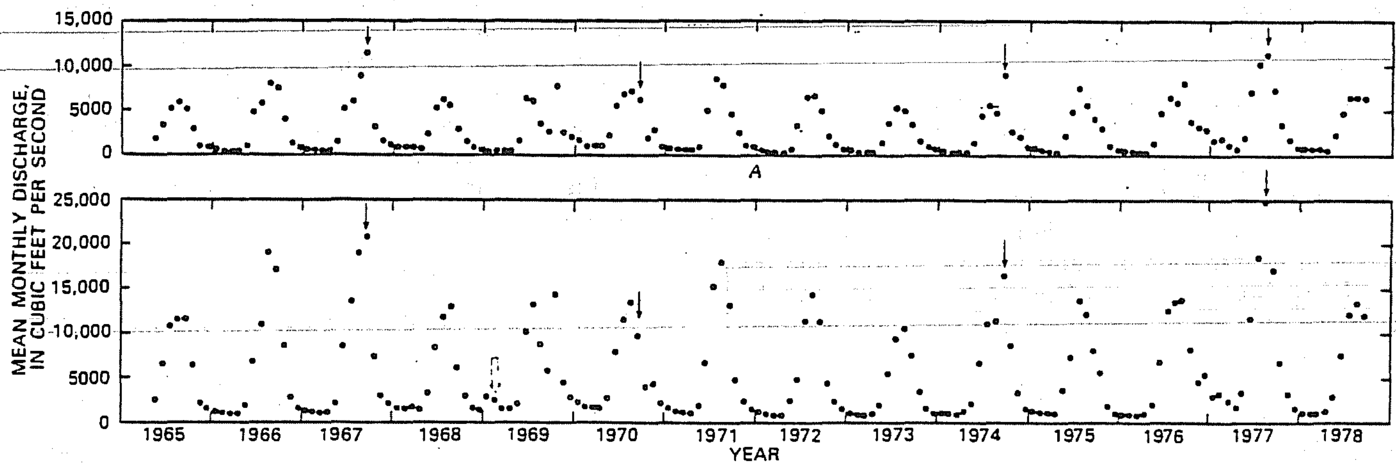
HYDROLOGY

The most obvious characteristic of flow in the Kenai River is the continuous rise in discharge that begins in May, followed by flow at sustained high levels throughout the summer and then by recession during the period from October to January (fig. 2). It is this unusual pattern of relatively uniform high flow during the summer months, reflecting the melting of glaciers and lake storage of melt water, that makes feasible the riverbank development in which bed and bank material is simply bulldozed to form canals, boat slips, and groins. The stage variation of a typical subarctic stream would make this kind of development nearly useless.

The mean annual flow of the Kenai River at Soldotna is 5,617 ft^3/s or 37.95 in. (1965-78). Annual peak flows generally occur in August or September at discharges in the range 20,000-30,000 ft^3/s. From freezeup in late November or December to breakup, occurring ordinarily in April but as early as February, flow levels base within the range 800-1,700 ft^3/s.

The Kenai River begins at the outlet of Kenai Lake, a glacially sculpted lake extending fiordlike for 22 mi inland from the front of the Kenai Mountains to within 15 mi of Seward on the Gulf of Alaska. Downstream from the outlet of Kenai Lake at Cooper Landing, the river flows for 17 mi before entering Skilak Lake. The 50-mi course of the stream between Skilak Lake and Cook Inlet is the subject of this report; the 17-mi segment between the major lakes is excluded.

Major headwater tributaries of the Kenai River are the Trail and Snow Rivers, which enter Kenai Lake from the north and south, respectively. The major tributary entering the Kenai River between the lakes is the Russian River, famous for a run of sockeye salmon during which they can be taken on artificial lures. Other large tributaries include the Skilak River, which drains the Harding Icefield and flows directly into Skilak Lake, and the Killey River, which joins the Kenai River 6 mi below the outlet of Skilak Lake. All these streams have significant areas of their headwaters covered by permanent ice and snow, and as a group they supply the high summer melt-water flow of the Kenai River.



B

FIGURE 2. —Mean monthly discharges at gaging stations. *A*, Kenai River at Cooper Landing. *B*, Kenai River at Soldotna. Black arrows show times of release of glacial lakes in Snow River; white arrow shows times of release of glacial lakes in Skilak River.

Downstream from the Killey River, all tributaries to the Kenai River drain only the Kenai Lowlands. Runoff from these streams is dominated by snowmelt runoff, with annual peaks generally in April or May. Poorly integrated drainage and numerous lakes and marsh areas, as well as lower rates of precipitation, result in comparatively low annual runoff. The largest of these streams is the Moose River, which joins the Kenai River at river mile 36.2. The Funny River, and Beaver, Soldotna, and Slikok Creeks, are other lowland tributaries, of which Beaver Creek is the only stream with more than sporadic flow records (1967-78).

Anderson and Jones (1972, pl. 2) presented a summary of all discharge information for the Kenai River downstream from Skilak Lake as of 1972. These data and subsequent information can be obtained from the series of annual reports entitled "Water Resources Data for Alaska," published by the U.S. Geological Survey. Gaging-station records on the Kenai River have been obtained since 1947 at Cooper Landing, and since 1965 at the Soldotna bridge at river mile 21.1.

The Kenai River is noteworthy for a low variation in annual peak flows during the period of measurement. There are, however, three potential sources of major flooding on the stream in addition to the normal sources of flow—melt water and storm runoff: (1) sudden discharges from glacially dammed lakes, (2) outburst floods of water stored in or under glaciers, and (3) ice jams. Each is discussed in the following paragraphs.

The annual peak discharges from melt water and storm runoff have been generally less than the annual peaks that resulted from the sudden release of glacially dammed lakes. The historical peak discharge at Soldotna occurred September 9, 1977—instantaneous peak discharge was 33,700 ft^3/s—in response to the release of a glacially dammed lake in the Snow River drainage basin (fig. 1). The lake is one of two potentially hazardous such lakes in the watershed for which Post and Mayo (1971, sheet 1) recommended monitoring. The lake at the headwaters of the Snow River has caused outburst flooding periodically since 1911 or earlier. Typical of the floods is that occurring in 1974 (fig. 3) and yielding the peak discharge of record on the Kenai River at Cooper Landing. This lake has yielded floods at intervals, most commonly from 2 to 4 years in length and at levels apparently related to systematic changes in glacier size. Post and Mayo (1971, p. 4) cited reports that flooding historically has occurred most commonly in November, December, or January. In recent years (1964, 1967, 1970, 1974, 1977), however, flooding has occurred in August and September at times of high base flow derived from melt water. If this trend continues, the flood hazard from lake releases will increase.

The second potentially hazardous glacial lake occurs in the headwaters of the Skilak River (fig. 1) and discharges directly to Skilak Lake. This glacial lake yielded a comparatively small volume of flow in January 1969 (fig. 2), but the flood wave fractured large volumes of ice on the Kenai River, thereby causing locally serious flooding from the resulting ice jams (Post and Mayo, 1971, p. 4). Aerial observations by the U.S. Weather Service on October 18, 1979, revealed that the lake has refilled (S. H. Jones, oral commun., 1980), apparently setting the stage for another outburst flood.

A phenomenon similar to glacial lake discharges is the outburst of water impounded beneath glaciers. Though potentially originating from any glacier of at least moderate size, floods entirely from subglacial outbursts have not been specifically recorded on the Kenai River. They may not, however, have been observed if originating in uninhabited areas like the Skilak or Killey River drainage basins in the period before to flow measurement at Soldotna (before 1965). Part of the glacial lake in the Skilak River headwaters is formed beneath the Skilak Glacier, and that lake discharges subglacially into the Skilak River (S. H. Jones, written commun., 1980).

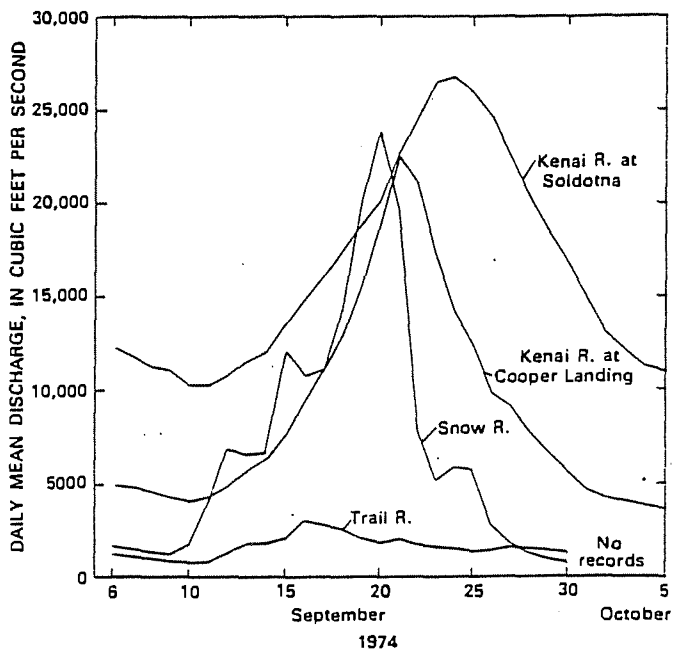


FIGURE 3.—Successive downstream hydrographs for flood of September 1974 originating from an unnamed glacially dammed lake (No. 26 of Post and Mayo, 1971) in headwaters of the Snow River. Concurrent discharge record of nearby Trail River is illustrated for comparison. Instantaneous peak discharges were 26,400 ft^3/s in the Snow River, 23,100 ft^3/s in the Kenai River at Cooper Landing, and 26,900 ft^3/s in the Kenai River at Soldotna.

The final cause of flooding is ice jams, from which an additional hazard is the channel-erosion effects with which they are associated on other northern rivers (MacKay and others, 1974). Jams on the Kenai River are most common near Big Eddy, a point of constriction in a tight meander at river mile 14.3 (fig. 1). The probability of ice jamming at Big Eddy led the U.S. Army Corps of Engineers (1967, exhibit 4) to calculate upstream flood-hazard levels that are as much as 10 ft above the stage of a flood, with a recurrence interval of 50 years. Potential levels of flooding from ice jams at Big Eddy exceed levels of the 50-year flood as far upstream as Soldotna.

QUATERNARY HISTORY OF THE KENAI RIVER VALLEY

The flood plain, terraces, and valley of the Kenai River reflect the influence of glacial events to a high degree. The modern landscape of the river, extending even to variations in channel pattern and size of channel-bed material, is partly a function of glacial action, including sculpture by glacial ice, deposition from receding ice sheets, and changing base levels related to the effects of glaciation or tectonics. The final major Quaternary glaciation of the Kenai Lowlands did not end until about 5,000 years ago, and today an outlet glacier from the Harding Icefield reaches to within 7 mi of the head of Skilak Lake.

An understanding of the recent glacial history of the Kenai Lowlands is prerequisite to interpreting the modern Kenai River. The sequence of events, their ages, and an interpretation of their effects on the river are presented in table 1. The glacial history of the Kenai River area and the surrounding region was studied in detail by Karlstrom (1964), and most of the general aspects and terminology in the following discussion are based on his work.

The Cook Inlet region has undergone five major Pleistocene glaciations and two major subsequent advances. In stratigraphic order (youngest to oldest), the major glaciations are:

Naptowne
Knik
Eklutna
Caribou Hills
Mount Susitna

Much of the Kenai Lowlands was covered by ice during the first three major glaciations. During Knik time, however, glaciers from the Kenai Mountains reached only as far as river mile 26.7. According to Karlstrom (1964), farther southwest in Cook Inlet, Knik glaciers from the Kenai Mountains coalesced with those from the Alaska Range and dammed the regional drainage into a proglacial lake that existed periodically and at successively lower levels until near the end of the Naptowne Glaciation. However, the periodic existence of this lake—a major premise of Karlstrom's interpretations—has not been verified by subsequent investigations in the Cook Inlet region.

Deposits of the three youngest major glaciations are present along the Kenai River in the study area, but it is the events of the youngest episode, the Naptowne Glaciation, that dominate the geomorphic history of the stream. The spatulate Naptowne end moraines are the most prominent topographic feature of the Kenai Lowlands, extending as far as river mile 38.9. The type localities of the Naptowne Glaciation and several of its subsidiary advances are located along the river within the study area (the town of Naptowne is now known as Sterling). The sequence of advances within the Naptowne Glaciation is, stratigraphically:

Tanya
Skilak
Killey
Moosehorn

The age of the Naptowne Glaciation has been revised downward to less than 14,000 B.P. (Péwé, 1975, p. 14), considerably later than reported by Karlstrom (1964). Dating by Karlstrom of the post-Moosehorn events appears reasonable in light of this revised age and is shown in table 1.

The initial phase of the Naptowne Glaciation, the Moosehorn advance, was named for the Moosehorn Rapids in the Kenai River at river mile 39.4 near the margin of the Naptowne end moraine. Moraines of the Killey advance, named for exposures along the Killey River, a major tributary to the Kenai River, extend to river mile 40.5; and those of the subsequent Skilak advance, named for exposures around the edge of Skilak Lake, occur as far downstream as river mile 48.4.

EVIDENCE OF PROGLACIAL LAKE IN COOK INLET

The existence of a proglacial lake in Cook Inlet, or at least its chronology as interpreted by Karlstrom, has been thrown open to question by a revised origin and radiometric age of a unit previously thought to represent a middle Wisconsinan interstadial event. In the Anchorage area a distinctive deposit of silty clay, the Bootlegger Cove Clay (Miller and Dobrovolny, 1959), occurs beneath and adjacent to the local equivalent of the Naptowne end moraine (Trainer and Waller, 1965, p. 170). The unit was believed to be mainly lacustrine in origin and middle Wisconsinan in age (Karlstrom, 1964, p. 37-38). Because failure of the Bootlegger Cove

TABLE 1.—*Late Quaternary (Wisconsinan to present) history of the Cook Inlet area and correlation with the geomorphology of the Kenai River*

[Glacial events and strandlines after Karlstrom (1964, table 3); correlation with classical sequence in part modified from Péwé (1975, table 2)]

Epoch	Glaciation	Thousands of years before present	Glaciation	Glacial event	Associated radiocarbon dates	Strandlines of hypothesized proglacial lakes (feet above present sea level)	History of the Kenai River in study area: Depositional events	History of the Kenai River in study area: Erosional events
Holocene			Alaska Glaciation	Tunnel II advance	A.D. 1550±150 A.D. 1500±200			
		1		Tunnel I advance	A.D. 565±200			
		2		Tustumena III advance	300±300 B.C. 420±100 B.C.			
		3		Tustumena II advance	1250±150 B.C.			
		4		Tustumena I advance	2550±450 B.C.			
				Pro-Tustumena advance				
		5	Naptowne Glaciation			5–10 (marine transgression)	Deposition of tidal sediment exposed below river mile 12.3	Erosion of tidal flats continuing to present
		6		Tanya III advance	3850±500 B.C. 4850±550 B.C.			
		7		Tanya II advance		50 (Best developed levels)		Entrenchment of river into Soldotna terrace begins and continues to present
		8		Tanya I advance		100–125 (Best developed levels)	Fluctuating levels of hypothesized proglacial lake in inlet with one or more complete withdrawals	Soldotna terrace formed
		9		Skilak III advance	7050±750 B.C.		Possible lacustrine, glaciolacustrine, and deltaic deposition in river valleys below strandlines indicated	
Pleistocene	Wisconsin, Late	10 (Scale variable)		Skilak II advance	7920±250 B.C. 8420±350 B.C.	275		
				Skilak I advance			Glacial advance to river mile 48.4	
				Killey advances	10,950±300 B.C. 11,550±400 B.C.	500	Glacial advance to river mile 40.5	Fluctuating levels of hypothesized proglacial lake in Cook Inlet with one or more complete withdrawals. Lake terraces possibly cut at strandlines indicated
				Moosehorn advance		750	Glacial advance to river mile 38.9	
				Pro-Naptowne advance.				
	?							
	Wisconsin, Early			Knik Glaciation		~1000	Glacial advance to river mile 26.7	

Clay caused disastrous slides during the 1964 Alaska earthquake, it has been the subject of additional study that has established an entirely marine origin (Hansen, 1965, p. 20) and an age of about 14,000 B.P. (Schmoll and others, 1972, p. 1109). Péwé (1975, p. 74) concluded that the interpretation of a glacial lake occupying the upper part of Cook Inlet during Knik and Naptowne time is refuted by this later evidence.

At least some of the features attributed by Karlstrom to a freshwater lake have other explanations. The Soldotna terrace, a well-developed surface bordering the Kenai River over much of its lower course, was interpreted as a lake terrace in mapping by Karlstrom (1964, pl. 4) but is described here as a former floodplain surface, an origin in common with other alluvial terraces. The Soldotna terrace grades to one of two well-developed terrace levels bordering Cook Inlet. These levels occur 50 and between 100 and 125 ft above present sea level and were interpreted by Karlstrom as lake terraces (table 1). They are, however, more likely marine in origin, on the basis of the extent of their development. It is difficult to envision an ice-floored lake spillway being sufficiently stable for the interval necessary for cutting of the terraces. The changes in base level consequently are more likely due to isostatic rebound or tectonic uplift than to changes in level of the hypothesized lake. Favoring the lake hypothesis is Karlstrom's mapping of other higher strandlines indicating lake levels at altitudes too high (table 1) for reasonable explanation by sea-level change due to isostatic rebound or tectonics. The existence of these higher strandlines could not, however, be confirmed during field investigations in the Kenai River watershed.

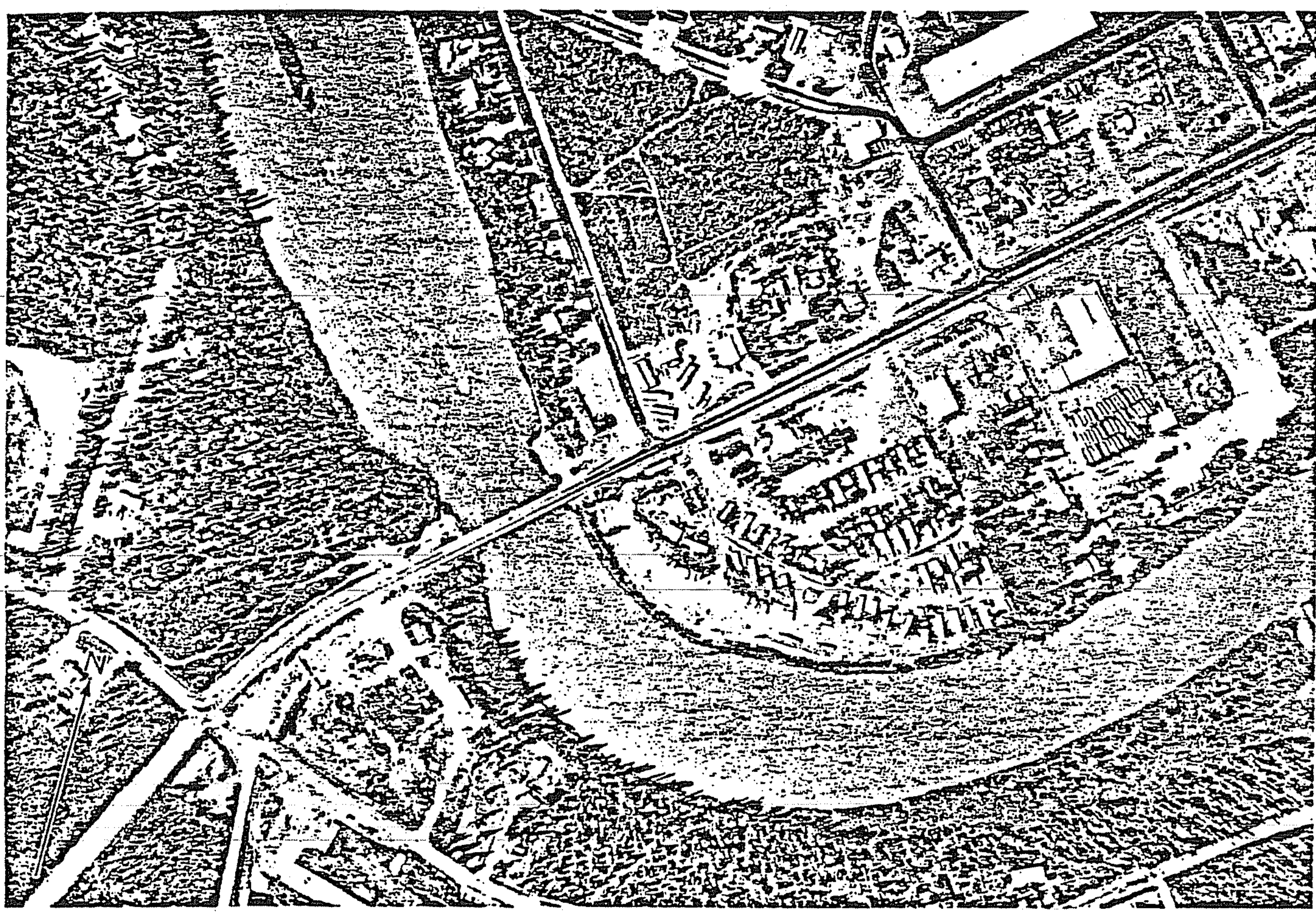


FIGURE 4.—Kenai River at the Soldotna bridge. The river is entrenched 30 to 40 ft below the Soldotna terrace, upon which part of the town of Soldotna is visible here. Wakes in the river are caused by large boulders, the presence of which is characteristic of the entrenched section of the stream. Direction of flow is toward upper left. Reach visible in photograph extends from approximately river miles 21.5 to 20.7. Scale, 1:4,800, or 1 in.= 400 ft. Photograph credit: U.S. Army Corps of Engineers.

TERRACES AND RIVER ENTRENCHMENT

The Soldotna terrace, here named informally for the town constructed upon it (fig. 4), is the most prominent topographic feature in the Kenai River valley between river miles 13 and 31. The terrace averages about a mile in width, is covered with mature taïga vegetation, and occurs at altitudes generally from 25 to 50 ft above the present Kenai River flood plain. It dominates the valley upstream from river mile 17.6, above which point the river is entrenched in the terrace surface and little modern flood plain exists. The entrenchment, which extends beyond the upstream end of the terrace as far as river mile 39.4, is a result of a lowering in base level, from the level to which the terrace was graded, to present sea level.

Karlstrom (1964, pl. 4) interpreted the section of the Soldotna terrace between river miles 31 and 27 as a river terrace and the remaining part as a hanging deltaic complex associated with a proglacial lake of Naptowne age. The entire terrace upstream from Soldotna (river mile 22) is here interpreted as a former flood plain of the Kenai River. Profiles of the terrace and river channel measured along the valley axis (fig. 5) show that the terrace is graded to a height above present sea level.

The extension of the Soldotna terrace below the town probably correlates with the 100- to 125-ft-high marine terrace. A well-developed 50-ft marine terrace is also present, and figure 5 portrays possibility that the alluvial part of the Soldotna terrace grades to this lower level. The town of Kenai is mainly on this lower terrace, which is not represented by obviously correlative alluvial equivalents along the Kenai River.

TOPOGRAPHY OF THE KENAI LOWLANDS AND COURSE OF THE KENAI RIVER

The poorly drained, lake-dotted Kenai Lowlands contain many abandoned channels that are visible on aerial photographs yet do not form a drainage system which is obviously integrated with the present network. The channels, though well developed at some localities, are discontinuous and not easily traceable. Karlstrom (1964, p. 15) believed that the pattern locally suggests scabland topography formed under torrential-flood conditions.

Changes in the drainage of the Kenai River system have occurred within a geologic time span that is apparently too short for any but partial adjustment of the channel—in pattern and bed material size, for example. A change in pattern (an increase in wavelength downstream from river mile 36; fig. 6) below the point of inflow of the tributary Moose River suggests that discharges proportionally larger than those now supplied by the Moose River have occurred in the past. If true, the Kenai River downstream from the Moose River is underfit to a greater degree than is the river

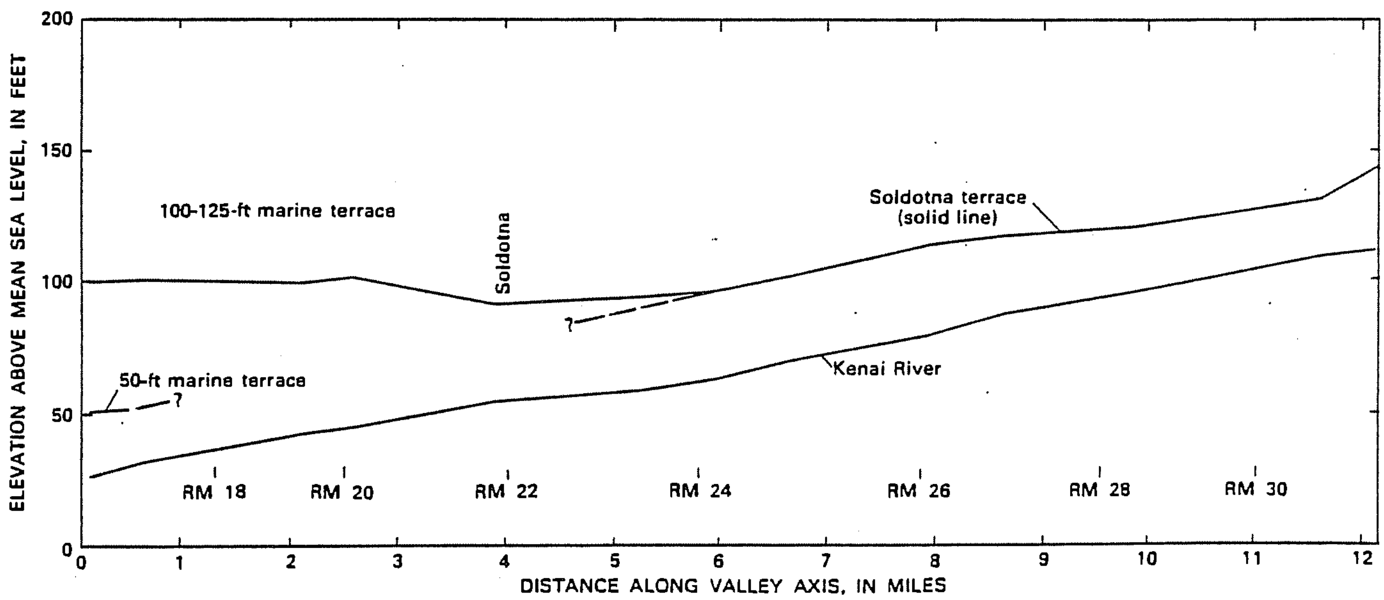


FIGURE 5.—Profiles of the Soldotna terrace and the Kenai River (water surface at intermediate flow level) measured along the valley axis. River miles are shown inset. Altitudes were derived photogrammetrically, and absolute values are only accurate within the approximate range of ±10 ft. Relative differences between altitudes of terrace and river at a point are believed accurate to within ±2 ft.

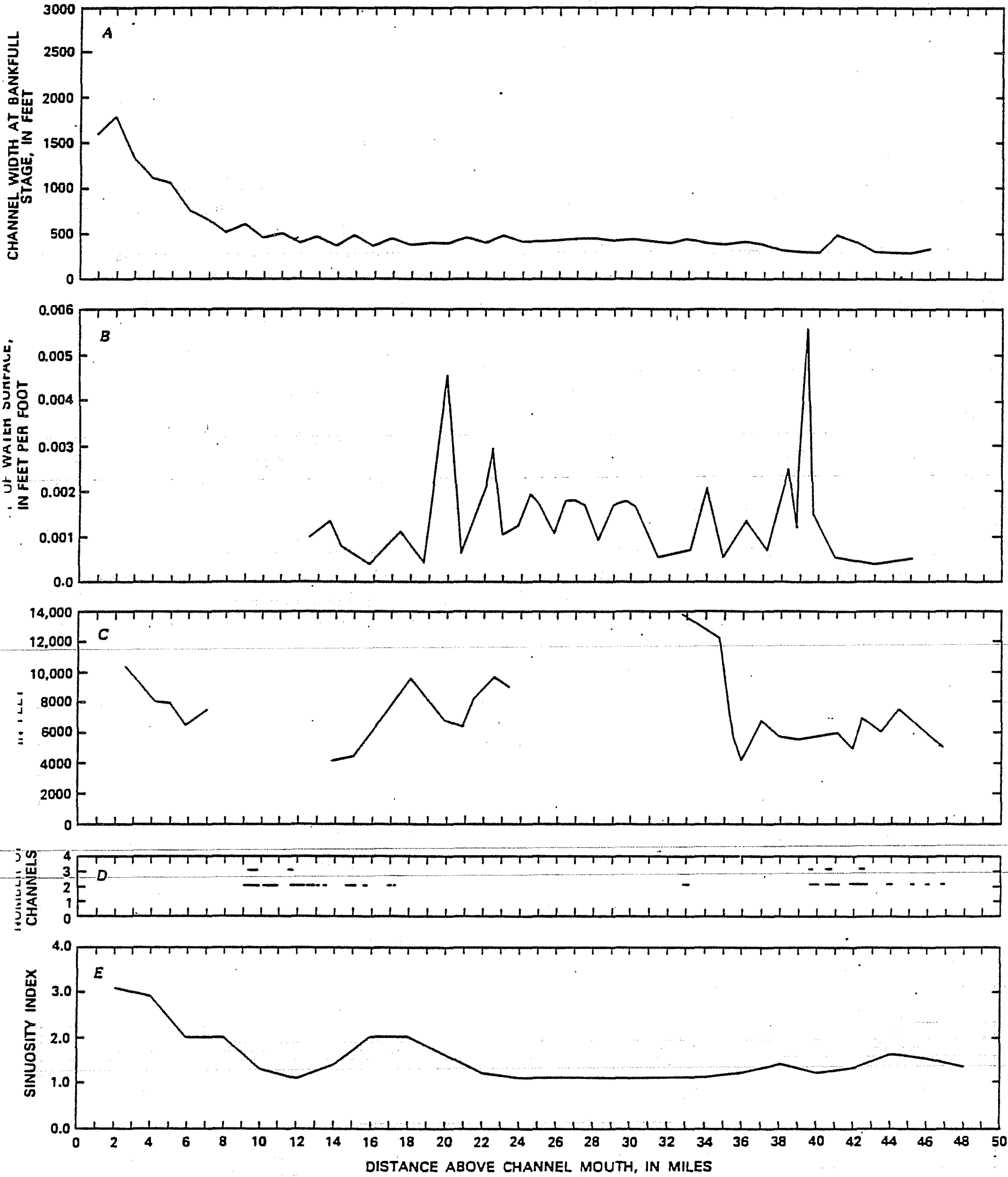


FIGURE 6.—Distance above channel mouth (in river miles) against: channel width at bankfull stage (*A*), slope of water surface (*B*), meander wavelength (*C*), number of channels (*D*), and sinuosity index (*E*).

upstream from the junction. This effect would be in addition to the probable basinwide underfit condition reflecting the general reduction in precipitation that has occurred with glacial recession.

Figure 7 illustrates the channel of the Moose River a short distance upstream from its junction with the Kenai River. The underfit condition is pronounced. The present channel is approximately 80 ft wide where it meanders within a paleochannel 600 to 700 ft wide. The Moose River paleochannel appears to be a natural upstream extension of the lower part of the Kenai River, from both the similarity in pattern and the trends of the two channels at their junction.

Topography at the front of the Kenai Mountains indicates several past variations in drainage in which the Moose River would have yielded much greater flow than at present. It is possible to project an extension of the Skilak Glacier to the head of Skilak Lake where it could divert the Kenai River into the headwaters of the East Fork of the Moose River (fig. 8). The course of probable diversion is today a chain of lakes, beginning with Hidden Lake in the gap between Hideout Hill and the hills north of Skilak Lake and continuing with the Seven Lakes, each connected by the drainage that becomes the East Fork of the Moose River. This hypothesized diversion probably occurred with the Skilak advance of the Naptowne Glaciation and could also have occured during the Tanya advance. Tanya end moraines have not been recognized in the Skilak Lake area, although they were mapped by Karlstrom (1964, pl. 4) at their type locality near Tustumena Lake. An advance of the Skilak Glacier similar in distance and gradient to the relation between the Tanya end moraines and the Tustumena Glacier, the extension of which was the type Tanya advance, could have diverted the Kenai River into the Moose River drainage.

The effects of earlier glaciations on the drainage pattern would have been greater. Drainage from the area of Kenai Lake, which was glacier filled during much of pre-Tanya Naptowne time, may also have entered the Moose River drainage north of Hideout Hill (fig. 8). During the maxima of Skilak and earlier Naptowne advances, glacial lobes from the Kenai Lake valley entered the Moose River basin and discharged large volumes of melt water.

No matter what scenario of melt-water drainage is hypothesized, during each of the Naptowne advances the tendency was for greater proportions of the total discharge of the Kenai River basin to have entered the Kenai Lowlands from the Moose River than from the present Kenai River channel above the confluence with the Moose River. The Kenai River channel downstream from the Moose River thus has had a constant drainage area, and the overall decrease in discharge in that channel has reflected the general climatic change. The channel upstream from the Moose River, however, re-

FIGURE 7.—Moose River channel between 1.3 and 2.6 mi upstream from its junction with the Kenai River—a striking example of confined meanders occurring within a large sinuous paleochannel. Flow is toward bottom of photograph. Downstream change in pattern of present channel from meandering to straight is in response to entrenchment of the Kenai River. Scale, 1:12,000, or 1 in. = 1,000 ft. Photograph credit: U.S. Army Corps of Engineers.

flects partially offsetting changes in climate and drainage area. The effects of change in drainage area have been to reduce the high discharges at times of glacial maxima. In consequence, the channel of the Kenai River below the Moose River reflects a history of adjustment to greater absolute change in discharge than does the channel upstream from the tributary, and this difference in adjustment is reflected in the channel and sediment characteristics described in the following sections.

CHANNEL OF THE KENAI RIVER

Study of the channel pattern, degree of entrenchment, position of riffle bars, symmetry of cross sections, and slope permits a description of the Kenai River that, in combination with the subsequent sections on bank erosion and development, can be used to assess the relative susceptibility of various sections of the stream to the actions of man. The information will be presented in the following section but will be applied in the final section on river development.

STREAM TYPE

The Kenai River can be fitted to an engineering classification of streams (Brice and Blodgett, 1978, p. 94; Brice, 1981, fig. 5) that emphasizes lateral stability—the potential for bank erosion. The classification is based on observable channel properties that show an association with varying degrees of lateral stability. The section of the Kenai River between river miles 39.4 and 17.6 has characteristics similar to the type described as equiwidth point bar. Such streams are relatively stable. Upstream and downstream from this section the Kenai River more closely fits the category described as wide-bend point bar. This type of stream is generally less stable than equiwidth point-bar streams.

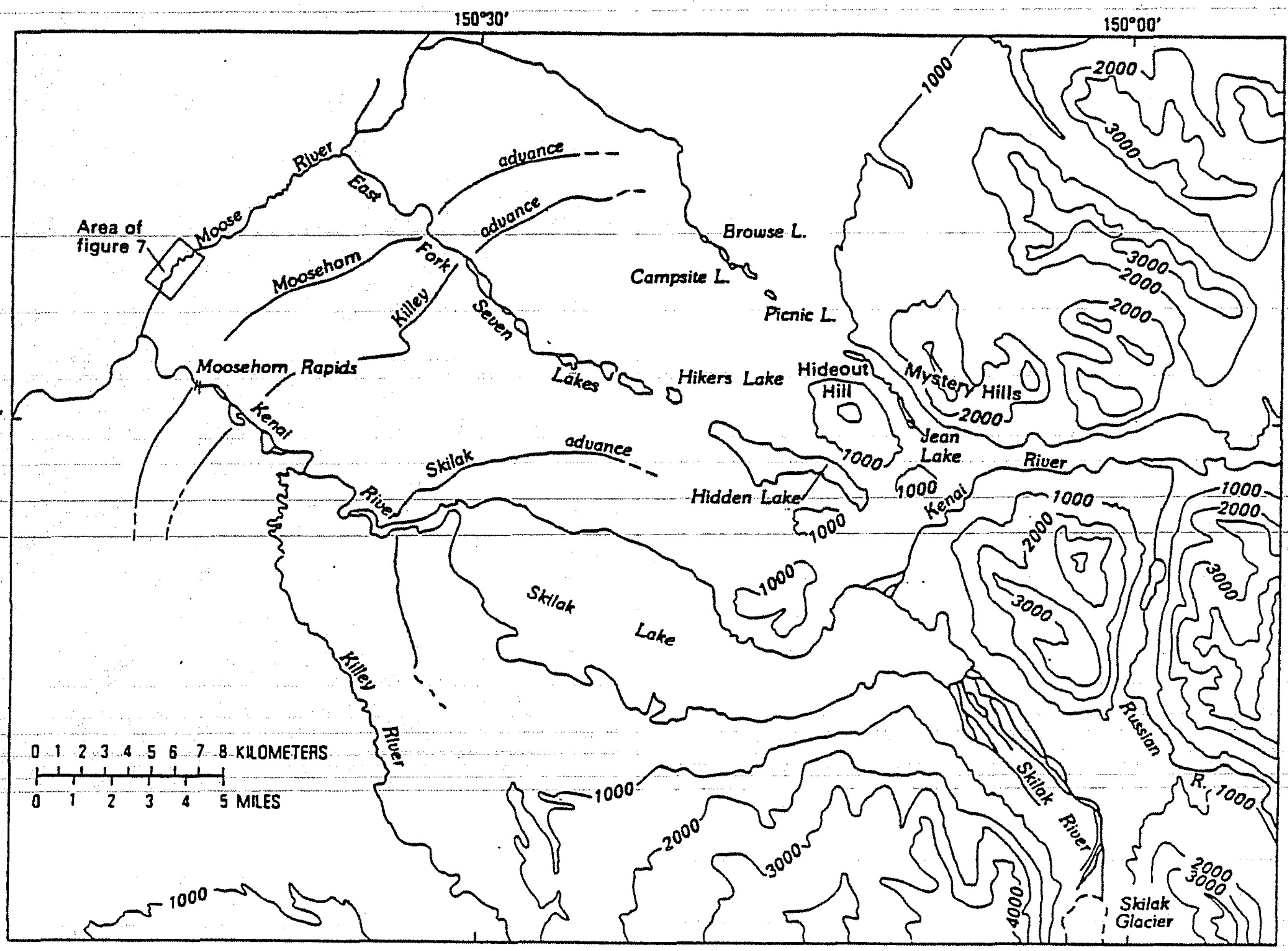


FIGURE 8.—Drainage network in the Kenai River watershed near the front of the Kenai Mountains. Limits of subsidiary advances within the Naptown Glaciation are shown (mainly from Karlstrom, 1964, pl. 4).

CHANNEL PATTERN

Variations in channel pattern can be empirically useful in assessing differences in susceptibility to bank erosion. For example, the straighter, less sinuous reaches of a stream tend to be significantly more stable than the more sinuous reaches, solely on the basis of the observation that bank erosion is most intense at channel bends. Channel pattern can be in part described by means of a sinuosity index (*S.I.*), defined as the ratio of the thalweg length to the length of the meander-belt axis (Brice, 1964, p. 25). Although the symmetry of channel bends is not considered in calculating the index, channels can be described by boundary values of the index. In the classification used here, reaches with a sinuosity index greater than 1.25 are described as meandering, those with an index between 1.05 and 1.25 are sinuous, and those with an index less than 1.05 are straight (Brice and Blodgett, 1978, p. 70).

The sinuosity indexes of overlapping reaches 4 mi in length are shown in figure 6, where values are plotted at midpoints 2 mi apart. That the Kenai River varies in sinuosity is readily seen. Three intervals of meandering channel are present: the first, between Skilak Lake and river mile 34.8; the second, between river miles 21.8 and 13.4; and that farthest downstream, between river mile 9.0 and the mouth. This last interval shows the downstream increase in channel width and meander amplitude associated with tidal augmentation of flow.

The river branches into multiple distinct channels (anabranches) in two reaches (fig. 6). The upstream anabranched reach, between river miles 42.7 and 39.6, is part of the first meandering section. The downstream anabranched reach, between river miles 15.8 and 11.4, includes part of the middle meandering section. The islands within the upstream anabranched section of channel are mainly covered with mature spruce. Vegetation on islands in the downstream anabranched section is less dense, but is generally mature and indicates that the islands are only rarely inundated.

INVESTIGATION OF UNDERFIT CONDITION

The possibility of an underfit condition can be investigated by comparison of the channel pattern with discharge and channel width. Paired observations have shown that meander wavelength is a function of bankfull discharge according to the relation (Inglis, 1949, p. 147; Leopold and Wolman, 1970, p. 216)

$$\lambda = 36Q^{0.5}.$$

Dury (1965, p. 5; 1970, p. 273; 1976, p. 223) analyzed several sets of paired observations of wavelength and discharge. His original set of 105 pairs of data gives the relation (Dury, 1970, p. 273)

$$\lambda = 30Q^{0.5}.$$

Also, meander wavelength is related to width of bankfull channel according to the relation (Leopold and Wolman, 1970, p. 216)

$$\lambda = 6.5w^{1.1}.$$

Dury (1976, fig. 2) summarized 173 pairs of values of wavelength and width and calculated the relation

$$\lambda = 9.76w^{1.019}.$$

Leopold and Wolman (1970, p. 216-217) showed that wavelength was more directly dependent on width than on discharge when data were compared for a large range of stream sizes. Bankfull discharge is considered here as equivalent to channel-forming discharge and is calculated as the discharge at a recurrence interval of 1.58 years in the annual series.

The plot of wavelength with bankfull discharge (fig. 9) indicates that the channel in each of the three meandering sections tends to be underfit; that is, the data points are in or above the upper ranges of the data of Inglis and Dury. In such cases of apparent underfit, a meander of a given size is associated with an uncommonly low channel-forming discharge, leading

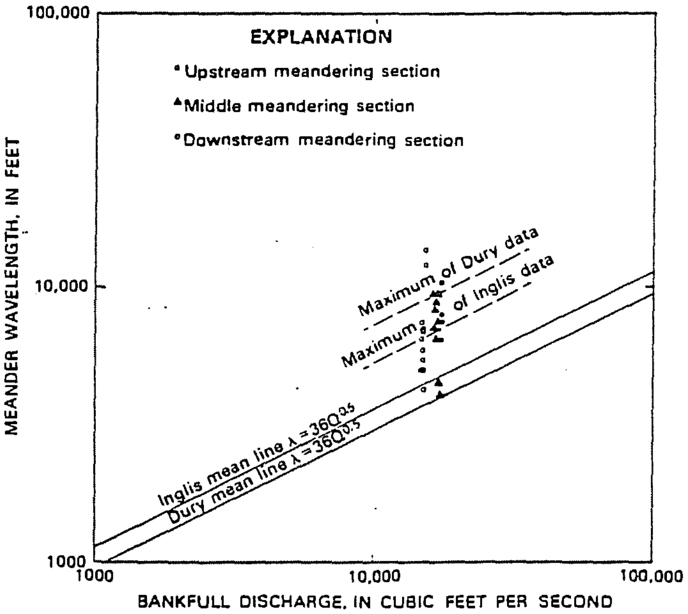


FIGURE 9.—Meander wavelength against bankfull discharge. Lines representing limits of Inglis (1949) and Dury (1965, 1970, 1976) data are approximate.

to the assumption that discharge has decreased since the meanders were formed.

The data points in the plot of wavelength against width at bankfull stage (fig. 10) tend to cluster in or above the upper ranges of the data plotted by Leopold and Wolman (1970, fig. 7.13) and Dury (1976, fig. 2). Thus the channel width is smaller for a given wavelength than would be expected by comparison with other streams, as the likely result of the meander pattern of the Kenai River having been formed during a previous period of higher discharge with, of course, the width of the channel reflecting the present, lower discharge.

Meanders from the tidal section of channel mainly plot below the mean lines of the data in the Leopold-Wolman and Dury studies (fig. 10), but the significance of this relation is not known because those authors included no data from tidal reaches. The downstream meandering channel reflects tidally augmented flow and shows the consequent characteristic increase in channel width, and so it should expectably indicate an underfit condition relative to the freshwater discharge of the stream, as it does in the plot of figure 9.

FLOW DEPTH VARIATION WITHIN MEANDERS AND WITH DIFFERING CHANNEL PATTERN

The measurement of a series of cross sections by the U.S. Army Corps of Engineers (1967, 1973, 1975, 1978) permits analysis of flow depths according to position in the meander course and the type of channel pattern. The discharge at Soldotna during the 2-day period of the survey was in the relatively narrow range of approximately 11,500 to 11,900 ft^3/s. The cross sections, therefore, represent the bed at a moderate flow level, approximately 70 percent of bankfull discharge, in the reaches between river miles 47 and 26.

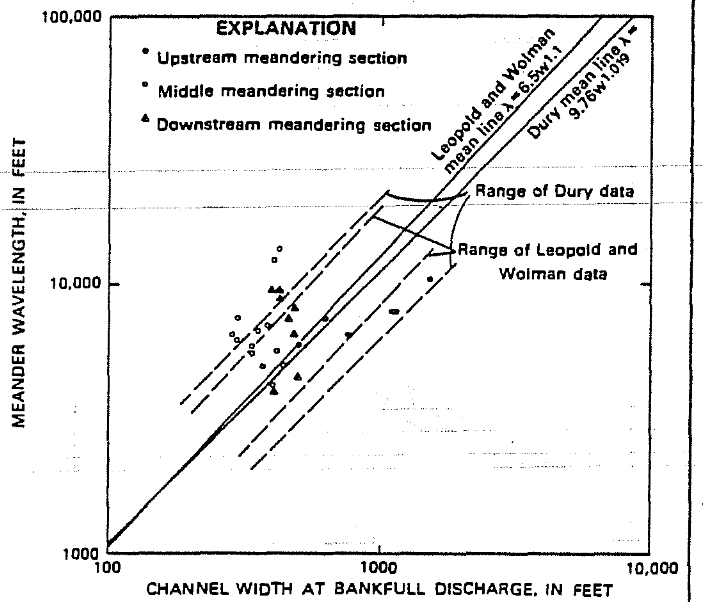


FIGURE 10.—Meander wavelength against channel width at bankfull stage. Lines representing ranges of previous data are approximate.

In meandering streams the shallows analogous to riffles occur at the crossovers or points of inflection in the meander curve, and the pools are found at the bends, with the deepest point near the outside or concave bank. If this pattern of pools and riffles is not present or if it occurs with a different spacing relative to the meanders, some aspect of the fluvial environment is preventing the normal adjustment of the bed response to flow. For example, the meanders may be relict from a period of previous, generally higher discharge, or the mobility of the bed may have been reduced by the process of armoring, in which finer sediment is selectively removed and the bed is rendered progressively immobile. Dury (1970, p. 268) recognized an underfit condition in which the old meanders continue as the stream channel, but in which the pools and riffles assume an irregular distribution reflecting the new reduced discharge.

The following statistical analysis was made to investigate the spacing of bars. Maximum depths in selected sections were grouped in table 2 according to whether the channel was meandering or sinuous to straight. The data from meandering channels were subdivided by location—whether the section was at a bend or at or near a crossover—and were further grouped according to whether the meander was free to migrate laterally or was entrenched. Hypothesis testing of the differences between the means of the data subgroups for meandering channels yielded unexpected results. There was no significant difference between the maximum depths in bends and at crossovers, a result suggesting, when considered with other evidence, that the channel is underfit. The morphology is similar in some respects to that of the Illinois River (Rubey, 1952, p. 123-136), a stream with a stable and deep uniform channel that occupies a valley formed by large proglacial discharges.

There was also no significant difference between the maximum depths in the channels of meanders that are free to migrate and those that appear to be entrenched. The only significant difference was found between the depths in all meandering channels and the depths of sinuous or straight reaches. Maximum depths in the channel where it is sinuous or straight are less than those where the channel meanders, with a probability in excess of 0.99.

ASYMMETRY OF CROSS SECTIONS AT BENDS

Cross sections of the channel of a meandering stream are characteristically asymmetric at bends, with the point of maximum depth close to the outside of the bend. Of the nine sections located at meander bends, only four show the expected asymmetry, each in meanders free to migrate. Although none of the sections from entrenched meanders shows asymmetry, the sample size is too small for significance tests. Absence of or abnormal asymmetry can be regarded as evidence of underfitness, as exemplified by the Illinois River (Rubey, 1952, p. 129), where the normal asymmetry is reversed and the deepest part of the channel is close against the inside of meander bends.

SLOPE

The slope of the water surface of the Kenai River has a variation of at least an order of magnitude in the values determined from 5-ft contour increments and plotted at the midpoint of each increment (fig. 6). These data should be viewed as approximations to the actual slope because of their photogrammetric derivation. The accuracy of photogrammetric altitudes is such that, over short longitudinal increments of channel, expectable inaccuracies in altitude can yield significant differences in slope. Field observations likewise fail to confirm some of the slope data in figure 6 as more than approximations, useful for comparison only.

At the largest scale there is a difference in slope between the meandering reaches and the long middle section of the river with only a slightly sinuous configuration. The meandering reaches generally have the lesser slope, in accord with the general inverse correlation between sinuosity and slope.

At a smaller scale within the meandering reaches, the tendency toward anabranching, which is commonly associated with an increased gradient (see Mollard, 1973, fig. 1), does not fit this tendency, according to the data of figure 6. The anabranched and meandering sections of the river apparently have a lesser slope than some sections of single meandering channel. The reason for this anomaly is that parts of the upstream and middle meandering sections are entrenched. The entrenched meanders have the greatest slope, shown in figure 6 and verified by field observations, of any part of the river except the Moosehorn Rapids.

BED MATERIAL

The bed material of the Kenai River is among the coarsest recorded for a meandering channel of similar size (compare data in Kellerhals and others, 1972). The reasons are both geologic and hydrologic. The coarse material reflects initial transport by glaciers, which throughout the Pleistocene covered at first all, and then successively lesser, parts of the drainage basin. Coarse bed material was supplied directly from melting ice and outwash discharges and subsequently was derived throughout the length of the stream from erosion of previous glacial deposits. Numerous boulders too large for transport by even the highest discharges remain in the channel throughout the entrenched sections of the river (fig. 4).

TABLE 2.—*Statistical analysis of maximum flow depths at cross sections measured August 23-24, 1974*
[Location of sections, between river miles 26 and 47. Probable variation in discharge, less than 5 percent. Depths are in feet. *S.I.*, sinuosity index]

						Data grouped as indicated			
Channel pattern	Position in meander	Channel "free" or entrenched	n	$\bar{x}$ (range)	σ_x	$\bar{x}$ (range)	σ_x	$\bar{x}$ (range)	σ_x
meandering (S.I.>1.25)	Bend	Nonentrenched meanders	6	11.1 (8.7-13.5)	1.9	10.9 (7.7-13.7)	2.1	10.8 (7.7-15.1)	2.1
		Entrenched meanders	3	10.7 (7.7-13.7)	3.0				
	Crossover	Nonentrenched meanders	4	10.3 (8.3-12.0)	1.5	10.7 (8.3-15.1)	2.2		
		Entrenched meanders	3	11.4 (9.2-15.1)	3.3				
Sinuous or straight (S.I.<1.25)	Not determined	Entrenched to varying degrees	8	7.9 (5.8-10.2)	1.7				

As glaciers receded within the Kenai Mountains, transition from a braided to a meandering channel occurred as the flow regime changed to one of lesser discharge and greatly decreased sediment supply. Similar changes in pattern have been widely noted throughout areas peripheral to receding glaciers. In the Kenai River, formation of the large lakes left by the receding glaciers—first Skilak Lake and then Kenai Lake—acted much as the construction of reservoirs. Downstream degradation and partial armoring of the channel occurred in response to the sediment-entrapment effects of the lakes. The pronounced entrenchment of the channel below the Soldotna terrace, however, is attributed mainly to degradation consequent to change in base level rather than to the downstream effects of the lakes.

The size of bed material in the active channel is shown in figure 11 as the median diameter (D_{50}). These data were obtained from large emersed bars by pebble-counting techniques that are statistically valid for coarse sediment (Wolman, 1954). Several estimates of the median grain size were made during a boat traverse of the river, and these points are so designated. The estimates were made only for the submersed gravel dunes found in the reaches downstream from Skilak Lake (fig. 12).

The distribution of median sizes of bed material (fig. 11) reflects the entrenchment and partial armoring of parts of the river. The comparatively finer grained bed material upstream from river mile 39.4, site of the Naptowne end moraine and the Moosehorn Rapids, coincides with the reaches in which higher erosion rates were documented (see section on bank erosion). The extremely coarse bed material (D_{50} = 122 mm) in the channel at the end moraine functions as the base level for the river upstream to Skilak Lake and has prevented upstream extension of the entrenchment. The bed material below river mile 39.4 is coarser than that upstream, remaining in the range 40-60 mm throughout the entrenched part of the channel downstream from the Moose River. Below river mile 20, bed material becomes gradually finer, and, correspondingly, bank-erosion rates locally increase to rates comparable to those in the reaches upstream from river mile 39.4.

The roundness (Meehan and Swanston, 1977) and size (McNeil and Ahnell, 1964) of bed material have been related to success rates of salmon spawning in southeastern Alaska. Survival of salmon eggs was slightly higher in angular than in round gravel. The roundness of Kenai River bed material fell within categories defined as subrounded or rounded, and no significant longitudinal variation was detected. Little variation in productivity consequently can be ascribed to this factor. Gravel permeability, which correlated strongly with salmon survival rates, was found to be negatively related to the percentage by volume of sediment passing a 0.833-mm sieve. In measuring the size distribution of Kenai River bed material, the percentage of material in size fractions finer than sand was not determined because, for statistical validity of the results, large volumes of material would have to be excavated and separated before the fine components could be sieved. However, the percentage of sediment of sand size or finer (<2 mm) was determined during the pebble-counting process. Using those percentages for comparison—a conservative approach because only part of the sediment finer than 2 mm would pass the 0.833-mm sieve—the bed material of the Kenai River is highly permeable and contains a relatively small proportion of fine sediment. The streams studied by McNeil and Ahnell (1964, fig. 7) contained bed material of which 5 and 20 percent was finer than 0.833

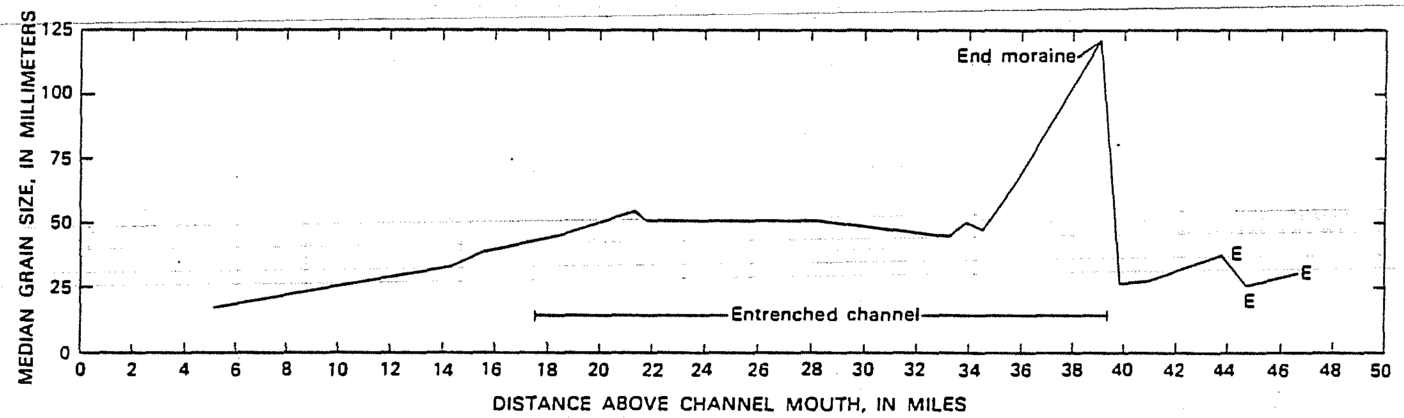


FIGURE 11.—Bed-material size against river miles. *E*, estimated.

mm. At all measurement sites the surficial bed material of the Kenai River contained less than 5 percent sediment finer than 2 mm. No great significance should be placed on this comparison because of the greater coarseness of the Kenai River bed material and the differences in sampling techniques. If it had been possible to measure samples of the Kenai River bed near the thalweg, the percentage of fine sediment would have been greater.

GRAVEL DUNES IN CHANNEL BELOW SKILAK LAKE

The reach containing crescentic gravel dunes that are visible on aerial photographs between the outlet of Skilak Lake and river mile 46.5 is among the most productive on the river in its ability to support heavy spawning of several types of salmon (see data summarized by U.S. Army Corps of Engineers, 1978, fig. 27). Whether the productivity relates to the bedforms or to the effects of suspended-sediment retention in Skilak Lake, leading to minimal deposition of fine sediment in this reach, is not known. Crescentic dunes are a highly unusual mode of transport in gravel-bed streams. Both the coarseness of the bed material composing the dunes in the Kenai River and the scale of the dune forms (fig. 12) are exceptional.

Active dunes of comparable and larger sizes occur in much larger rivers, such as the Mississippi and Missouri Rivers, but are associated with finer, generally sand size bed material. The dunes in the Mississippi River are as much as 22 ft in height and range in length from 100 to 3,000 ft (Lane and Eden, 1940). The dunes of the Kenai River likewise vary in size, as indicated by their submersed images on aerial photography. The largest dunes are at least 500 to 600 ft in length, approximately equivalent to the mean channel width in this reach. Smaller dunes are developed on the larger forms and are common in lengths of more than 50 ft. The maximum height of the dunes, estimated from water depths in the intervals between the shallow riffles that mark the crests of the forms, is at least 15 ft. The ratio of height to length for the Kenai River gravel dunes appears to be greater than that for the sand dunes measured in larger rivers.

Features of comparable coarseness and scale have been reported to result from an exceptional flood discharge, such as a surge from a dam failure (Scott and Gravlee, 1968, fig. 18), but in these unusual instances the features are not subsequently active. The gravel dunes of the Kenai River were examined with aerial photography taken in 1950, 1972, and 1977 to determine the degree of their activity. Where best developed, between river miles 48.5 and 46.5, the dunes show a surprising and remarkable similarity in position. Resolution is relatively poor on the 1950 photographs, but the positions of the major forms are clearly the same as those in 1972 and 1977. Striking comparisons of the 1972 and 1977 photographs show that even the small irregularities of dune morphology did not change in that interval, one that included a major flood

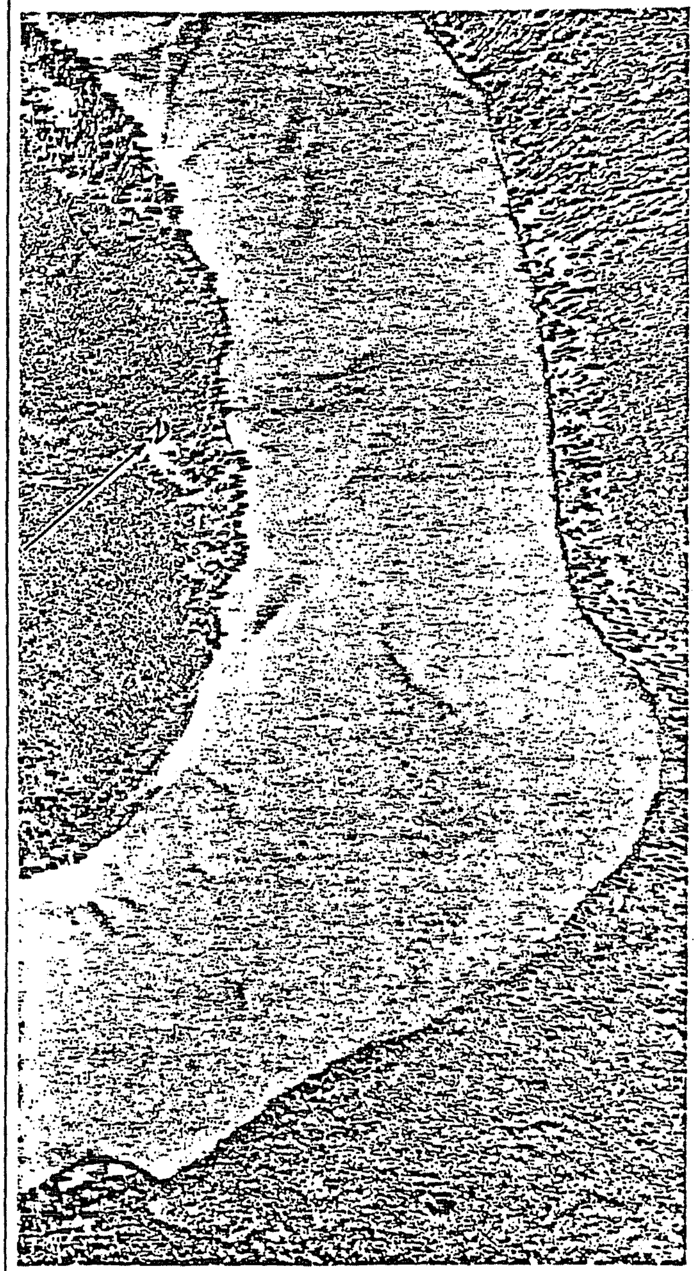


FIGURE 12.—Kenai River between approximate river miles 47.5 and 46.9. Crests of large crescentic gravel dunes appear just below water surface as darker areas. Flow is from bottom of photograph toward top. Scale 1:4,800 or 1 in. = 400 ft. Date: July 11, 1977. Photograph credit: U.S. Army Corps of Engineers.

discharge in 1974 (fig. 3). The dune forms, like the traveling bars of an incipiently meandering channel and nearly all other types of submersed dune forms, are the type of bedform that migrates progressively and changes position at least seasonally. The rate of movement of the Mississippi River dunes described above ranged from a few ft per day to as much as 81 ft per day (Lane and Eden, 1940). The historical stability of the Kenai River dunes indicates that, like the forms described by Scott and Gravlee (1968), they are the product of an exceptional flood event, one probably greatly in excess of any flood during the period of flow records.

The question of why the dune forms are confined to the 3.8 river miles downstream from Skilak Lake is not so easily answered. The presence of the dunes coincides almost exactly with the reach that appears "drowned"; that is, the channel shows evidence of having been formed at lower water-surface elevations. This part of the river presently functions in part as an extension of the lake—channel width is large and irregular; banks show little evidence of erosion. The most likely reason for the "drowned" channel is the presence of gravel in the form of the dunes, which have effectively plugged the reach. The cause of the flood that introduced the gravel and molded it into dunes is unknown, but, as noted, the event was of exceptional recurrence interval. The effect of wave action in introducing suspended sediment into the river at the outlet of Skilak Lake is described in the discussion of suspended sediment. Similarly, it is possible that a flood surge traversing the lake mobilized sufficient coarse sediment at the lake outlet to form the dunes and aggrade the channel to its present configuration.

ARMORING OF THE CHANNEL

Armoring is the process whereby finer sediment is progessively removed, leaving the coarsest material to armor the bed surface. It occurs when the high flows that transport the coarse material no longer occur, as happens when a reservoir is built upstream. In places where the change in flow regime is engineered, the armoring commonly involves only the surface of the bed, is one particle diameter in thickness, and is easily observable (Vanoni, 1975, p. 181-182). As the term is applied here, to the sedimentologic response to a long-term natural reduction in flow, the results are less obvious and do not appear as a pronounced size difference immediately below the bed surface.

The bed material within the entrenched channel (between river miles 39.4 and 17.6) has a size distribution in which a significant proportion of the particles is not erodible under the present flow regime, and the evidence of this condition includes sediment size and channel stability. The causes are threefold: the long-term decline in flow accompanying glacial recession, the reservoirlike effects of Skilak Lake, and, to an unknown extent, the presence of coarser underlying gravel than is present outside the entrenched reaches.

The size data in figure 11 are mainly from emersed bar surfaces; the average bed material in a cross section is likely to be coarser. The most visible feature of the armored reaches is the presence of large boulders, which protrude above the water surface at normal levels of summer flow (see fig. 4) and may exceed 13 ft in intermediate diameter. In other streams the size of the Kenai River, the bed material normally will be moved by discharges not greatly in excess of bankfull discharge. Field calculations of tractive force compared with known critical values (for example, Baker and Ritter, 1975, fig. 1) indicate that only discharges greatly in excess of bankfull or channel-forming discharge will transport the coarse fractions of the size distributions in the entrenched reaches. These calculations are not presented here because of the confidence limits applicable to the slope data and therefore to the values of tractive force. The general conclusion is believed to be valid.

It should not be concluded that no movement of coarse bed material occurs in the entrenched channel. Competence is sufficient to transport coarse sediment supplied from reaches upstream and from tributaries to the entrenched reaches. Both sources have lower flow competence, in the case of the upstream river because of a lesser slope. The basic gravel framework of the entrenched channel is, however, stable at bankfull flow.

As will be documented in the discussion of bank erosion, the entrenched channel has been generally stable since 1950. Over much of the entrenched channel no detectable erosion has occurred, within the limits of accuracy of the measurement techniques. This situation contrasts with that both upstream and downstream, where extensive amounts of bank erosion have occurred.

Excavation of the submersed bed material to determine the size gradation within the bed was not practical because of flow levels during the fieldwork in summer and early fall. The size gradation is probably slight compared with the armoring resulting from such engineered changes in flow as that seen in the channel downstream from a dam. The size difference may exist chiefly with respect to comparison of the size of bed material with that of the underlying outwash gravel. The important observation, however, concerns the competency of flood flows of a frequency that in nonarmored channels would readily move most sizes of particles present in the bed. In the Kenai River, only the most extreme floods would mobilize the bed material in the entrenched section of channel.

POSSIBLE EFFECTS OF ARMORING ON SALMON HABITAT

From spawning to the time the young salmon leave the interstices of the gravel, the oxygen supply is critical (see Phillips, 1974, p. 65-68). The initial shaping and sorting of the redd by the adult fish serves the dual purpose of increasing the flow rate within the gravel, through the irregularity of bed surface thus produced, and removing deposits of fine sediment from within the pores of the gravel. For the several months during which the young remain in the gravel, they are vulnerable to any renewed deposition of fine sediment. Even where dissolved-oxygen concentration is high, newly deposited sediment can act as a physical barrier to fry emergence.

Einstein (1968) studied the progressive clogging of spawning gravel in flume experiments and observed that silt particles filter slowly down through the pores without any systematic horizontal motion, settling on top of individual clasts and filling the pores from the bottom up. These observations show that the armoring of the channel has important implications for the productivity of the Kenai River in terms of its ability to support the spawning and rearing of salmon. If bed material is too coarse to be moved by a normal range of flow, as is the gravel in the entrenched channel, fine sediment will gradually accumulate within the pores of the gravel and reduce the permeability. Because the infiltrating fine sediment was observed to move only in a general vertical direction, lateral redistribution in the bed apparently will not occur. Thus, in an armored bed the clogging of the gravel pores is an irreversible process. Only the movement of the gravel framework, by either the spawning fish or an exceptional flood, will flush out the accumulating fine material.

Observations by personnel of the U.S. Fish and Wildlife Service (Wayne Pichon, oral commun, 1979) show that salmon, particularly king salmon, can construct redds in bed material as coarse as that in the armored channel. Study of spawning locations verifies that the armored reaches are the sites of active spawning (U.S. Army Corps of Engineers, 1978, fig. 27). Although salmon are capable of building redds in the material and thus cleansing it at a point, it seems likely that the productivity of a progressively silting reach would decline.

The historical rate of fine-sediment deposition in the gravel of the armored reach has not detectably reduced the permeability of the bed at the depth necessary for spawning and rearing. Before concluding that this will continue to be true, two factors should be considered. First, the rate of interstitial deposition will increase with any increase in suspended-sediment transport that may result from development or other man-induced change. Second, an exceptional flood competent to mobilize and cleanse the armored bed will not necessarily occur. The flood that emplaced the gravel dunes in the reach below Skilak Lake may have been competent to mobilize the bed material in the armored reach, but its magnitude and cause, as well as its age (other than pre-1950), are unknown. Similar floods are likely to be the result of geologic events, such as the breaching of landslide and glacial dams, and thus their probabilities are not predictable from a short series of annual flows.

The stability of the reach containing the gravel dunes indicates that the above conclusions apply to it as well. This at first seems unlikely because of the relatively finer bed material of which the dunes are composed. The dunes themselves, however, have dammed the channel and reduced the slope and thus the competence of a given discharge.

SURFICIAL DEPOSITS OF THE MODERN FLOOD PLAIN

A flood plain exists lateral to the nonentrenched sections of the Kenai River, but only small segments are found along the entrenched channel. Like the flood plains of the group of streams described by Wolman and Leopold (1957), the underlying material consists mainly of channel deposits. Only at the surface is there a distinct segregation of cohesive material within the size range of silt (0.004-0.625 mm) and clay (<0.004 mm). This layer of sediment deposited during overbank flow is as thick as 6 ft and is laced with roots that act as a strong binding agent. It is well developed in the interior of nonentrenched meander loops.

A "mat" of root-bound fine-grained sediment is a characteristic of northern rivers and, because of either the absence of permafrost or the presence of a thick active layer (depth of summer thaw in permafrost), is particularly well developed in subarctic streams. This layer serves the important function of stabilizing riverbanks by retarding the slumping that occurs in response to erosion of the underlying noncohesive channel deposits (Scott, 1978, p. 11). As the channel deposits are eroded, the cohesive layer may fold down to protect the bank from further erosion for a period as long as years. In such cases it has been likened by Russian observers of northern streams to a cloth draped over the edge of a table. The layer also acts to protect meander loops from cutoffs. Observations of arctic and subarctic streams by the writer indicate that cutoff is preceded by stripping of the surface cohesive layer.

This process may extend over several successive high flows in smaller streams, or it may occur entirely at the time of the flow causing the cutoff in larger streams.

Any cutting or removal of the surface layer where it occurs along the banks on the active flood plain of the Kenai River will create an increased potential for bank erosion. A boat slip without riprap, for example, and cut transverse to the flow direction creates a point of attack from which the cohesive layer can be stripped. Once the cohesive layer is lost, the underlying channel deposits are subject to rapid erosion that could lead to a meander cutoff.

SUSPENDED SEDIMENT

Sediment sufficiently fine grained to be transported in suspension affects the salmon habitat in a variety of direct and indirect ways (see Meehan, 1974, p. 5-7). As described previously, the main detrimental effect of fine sediment occurs consequent to deposition, through the reduction of gravel permeability during egg and fry development. Suspended sediment can be directly harmful to fish if concentrations are both high and persistant, but the requisite levels are not well defined. After a literature survey, Gibbons and Salo (1973, p. 6) concluded that prolonged exposure to sediment concentrations of 200-300 mg/L is lethal to fish, although other studies report higher levels. High concentrations may also detract from the esthetic and recreational values of a fishery. Because salmon are sight feeders, angling success is reduced and competition with species more tolerant of turbidity is increased with a significant rise in suspended-sediment concentration (Phillips, 1971, p. 65).

Subarctic alpine streams are characterized by a limited and specialized macroinvertebrate fauna that is adapted to the glacial melt-water environment (Hynes, 1970). It is logical to assume that even minor changes in habitat could affect the macroinvertebrate population and thus the fish fauna dependent on it for food (U.S. Army Corps of Engineers, 1978, p. 102).

Unfortunately, the effects on the salmon habitat of specific values of suspended-sediment concentration have not been established. The preferred environments and times for salmon spawning are clearly those with the least suspended sediment. Concentrations were observed to be "minor" (less than about 30-50 mg/L) during the spawning and incubation periods in the most stable producing areas for sockeye and pink salmon (Cooper, 1965, p. 6). Also, experiments comparing deposition rates from flows with 20 and 200 mg/L of suspended sediment indicate the "necessity for maintaining very low suspended sediment concentration in waters flowing over salmon spawning grounds" (Cooper, 1965, p. 61).

Values of suspended-sediment concentration in the Kenai River at Soldotna ranged as high as 151 mg/L in 24 samples collected from 1967 to 1977. The typical concentration during summer flow fell within the range 10-100 mg/L. A sample taken on September 9, 1977—the date of the peak discharge of record, 33,700 ft^3/s—yielded a concentration of 104 mg/L. The only comparable nearby stream, the Kasilof River, has a similar melt-water flow regime and likewise drains a large moraine-impounded lake, Tustumena Lake. The stream is, like the Kenai River, the site of important salmon runs. Suspended-sediment concentration in that stream, from 19 samples collected between 1953 and 1968, fell within the uncommonly narrow range 15-45 mg/L. This lower, narrower range can be ascribed mainly to the greater sediment-retention effect of Tustumena Lake, but it could be due in some part to lesser river use and bank development relative to the Kenai River.

Limited sampling from the Kenai River at Cooper Landing, at the outlet of Kenai Lake, suggests the presence of generally low concentrations of suspended sediment at that point. The concentrations in 24 samples taken between 1956 and 1974 at discharges from 420 to 19,100 ft^3/s ranged from 2 to 26 mg/L, except for one measurement of 72 mg/L. Concentration at the discharge of 19,100 ft^3/s was only 2 mg/L, sampled September 20, 1974—the day before the peak discharge of record that resulted from release of the glacial lake in the Snow River drainage (hydrograph in fig. 3).

All pre-1979 measurements from the Kenai River at Soldotna are plotted in figure 13. A sharp distinction in the relation between water discharge and sediment concentration is evident in the data representing discharges of January through May and those for the period June-September. A similar difference is evident in the sediment-transport curve for the station (not shown), in which water discharge is compared with sediment discharge rather than concentration. The groupings of data seen in figure 13 represent the sustained low-flow period of winter and spring and the prolonged period of high melt-water flow throughout the summer. They illustrate the important conclusion that concentrations can vary widely within each range of flow. The biota of the Kenai River consequently will be at greatest risk to increases in concentration due to construction activity during the low-flow period. An influx of sediment that caused little change in concentration levels during the summer could result in significant adverse impact during winter and spring.

Neither the base concentration levels nor the short-term variations in concentration are evident from the scattered historical samples shown in figure 13. To illustrate these aspects of the sediment system of the river and to provide a basis for future comparison, daily sampling at Soldotna was begun on August 23, 1979, and continued until December 5, 1979 (fig. 14). During this period, suspended-sediment concentration ranged from 1 to 52 mg/L, at mean daily discharges of 5,260 to 21,600 ft^3/s. In comparison with previous flow records (fig. 2), the mean discharge of 11,800 ft^3/s in September 1979 was typical. Unfortunately for purposes of comparison, flow later in the fall of 1979 was abnormally high. The mean discharge for October of 14,000 ft^3/s was more than 50 percent above the previous high mean discharge for the month, and the mean flow in November of 7,330 ft^3/s exceeded the previous high by a similar proportion.

Throughout the period of daily sampling, concentration levels based near or below 10 mg/L and generally increased above that level in the early stages of a rise in flow (fig. 14). An unexpected pattern of variations in concentration with flow is the seeming gradual rise in base concentration as discharge underwent its seasonal decline in late October and November. From base values of approximately 5 mg/L in early September and mid-October, the typical base concentration increased to about 10 mg/L in the period from late October to the end of data collection on December 5. Although the reason for this anomalous increase as flow declined is not known, one possible cause is wind-generated wave action on Skilak Lake.

Each daily rise in concentration of more than 5 mg/L accompanied a significant increase in discharge in comparison with the preceding day (fig. 14). The sharpest daily changes in concentration and discharge occurred early in both major rises in discharge during the measurement period. On days following the peak in concentration, discharge continued to increase, most notably during the rise in discharge that began on September 13. Concentration peaked on September 15 and then generally declined for the five subsequent days as discharge continued to increase.

Speculations concerning the sources of this suspended sediment are possible. The relation of water discharge and sediment concentration described in the preceding paragraph is designated as advanced (or leading) sediment concentration (Guy, 1970, p. 22); that is, the peak concentration precedes the peak of the water-discharge hydrograph, in this case markedly so. This relation is the most common and is consistent with transport of loose sediment by the first direct runoff. However, in the Kenai River at Soldotna the concentration is so advanced that the bulk of the sediment is clearly of local derivation, originating in the section of watershed downstream from Skilak Lake. This conclusion is expected, given the sediment-entrapping function of the lake, and narrows the sources of much of

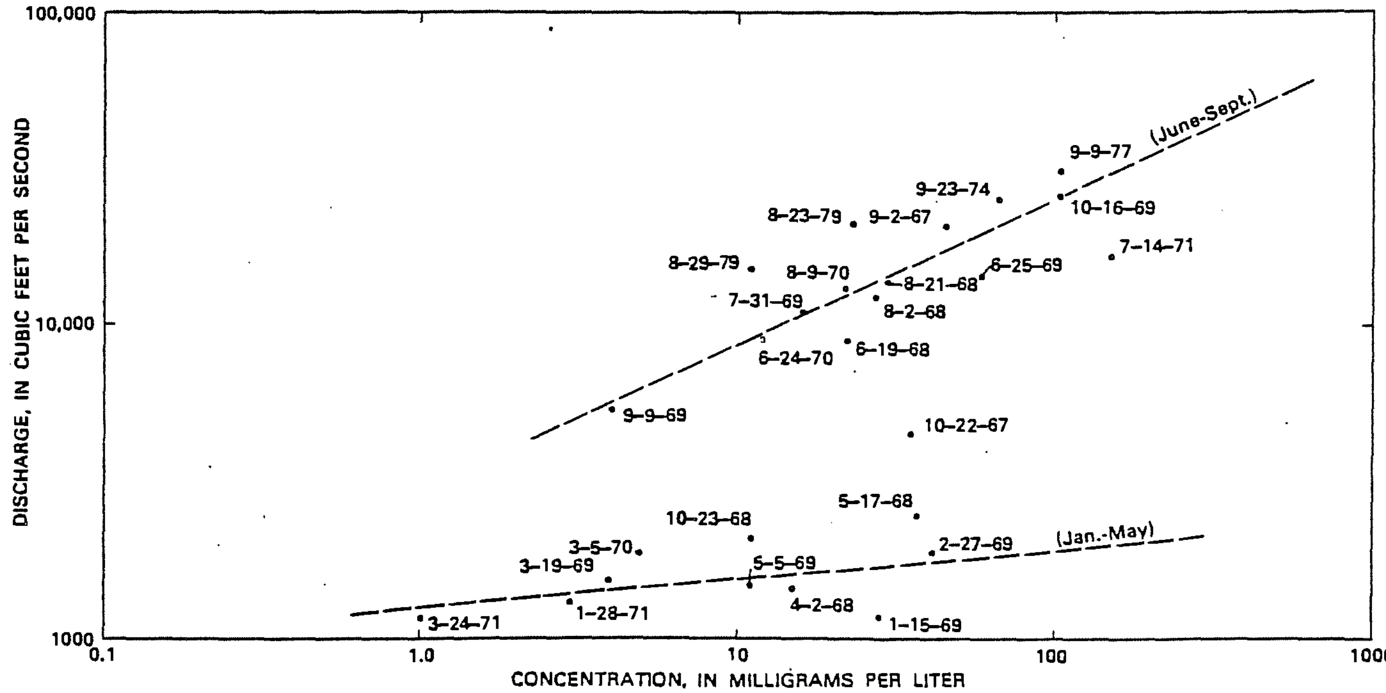


FIGURE 13.—Water discharge against suspended-sediment concentration, Kenai River at Soldotna. All pre-1979 data are shown.

the sediment to the Killey River basin and bank erosion along the Kenai River.

Scattered sampling of the tributaries entering the river downstream from Skilak Lake shows that suspended-sediment concentration is generally very low, especially in the subordinate storm-runoff peaks of middle and late summer. Snowmelt peaks are the dominant discharge events in the flow records of these lowland streams, and the runoff is greatly retarded—typical of marshy subarctic terrain. The Killey River is the exception: it drains a watershed that extends to nearly 6,000 ft in altitude (timberline is approximately 2,000 ft) and includes the Killey Glacier, an extension of the Harding Icefield. Runoff from the Killey River basin contributes to the early part of any rise in the Kenai River that occurs in response to a basinwide storm. Traveltime of flood waves from the headwaters is unknown, but it would be measured in hours as opposed to days for a flood wave from the Snow River drainage (fig. 3). Unfortunately, storm sediment concentrations of the Killey River are unknown. Observations indicate that they are relatively high. Two sets of aerial photographs (1950, 1977) of the Kenai-Killey confluence show a turbid plume, representing the unmixed contribution of the Killey River, extending several miles downstream in the Kenai River. Sequential aerial photography also indicates that the Killey River channel is actively eroding; a neck cutoff of a meander 1.5 mi upstream from the confluence occurred between 1950 and 1972.

The dispersion in concentration at a given discharge is mainly due to variations in natural sediment-producing processes. There is no increase in concentration over time evident in the limited data of figure 13 that can be ascribed to development or river use. This result may reflect the small number of samples taken at low flows. The effect of canal dredging and cleaning, which are probably accomplished mainly during low-flow periods, are limited in time and would have been sampled only by extreme change. Local residents report that episodes of abnormally high turbidity are caused by dredging of canals. This high turbidity prob-

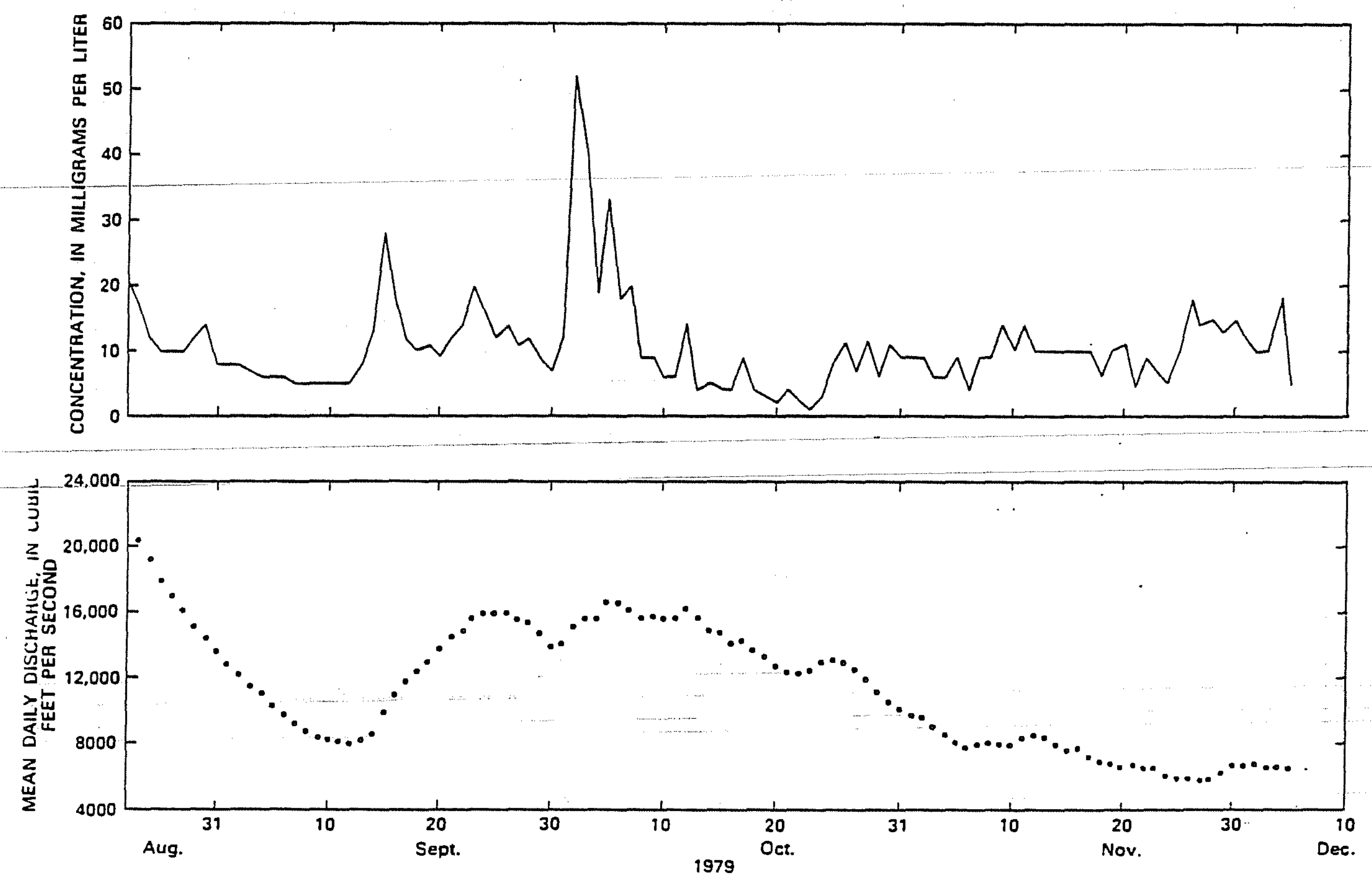


FIGURE 14.—Water discharge against suspended-sediment concentration, Kenai River at Soldotna, August 23 to December 5, 1979.

ably correlates with increased suspended-sediment concentration.

One cause of dispersion in concentration levels at a given discharge is wind action on Skilak Lake. The lake is at the foot of large icefields and is periodically swept by violent winds that have caused the deaths of more than 20 boaters. The association of wind action on the lake, high turbidity levels in the lake, and turbid flow in the downstream part of the Kenai River has been observed by S. H. Jones of the U.S. Geological Survey (written commun., 1979). These observations coincide with those of Smith (1978), who described sediment movement in a glacier-fed lake in Alberta in response to wind-generated currents. In addition to generating high turbidity throughout Skilak Lake, wind-induced waves may erode lake-bottom and shoreline sediment in the vicinity of the outlet. The entrained sediment may then be introduced into the river as part of the suspended-sediment load.

Size measurements of the suspended sediment from the Kenai River at Soldotna indicate that 38 to 71 percent falls within the size ranges of silt and clay. Comparison with data from other Alaskan streams, including those fed by glacial melt water and controlled by lakes, shows that size distribution to be typical. Turbidity measurements from the station are too few for comparison or generalization.

BANK EROSION

An unknown but probably significant amount of the suspended-sediment load in the Kenai River is presently derived from bank erosion. Future increases in suspended sediment thus will be caused by any type of development or river use that increases bank erosion. The historical rates at which banks have been eroded can indicate which sections of the river are likely to be the most vulnerable to future man-induced changes.

Bank-erosion rates were determined by comparing aerial photographs taken in 1950-51, 1972, and 1977 (table 3). Additionally, the 1977 photographs were compared with ground photographs of the present (1979) bank configuration in channel bends. These comparisons showed that since 1950 the entrenched section of the stream has been exceptionally stable. Elsewhere, erosion rates have been comparable with those to be expected in a river the size of the Kenai. There is an indication that a recent increase in bank erosion may be occurring in response to river-use practices.

METHODOLOGY

Amounts of erosion were measured by superimposing the projected image of one photograph on another of a differing date. If the projection is precise, the differences in bank position correspond to erosion and accretion of the channel in the interval between the sets of photography. For this study, projections were made with a Bausch & Lomb Zoom Transfer Scope. This technique permits immediate comparison of photographs of greatly differing scale—a distinct advantage over previous methods. Because the procedure is not described in the literature, it will be discussed here in detail.

TABLE 3.—*Aerial photography of the Kenai River downstream from Skilak Lake*

Date	Agency	Scale	Area covered
June, August 1950 June, August 1951	U.S. Geological Survey	1:36,000	Entire river
May 1965	U.S. Army Corps of Engineers	1:12,000	Downstream from Soldotna.
September 1972	U.S. Army Corps of Engineers	1:12,000	Upstream from Soldotna.
July 1977	U.S. Army Corps of Engineers	1:4,800	Entire river

Use of the Zoom Transfer Scope involves viewing one photograph directly through a binocular eyepiece. On that photograph is projected the image of a second photograph, with the scale of the projection continuously variable with a zoom control to as much as 14×. The image of the smaller scale photograph is projected on to the larger, and the illumination of either may be varied with a rheostat. In matching the images, it is useful to vary one of the illumination controls rapidly so that the two photographs are seen in alternating succession. Then, once the scale and position of the photographs have been correctly matched, channel changes will stand out with remarkable clarity.

The main obstacle to precise measurement of channel change is scale variation in the aerial photographs. On each photograph the scale changes with distance from the center, reflecting the vertical orientation of the camera. Consequently, on each pair of photographs it is necessary to match geographic features in the immediate vicinity of each bank segment as it is analyzed. Features useful in matching photographs of the Kenai River include individual trees, large boulders, roads, and houses. The need to match features on or near the bank segment being studied cannot be overemphasized. Generally, the scale variation was such that, if one bank was matched, the opposite bank of the stream would not be matched, even in reaches where no bank erosion had occurred.

MECHANICS OF BANK EROSION—LOW BANKS AND HIGH BANKS

Although permafrost is not present in significant amounts, the low banks bordering most of the nonentrenched parts of the Kenai River, and its flood plain where present, erode in a manner similar to the bank erosion of streams in permafrost areas (Scott, 1978, p. 10). Channel deposits erode, thereby undercutting the stabilizing surficial layer of cohesive sediment. All areas of relatively rapid bank erosion, with rates comparable to those of small and medium-sized rivers elsewhere (Wolman and Leopold, 1957, table 4), involve the low banks.

The low banks downstream from approximately river mile 14 are composed of cohesive, clay-rich sediment interbedded with less cohesive silt and sand, and locally with coarser sediment. Erosion progresses most rapidly in the sand and gravel layers and triggers bank failure by slumping. This bank material represents tidal and shallow marine deposition during the marine transgression near the close of the Naptowne Glaciation (table 1). Modern tidal deposition is occurring as far upstream as river mile 12, but the deposits now subject to erosion mainly represent the earlier interval of deposition.

The high banks are those extending well above the level of bankfull stage to heights as much as 70 ft. They occur along entrenched sections and locally along nonentrenched sections of the river. The banks are composed mainly of glacial-outwash gravel that is distinctly finer grained and more poorly sorted than the modern channel deposits. Most cut banks are covered with mature spruce and historically have been stable. Where the high banks are eroding, the slope is undercut at the base, and the vegetated surface is progressively unraveling. Trees and mats of vegetation slide into the river until the entire slope becomes composed of loose gravel at the angle of repose. The slope angle is nearly the same as that of the completely vegetated banks, showing that the history of the banks is one of erosion interrupted by a geologically recent interval of low erosion rates that has allowed the mantling and stabilizing of the slopes by vegetation. The period of high-bank stability may now be ending in response to increased river use, a possibility discussed below.

RATES OF BANK EROSION

The position of the high banks of the entrenched channel in 1977 was remarkably similar to their position in 1950–51. Rates of erosion less than 1 ft per year were the rule. At most sites there was no detectable change in bank position, within the limits of accuracy of photographic comparisons and with adjustments for differing flows levels shown on the photographs.

Unfortunately, this generalization does not apply to the entire river. Above river mile 39.4 and below river mile 17.6—the limits of the entrenched channel—are areas with low banks eroding at rates as high as 5 ft per year. Figures 15 and 16 illustrate the distribution of erosion within parts of these two sections of the river. Several observations on these figures are pertinent.

First, the eroding areas are local in distribution, and even in these less stable reaches, much of the bank has not been affected by measurable amounts of erosion. The positions of the rapidly eroding banks are not predictable from the configuration of the channel. This effect is not unusual and has been shown in some other rivers to be caused by a wandering thalweg. Composition of the banks is a chief control on erosion of the Kenai River banks, along with the correlative factor of bed-material size. For example, at river mile 40.4 (fig. 15) the flow impinges at a 90° angle on the right bank, yet only negligible erosion of that bank has occurred. This section of bank is part of a topographic lineament against which the north sides of meanders are deformed upstream from river mile 39.4 (fig. 1). Cut banks along the lineament reveal glacial till that is resistant to erosion because of its clay-rich matrix.

Second, erosion rates have been relatively constant during the period 1950–51 to 1977. This conclusion is based on the proportional amounts of erosion in subdivisions of this period. In the downstream area of high erosion rates (fig. 16), the amount of erosion between 1950 and 1965, a 15-year interval, is similar to or slightly greater than that between 1965 and 1977, a 12-year interval. Upstream (fig. 15), most of the erosion occurred between 1950 and 1972, with smaller amounts between 1972 and 1977. The intervals reflect the dates of the photographs.

Finally, the two sections of the river with the highest erosion rates coincide with those sections of the river having a tendency to anabranch. In each case the slope of the eroding reaches is controlled by a base level a short distance downstream. In the upstream reach the control is the Naptowne end moraine; in the downstream reach the control is sea level.

Tidal action extends upstream approximately as far as river mile 12 and affects the reach shown in figure 16. Jones (1969), in a study of the Kenai River estuary, measured tidal velocities at sections as far upstream as river mile 11.4, above the illustrated reach. The measurements revealed significant floodtide velocities at that point at a time of low streamflow and high tides (May, 1969). Bank erosion from upstream tidal flow is possible during such periods. The distribution of the re-

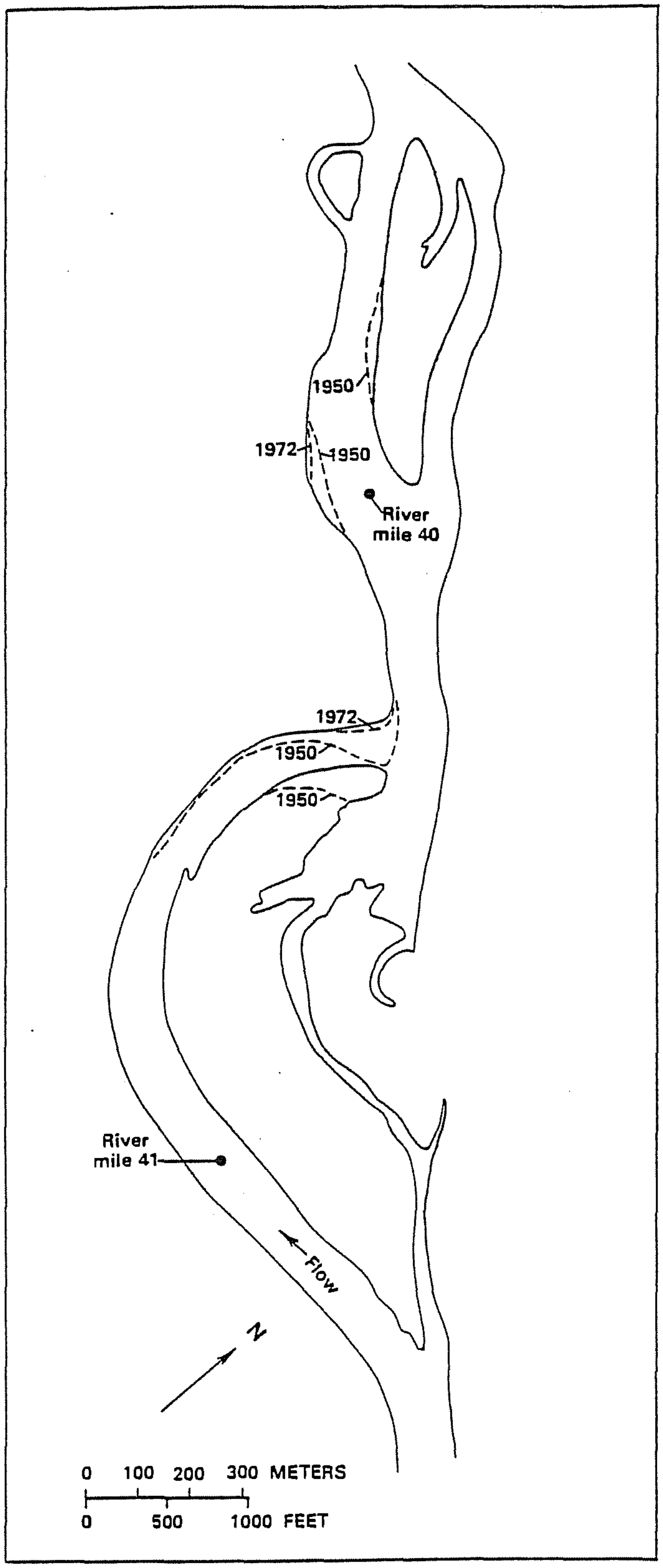


FIGURE 15.—Reach in upper section of the Kenai River, showing bank erosion rates. Solid line is bank position in 1977.

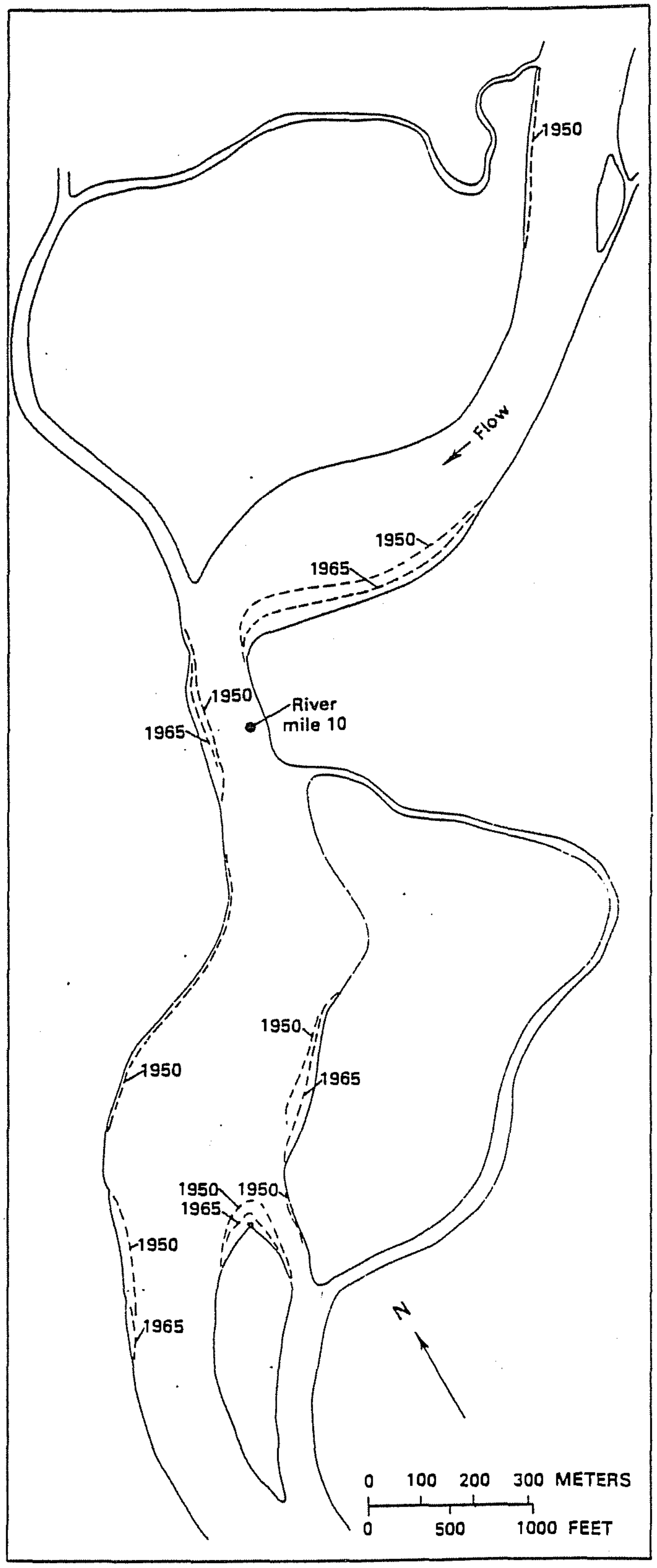


FIGURE 16.—Reach in lower section of the Kenai River, showing bank-erosion rates. Solid line is bank position in 1977.

corded erosion (fig. 16) indicates, however, that downstream flow is the main cause. The erosion of the head of the island at the bottom of figure 16 is an example, as is the erosion on the inner, upstream side of the bend immediately above river mile 10.

POSSIBLE RECENT INCREASE IN BANK EROSION

Although no obvious changes in bank-erosion rates could be determined in the period 1950-51 to 1977, there is evidence of recent change that possibly forecasts a period of more rapid erosion. The most noticeable change is the number of fresh slide scars on the high banks visible in the 1977 photographs. Figure 17 illustrates these scars on the high banks along the outside of meander 3-H. The features occur where a maturely vegetated bank is undercut and the bank surface slides off into the river. The amount of erosion in terms of distance of bank retreat has thus far been small. Nevertheless, if sliding continues and the entire lengths of meander cut banks become active, a serious erosion problem will result. Because of the heights of some banks (50-70 ft), small amounts of bank retreat will add large volumes of sediment to the stream.

To investigate this increase in erosion of the high banks, ground photographs were made of the inside of all meander bends and then compared with the 1977 aerial photography. The results suggest that the instability is of recent occurrence and is continuing and possibly increasing at the present time (1979). The evidence for this conclusion is based on the 1977 photographs, which are of larger scale (1:4,800) and consequently of greater resolution than any preceding photographs, as well as on a comparison of that photography with ground photographs. To establish the recent instability of the high banks without qualification, it may be necessary to compare the 1977 photography with a later set that is equivalent in scale and resolution.

There are several explanations for this apparent increase in slide scars on the high banks. The possibility that construction debris was dumped over the banks was excluded in most instances. Another possibility is that the increased deflection of flow into cut banks as a result of construction of groins, boat ramps, and bank-protection structures has thus far caused small amounts of erosion. The most obvious example is meander 1-P near Sterling, where the inside of the entrenched-meander bend is studded with 13 groins from 15 to 75 ft long (fig. 18). These groins create the potential for bank erosion of at least an equivalent distance on the opposite cut bank and the possibility of larger amounts once the stability of the bank is destroyed. The groins were constructed before 1972, and the opposite high bank is beginning to fail by slumping near the point opposite the largest groins.

Another explanation is a recent change in river use. Beginning approximately in 1974, it was discovered that the most efficient sport-fishing technique for king salmon consisted of "drifting"—the practice of trolling from a boat while floating downstream without power through a promising reach, and than using power to return to the head of the reach and repeat the maneuver. Fishing for most other species, such as silver salmon, has continued in large part from anchored boats. The practice of "drifting" for king salmon has resulted in a substantial increase in the use of high-horsepower sport boats and more intensive usage of the boats per man-day on the river. These effects are additive to the general increase in sport-fishing popularity (table 4). An assessment of this problem is beyond the scope of this report and should await conclusive study of the possible recent increase in erosion rates mentioned above. The potential for river-use practices as contributors to increased bank erosion is a significant one, however, and should be considered by planners whether an increase in erosion can be documented or not. Once the stabilizing vegetation on the high banks is lost, erosion can potentially accelerate, even if river use is subsequently controlled.

The effect of boat wakes on the banks is sufficient to initiate and cause continued erosion of the high banks without other significant changes. Observations along the cut bank of meander 3-H reveal that each wake runs up the loose gravel bank as much as 3 or 4 ft, eroding and entraining sediment and creating a zone of visibly turbid water at the edge of the stream. The bank is progressively undercut, and the slope profile is maintained by sediment from the upper sections of the bank. Where the bank is vegetated or formed of cohesive sediment, the resistance to boat-wake erosion is greater.

TABLE 4.—*King salmon taken by sport fishing in the Kenai River, 1974-79*

[Data from Alaska Department of Fish and Game. Annual catch is limited by State regulations]

Year	Early run (June)	Late run (July)	Total
1974	1,685	3,225	4,910
1975	615	2,355	2,970
1976	1,555	4,477	6,032
1977	2,173	5,148	7,321
1978	1,542	5,578	7,120
1979	3,661	4,634	8,295

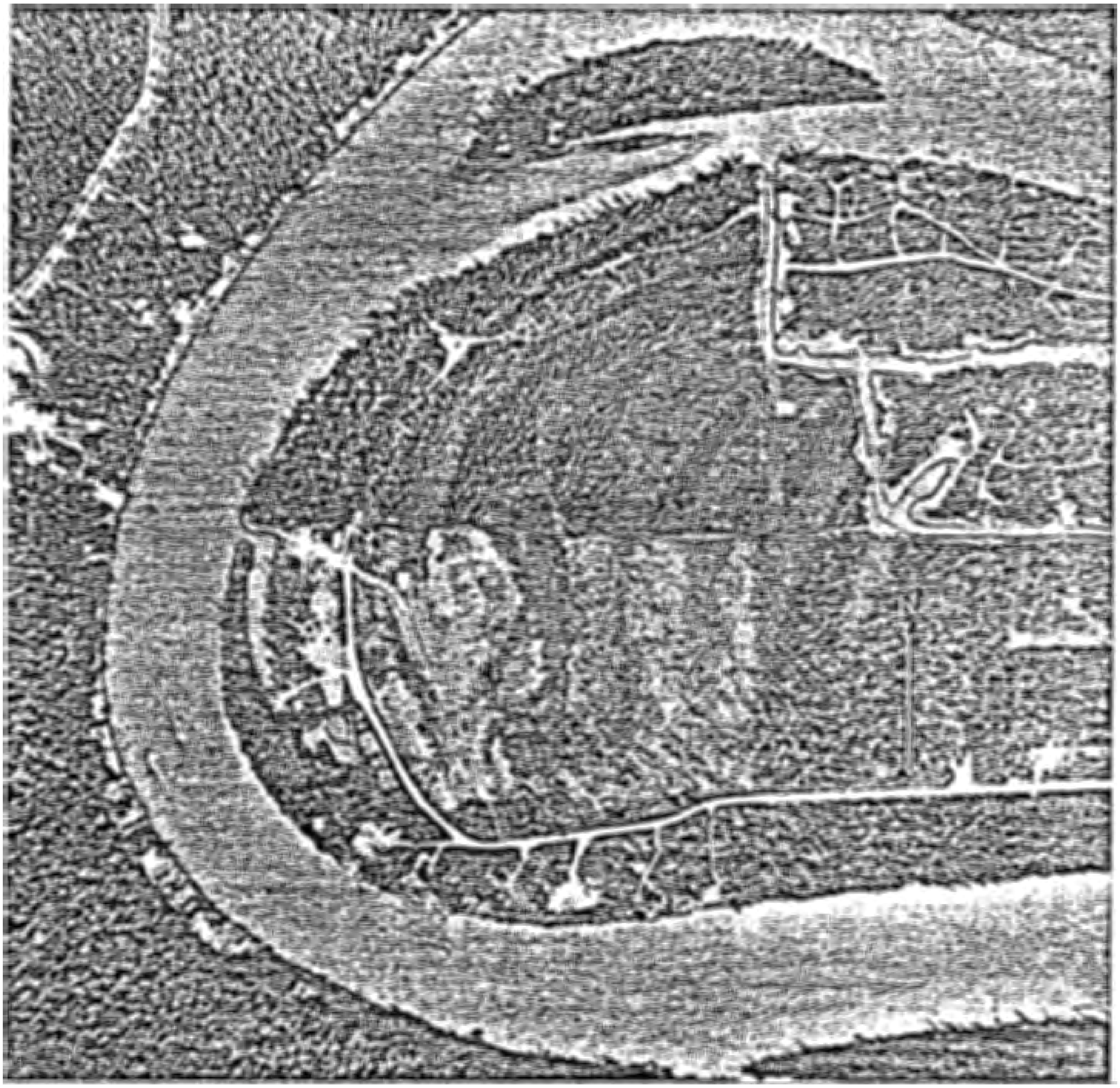


FIGURE 17.—Kenai River between approximate river miles 16.7 and 15.3. Note concave high bank with slide scars, and canal development and forest clearing on flood plain within meander loop. Wakes are caused by boats. Flow is from bottom of photograph to top. Scale, 1:4,800, or 1 in.= 400 ft. Date: July 9, 1977. Photograph credit: U.S. Army Corps of Engineers.

DEVELOPMENT AND THE KENAI RIVER CHANNEL

This part of the report discusses which sections of the river are most vulnerable to development and the types of development and impacts associated with each. Table 5 summarizes the channel characteristics and the sensitivity of each section of the stream to development. It will serve as background information on the channel for the discussion of development types that follows. For use by planners, this section is intended to be used in conjunction with the flood-hazard maps prepared by the U.S. Army Corps of Engineers (1967, 1973, 1975). The existing criteria for development permits are presented in the comprehensive report by the U.S. Army Corps of Engineers (1978, p. 16–52).

CONSEQUENCES OF DEVELOPMENT

Because the risks of development cannot be quantified, the definition of the hazards to the Kenai River salmon fishery must be subjective. The exact erosional response of the river's banks to certain types of development is unknown, although a significant response can be expected on the basis of our knowledge of river behavior. Nor can the increase in suspended-sediment transport that will result from increased bank erosion be stated with any degree of certainty. We know that suspended sediment will increase as bank erosion increases, and the studies cited in the section on suspended sediment indicate the potential for decline in the salmon fishery with increases in concentration only moderately above present levels. Conclusions regarding the range of concentration levels that may prove harmful will not, however, meet with agreement among those studying salmon habitats.

Additions to suspended sediment that will occur directly from construction activities should be distinguished from the more significant increases in concentration that can occur with the increased bank ero-

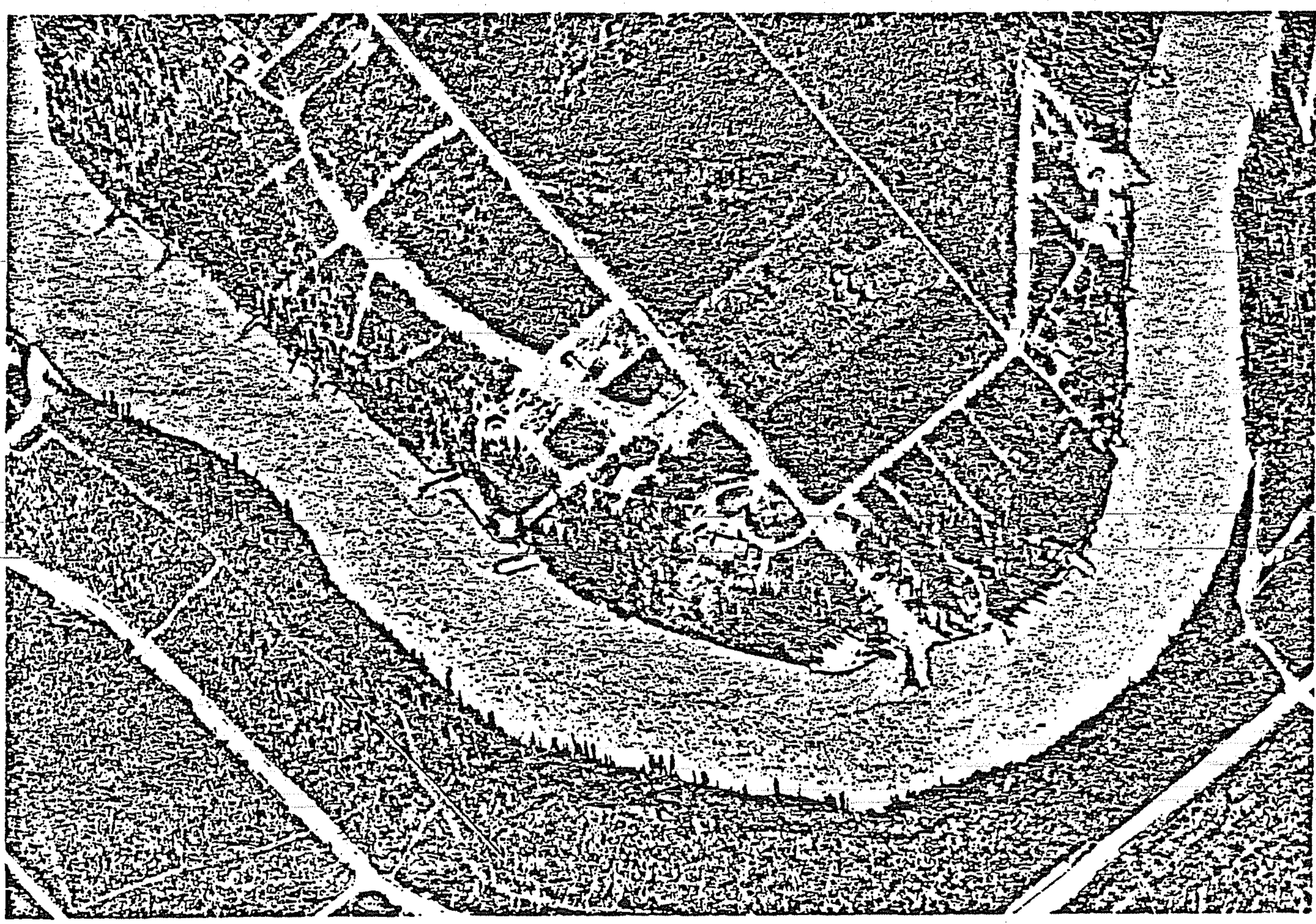


FIGURE 18.—Kenai River between approximate river miles 38.2 and 37.0. Flow is from right to left. Scale, 1:4,800, or 1 in. = 400 ft. Date: July 11, 1977. Photograph credit: U.S. Army Corps of Engineers.

sion triggered by some types of development. (This section deals with the latter type of hazard unless stated otherwise.) An additional potential cause of increased suspended-sediment transport is such upland land-use changes as logging, but these effects are excluded from the analysis. And possibly more significant than any effect of development is the potential adverse impact from river-use practices described in the previous section.

In determining what types of development to allow, planners are faced with two problems. The first problem involves the fact that, although a type of development may now be insignificant in its effects on the river, the cumulative effect of many such developments, combined with other actions in the future, may have an important negative effect. An example of such a situation, discussed below, is the excavation of boat slips in the entrenched section of the river. An approach to this general problem is to continue to monitor the productivity and sediment content of the stream as development progresses.

The second problem involves the fact that, because none of the risks associated with any of the development types can be quantified, cost-benefit analysis cannot be used directly. This, however, should no serve as a rationale for lack of decisions concerning development. This report defines the impacts of eac common type of development, ranks them in order o risk, and indicates (table 5) how the impact will var along the river.

Each development type can be assessed for its potential to cause channel change. The most dramati change, and one that poses a short-term hazard to th stream by increasing erosion and suspended sediment is the cutoff of a meander loop. A cutoff is a sudden diversion of the main channel that may set up a disequilibrium which causes substantial channel chang extending beyond the vicinity of the diversion. Cutoff consist of two types: loop or neck cutoffs, in which a meander loop tightens until flow cuts across the narrow neck; and chute cutoffs, in which flow cuts across a meander loop, generally one less tightly developed and one which may have incipient channels between ridges of point-bar deposits.

The first effect of a loop cutoff will be seen in the change of shape of adjacent meanders in response to the local change in slope. The extent of this change has been variously reported to be slight or to consist of

TABLE 5.—*Summary of channel characteristics pertinent to determining sensitivity of the Kenai River to development*

Segment of channel (river miles)	Pattern and degree of entrenchment	Underfit conditions	Degree of armoring	Rate of bank erosion under present regime (ft/yr)	Relative sensitivity to development
50.3 to 45.7	Meandering; slightly entrenched.	Channel appears "drowned"—formed at lower streambed elevations.	Partly armored (stable crescentric dunes).	1.0	Low
45.7 to 39.4	Meandering; free to migrate.	Channel is product of present flow regime.	None	5.0	High
39.4 to 34.8	Meandering; entrenched.	Underfit, especially below junction with Moose River.	Mainly armored	<1.0	Low
34.8 to 21.8	Sinuous to straight; entrenched within Soldotna terrace.	Most underfit section of entire river.	do	<1.0	Do.
21.8 to 17.6	Meandering; entrenched within Soldotna terrace.	Underfit	do	<1.0	Do.
17.6 to 13.4	Meandering; Partially entrenched, but meanders are migrating.	Slightly underfit	Parts may be slightly armored.	2.0	High
13.4 to 9.0	Sinuous and anabranching.	Channel is product of present flow regime.	None	5.0	Do.
9.0 to mouth	Meandering in tidal regime; channel is free to migrate.	Channel is mainly product of present flow regime.	do	2.0	Moderate

channel realinement extending for miles beyond the site of the cutoff. Case histories of cutoffs in streams similar to the Kenai River are not useful in forecasting the likely effects. A loop cutoff of an entrenched subarctic stream—the Pembina River in Alberta—was described by Crickmay (1960), but little bank erosion outside the point of cutoff apparently occurred because the stream, unlike the Kenai River, was entrenched in resistant bedrock. Loop cutoffs on the White River in Indiana resulted in rapid growth of adjoining meanders, but the effect did not extend very far upstream or downstream (Brice, 1973, p. 191). In a new meander formed after a chute cutoff on the Des Moines River, erosion rates were initially high and then decreased as the equilibrium position approximated by the meander belt was approached (Handy, 1972). A contrasting result was described by Konditerova and Ivanov (1969), who documented a pattern of change in the Irtysh River, a tributary of the Ob River in Siberia, in which changes in a single "key" meander controlled the deformation of a long sequence of meanders. Perhaps the most comprehensive study of the effects of cutoffs is that by Brice (1980), who has compiled case histories on approximately 60 sites where artificial cutoffs have been made. In most places the results were slight, but in a few there were drastic effects. The reasons for this differential response are not yet known.

Probably the greatest long-term hazard to the stream is the loss of stability of the high banks. Once the vegetative cover of the banks is lost, erosion rates and sediment loads could increase rapidly to levels endangering the productivity of the river. After the process begins, the only means of restoring the stability of these banks could be a costly engineering solution. The possible effects of river use on the high banks were discussed in the section on bank erosion. A type of development that could have a similar effect is the building of groins and boat ramps on the convex banks of meanders. Some loss of high-bank stability could also result from a meander cutoff on a nonentrenched part of the stream.

CANALS

Where the channel is not entrenched, the interior of several meander loops has been developed by means of canals bulldozed within the active flood plain for the purpose of providing waterfront access to trailer sites and homesites. This unusual form of development is possible only because of the sustained high flow that keeps the water level in the canals within a restricted range throughout most of middle and late summer. The most extensive canal developments occur within meanders 3-H and 1-H (figs. 17 and 19, respectively).

The unriprapped canals in the interior of meander loops are of concern to the stability of the river. The canals create a point of attack for flood flows to cut through and peel away the surficial layer and erode the underlying channel deposits. Once a channel is formed in the underlying gravel, the potential is for a cutoff and a diversion of the entire channel through that point in the neck of the meander.

Meander cutoffs have occurred on the Kenai River, probably within historical time, although none has occurred within the post-1950 period documented by aerial photography. The bend labeled meander "1-J" may have been a fully developed meander, now cut off, the previous course of which is in part marked by a small residual channel. Meander loop 1-L (fig. 15) is a meander probably in the process of a gradual chute cutoff.

The areas at risk from a meander cutoff are those where the river channel is not entrenched and the level of the interior surface of the meander loop is below the level of the Intermediate Regional Flood—that which will recur once in 100 years on the average but which could occur in any given year. The risk of a cutoff is associated with lesser floods, but the frequency of flows or the depth of flow on the flood plain with which the risk is associated cannot be accurately stated.

In the upstream part of the river the areas at greatest risk of cutoff potentially triggered by unriprapped canal development include the meander loops in the reach that extends from river mile 45.7 to river mile 39.4. Below this section of channel the river is fully entrenched, and upstream to the mouth of Skilak Lake the meanders are stable, and the normal pattern of pools and riffles are replaced by gravel dunes.

In the downstream part of the river the area at risk from channel changes initiated by canals extends from river mile 17.6 to river mile 9.0. The channel upstream from river mile 17.6 is entrenched, and that downstream from approximately river mile 9 is relatively stable within the tidal regime. This section of the river includes the area of single greatest risk, meander 3-H. Here the stream is partly entrenched—the interior of the meander loop is active flood plain; the outside high bank is 40 to 45 ft in height. This bend is the tightest of any meander on the river, and the interior of the loop has been subject to canal development and forest clearing (fig. 17). The consequences of a loop cutoff of meander 3-H could be significant. Much of the area within downstream loop 3-I would potentially be subject to erosion as the channel adjusted to the postcutoff configuration. There is little impediment to a major realinement of the stream at this point. The high bank on the downstream side of meander 3-H is actively eroding; vegetative cover has been lost, and the bank is composed of relatively fine grained glaciofluvial sediment.

The area upstream from meander 3-I, the apex of which is the tight bend known as Big Eddy, is subject to periodic ice-jam flooding. The potential for channel cutting through the neck of meander 3-H is consequently increased. Ice scars in spruce trees growing on the interior-meander flood plain extend to heights of approximately 20 ft. Flooding and erosion risks associated with ice jams are present on the entire river, of course, but they are pronounced in this place.

GROINS AND BOAT RAMPS

Groins are structures placed at approximately a right angle to the bank, commonly for the purpose of preventing bank erosion. Along the Kenai River the structures are emplaced most commonly to provide docking facilities and a protected area for boat mooring. The coarseness of the bed material allows it to be formed into groins that are sufficiently stable to remain for years with the addition of riprap on the point and upstream side. The riprap may consist of rock- or concrete-filled drums, iron bars and cable, tires linked with chain, or dumped scrap metal. Without minimally maintained riprap, the groins and boat ramps are observed on the sequential aerial photographs to become blunted over a period of years as the material is slowly eroded.

The greatest development of groins is found on meander 1-P (fig. 13), as described in the section on bank erosion. They are mainly confined to the entrenched section of the channel, where they are the alternative to canals and boat slips because of the impracticality of excavation in the high banks.

Characteristic of a groin is the formation of an eddy downstream from its tip and a resulting deflection of flow that can erode the bank. The problem can be

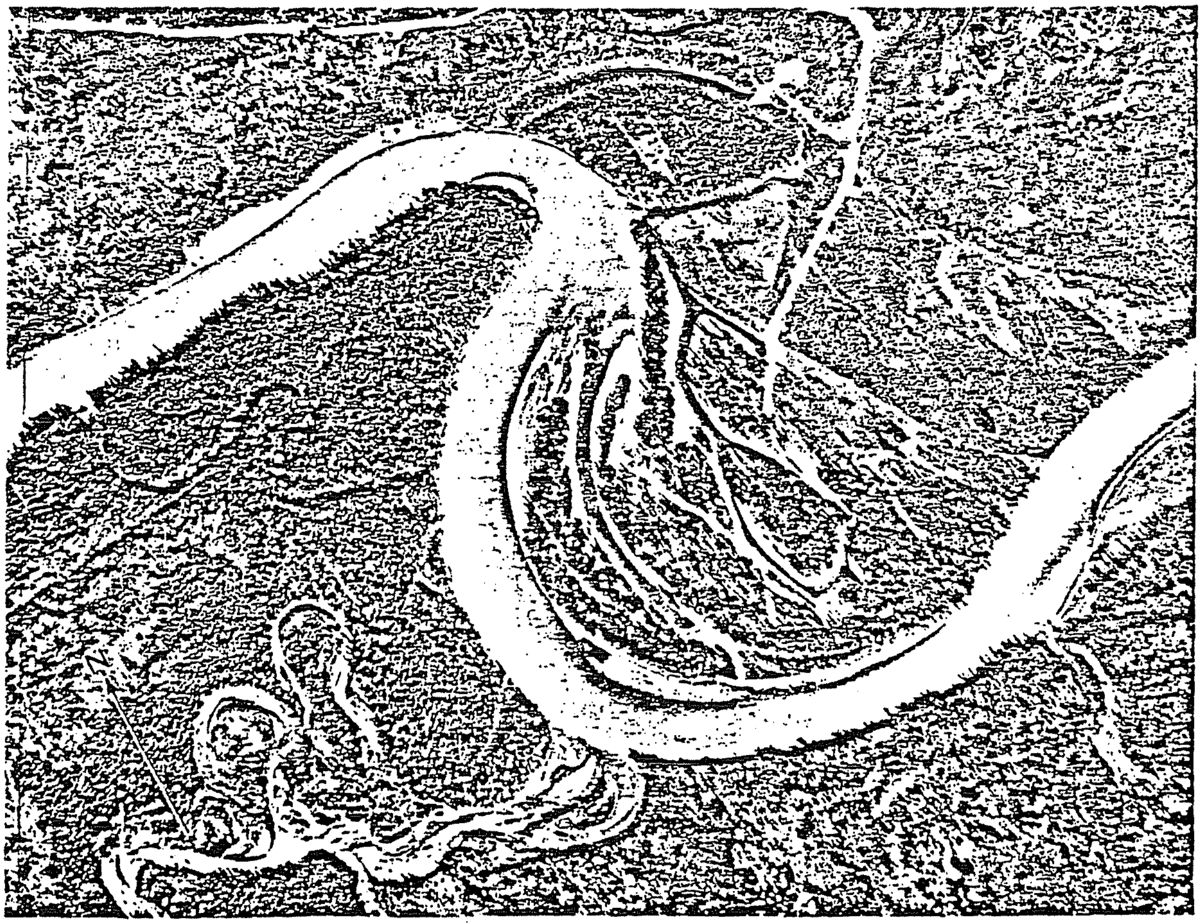


FIGURE 19.—Kenai River between approximate river miles 44.8 and 42.9. Interior of meander loop has been developed with canals. Note natural channels across neck of meander; one channel has been partly excavated to form a canal. The Killey River enters from bottom of photograph. Flow direction is from right to left. Scale, 1:12,000, or 1 in.= 1,000 ft. Date: September 24, 1972. Photograph credit: U.S. Army Corps of Engineers.

minimized by emplacing the groin at a slight upstream angle. This type of bank scour associated with groins and boat ramps on the Kenai River is not normally a problem because of the coarse bed material.

The most obvious deleterious result of groin and ramp construction is the potential for displacement of the channel toward the opposite bank a distance equivalent to the length of the structure. This result has yet to occur at meander 1-P because the bank on the outside of the meander bend was stabilized by vegetation at the time of construction. At present (1979) the bank is beginning to fail by undercutting and slumping, a process that can be expected to increase in future years if the groins are maintained with the addition of riprap.

If the distance of channel displacement was confined to the length of the structures, a cost-benefit analysis of their construction would be possible. Unfortunately, once the stabilizing vegetation on the bank is lost, the erosion potential is much greater, and it is possible for a cycle of increased erosion over a period of years to begin.

EXCAVATED BOAT SLIPS

Boat slips excavated in the channel bank are probably the most common type of development along the Kenai River. In the past the excavated material has been dumped to form a small protective groin on the upstream side of the slip or just pushed into the channel. Both methods of disposal, however, are presently contrary to the conditions attached to a construction permit (U.S. Army Corps of Engineers, 1978, p. 43). The slips and the canal systems are excavated and cleaned, most commonly during the low-flow period.

The potential for harmful effects of unriprapped boat slips varies with location. Where excavated on the upstream side of a meander loop in the nonentrenched part of the stream, a single boat slip can pose a hazard by creating a point of attack for flood flows. Meander 1-H is a bend that would become more vulnerable to utoff through the construction of slips on the upream side, especially at the locations of natural chanls visible in figure 19. Where slips are excavated at st locations on the entrenched part of the stream ble 5), the individual hazard will be slight, but each form part of a cumulative effect. The need for ripvill also vary greatly with location. Where excavas in the coarse channel deposits characteristic of ntrenched and partly armored sections of the he need for lining by even coarser material will t at most locations. Riprap will be advisable at s outside the entrenched channel.

re other considerations illustrating the com- the impact of boat slips. Excavated boat slips are a type of development that is not necessary for recreational use of the river. For most owners of riverfront property, a slip can be viewed as a matter of convenience; small boats can be drawn up on the bank at any place where the bank height is low enough to make a slip feasible. Excavated slips, however, may encourage the use of large, high-horsepower boats of the sizes that may be contributing, disproportionate to their numbers, to the possible increase in bank erosion discussed previously. With unlimited river use, the granting of permits for boat slips could logically, therefore, be assessed for the potential additional effect of encouraging larger boats.

BANK-PROTECTION STRUCTURES

A variety of measures have been employed to support and protect homes constructed on the banks of the Kenai River. They include concrete walls, gravel berms, earthen embankments, piles driven into the bank, and chained tires. The purpose is commonly multifold: to provide docks, to provide foundations for structures, porch and patio areas, or to expand usable lot size, as well as acting as revetments to provide protection from bank erosion.

The effects on the stream channel of most such bank modifications will be slight as long as the original bank profile is not greatly changed. Loss of channel capacity and concentration of flow toward the opposite bank, leading to erosion of that bank, are possible if the structures are sufficiently extensive and of sufficient height to function locally as flood levees. Indirect effects, related to excavation of gravel and removal of the cohesive surface to supply fill for berms and levees, are also possible.

GRAVEL MINING AND COMMERCIAL DEVELOPMENTS

At several locations visible on the 1977 aerial photographs it appears that the banks have been mined for aggregate. The largest of these sites is on the north bank of the Kenai River, approximately 0.2 miles upstream from the junction of the Moose River. The impacts of gravel mining on stream channels have been described previously (for example, Scott, 1973; Bull and Scott, 1974) and need not be elaborated here. The hazards are clear, and, because of abundant sand and gravel deposits throughout the area, little rationale presently exists for permitting mining of the Kenai River banks. In addition to channel diversion and bank erosion, there is risk of dumping of the unmarketable fine-grained sediment fractions into the river.

Operators of many small fishing resorts have modified the banks to provide ramp access to the stream as well as convenient parking. At a few sites large volumes of gravel have been displaced, most of which has been used for fill. At a few resorts developed on higher banks, large volumes of gravel apparently have been pushed into the channel and subsequently transported by the stream. In some cases the gravel ramps extending into the stream are periodically maintained with newly excavated gravel. The impacts of these commercial developments, whether they involve extending or cutting the natural bank, will correspond to those previously discussed for groins, boat ramps, and slips.

CONCLUSIONS

Suspended-sediment concentrations in the Kenai River are naturally low because of sediment retention in upstream lakes; levels known from other streams to be harmful to salmon habitat are reached only rarely. More frequent elevated concentrations may result from increase in development of the types now present along the navigable channel of the river. These types of development are listed in the preceding section in the order of their magnitude of impact on the sediment system of the stream.

Rates of bank erosion since 1950-51 show that sections of the river differ greatly in their sensitivity to development, as indicated in table 5. Throughout the central section of the river (between river miles 39.4 and 17.6) the channel is entrenched, partly armored, and has undergone rates of bank erosion that are very low to undetectable. Upstream and downstream from this section the bank erosion rates are more typical of proglacial streams—as high as 5 ft per year. Two additional sections of channel are exceptions to this pattern: the initial 3.8 river miles of channel below Skilak Lake are highly stable because of the presence of large gravel dunes emplaced by a pre-1950 flood surge; also, the downstream 9.0 river miles of channel are moderately stable because of the dominance of the tidal regime.

Development along the navigable channel will affect the sediment system of the stream in several ways. Construction may increase suspended-sediment concentration temporarily, with the greatest potential for harmful impact between January and May, as indicated by the relation between discharge and concentration for that period. Development can increase bank erosion, and thus the suspended-sediment concentration, over the longer term by causing cutoff of meander loops, loss of stabilizing vegetation on banks, and loss of the cohesive surface layer of flood-plain sediment.

Throughout this report, emphasis has been placed on the potential for increased suspended-sediment transport because that is the first general effect of development which is likely to be harmful to the physical stream system. The effect on salmon habitat occurs mainly through deposition of fine sediment in the pores of the streambed gravel in reaches used for spawning and rearing. There is additional concern for habitat conditions throughout the entrenched and partly armored section of channel. Without the cleansing action of flood flows competent to mobilize the coarser bed material of those reaches, increased transport of fine sediment will result in deleterious rates of deposition within the bed. In contrast with normal reaches, flow magnitudes competent to move the bed material of the armored reaches are greatly in excess of bankfull discharge and may not recur at the frequencies necessary to maintain a viable fishery if suspended-sediment transport increases.

Bank-erosion rates have been generally constant since 1950-51. The high cut banks present in entrenched and partially entrenched sections of channel have been mainly vegetated and stable through the same period. Loss of stability of the high banks is of special concern because of the potential for large, long-term contributions to the sediment load of the river. Ground photography in 1979 suggests that the high banks have locally begun to erode more rapidly, although verification of this possibility must await future study. A likely contributing cause of such erosion is increased intensity of river use and a recent change in sport-fishing technique.

The Kenai River salmon fishery is a major component of the economic base of the Kenai Peninsula. It justifies continued concern for changes in the sediment system of the stream, in response to channel and flood-plain development as well as trends in land use and other changes within the watershed. This can be best accomplished by monitoring the suspended-sediment concentration and the stability of the high banks.

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APPLICATION; REFERENCE TO
COMMENT(S): C. 62, I. 373

SUSITNA HYDROELECTRIC PROJECT

HYPOTHETICAL DAM-BREAK ANALYSES

TASK 3 – HYDROLOGY

MARCH 1982

Prepared by:

ACRES

ALASKA POWER AUTHORITY

ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT

TASK 3.05 - FLOOD STUDIES

SUBTASK 3.05(iv)
HYPOTHETICAL DAM BREAK ANALYSES - CLOSEOUT REPORT

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3 - SCOPE OF WORK

The objectives of this study are to analyze extreme cases of flood waves produced by hypothetical failures of the proposed dams of the Susitna Hydroelectric Project. The analyses are carried out over the reach of the Susitna River from the most upstream point in the reservoir of the dam being considered to the confluence of Trapper Creek, approximately 5 miles downstream from Talkeetna (see Figure 3.1).

To satisfy the study objectives, the work was organized and carried out in the following manner:

- Scenarios of worst case hypothetical dam failures were postulated for the Watana dam, the Devil Canyon dam, the Watana upstream cofferdam, and a domino type failure of both the Watana and Devil Canyon dams.

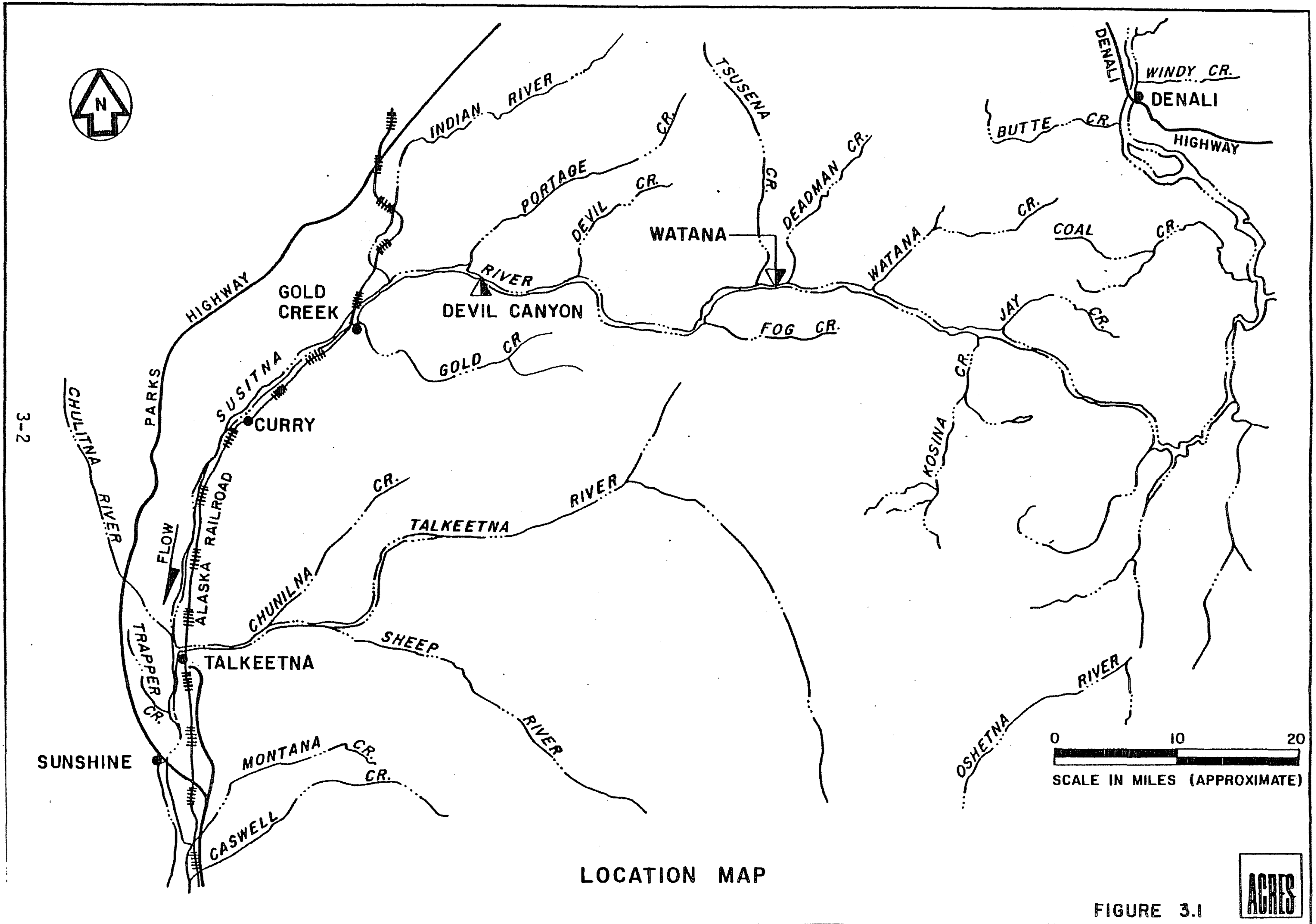
- A dam break computer program was selected to assist in analyses.

- Final dam breach dimensions and time of breach formation were estimated for each scenario.

- Downstream valley topographical and vegetative information were assembled and the geometric models were prepared.

- Dam break hydrographs were developed and routed downstream. Peak flood elevations, time to peak, and peak discharges were determined at various downstream locations for each of the postulated failures.

- The study was completed with analyses of the routed hydrographs and a comparison of flood wave crest levels in the river reach under dam break and probable maximum flood conditions together with the 50 year flood conditions.



LOCATION MAP

FIGURE 3.1

4 - HYPOTHETICAL DAM FAILURE SCENARIOS

Earth/rockfill dams are extremely safe structures capable of safely withstanding severe seismic shaking. The structure is normally designed to slump during a severe earthquake without being overtopped. As with all major water retaining structures, the safety of the development is also dependent on the performance of properly designed spillway facilities to safely discharge severe floods. Should spillway facilities not perform satisfactorily during a major seismic event (they are normally very conservatively designed to do so), there is a risk of overtopping of the earth/rockfill dam which could lead to a breach and subsequent failure.

Concrete dams are also extremely safe structures capable of safely withstanding severe seismic shaking and flood conditions. However, there is a very remote possibility of a flood of unforeseen magnitude occurring simultaneously with severe seismic shaking which together with spillway malfunction might lead to overtopping of the dam and under extremely adverse conditions, breaching of the structure.

Four hypothetical dam failure scenarios which create extreme conditions in the river reach have been postulated. The probability of any of these scenarios actually occuring is considered to be extremely small, but still not equal to zero. The hypothetical dam failure scenarios are described below.

4.1 - Hypothetical Watana Dam Failure

The remote possibility of a failure at Watana would have to be based on a combination of unlikely events. For study purposes these events are assumed as follows: Prior to the construction of the Devil Canyon dam, a major earthquake and a Probable Maximum Flood (PMF) simultaneously occur at Watana. All normal outflow facilities are inoperable and only the emergency spillway is left to discharge flows from the reservoir. Seismic activity causes the Watana dam to slump to a crest elevation of 2205. The rockfill dam catastrophic failure is initiated when the reservoir level is three above over the crest level (El. 2208).

4.2 - Hypothetical Devil Canyon Dam Failure

Similarly, at Devil Canyon the following combination of unlikely events is assumed: The Devil Canyon arch dam fails during a PMF routed through the Watana reservoir. All of the Devil Canyon dam normal outflow facilities are inoperable and only the emergency spillway discharges flows downstream. The Devil Canyon arch dam failure is initiated when the Devil Canyon reservoir reaches the maximum level or when thirty feet of water is flowing over the arch dam, whichever occurs first. Failure of the saddle dam is not considered since this case would produce lower discharges and water levels below the dam compared to the failure of the arch dam.

4.3 - Hypothetical Domino Type Failures

In this case, the following combination of unlikely events is assumed: This scenario is a combination of the Watana and Devil Canyon failure scenarios. The Watana dam failure triggers a failure of the Devil Canyon arch dam. The Watana dam failure is the same as that postulated in Section 4.1 followed by Devil Canyon arch dam failure as postulated in Section 4.2. The Devil Canyon reservoir level at which catastrophic failure begins is that level which is determined during the analysis of the hypothetical Devil Canyon dam failure.

4.4 - Hypothetical Watana Cofferdam Failure

In this case, the following scenario is assumed: The upstream Watana cofferdam fails during a fifty year flood. The diversion tunnels are sufficiently obstructed to raise the pool level three feet over the dam crest. The cofferdam crest elevation is 1545 and catastrophic failure is initiated at a pool level of 1548.

5 - TECHNICAL METHODOLOGY

The technical methodology employed yields the most accurate results reasonably achievable given the constraints of the problem. This methodology employs state-or-the-art analysis of the problem and is described in the following sections.

5.1 - Dam Break Computer Program Selection

The National Weather Service (NWS) dam break flood forecasting model, "DAMBRK," by Dr. Danny Fread (2) was selected to model the hypothetical dam failures. McMahon (4), United States Geological Survey (5), and others have judged this model to be the best dam break model currently available. The NWS DAMBRK model includes an extremely versatile dynamic flood routing program which solves the Saint Venant equations by implicit finite difference techniques.

The dam break hydrograph is developed internally by the Fread method. The hydrograph is dependent on the final breach shape and the time over which the breach develops. Specific breach input parameters are bottom width, bottom elevation, side slopes, and time of failure (see Figure 5.1).

The program requires minimal river cross section data. Of major importance is river slope, roughness, and valley geometry. DAMBRK interpolates cross sections at intervals as needed and specified by the user. This capability is nearly essential for numerical stability requires that the distance between cross sections be approximately equal to the product of the wave speed and the time step used in the analysis.

To determine the hypothetical failure pool level of the Devil Canyon arch dam discussed in Section 4.2, the Modified Puls method, a storage routing technique based on the continuity principle, was employed to rout the PMF through the Watana and the Devil Canyon reservoirs. This method was also used to determine the point on the PMF hydrograph at which the hypothetical Watana dam failure commences. The Modified Puls routing was accomplished with an Acres' in-house computer program.

5.2 - Breach Dimensions and Time of Failure

The final breach geometry is specified in DAMBRK by bottom width, bottom elevation, and side slopes which must be equal on both sides. The natural channel width and elevation at the sites have been used as breach dimensions. Breach side slopes are assumed to be one horizontal to one vertical for an earth/rockfill dam and the average valley slope for the arch dam.

Development of the breach commences when the pool level is equal to or greater than the assumed failure elevation. Breach progression is directly related to the ratio of the time passed since start of failure to the total duration of failure, or "time of failure". The time of failure pertains to only the catastrophic event and not to the relatively lower antecedant discharges. Dam break hydrographs can be very sensitive to the time of failure. Unfortunately, there is no method available to accurately determine time of failures. Time of failures may be either crudely estimated based on erosion characteristics of the dam and/or determined as that time which would produce a hydraulically instantaneous failure. The unreliability of time of failure prediction necessitated a sensitivity analysis. Watana dam time of failures of 2.5 hours and 3.0 hours were analyzed. These times are based on a conservative estimate of time required to erode approximately 49 million cubic yards of material. Devil Canyon time of failures of 0.4 hours and 0.5 hours were analyzed. A Watana cofferdam time of failure of 0.5 hours was assumed. The domino failure scenario is based on a Watana time of failure of 2.5 hours and a Devil Canyon time of failure of 0.5 hours.

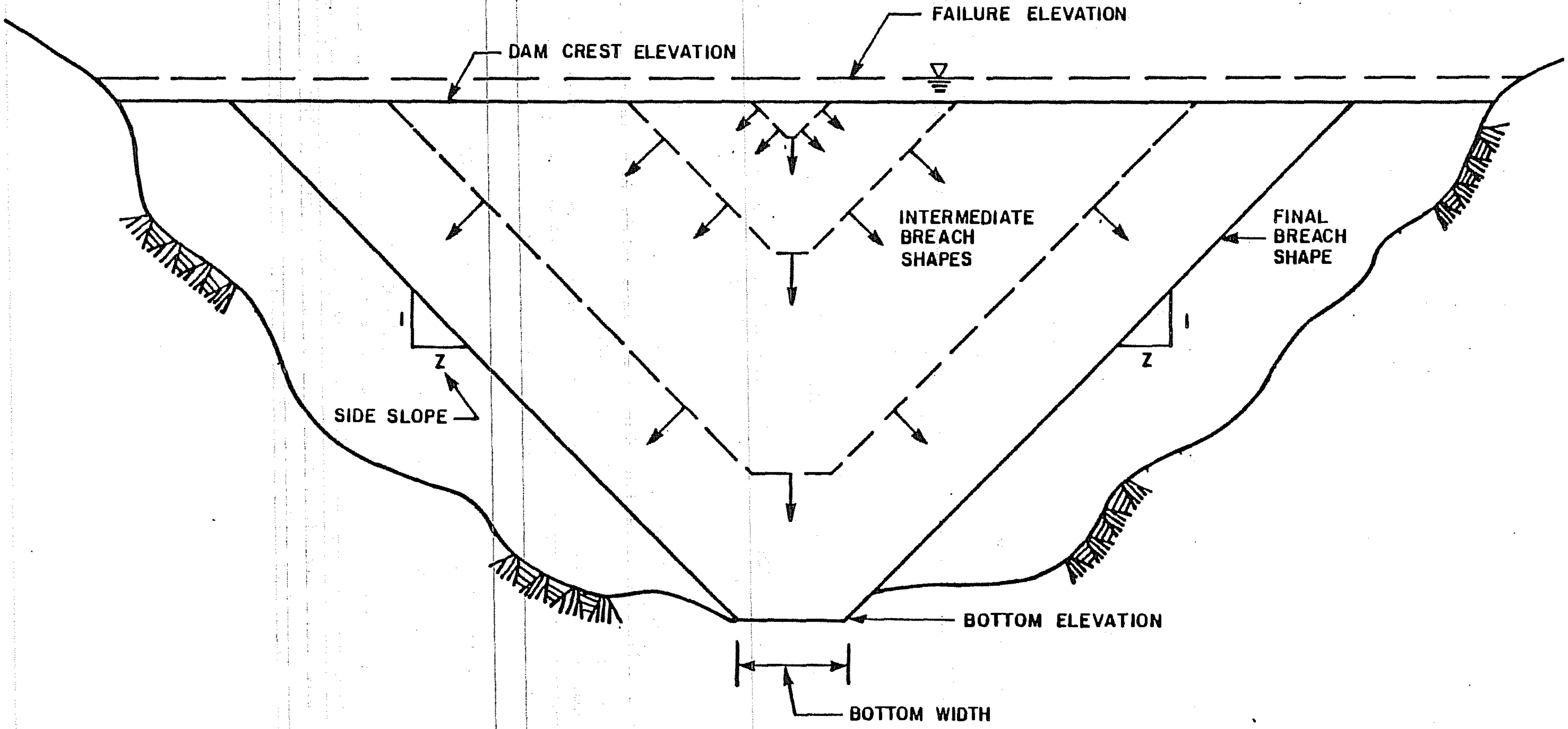
5.3 - Geometric Model

A simplified geometric model representative of the river valley is input into DAMBRK. Cross sections are required only at significant changes in river slope or valley cross section. Eight elevations and corresponding valley widths are input to define each river cross section. Additional sections are created in the model by interpolation. Surface roughness is expressed as the Manning coefficient "n" and input for each reach defined by the original sections.

The majority of cross section information was taken from United States Geological Survey quadrangle maps with a horizontal scale of 1:63360 and 100 foot contour intervals upstream of the Town of Chase and 50 foot intervals downstream of Chase. More detailed river valley topographical information is available only in the vicinity of Devil Canyon and Watana.

To define the downstream cross section geometry it is desirable to have more detailed information than currently available. This is especially true in the vicinity of Talkeetna where the river valley width is in the range of two to three miles and only 50 foot contour intervals are available. Nevertheless, the available topographical information is sufficient to analyze flood waves with reasonable accuracy.

The Manning coefficients were predicted for the reaches of the Susitna River. Manning's coefficient calculations for the over bank area are based on bottom friction and drag from partially submerged obstructions (6). Composite "n" values were determined using the assumption of equal velocity across the section (1). Preliminary DAMBRK runs showed that in a few reaches the flow regime changed with time from subcritical to supercritical and back to subcritical as the dam break flood wave passed through a reach. At numerous sections, the Froude number became so large that mathematical nonconvergence occurred in the computer run or the computed flow area at a cross section became zero. To eliminate modeling problems due to supercritical flow in a subcritical run, it is common practice to either alter the cross section geometry or increase the "n" value (3). Thus, in a number of reaches, the "n" values were increased to values above the predicted "n" value. The artifically high "n" values tend to reduce the speed of the wave and increase the depth of flow in the reach. The DAMBRK output has been adjusted slightly in an attempt to smooth errors created by computer modeling limitations.



BREACH DEFINITION SKETCH

FIGURE 5.1

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6 - ANALYSES OF DAM BREAK FLOOD WAVES

Dam break hydrographs have been dynamically routed down the Susitna River to the confluence of Trapper Creek which is approximately 5 miles downstream from Talkeetna. Peak flood levels, peak discharges, and time to peak were determined along the river. The following sections summarize the study results and discuss sensitivity of the analysis to time of failure assumed.

Peak dam break flood levels are compared to the PMF and 50 year flood levels at selected cross sections and shown graphically in Figures 6.1, 6.2 and 6.3.

6.1 - Watana Failure Analyses

The hypothetical Watana dam break was analyzed for failure times of 3.0 hours and 2.5 hours. The Watana dam break hydrograph superposed on the PMF hydrograph is shown in Figure 6.4. The Watana dam break hydrograph at Watana and Talkeetna is shown in Figure 6.5. Maximum stage, flow rate, velocity, and time to peak stage are given in Table 6.1 at six locations along the Susitna River.

6.2 - Devil Canyon Failure Analyses

The hypothetical Devil Canyon dam break was analyzed for failure times of 0.5 hours and 0.4 hours. The Devil Canyon dam break hydrograph at Devil Canyon and Talkeetna is shown in Figure 6.6. Maximum stage, flow rates, velocities, and times to peak stage are given in Table 6.2.

6.3 - Domino Failure Analyses

The hypothetical domino type failure analysis is based on failure times of 2.5 hours and 0.5 hours at Watana and Devil Canyon, respectively. The dam break hydrograph at the Devil Canyon dam and Talkeetna is shown in Figure 6.7. Maximum stage, flow rates, velocities, and times to peak stage are given in Table 6.3.

6.4 - Watana Cofferdam Failure Analysis

The hypothetical Watana cofferdam failure analysis is based on a failure time of 0.5 hours. The Watana cofferdam hydrograph at Watana and Talkeetna is shown in Figure 6.8. Maximum stage, flow rates, velocities, and times to peak stage are given in Table 6.4.

6.5 - Sensitivity Analysis Discussion

The sensitivity analysis conducted revealed that the failure times chosen give results not significantly different from those for hydraulically instantanous failure times. Both the Devil Canyon and Watana peak discharges increased only slightly with reduced failure times. Differences in downstream effects are not discernible over the range of failure times tested. However, since much longer failure times would be outside of the hydraulically instantanous failure range, they should significantly reduce the downstream affects of dam failure.

TABLE 6.1: WATANA DAM BREAK ANALYSES SUMMARY TABLE

Location	Maximum Stage (ft)		Maximum Flow (cfs)		Maximum Velocity (fps)		Time to Peak Stage (hr)		PMF Stage (ft)
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	
Watana	N.A.	N.A.	42,624,000	40,464,000	76	73	N.A.	N.A.	N.A.
Indian River	126	125	30,121,000	29,390,000	63	63	3.9	4.3	22
Gold Creek	179	177	29,980,000	29,239,000	40	39	4.2	4.6	31
Curry	205	203	27,939,000	27,439,000	62	62	4.5	4.9	53
Talkeetna	77	77	26,331,000	25,992,000	16	17	5.4	5.7	25
Trapper Creek	85	85	26,175,000	25,910,000	21	21	5.9	6.2	15

(1) 2.5 hour time of failure
(2) 3.0 hour time of failure

TABLE 6.2: DEVIL CANYON DAM BREAK ANALYSES SUMMARY TABLE

Location	Maximum Stage (ft)		Maximum Flow (cfs)		Maximum Velocity (fps)		Time to Peak Stage (hr)		PMF Stage (ft)
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	
Devil Canyon	N.A.	N.A.	11,453,000	10,963,000	60	59	N.A.	N.A.	N.A.
Indian River	73	73	9,054,000	9,116,000	43	43	0.8	0.9	22
Gold Creek	103	103	8,512,000	8,598,000	31	31	0.8	1.0	31
Curry	112	112	6,391,000	6,408,000	37	37	1.9	1.9	53
Talkeetna	42	42	5,271,000	5,274,000	9	9	3.3	3.3	25
Trapper Creek	56	56	4,608,000	4,609,000	8	8	4.1	4.2	15

(1) 0.4 hour time of failure
(2) 0.5 hour time of failure

N.A. - Not Applicable

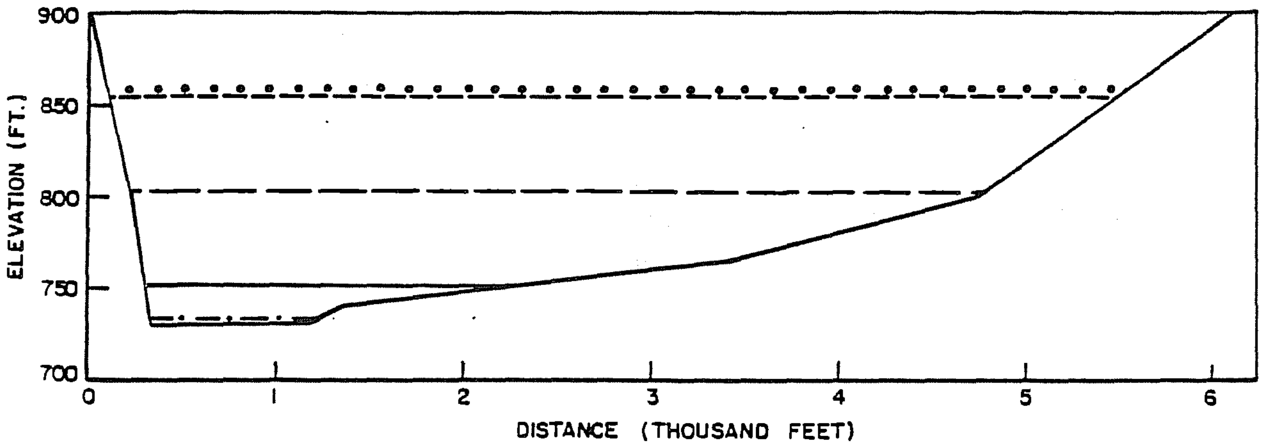
TABLE 6.3: DOMINO FAILURE ANALYSES SUMMARY TABLE

Location	Maximum Stage (ft)	Maximum Flow (cfs)	Maximum Velocity (fps)	Time to Peak Stage (hr)	PMF Stage (ft)
Watana	N.A.	42,587,000	75	N.A.	N.A.
Devil Canyon	579	31,112,000	90	3.6	N.A.
Indian River	128	31,036,000	64	3.8	22
Gold Creek	183	30,853,000	39	4.1	31
Curry	208	28,991,000	63	4.3	53
Talkeetna	79	27,553,000	17	5.2	25
Trapper Creek	86	27,457,000	21	5.7	15

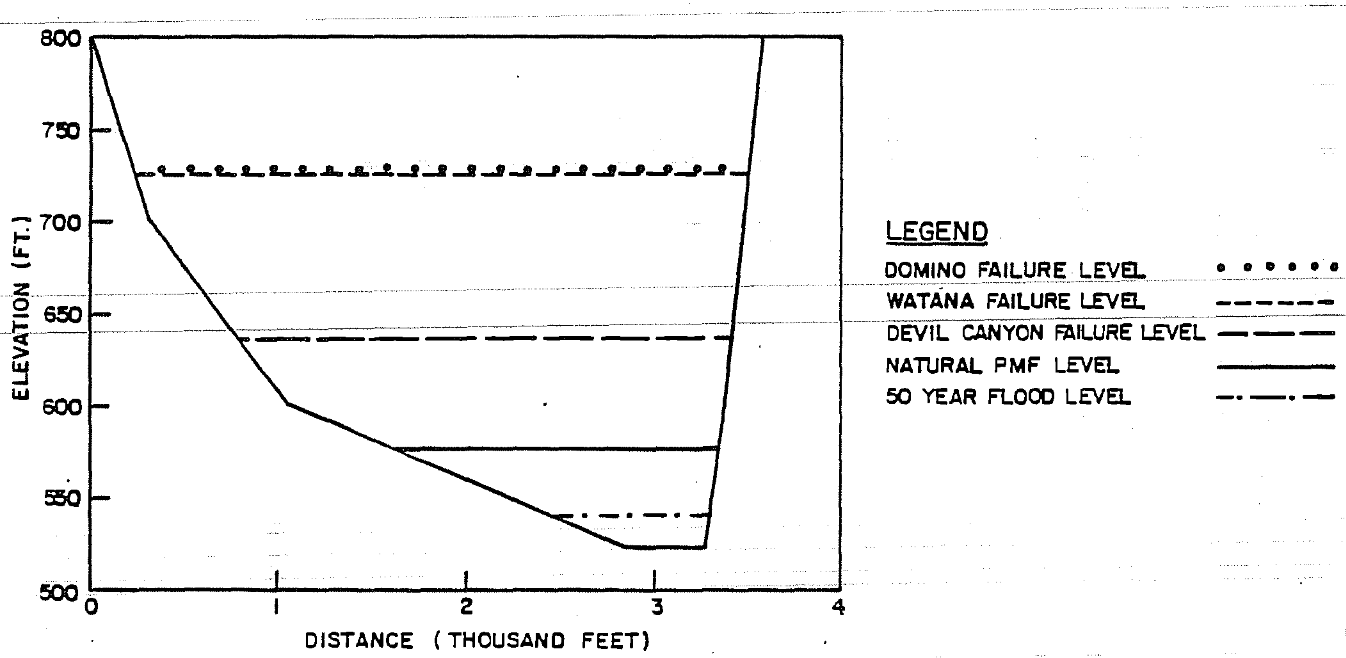
TABLE 6.4: WATANA COFFERDAM FAILURE ANALYSE SUMMARY TABLE

Location	Maximum State (ft)	Maximum Flow (cfs)	Maximum Velocity (fps)	Time to Peak Stage (hr)	50 Yr Flood Stage (ft)
Watana	N.A.	469,800	19	N.A.	N.A.
Indian River	18	321,400	15	5.0	3
Gold Creek	27	323,700	12	5.3	9
Curry	30	298,400	21	7.2	18
Talkeetna	11	290,000	6	10.1	7
Trapper Creek	11	354,900	6	10.8	5

N.A. - Not Applicable



INDIAN RIVER CROSS SECTION



CURRY CROSS SECTION

FIGURE 6.1

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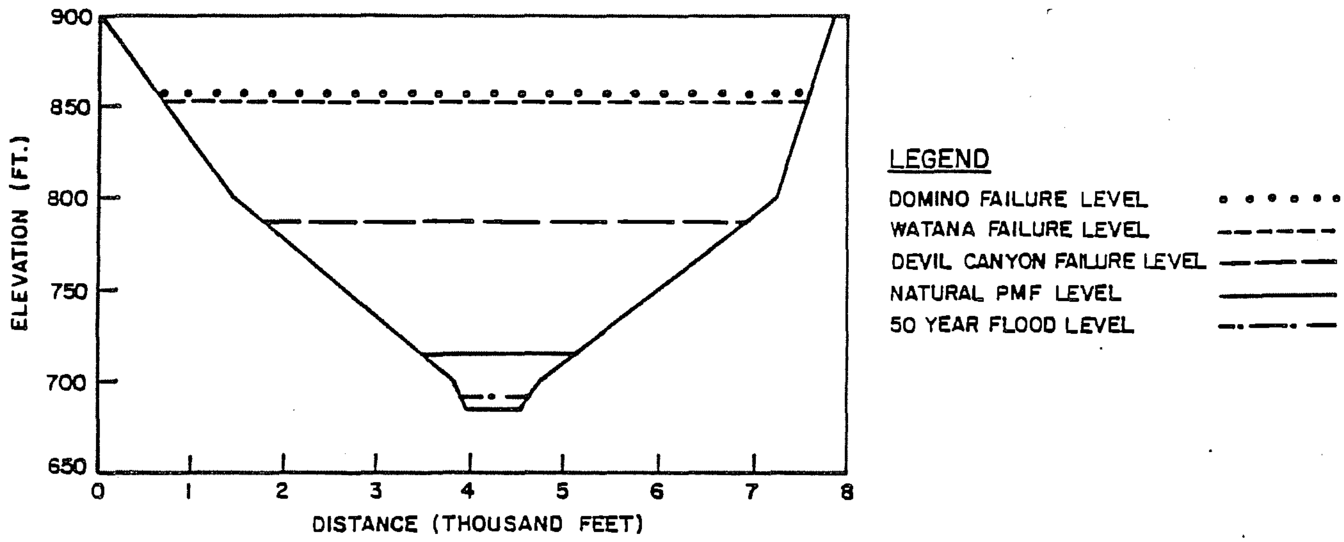
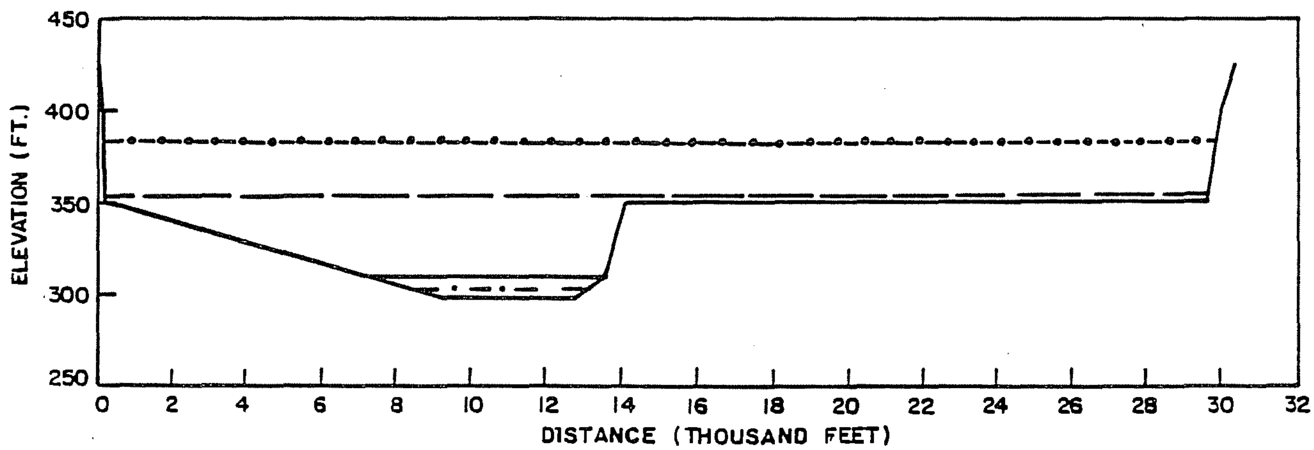
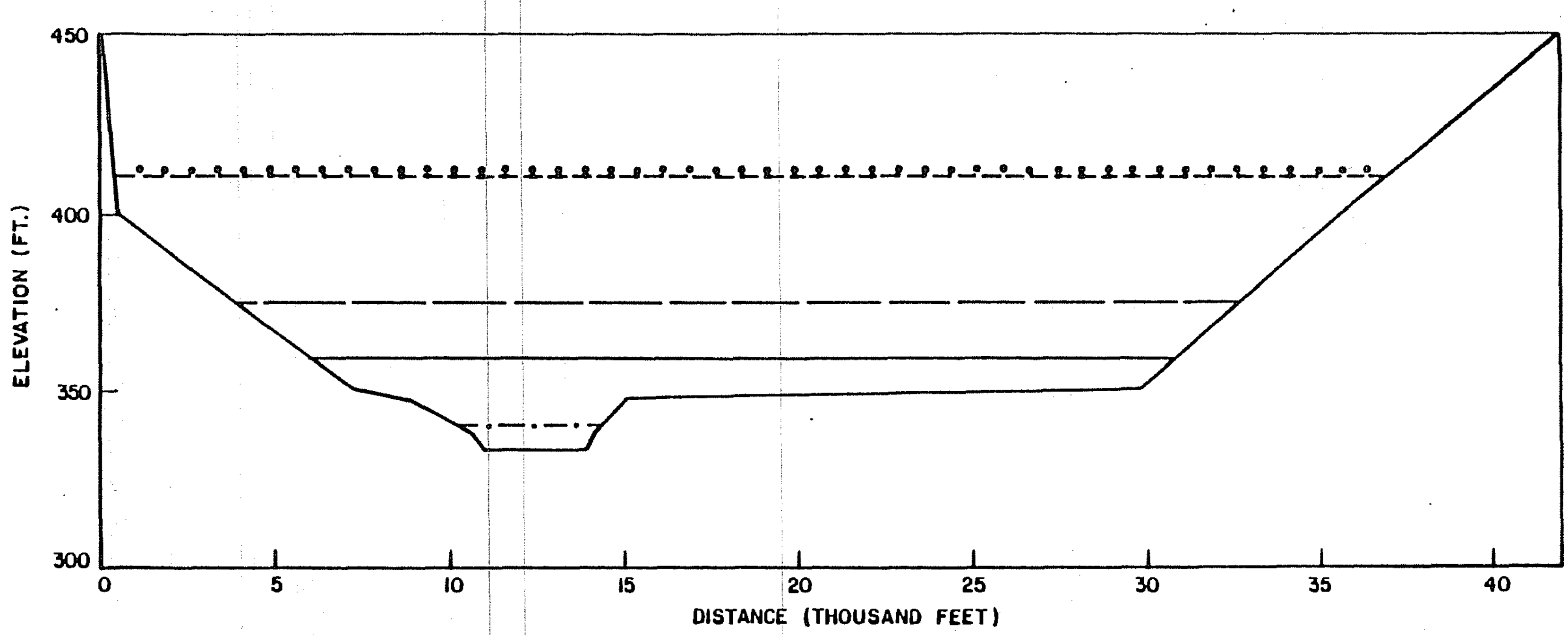


GOLD CREEK CROSS SECTION



TRAPPER CREEK CROSS SECTION

FIGURE 6.2 ACRES



LEGEND

DOMINO FAILURE LEVEL • • • • •

WATANA FAILURE LEVEL - - - - - -

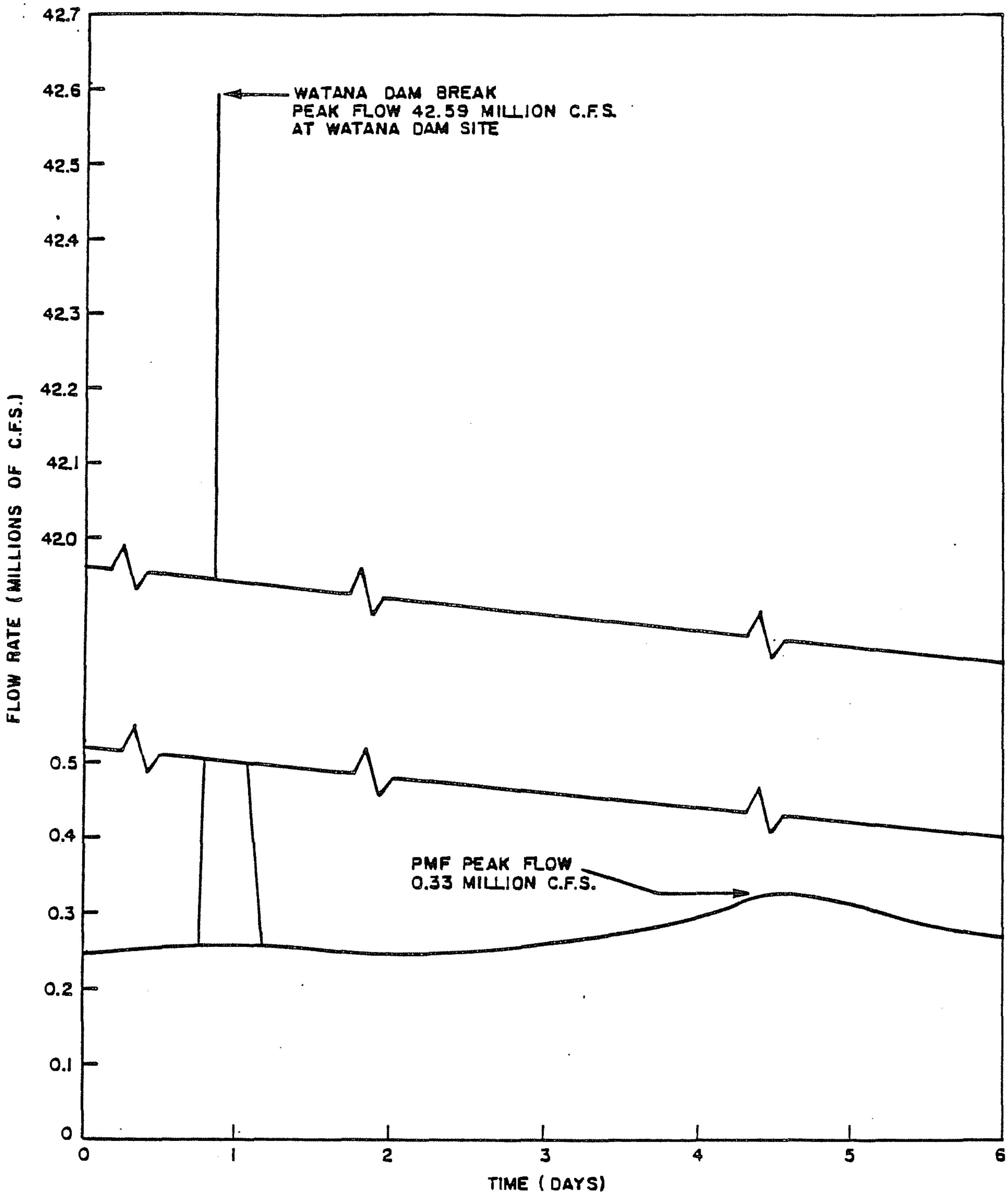
DEVIL CANYON FAILURE LEVEL — — —

NATURAL PMF LEVEL ———

50 YEAR FLOOD LEVEL —·—·—

TALKEETNA CROSS SECTION

FIGURE 6.3 ACRES



WATANA DAM BREAK HYDROGRAPH
SUPERPOSED ON THE PMF HYDROGRAPH

FIGURE 6.4

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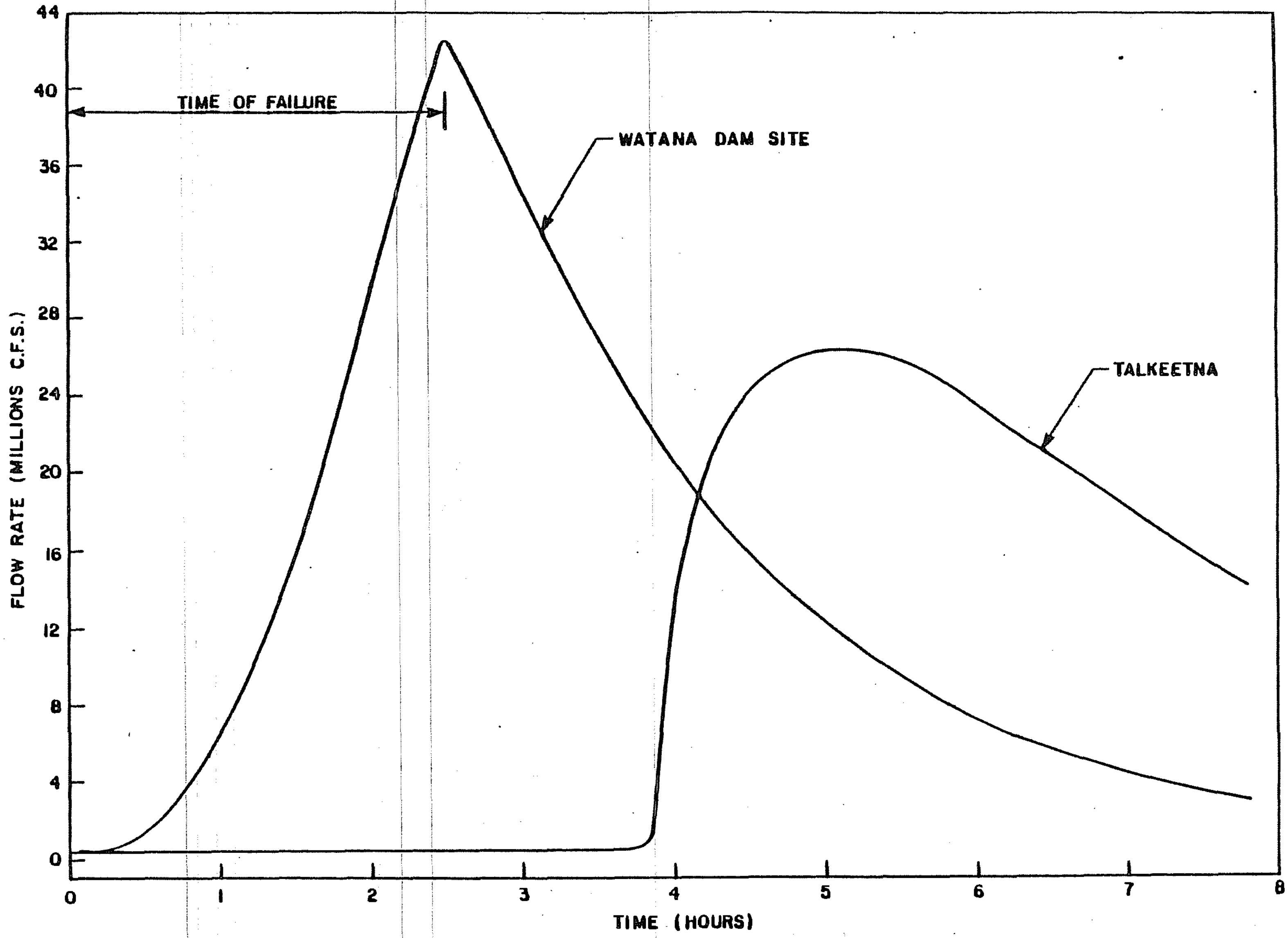
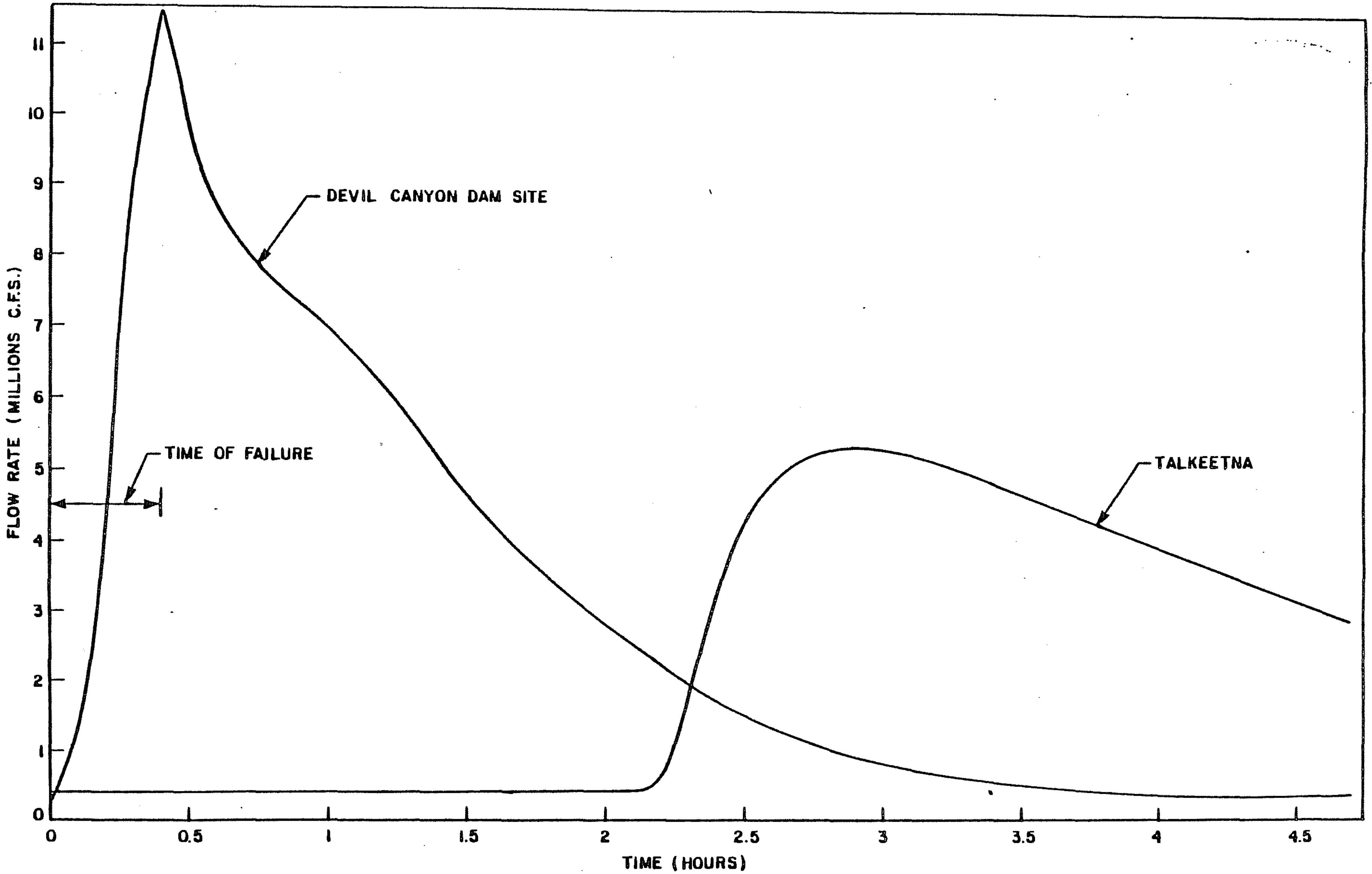


WATANA DAM BREAK HYDROGRAPH

FIGURE 6.5

6-9



DEVIL CANYON DAM BREAK HYDROGRAPH

FIGURE 6.6

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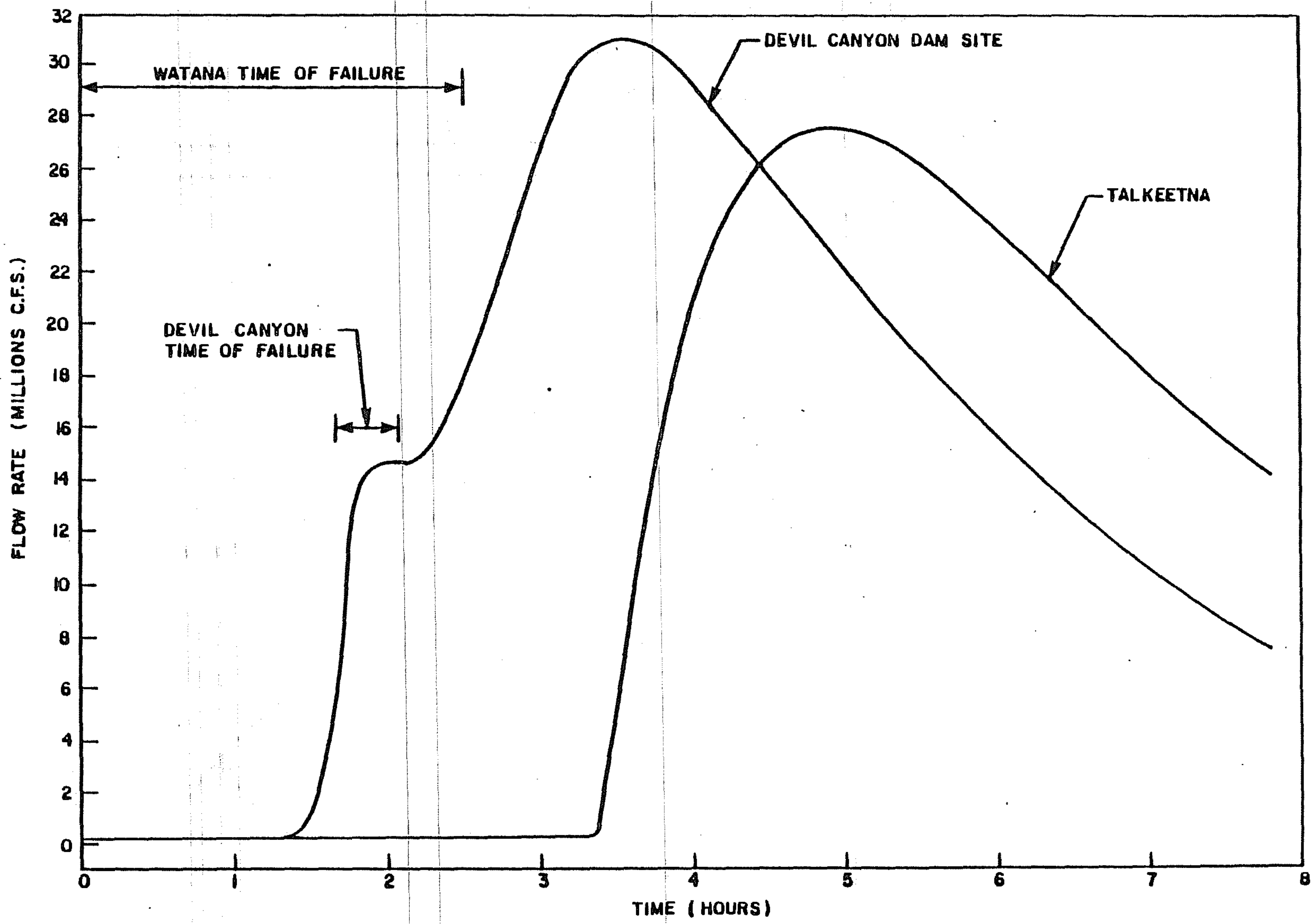
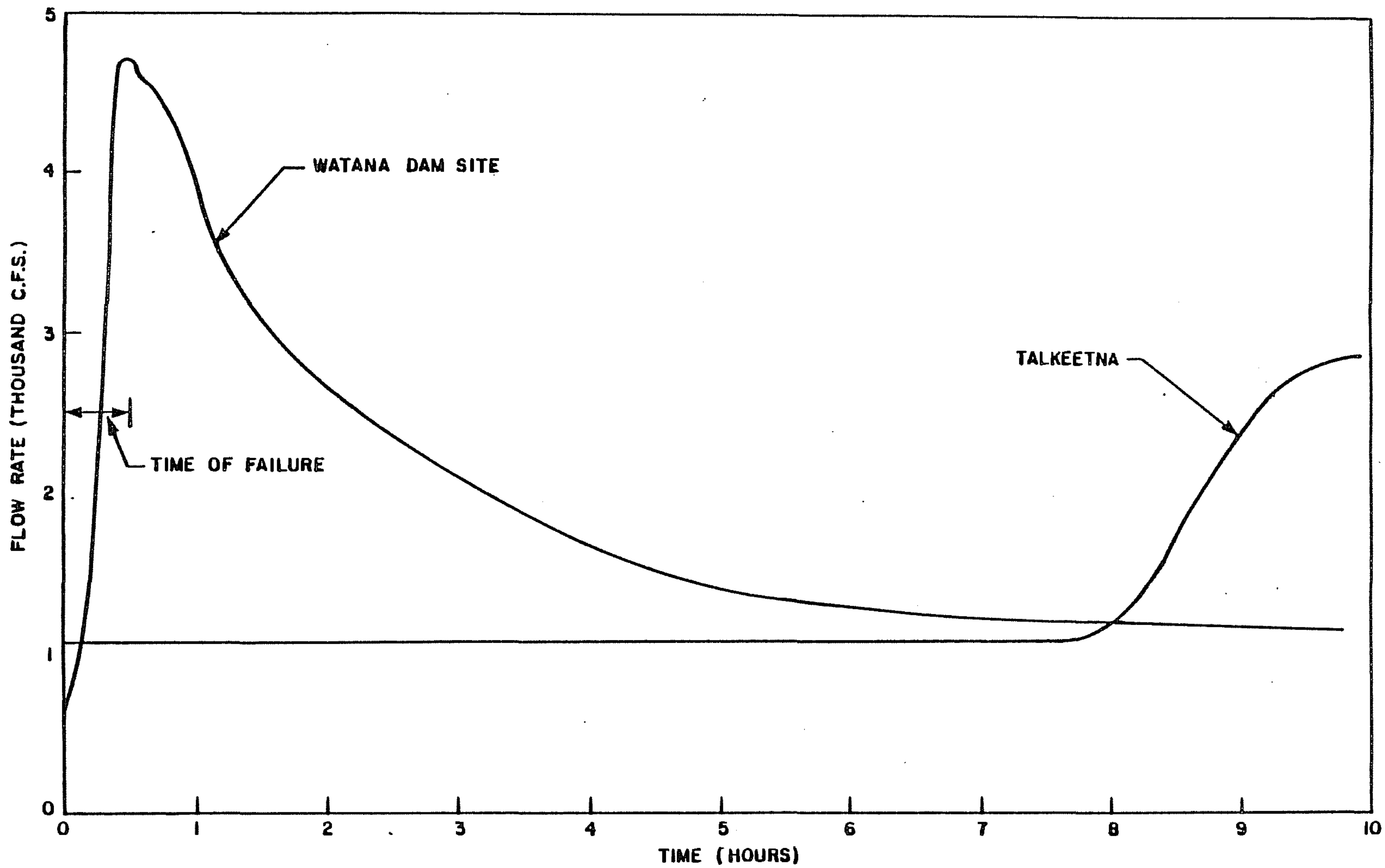


DOMINO DAM BREAK HYDROGRAPH

FIGURE 6.7



WATANA COFFERDAM DAM BREAK HYDROGRAPH

FIGURE 6.8

7 - CONCLUSIONS

7.1 - Conclusions

The conclusions of this study are:

- The hypothetical dam failure at Watana produces a peak flood level at Talkeetna 52 feet above the level which would be produced by the PMF.

- The hypothetical dam failure at Devil Canyon produces a peak flood level at Talkeetna 17 feet above the level which would be produced by the PMF.

- The hypothetical domino failure downstream effects are not significantly different from those of the Watana dam failing prior to the construction of the Devil Canyon dam.

- The hypothetical failure effects of Devil Canyon dam failing singly are less devastating than those of the failure of Watana singly.

- The Devil Canyon dam will fail if the Watana dam fails.

- Peak discharges and elevations produced by the hypothetical Watana cofferdam failure are less than those which would be produced by the PMF but approximately 4 feet higher than the 50 year flood at Talkeetna.

- A period of approximately 5 hours would elapse between initiation of a failure at Watana and the arrival of the flood peak at Talkeetna. Additional time might be available prior to the failure with appropriate flood and other event warning systems.

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APPENDIX A

EXCERPT FROM DAMBRK: THE NWS DAM-BREAK FLOOD FORECASTING MODEL (2)

DAMBRK: THE NWS DAM-BREAK FLOOD FORECASTING MODEL

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February 10, 1981

1. INTRODUCTION

Catastrophic flash flooding occurs when a dam is breached and the impounded water escapes through the breach into the downstream valley. Usually the response time available for warning is much shorter than for precipitation-runoff floods. Dam failures are often caused by overtopping of the dam due to inadequate spillway capacity during large inflows to the reservoir from heavy precipitation runoff. Dam failures may also be caused by seepage or piping through the dam or along internal conduits, slope embankment slides, earthquake damage and liquefaction of earthen dams from earthquakes, and landslide-generated waves within the reservoir. Middlebrooks (1952) describes earthen dam failures occurring within the U.S. prior to 1951. Johnson and Illes (1976) summarize 300 dam failures throughout the world.

The potential for catastrophic flooding due to dam failures has recently been brought to the Nation's attention by several dam failures such as the Buffalo Creek coal-waste dam, the Toccoa Dam, the Teton Dam, and the Laurel Run Dam. A report by the U.S. Army (1975) gives an inventory of the Nation's approximately 50,000 dams with heights greater than 25 ft. or storage volumes in excess of 50 acre-ft. The report also classifies some 20,000 of these as being "so located that failure of the dam could result in loss of human life and appreciable property damage...."

The National Weather Service (NWS) has the responsibility to advise the public of downstream flooding when there is a failure of a dam. Although this type of flood has many similarities to floods produced by precipitation runoff, the dam-break flood has some very important differences which make it difficult to analyze with the common techniques which have worked so well for the precipitation-runoff floods. To aid NWS flash flood hydrologists who are called upon to forecast the downstream flooding (flood inundation information and warning times) resulting from dam-failures, a numerical model (DAMBRK) has been recently developed. Herein is presented an outline of the model's theoretical basis, its predictive capabilities, and ways of utilizing the model for forecasting of dam-break floods. The DAMBRK model may also be used for a multitude of purposes by planners, designers, and analysts who are concerned with possible future or historical flood inundation mapping due to dam-break floods and/or reservoir spillway floods, or any specified flood hydrograph.

2. MODEL DEVELOPMENT

The DAMBRK model attempts to represent the current state-of-the-art in understanding of dam failures and the utilization of hydrodynamic theory to predict the dam-break wave formation and downstream progression. The model has wide applicability; it can function with various levels of input data ranging from rough estimates to complete data specification; the required data is readily accessible; and it is economically feasible to use, i.e., it requires a minimal computation effort on large computing facilities.

The model consists of three functional parts, namely: (1) description of the dam failure mode, i.e., the temporal and geometrical description of the breach; (2) computation of the time history (hydrograph) of the outflow through the breach as affected by the breach description, reservoir inflow, reservoir storage characteristics, spillway outflows, and downstream tailwater elevations; and (3) routing of the outflow hydrograph through the downstream valley in order to determine the changes in the hydrograph due to valley storage, frictional resistance, downstream bridges or dams, and to determine the resulting water surface elevations (stages) and flood-wave travel times.

DAMBRK is an expanded version of a practical operational model first presented in 1977 by the author (Fread, 1977). That model was based on previous work by the author on modeling breached dams (Fread and Harbaugh, 1973) and routing of flood waves (Fread, 1974, 1976). There have been a number of other operational dam-break models that have appeared recently in the literature, e.g., Price, et al. (1977), Gundlach and Thomas (1977), Thomas (1977), Keefer and Simons (1977), Chen and Druffel (1977), Balloffet, et al. (1974), Balloffet (1977), Brown and Rogers (1977), Rajar (1978), Brevard and Theurer (1979). DAMBRK differs from each of these models in the treatment of the breach formation, the outflow hydrograph generation, and the downstream flood routing.

6. SUMMARY AND CONCLUSIONS

A dam-break flood forecasting model (DAMBRK) is described and applied to some actual dam-break flood waves. The model consists of a breach component which utilizes simple parameters to provide a temporal and geometrical description of the breach. A second component computes the reservoir outflow hydrograph resulting from the breach via a broad-crested weir-flow approximation, which includes effects of submergence from downstream tailwater depths and corrections for approach velocities. Also, the effects of storage depletion and upstream inflows on the computed outflow hydrograph are accounted for through storage routing within the reservoir. The third component consists of a dynamic routing technique for determining the modifications to the dam-break flood wave as it advances through the downstream valley, including its travel time and resulting water surface elevations. The dynamic routing component is based on a weighted, four-point non-linear finite difference solution of the one-dimensional equations of unsteady flow which allows variable time and distance steps to be used in the solution procedure. Provisions are included for routing supercritical flows as well as subcritical flows, and incorporating the effects of downstream obstructions such as road-bridge embankments and/or other dams.

Model data requirements are flexible, allowing minimal data input when it is not available while permitting extensive data to be used when appropriate.

The model was tested on the Teton Dam failure and the Buffalo Creek coal-waste dam collapse. Computed outflow volumes through the breaches coincided with the observed values in magnitude and timing. Observed peak discharges along the downstream valleys were satisfactorily reproduced by the model even though the flood waves were severely attenuated as they advanced downstream. The computed peak flood elevations were within an average of 1.5 ft and 1.8 ft of the observed maximum elevations for Teton and Buffalo Creek, respectively. Both the Teton and Buffalo Creek simulations indicated an important lack of sensitivity of downstream discharge to errors in the forecast of the breach size and timing. Such errors produced significant differences in the peak discharge in the vicinity of the dams; however, the differences were rapidly reduced as the waves advanced downstream. Computational requirements of the model are quite feasible; CPU time (IBM 360/195) was 0.005 second per hr per mile of prototype dimensions for the Teton Dam simulation, and 0.095 second per hr per mile for the Buffalo Creek simulation. The more rapidly rising Buffalo Creek wave (τ = 0.008 hr as compared to Teton where τ = 1.25 hr) required smaller Δt and Δx computational steps; however, total computation times (Buffalo: 19 sec and Teton: 18 sec) were similar since the Buffalo Creek wave attenuated to insignificant values in a shorter distance downstream and in less time than the Teton flood wave.

Suggested ways for using the DAMBRK model in preparation of pre-computed flood information and in real-time forecasting were presented.

APPENDIX B

SAMPLE DAMBRK OUTPUT

TY COSOUT.OUT

1/23/83 RJW

PROGRAM DAMBRK---VERSION-A-09/10/80

Watana & Devil Canyon Failure

COSOUT.OUT

Watana TF = 2.5
D.C. TF = 0.5

ANALYSIS OF THE DOWNSTREAM FLOOD HYDROGRAPH

PRODUCED BY THE DAM BREAK OF

MULTIPLE FAILURES

ON

SUSITNA RIVER

ANALYSIS BY

ACRES AMERICAN INC.
LIBERTY BANK BLD., MAIN AT COURT ST.
BUFFALO, NEW YORK 14202

BASED ON PROCEDURE DEVELOPED BY

DANNY L. FREAD, PH.D., RESEARCH HYDROLOGIST
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NOAA, NATIONAL WEATHER SERVICE
SILVER SPRING, MARYLAND 20910

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*******************************
*******************************
***                         ***
***  SUMMARY OF INPUT DATA  ***
***                         ***
*******************************
*******************************
```

INPUT CONTROL PARAMETERS FOR MULTIPLE FAILURES

PARAMETER	VARIABLE	VALUE
NUMBER OF DYNAMIC ROUTING REACHES	KKN	1
TYPE OF RESERVOIR ROUTING	KUI	1
MULTIPLE DAM INDICATOR	MULDAM	2
PRINTING INSTRUCTIONS FOR INPUT SUMMARY	KDMP	3
NO. OF RESERVOIR INFLOW HYDROGRAPH POINTS	ITEH	5
INTERVAL OF CROSS-SECTION INFO PRINTED OUT WHEN JNK=9	NPRT	0
FLOOD-PLAIN MODEL PARAMETER	KFLP	0
LANDSLIDE PARAMETER	KSL	0

IDAM= 5

IDAM= 12

DAM NUMBER 1

MULTIPLE FAILURES RESERVOIR AND BREACH PARAMETERS

PARAMETER	UNITS	VARIABLE	VALUE
ELEVATION OF WATER SURFACE	FT	YO	2208.01
SIDE SLOPE OF BREACH		Z	1.00
ELEVATION OF BOTTOM OF BREACH	FT	YBMIN	1460.00
WIDTH OF BASE OF BREACH	FT	BB	420.00
TIME TO MAXIMUM BREACH SIZE	HR	TFH	2.50
ELEVATION OF WATER WHEN BREACHED	FT	HF	2208.00
ELEVATION OF TOP OF DAM	FT	HD	2205.00
ELEVATION OF UNCONTROLLED SPILLWAY CREST	FT	HSP	0.00
ELEVATION OF CENTER OF GATE OPENINGS	FT	HGT	0.00
DISCHARGE COEF. FOR UNCONTROLLED SPILLWAY		CS	0.00
DISCHARGE COEF. FOR GATE FLOW		CG	0.00
DISCHARGE COEF. FOR UNCONTROLLED WEIR FLOW		CDO	6720.00
DISCHARGE THRU TURBINES	CFS	QT	326000.00

DAM NUMBER 2

MULTIPLE FAILURES RESERVOIR AND BREACH PARAMETERS

PARAMETER	UNITS	VARIABLE	VALUE
ELEVATION OF WATER SURFACE	FT	YO	1455.00
SIDE SLOPE OF BREACH		Z	1.34
ELEVATION OF BOTTOM OF BREACH	FT	YBMIN	907.00
WIDTH OF BASE OF BREACH	FT	BB	120.00
TIME TO MAXIMUM BREACH SIZE	HR	TFH	0.50

ELEVATION OF WATER WHEN BREACHED	FT	HF	1475.90
ELEVATION OF TOP OF DAM	FT	HD	1465.00
ELEVATION OF UNCONTROLLED SPILLWAY CREST	FT	HSP	1470.00
ELEVATION OF CENTER OF GATE OPENINGS	FT	HGT	0.00
DISCHARGE COEF. FOR UNCONTROLLED SPILLWAY		CS	2900.00
DISCHARGE COEF. FOR GATE FLOW		CG	0.00
DISCHARGE COEF. FOR UNCONTROLLED WEIR FLOW		CDO	4277.50
DISCHARGE THRU TURBINES	CFS	QT	160500.00

DHF(INTERVAL BETWEEN INPUT HYDROGRAPH ORDINATES) = 0.00 HRS.

TEH(TIME AT WHICH COMPUTATIONS TERMINATE) = 8.00 HRS.

INFLOW HYDROGRAPH TO MULTIPLE FAILURES
****

252743. 255000. 257000. 257500. 258000.

TIME OF INFLOW HYDROGRAPH ORDINATES

0.00 2.00 4.00 6.00 15.00

CROSS-SECTIONAL PARAMETERS FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	VARIABLE	VALUE
NUMBER OF CROSS-SECTIONS	NS	24
MAXIMUM NUMBER OF TOP WIDTHS	NCS	8
NUMBER OF CROSS-SECTIONAL HYDROGRAPHS TO PLOT	NTT	5
TYPE OF OUTPUT OTHER THAN HYDROGRAPH PLOTS	JNK	4
CROSS-SECTIONAL SMOOTHING PARAMETER	KSA	0
DOWNSTREAM SUPERCRITICAL OR NOT	KSUPC	0
NO. OF LATERAL INFLOW HYDROGRAPHS	LQ	7

NUMBER OF CROSS-SECTION WHERE HYDROGRAPH DESIRED
(MAX NUMBER OF HYDROGRAPHS = 6)

6 12 16 18 23

CROSS-SECTIONAL VARIABLES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	UNITS	VARIABLE
LOCATION OF CROSS-SECTION	MI	XS(I)
ELEVATION (MSL) OF FLOODING AT CROSS-SECTION	FT	FSTG(I)
ELEV CORRESPONDING TO EACH TOP WIDTH	FT	HS(K,I)
TOP WIDTH CORRESPONDING TO EACH ELEV (ACTIVE FLOW PORTION)	FT	BS(K,I)
TOP WIDTH CORRESPONDING TO EACH ELEV	FT	BSS(K,I)

```
SURFACE AREA CORRESPONDING TO EACH ELEV    ACRES   DSA(K,I)
     (ACTIVE FLOW PORTION)
SURFACE AREA CORRESPONDING TO EACH ELEV    ACRES   SSA(K,I)
     (OFF-CHANNEL PORTION)

NUMBER OF CROSS-SECTION                              I
NUMBER OF ELEVATION LEVEL                            K
```

```
CROSS-SECTION NUMBER  1
*************************

XS(I) =   0.000   FSTG(I) =    0.00         XSL(I) =     0.0          XSR(I) =     0.0

HS  ...   2200.0  2230.0  2380.0  2585.0  2643.0  2765.0  2862.0  3060.0

BS  ...    792.8   987.9  1963.5  3296.8  3674.0  4467.5  5098.4  6386.2

BSS ...      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER  2
*************************

XS(I) =   3.784   FSTG(I) =    0.00         XSL(I) =     0.0          XSR(I) =     0.0

HS  ...   2160.0  2190.0  2340.0  2545.0  2603.0  2725.0  2822.0  3020.0

BS  ...    792.8   987.9  1963.5  3296.8  3674.0  4467.5  5098.4  6386.2

BSS ...      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER  3
*************************

XS(I) =  35.000   FSTG(I) =    0.00         XSL(I) =     0.0          XSR(I) =     0.0

HS  ...   1830.0  1860.0  2010.0  2215.0  2273.0  2395.0  2492.0  2690.0

BS  ...    792.8   987.9  1963.5  3296.8  3674.0  4467.5  5098.4  6386.2

BSS ...      0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
```

CROSS-SECTION NUMBER 4
****

XS(I) = 63.000 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1465.0	1495.0	1645.0	1850.0	1908.0	2030.0	2127.0	2325.0
BS ...	792.8	1114.0	2723.0	4921.0	5543.0	6852.0	7892.0	10015.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 5
****

XS(I) = 70.500 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1460.0	1490.0	1640.0	1845.0	1903.0	2025.0	2122.0	2320.0
BS ...	250.0	350.0	825.0	1340.0	1830.0	2300.0	2920.0	4800.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 6
****

XS(I) = 71.000 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1455.0	1500.0	1600.0	1700.0	1800.0	2000.0	2100.0	2200.0
BS ...	370.0	725.0	980.0	1550.0	1720.0	2560.0	3200.0	5680.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 7
****

XS(I) = 73.300 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1450.0	1500.0	1550.0	1600.0	1700.0	1800.0	1900.0	2000.0
BS ...	260.0	1680.0	2130.0	2785.0	3700.0	4440.0	5325.0	6430.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 8
****

XS(I) = 78.200 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1379.0	1400.0	1500.0	1600.0	1700.0	1800.0	1900.0	2000.0
BS ...	475.0	2120.0	3395.0	4175.0	5010.0	5800.0	6940.0	8175.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 9
****

XS(I) = 85.900 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1265.0	1300.0	1400.0	1500.0	1600.0	1700.0	1800.0	1900.0
BS ...	785.0	990.0	1115.0	1590.0	1960.0	2850.0	3375.0	4225.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 10
****

XS(I) = 91.500 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	1122.0	1200.0	1300.0	1400.0	1500.0	1600.0	1700.0	1900.0
BS ...	325.0	520.0	890.0	1150.0	1590.0	2640.0	3275.0	4545.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 11
****

XS(I) = 97.700 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	995.0	1100.0	1200.0	1300.0	1400.0	1500.0	1800.0	1900.0
BS ...	310.0	535.0	845.0	1125.0	1530.0	1900.0	4165.0	5210.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 12
****

XS(I) = 101.800   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	907.0	1100.0	1200.0	1300.0	1400.0	1500.0	1600.0	1700.0
BS ...	265.0	565.0	765.0	960.0	1400.0	2650.0	3240.0	4120.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 13
****

XS(I) = 102.200   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	902.0	1100.0	1200.0	1300.0	1400.0	1500.0	1600.0	1700.0
BS ...	265.0	565.0	765.0	960.0	1400.0	2650.0	3240.0	4120.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 14
****

XS(I) = 103.800   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	880.0	950.0	1000.0	1050.0	1100.0	1200.0	1300.0	1400.0
BS ...	370.0	530.0	630.0	1100.0	1570.0	1900.0	2210.0	2550.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 15
****

XS(I) = 109.000   FSTG(I) = 0.00   XSL(I) = 0.0   XSR(I) = 0.0

HS ...	800.0	825.0	850.0	875.0	900.0	1000.0	1100.0	1200.0
BS ...	1575.0	1865.0	2110.0	2600.0	3060.0	3540.0	4865.0	5385.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 16
****

XS(I) = 112.900 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	730.0	745.0	800.0	850.0	900.0	950.0	1000.0	1100.0
BS ...	1695.0	3100.0	4550.0	5350.0	6125.0	6425.0	6750.0	7470.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 17
****

XS(I) = 119.900 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	635.0	650.0	675.0	700.0	750.0	800.0	850.0	900.0
BS ...	2220.0	2770.0	3720.0	4650.0	4800.0	4950.0	5225.0	5500.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 18
****

XS(I) = 130.800 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	523.0	540.0	550.0	575.0	600.0	650.0	700.0	750.0
BS ...	400.0	490.0	550.0	1465.0	2315.0	2735.0	3165.0	3380.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CROSS-SECTION NUMBER 19
****

XS(I) = 135.200 FSTG(I) = 0.00 XSL(I) = 0.0 XSR(I) = 0.0

HS ...	480.0	490.0	500.0	525.0	550.0	600.0	650.0	700.0
BS ...	660.0	825.0	970.0	1340.0	1675.0	2365.0	2915.0	3455.0
BSS ...	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

```
CROSS-SECTION NUMBER 20
*************************

XS(I) = 141.300   FSTO(I) =    0.00          XSL(I) =     0.0          XSR(I) =     0.0

HS  ...     440.0   445.0   450.0   475.0   500.0   525.0   550.0   600.0
BS  ...    1155.0  1250.0  1400.0  2445.0  3475.0  3600.0  3700.0  4005.0
BSS ...       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER 21
*************************

XS(I) = 144.000   FSTO(I) =    0.00          XSL(I) =     0.0          XSR(I) =     0.0

HS  ...     412.0   416.0   420.0   432.0   448.0   457.0   482.0   557.0
BS  ...     720.0   760.0   800.0  3150.0  3260.0  3370.0  3600.0  4665.0
BSS ...       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER 22
*************************

XS(I) = 148.600   FSTO(I) =    0.00          XSL(I) =     0.0          XSR(I) =     0.0

HS  ...     365.0   372.0   380.0   390.0   400.0   415.0   430.0   450.0
BS  ...    1010.0  1500.0  2100.0  6000.0 10000.0 15900.0 17200.0 19000.0
BSS ...       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0


CROSS-SECTION NUMBER 23
*************************

XS(I) = 152.800   FSTO(I) =    0.00          XSL(I) =     0.0          XSR(I) =     0.0

HS  ...     333.0   338.0   345.0   355.0   365.0   375.0   385.0   400.0
BS  ...    2950.0  3600.0  8000.0 13700.0 19000.0 24500.0 29500.0 33200.0
BSS ...       0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
```

```
CROSS-SECTION NUMBER 24
************************

XS(I) = 157.700   FSTG(I) =     0.00          XSL(I) =     0.0          XSR(I) =     0.0

HS  ...    298.0    308.0    320.0    335.0    350.0    365.0    380.0    400.0

BS  ...   3500.0   6000.0   8200.0  11000.0  17000.0  23000.0  29000.0  29750.0

BSS ...      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0



MANNING N ROUGHNESS COEFFICIENTS FOR THE GIVEN REACHES
      (CN(K,I),K=1,NCS) WHERE I = REACH NUMBER
*************************************************************

REACH  1 ... 0.045  0.045  0.045  0.045  0.045  0.045  0.045  0.045

REACH  2 ... 0.035  0.035  0.035  0.035  0.035  0.035  0.035  0.035

REACH  3 ... 0.035  0.035  0.035  0.035  0.035  0.035  0.035  0.035

REACH  4 ... 0.035  0.035  0.035  0.035  0.035  0.035  0.035  0.035

REACH  5 ... 0.045  0.045  0.045  0.045  0.045  0.045  0.045  0.045

REACH  6 ... 0.095  0.095  0.095  0.095  0.095  0.095  0.095  0.095

REACH  7 ... 0.089  0.089  0.089  0.089  0.089  0.089  0.089  0.089

REACH  8 ... 0.075  0.075  0.075  0.075  0.075  0.075  0.075  0.075

REACH  9 ... 0.075  0.075  0.075  0.075  0.075  0.075  0.075  0.075

REACH 10 ... 0.075  0.075  0.075  0.075  0.075  0.075  0.075  0.075

REACH 11 ... 0.070  0.070  0.070  0.070  0.070  0.070  0.070  0.070
```

REACH 12 ...	0.095	0.095	0.095	0.095	0.095	0.095	0.095	0.095
REACH 13 ...	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
REACH 14 ...	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
REACH 15 ...	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055
REACH 16 ...	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
REACH 17 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 18 ...	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
REACH 19 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 20 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 21 ...	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
REACH 22 ...	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
REACH 23 ...	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060

CROSS-SECTIONAL VARIABLES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	UNITS	VARIABLE
MINIMUM COMPUTATIONAL DISTANCE USED BETWEEN CROSS-SECTIONS	MI	DXM(I)
CONTRACTION - EXPANSION COEFFICIENTS BETWEEN CROSS-SECTIONS		FKC(I)

REACH NUMBER	DXM(I)	FKC(I)
1	3.000	0.000
2	4.000	0.000
3	7.000	0.000
4	8.000	0.200
5	0.500	-0.700
6	0.500	-0.700
7	0.900	0.000
8	1.500	0.000
9	1.500	0.000
10	1.500	0.000
11	1.500	0.000
12	1.500	0.000
13	0.500	0.000
14	1.300	-0.500

15	0.700	0.000
16	0.350	0.000
17	0.520	0.000
18	0.880	0.000
19	0.870	0.000
20	1.350	0.000
21	0.420	-0.700
22	0.250	0.000
23	0.320	0.000

DOWNSTREAM FLOW PARAMETERS FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

PARAMETER	UNITS	VARIABLE	VALUE
**	*******	******	*************
MAX DISCHARGE AT DOWNSTREAM EXTREMITY	CFS	QMAXD	0.0
MAX LATERAL OUTFLOW PRODUCING LOSSES	CFS/FT	QLL	0.000
INITIAL SIZE OF TIME STEP	HR	DTHM	0.040
INITIAL WATER SURFACE ELEVATION DOWNSTREAM	FT	YDN	0.00
SLOPE OF CHANNEL DOWNSTREAM OF DAM	FT/MI	SOM	0.00
THETA WEIGHTING FACTOR		THETA	0.00
CONVERGENCE CRITERION FOR STAGE	FT	EPSY	0.100
TIME AT WHICH DAM STARTS TO FAIL	HR	TFI	0.00

LATERAL INFLOW REACH NUMBER

LQX(I)

7

10

14

16

18

20

23

(QL(L, 1),L=1,ITEM)

27000. 27000. 27000. 27000. 27000.

```
          (QL(L, 2),L=1,ITEM)
  27000.     27000.     27000.     27000.     27000.

          (QL(L, 3),L=1,ITEM)
  14000.     14000.     14000.     14000.     14000.

          (QL(L, 4),L=1,ITEM)
  14000.     14000.     14000.     14000.     14000.

          (QL(L, 5),L=1,ITEM)
   6000.      6000.      6000.      6000.      6000.

          (QL(L, 6),L=1,ITEM)
   6000.      6000.      6000.      6000.      6000.

          (QL(L, 7),L=1,ITEM)
 228000.    228000.    228000.    228000.    228000.
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***                           ***
***   SUMMARY OF OUTPUT DATA  ***
***                           ***
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CROSS-SECTION NO.	MILE	BOTTOM ELEVATION FEET	REACHNO.	REACH LENGTH MILES	SLOPE FT/MI	MESSAGE
1	0.00	2200.00				
2	3.78	2160.00	1	3.78	10.57	
3	35.00	1830.00	2	31.22	10.57	
4	63.00	1465.00	3	28.00	13.04	
5	70.50	1460.00	4	7.50	0.67	
6	71.00	1455.00	5	0.50	10.00	
7	73.30	1450.00	6	2.30	2.17	
8	78.20	1379.00	7	4.90	14.49	
9	85.90	1265.00	8	7.70	14.81	
10	91.50	1122.00	9	5.60	25.54	
11	97.70	995.00	10	6.20	20.48	
12	101.80	907.00	11	4.10	21.46	
13	102.20	902.00	12	0.40	12.50	
14	103.80	880.00	13	1.60	13.75	
15	109.00	800.00	14	5.20	15.38	
16	112.90	730.00	15	3.90	17.95	
17	119.90	635.00	16	7.00	13.57	
18	130.80	523.00	17	10.90	10.28	
19	135.20	480.00	18	4.40	9.77	
20	141.30	440.00	19	6.10	6.56	
21	144.00	412.00	20	2.70	10.37	
22	148.60	365.00	21	4.60	10.22	
23	152.80	333.00	22	4.20	7.62	
24	157.70	298.00	23	4.90	7.14	

NUMBER OF INTERMEDIATE STATIONS (N) = 146 (MAXIMUM ALLOWABLE = 200

RE-NUMBERED VALUES FOR IDAM

IDAM(1) = 14

IDAM(2) = 38

1 252743.00
2 252743.00
3 252743.00
4 252743.00

5	252743.00
6	252743.00
7	252743.00
8	252743.00
9	252743.00
10	252743.00
11	252743.00
12	252743.00
13	252743.00
14	361093.06
15	361093.06
16	361093.06
17	361093.06
18	361093.06
19	361093.06
20	388093.06
21	388093.06
22	388093.06
23	388093.06
24	388093.06
25	388093.06
26	388093.06
27	388093.06
28	388093.06
29	388093.06
30	388093.06
31	388093.06
32	388093.06
33	415093.06
34	415093.06
35	415093.06
36	415093.06
37	415093.06
38	160500.00
39	160500.00
40	160500.00
41	160500.00
42	160500.00
43	174500.00
44	174500.00
45	174500.00
46	174500.00
47	174500.00
48	174500.00
49	174500.00
50	174500.00
51	174500.00
52	188500.00
53	188500.00
54	188500.00
55	188500.00
56	188500.00
57	188500.00
58	188500.00
59	188500.00
60	188500.00
61	188500.00
62	188500.00
63	188500.00
64	188500.00
65	188500.00
66	188500.00
67	188500.00
68	188500.00
69	188500.00
70	188500.00
[illegible]	[illegible]

71	188500.00
72	188500.00
73	188500.00
74	188500.00
75	188500.00
76	188500.00
77	188500.00
78	188500.00
79	188500.00
80	188500.00
81	188500.00
82	188500.00
83	188500.00
84	188500.00
85	188500.00
86	188500.00
87	188500.00
88	188500.00
89	188500.00
90	188500.00
91	188500.00
92	194500.00
93	194500.00
94	194500.00
95	194500.00
96	194500.00
97	194500.00
98	194500.00
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104	200500.00
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127	200500.00
128	200500.00
129	200500.00
130	200500.00
131	200500.00
132	428500.00
133	428500.00
134	428500.00
135	428500.00
136	428500.00

137 428500.00
138 420500.00
139 428500.00
140 428500.00
141 420500.00
142 420500.00
143 428500.00
144 428500.00
145 428500.00
146 428500.00

L=146	X(L)=	157.700	YD(L)=	314.18	HO=	316.51	K= 0
L=145	X(L)=	157.373	YD(L)=	316.54	HO=	316.51	K= 2
L=144	X(L)=	157.047	YD(L)=	318.95	HO=	318.86	K= 2
L=143	X(L)=	156.720	YD(L)=	321.40	HO=	321.24	K= 2
L=142	X(L)=	156.393	YD(L)=	323.86	HO=	323.67	K= 3
L=141	X(L)=	156.067	YD(L)=	326.33	HO=	326.13	K= 3
L=140	X(L)=	155.740	YD(L)=	328.80	HO=	328.60	K= 3
L=139	X(L)=	155.413	YD(L)=	331.27	HO=	331.07	K= 3
L=138	X(L)=	155.087	YD(L)=	333.72	HO=	333.53	K= 3
L=137	X(L)=	154.760	YD(L)=	336.16	HO=	335.99	K= 3
L=136	X(L)=	154.433	YD(L)=	338.57	HO=	338.44	K= 2
L=135	X(L)=	154.107	YD(L)=	340.96	HO=	340.87	K= 2
L=134	X(L)=	153.780	YD(L)=	343.32	HO=	343.27	K= 2
L=133	X(L)=	153.453	YD(L)=	345.64	HO=	345.64	K= 2
L=132	X(L)=	153.127	YD(L)=	347.93	HO=	347.98	K= 2
L=131	X(L)=	152.800	YD(L)=	349.65	HO=	350.29	K= 3
L=130	X(L)=	152.538	YD(L)=	349.77	HO=	351.96	K= 4
L=129	X(L)=	152.275	YD(L)=	350.02	HO=	352.71	K= 4
L=128	X(L)=	152.013	YD(L)=	350.52	HO=	352.89	K= 4
L=127	X(L)=	151.750	YD(L)=	351.48	HO=	353.27	K= 4
L=126	X(L)=	151.488	YD(L)=	353.00	HO=	354.00	K= 3
L=125	X(L)=	151.225	YD(L)=	354.96	HO=	355.24	K= 3
L=124	X(L)=	150.963	YD(L)=	357.13	HO=	356.98	K= 3
L=123	X(L)=	150.700	YD(L)=	359.39	HO=	359.05	K= 3
L=122	X(L)=	150.438	YD(L)=	361.68	HO=	361.26	K= 3
L=121	X(L)=	150.175	YD(L)=	364.00	HO=	363.53	K= 3
L=120	X(L)=	149.913	YD(L)=	366.34	HO=	365.84	K= 3
L=119	X(L)=	149.650	YD(L)=	368.71	HO=	368.17	K= 3
L=118	X(L)=	149.388	YD(L)=	371.11	HO=	370.52	K= 3
L=117	X(L)=	149.125	YD(L)=	373.54	HO=	372.91	K= 3
L=116	X(L)=	148.863	YD(L)=	376.00	HO=	375.32	K= 3
L=115	X(L)=	148.600	YD(L)=	378.50	HO=	377.77	K= 3
L=114	X(L)=	148.140	YD(L)=	384.29	HO=	382.95	K= 3
L=113	X(L)=	147.680	YD(L)=	389.73	HO=	388.45	K= 4
L=112	X(L)=	147.220	YD(L)=	395.21	HO=	394.06	K= 4
L=111	X(L)=	146.760	YD(L)=	400.39	HO=	399.52	K= 3
L=110	X(L)=	146.300	YD(L)=	405.41	HO=	404.85	K= 3
L=109	X(L)=	145.840	YD(L)=	410.35	HO=	409.95	K= 3
L=108	X(L)=	145.380	YD(L)=	415.28	HO=	414.93	K= 3
L=107	X(L)=	144.920	YD(L)=	420.22	HO=	419.87	K= 3
L=106	X(L)=	144.460	YD(L)=	425.18	HO=	424.80	K= 3
L=105	X(L)=	144.000	YD(L)=	430.18	HO=	429.75	K= 3
L=104	X(L)=	142.650	YD(L)=	443.72	HO=	444.03	K= 3
L=103	X(L)=	141.300	YD(L)=	455.49	HO=	457.95	K= 3
L=102	X(L)=	140.429	YD(L)=	462.38	HO=	462.32	K= 2
L=101	X(L)=	139.557	YD(L)=	468.74	HO=	467.51	K= 3
L=100	X(L)=	138.686	YD(L)=	475.10	HO=	474.13	K= 3
L= 99	X(L)=	137.814	YD(L)=	481.50	HO=	480.50	K= 3
L= 98	X(L)=	136.943	YD(L)=	487.96	HO=	486.88	K= 3
L= 97	X(L)=	136.071	YD(L)=	494.49	HO=	493.30	K= 3
L= 96	X(L)=	135.200	YD(L)=	501.12	HO=	499.80	K= 3
L= 95	X(L)=	134.320	YD(L)=	508.98	HO=	509.26	K= 3
L= 94	X(L)=	133.440	YD(L)=	518.85	HO=	517.95	K= 3
L= 93	X(L)=	132.560	YD(L)=	528.71	HO=	526.81	K= 3
L= 92	X(L)=	131.680	YD(L)=	538.76	HO=	536.68	K= 3
L= 91	X(L)=	130.800	YD(L)=	549.10	HO=	546.64	K= 3

L= 90	X(L)=	130.255	YD(L)=	555.11	HU=	553.65	K= 3
L= 89	X(L)=	129.710	YD(L)=	559.09	HO=	560.51	K= 3
L= 88	X(L)=	129.165	YD(L)=	562.63	HO=	565.50	K= 4
L= 87	X(L)=	128.620	YD(L)=	566.19	HO=	569.26	K= 4
L= 86	X(L)=	128.075	YD(L)=	569.98	HO=	572.81	K= 4
L= 85	X(L)=	127.530	YD(L)=	574.06	HO=	576.40	K= 3
L= 84	X(L)=	126.985	YD(L)=	578.42	HO=	580.42	K= 4
L= 83	X(L)=	126.440	YD(L)=	583.03	HO=	584.64	K= 3
L= 82	X(L)=	125.895	YD(L)=	587.83	HO=	589.13	K= 3
L= 81	X(L)=	125.350	YD(L)=	592.74	HO=	593.83	K= 3
L= 80	X(L)=	124.805	YD(L)=	597.75	HO=	598.68	K= 3
L= 79	X(L)=	124.260	YD(L)=	602.82	HO=	603.65	K= 3
L= 78	X(L)=	123.715	YD(L)=	607.95	HO=	608.69	K= 3
L= 77	X(L)=	123.170	YD(L)=	613.13	HO=	613.79	K= 3
L= 76	X(L)=	122.625	YD(L)=	618.34	HO=	618.94	K= 3
L= 75	X(L)=	122.080	YD(L)=	623.59	HO=	624.14	K= 3
L= 74	X(L)=	121.535	YD(L)=	628.87	HO=	629.37	K= 3
L= 73	X(L)=	120.990	YD(L)=	634.17	HO=	634.63	K= 3
L= 72	X(L)=	120.445	YD(L)=	639.49	HO=	639.92	K= 3
L= 71	X(L)=	119.900	YD(L)=	644.83	HO=	645.23	K= 3
L= 70	X(L)=	119.550	YD(L)=	649.42	HO=	649.71	K= 3
L= 69	X(L)=	119.200	YD(L)=	654.24	HO=	654.25	K= 2
L= 68	X(L)=	118.850	YD(L)=	659.05	HO=	658.95	K= 2
L= 67	X(L)=	118.500	YD(L)=	663.87	HO=	663.77	K= 2
L= 66	X(L)=	118.150	YD(L)=	668.69	HO=	668.59	K= 2
L= 65	X(L)=	117.800	YD(L)=	673.51	HO=	673.41	K= 2
L= 64	X(L)=	117.450	YD(L)=	678.33	HO=	678.22	K= 2
L= 63	X(L)=	117.100	YD(L)=	683.15	HO=	683.04	K= 2
L= 62	X(L)=	116.750	YD(L)=	687.97	HO=	687.86	K= 2
L= 61	X(L)=	116.400	YD(L)=	692.80	HO=	692.69	K= 2
L= 60	X(L)=	116.050	YD(L)=	697.63	HO=	697.51	K= 2
L= 59	X(L)=	115.700	YD(L)=	702.45	HO=	702.34	K= 2
L= 58	X(L)=	115.350	YD(L)=	707.28	HO=	707.16	K= 2
L= 57	X(L)=	115.000	YD(L)=	712.11	HO=	711.99	K= 2
L= 56	X(L)=	114.650	YD(L)=	716.95	HO=	716.82	K= 2
L= 55	X(L)=	114.300	YD(L)=	721.78	HO=	721.65	K= 2
L= 54	X(L)=	113.950	YD(L)=	726.62	HO=	726.49	K= 2
L= 53	X(L)=	113.600	YD(L)=	731.45	HO=	731.32	K= 2
L= 52	X(L)=	113.250	YD(L)=	736.29	HO=	736.16	K= 2
L= 51	X(L)=	112.900	YD(L)=	741.13	HO=	741.00	K= 2
L= 50	X(L)=	112.120	YD(L)=	756.31	HO=	755.09	K= 3
L= 49	X(L)=	111.340	YD(L)=	769.99	HO=	769.72	K= 2
L= 48	X(L)=	110.560	YD(L)=	784.34	HO=	784.15	K= 2
L= 47	X(L)=	109.780	YD(L)=	798.42	HO=	798.16	K= 2
L= 46	X(L)=	109.000	YD(L)=	812.65	HO=	812.38	K= 2
L= 45	X(L)=	107.700	YD(L)=	841.30	HO=	832.54	K= 4
L= 44	X(L)=	106.400	YD(L)=	860.86	HO=	856.97	K= 3
L= 43	X(L)=	105.100	YD(L)=	887.07	HO=	881.08	K= 3
L= 42	X(L)=	103.800	YD(L)=	913.94	HO=	903.97	K= 3
L= 41	X(L)=	103.267	YD(L)=	928.34	HO=	917.84	K= 4
L= 40	X(L)=	102.733	YD(L)=	939.23	HO=	932.14	K= 4
L= 39	X(L)=	102.200	YD(L)=	949.73	HO=	914.79	K= 3
L= 38	X(L)=	101.800	YD(L)=	949.73	HO=	993.73	K= 0
L= 37	X(L)=	99.750	YD(L)=	999.41	HO=	993.73	K= 3
L= 36	X(L)=	97.700	YD(L)=	1060.12	HO=	1040.57	K= 4
L= 35	X(L)=	96.150	YD(L)=	1089.43	HO=	1083.52	K= 3
L= 34	X(L)=	94.600	YD(L)=	1120.69	HO=	1122.40	K= 3
L= 33	X(L)=	93.050	YD(L)=	1151.93	HO=	1152.68	K= 3
L= 32	X(L)=	91.500	YD(L)=	1182.66	HO=	1183.94	K= 3
L= 31	X(L)=	89.633	YD(L)=	1218.14	HO=	1230.84	K= 3
L= 30	X(L)=	87.767	YD(L)=	1256.77	HO=	1271.90	K= 3
L= 29	X(L)=	85.900	YD(L)=	1299.27	HO=	1308.96	K= 3
L= 28	X(L)=	84.360	YD(L)=	1326.48	HO=	1324.65	K= 3
L= 27	X(L)=	82.820	YD(L)=	1347.38	HO=	1347.08	K= 2
L= 26	X(L)=	81.280	YD(L)=	1368.46	HO=	1371.13	K= 2
L= 25	X(L)=	79.740	YD(L)=	1389.35	HO=	1392.12	K= 3

L=	24	X(L)=	78.200	YD(L)=	1410.17	HO=	1413.11	K=	3
L=	23	X(L)=	77.220	YD(L)=	1427.97	HO=	1425.36	K=	3
L=	22	X(L)=	76.240	YD(L)=	1445.14	HO=	1410.37	K=	3
L=	21	X(L)=	75.260	YD(L)=	1462.49	HO=	1457.85	K=	3
L=	20	X(L)=	74.280	YD(L)=	1479.92	HO=	1475.11	K=	4
L=	19	X(L)=	73.300	YD(L)=	1496.80	HO=	1492.51	K=	3
L=	18	X(L)=	72.725	YD(L)=	1505.02	HO=	1496.71	K=	4
L=	17	X(L)=	72.150	YD(L)=	1510.59	HO=	1502.78	K=	4
L=	16	X(L)=	71.575	YD(L)=	1515.46	HO=	1509.68	K=	3
L=	15	X(L)=	71.000	YD(L)=	1520.30	HO=	1514.90	K=	3
L=	14	X(L)=	70.500	YD(L)=	1520.30	HO=	1525.30	K=	0
L=	13	X(L)=	63.000	YD(L)=	1529.09	HO=	1525.30	K=	3
L=	12	X(L)=	56.000	YD(L)=	1531.88	HO=	1618.45	K=	7
L=	11	X(L)=	49.000	YD(L)=	1659.46	HO=	1667.36	K=	4
L=	10	X(L)=	42.000	YD(L)=	1765.17	HO=	1732.55	K=	7
L=	9	X(L)=	35.000	YD(L)=	1844.03	HO=	1849.19	K=	3
L=	8	X(L)=	30.541	YD(L)=	1903.44	HO=	1897.37	K=	4
L=	7	X(L)=	26.081	YD(L)=	1942.04	HO=	1944.45	K=	3
L=	6	X(L)=	21.622	YD(L)=	1995.04	HO=	1993.46	K=	3
L=	5	X(L)=	17.162	YD(L)=	2038.14	HO=	2039.25	K=	3
L=	4	X(L)=	12.703	YD(L)=	2088.06	HO=	2087.30	K=	3
L=	3	X(L)=	8.243	YD(L)=	2133.28	HO=	2133.81	K=	3
L=	2	X(L)=	3.784	YD(L)=	2181.74	HO=	2181.38	K=	3
L=	1	X(L)=	0.000	YD(L)=	2226.18	HO=	2221.08	K=	3
L=	146	X(L)=	157.700	YD(L)=	314.18	HO=	316.51	K=	0
L=	145	X(L)=	157.373	YD(L)=	316.54	HO=	316.51	K=	2
L=	144	X(L)=	157.047	YD(L)=	318.95	HO=	318.86	K=	2
L=	143	X(L)=	156.720	YD(L)=	321.40	HO=	321.24	K=	2
L=	142	X(L)=	156.393	YD(L)=	323.86	HO=	323.67	K=	3
L=	141	X(L)=	156.067	YD(L)=	326.33	HO=	326.13	K=	3
L=	140	X(L)=	155.740	YD(L)=	328.80	HO=	328.60	K=	3
L=	139	X(L)=	155.413	YD(L)=	331.27	HO=	331.07	K=	3
L=	138	X(L)=	155.087	YD(L)=	333.72	HO=	333.53	K=	3
L=	137	X(L)=	154.760	YD(L)=	336.16	HO=	335.99	K=	3
L=	136	X(L)=	154.433	YD(L)=	338.57	HO=	338.44	K=	2
L=	135	X(L)=	154.107	YD(L)=	340.96	HO=	340.87	K=	2
L=	134	X(L)=	153.780	YD(L)=	343.32	HO=	343.27	K=	2
L=	133	X(L)=	153.453	YD(L)=	345.64	HO=	345.64	K=	2
L=	132	X(L)=	153.127	YD(L)=	347.93	HO=	347.98	K=	2
L=	131	X(L)=	152.800	YD(L)=	349.65	HO=	350.29	K=	3
L=	130	X(L)=	152.538	YD(L)=	349.77	HO=	351.96	K=	4
L=	129	X(L)=	152.275	YD(L)=	350.02	HO=	352.71	K=	4
L=	128	X(L)=	152.013	YD(L)=	350.52	HO=	352.89	K=	4
L=	127	X(L)=	151.750	YD(L)=	351.48	HO=	353.27	K=	4
L=	126	X(L)=	151.488	YD(L)=	353.00	HO=	354.00	K=	3
L=	125	X(L)=	151.225	YD(L)=	354.96	HO=	355.24	K=	3
L=	124	X(L)=	150.963	YD(L)=	357.13	HO=	356.98	K=	3
L=	123	X(L)=	150.700	YD(L)=	359.39	HO=	359.05	K=	3
L=	122	X(L)=	150.438	YD(L)=	361.68	HO=	361.26	K=	3
L=	121	X(L)=	150.175	YD(L)=	364.00	HO=	363.53	K=	3
L=	120	X(L)=	149.913	YD(L)=	366.34	HO=	365.84	K=	3
L=	119	X(L)=	149.650	YD(L)=	368.71	HO=	368.17	K=	3
L=	118	X(L)=	149.388	YD(L)=	371.11	HO=	370.52	K=	3
L=	117	X(L)=	149.125	YD(L)=	373.54	HO=	372.91	K=	3
L=	116	X(L)=	148.863	YD(L)=	376.00	HO=	375.32	K=	3
L=	115	X(L)=	148.600	YD(L)=	378.50	HO=	377.77	K=	3
L=	114	X(L)=	148.140	YD(L)=	384.29	HO=	382.95	K=	3
L=	113	X(L)=	147.680	YD(L)=	389.73	HO=	388.45	K=	4
L=	112	X(L)=	147.220	YD(L)=	395.21	HO=	394.06	K=	4
L=	111	X(L)=	146.760	YD(L)=	400.39	HO=	399.52	K=	3
L=	110	X(L)=	146.300	YD(L)=	405.41	HO=	404.85	K=	3
L=	109	X(L)=	145.840	YD(L)=	410.35	HO=	409.95	K=	3
L=	108	X(L)=	145.380	YD(L)=	415.28	HO=	414.93	K=	3
L=	107	X(L)=	144.920	YD(L)=	420.22	HO=	419.87	K=	3
L=	106	X(L)=	144.460	YD(L)=	425.18	HO=	424.80	K=	3
L=	105	X(L)=	144.000	YD(L)=	430.18	HO=	429.75	K=	3

L=104	X(L)=	142.65	YD(L)=	44[illegible].12	HO=	[illegible].93	K=3
L=103	X(L)=	141.300	YD(L)=	455.49	HO=	457.95	K= 3
L=102	X(L)=	140.429	YD(L)=	462.38	HO=	462.32	K= 2
L=101	X(L)=	139.557	YD(L)=	468.74	HO=	467.51	K= 3
L=100	X(L)=	138.686	YD(L)=	475.10	HO=	474.13	K= 3
L= 99	X(L)=	137.814	YD(L)=	481.50	HO=	480.50	K= 3
L= 98	X(L)=	136.943	YD(L)=	487.96	HO=	486.00	K= 3
L= 97	X(L)=	136.071	YD(L)=	494.49	HO=	493.30	K= 3
L= 96	X(L)=	135.200	YD(L)=	501.12	HO=	499.00	K= 3
L= 95	X(L)=	134.320	YD(L)=	508.98	HO=	509.26	K= 3
L= 94	X(L)=	133.440	YD(L)=	518.85	HO=	517.95	K= 3
L= 93	X(L)=	132.560	YD(L)=	528.71	HO=	526.81	K= 3
L= 92	X(L)=	131.680	YD(L)=	538.76	HO=	536.60	K= 3
L= 91	X(L)=	130.800	YD(L)=	549.10	HO=	546.64	K= 3
L= 90	X(L)=	130.255	YD(L)=	555.11	HO=	553.03	K= 3
L= 89	X(L)=	129.710	YD(L)=	559.09	HO=	560.51	K= 3
L= 88	X(L)=	129.165	YD(L)=	562.63	HO=	565.50	K= 4
L= 87	X(L)=	128.620	YD(L)=	566.19	HO=	569.26	K= 4
L= 86	X(L)=	128.075	YD(L)=	569.98	HO=	572.81	K= 4
L= 85	X(L)=	127.530	YD(L)=	574.06	HO=	576.48	K= 3
L= 84	X(L)=	126.985	YD(L)=	578.42	HO=	580.42	K= 4
L= 83	X(L)=	126.440	YD(L)=	583.03	HO=	584.64	K= 3
L= 82	X(L)=	125.895	YD(L)=	587.83	HO=	589.13	K= 3
L= 81	X(L)=	125.350	YD(L)=	592.74	HO=	593.83	K= 3
L= 80	X(L)=	124.805	YD(L)=	597.75	HO=	598.68	K= 3
L= 79	X(L)=	124.260	YD(L)=	602.82	HO=	603.65	K= 3
L= 78	X(L)=	123.715	YD(L)=	607.95	HO=	608.69	K= 3
L= 77	X(L)=	123.170	YD(L)=	613.13	HO=	613.79	K= 3
L= 76	X(L)=	122.625	YD(L)=	618.34	HO=	618.94	K= 3
L= 75	X(L)=	122.080	YD(L)=	623.59	HO=	624.14	K= 3
L= 74	X(L)=	121.535	YD(L)=	628.87	HO=	629.37	K= 3
L= 73	X(L)=	120.990	YD(L)=	634.17	HO=	634.63	K= 3
L= 72	X(L)=	120.445	YD(L)=	639.49	HO=	639.92	K= 3
L= 71	X(L)=	119.900	YD(L)=	644.83	HO=	645.23	K= 3
L= 70	X(L)=	119.550	YD(L)=	649.42	HO=	649.71	K= 3
L= 69	X(L)=	119.200	YD(L)=	654.24	HO=	654.25	K= 2
L= 68	X(L)=	118.850	YD(L)=	659.05	HO=	658.95	K= 2
L= 67	X(L)=	118.500	YD(L)=	663.87	HO=	663.77	K= 2
L= 66	X(L)=	118.150	YD(L)=	668.69	HO=	668.59	K= 2
L= 65	X(L)=	117.800	YD(L)=	673.51	HO=	673.41	K= 2
L= 64	X(L)=	117.450	YD(L)=	678.33	HO=	678.22	K= 2
L= 63	X(L)=	117.100	YD(L)=	683.15	HO=	683.04	K= 2
L= 62	X(L)=	116.750	YD(L)=	687.97	HO=	687.86	K= 2
L= 61	X(L)=	116.400	YD(L)=	692.80	HO=	692.69	K= 2
L= 60	X(L)=	116.050	YD(L)=	697.63	HO=	697.51	K= 2
L= 59	X(L)=	115.700	YD(L)=	702.45	HO=	702.34	K= 2
L= 58	X(L)=	115.350	YD(L)=	707.28	HO=	707.16	K= 2
L= 57	X(L)=	115.000	YD(L)=	712.11	HO=	711.99	K= 2
L= 56	X(L)=	114.650	YD(L)=	716.95	HO=	716.82	K= 2
L= 55	X(L)=	114.300	YD(L)=	721.78	HO=	721.65	K= 2
L= 54	X(L)=	113.950	YD(L)=	726.62	HO=	726.49	K= 2
L= 53	X(L)=	113.600	YD(L)=	731.45	HO=	731.32	K= 2
L= 52	X(L)=	113.250	YD(L)=	736.29	HO=	736.16	K= 2
L= 51	X(L)=	112.900	YD(L)=	741.13	HO=	741.00	K= 2
L= 50	X(L)=	112.120	YD(L)=	756.31	HO=	755.09	K= 3
L= 49	X(L)=	111.340	YD(L)=	769.99	HO=	769.72	K= 2
L= 48	X(L)=	110.560	YD(L)=	784.34	HO=	784.15	K= 2
L= 47	X(L)=	109.780	YD(L)=	798.42	HO=	798.16	K= 2
L= 46	X(L)=	109.000	YD(L)=	812.65	HO=	812.38	K= 2
L= 45	X(L)=	107.700	YD(L)=	841.30	HO=	832.54	K= 4
L= 44	X(L)=	106.400	YD(L)=	860.86	HO=	856.97	K= 3
L= 43	X(L)=	105.100	YD(L)=	887.07	HO=	881.08	K= 3
L= 42	X(L)=	103.800	YD(L)=	913.94	HO=	903.97	K= 3
L= 41	X(L)=	103.267	YD(L)=	928.34	HO=	917.04	K= 4
L= 40	X(L)=	102.733	YD(L)=	939.23	HO=	932.84	K= 4
L= 39	X(L)=	102.200	YD(L)=	949.73	HO=	944.79	K= 3

L	X(L)	YD(L)	HO	K
L= 38	X(L)= 101.800	YD(L)= 1453.00	HO= 1444.00	K= 0
L= 37	X(L)= 99.750	YD(L)= 1454.98	HO= 1499.00	K= 4
L= 36	X(L)= 97.700	YD(L)= 1455.00	HO= 1520.99	K= 4
L= 35	X(L)= 96.150	YD(L)= 1455.01	HO= 1508.74	K= 4
L= 34	X(L)= 94.600	YD(L)= 1455.02	HO= 1502.63	K= 4
L= 33	X(L)= 93.050	YD(L)= 1455.04	HO= 1502.64	K= 4
L= 32	X(L)= 91.500	YD(L)= 1455.08	HO= 1502.66	K= 4
L= 31	X(L)= 89.633	YD(L)= 1455.12	HO= 1518.60	K= 4
L= 30	X(L)= 87.767	YD(L)= 1455.17	HO= 1526.60	K= 4
L= 29	X(L)= 85.900	YD(L)= 1455.25	HO= 1526.65	K= 4
L= 28	X(L)= 84.360	YD(L)= 1455.35	HO= 1501.84	K= 4
L= 27	X(L)= 82.820	YD(L)= 1455.45	HO= 1489.50	K= 4
L= 26	X(L)= 81.280	YD(L)= 1455.57	HO= 1489.60	K= 4
L= 25	X(L)= 79.740	YD(L)= 1455.74	HO= 1489.71	K= 4
L= 24	X(L)= 78.200	YD(L)= 1456.05	HO= 1489.86	K= 4
L= 23	X(L)= 77.220	YD(L)= 1456.67	HO= 1481.50	K= 4
L= 22	X(L)= 76.240	YD(L)= 1458.58	HO= 1477.66	K= 4
L= 21	X(L)= 75.260	YD(L)= 1465.02	HO= 1478.93	K= 4
L= 20	X(L)= 74.280	YD(L)= 1479.79	HO= 1483.10	K= 3
L= 19	X(L)= 73.300	YD(L)= 1496.79	HO= 1493.71	K= 3
L= 18	X(L)= 72.725	YD(L)= 1505.02	HO= 1496.64	K= 4
L= 17	X(L)= 72.150	YD(L)= 1510.59	HO= 1502.78	K= 4
L= 16	X(L)= 71.575	YD(L)= 1515.46	HO= 1509.68	K= 3
L= 15	X(L)= 71.000	YD(L)= 1520.30	HO= 1514.90	K= 3
L= 14	X(L)= 70.500	YD(L)= 2208.01	HO= 2213.01	K= 0
L= 13	X(L)= 63.000	YD(L)= 2208.01	HO= 2213.01	K= 3
L= 12	X(L)= 56.000	YD(L)= 2208.01	HO= 2301.76	K= 4
L= 11	X(L)= 49.000	YD(L)= 2208.01	HO= 2344.89	K= 4
L= 10	X(L)= 42.000	YD(L)= 2208.01	HO= 2344.89	K= 4
L= 9	X(L)= 35.000	YD(L)= 2208.01	HO= 2344.89	K= 5
L= 8	X(L)= 30.541	YD(L)= 2208.01	HO= 2300.78	K= 4
L= 7	X(L)= 26.081	YD(L)= 2208.01	HO= 2278.73	K= 4
L= 6	X(L)= 21.622	YD(L)= 2208.01	HO= 2278.73	K= 4
L= 5	X(L)= 17.162	YD(L)= 2208.02	HO= 2278.73	K= 4
L= 4	X(L)= 12.703	YD(L)= 2208.03	HO= 2278.73	K= 5
L= 3	X(L)= 8.243	YD(L)= 2208.08	HO= 2278.74	K= 5
L= 2	X(L)= 3.784	YD(L)= 2208.38	HO= 2278.77	K= 5
L= 1	X(L)= 0.000	YD(L)= 2218.54	HO= 2271.80	K= 5

I	X(I)	YD(I)	YNORM(I)
1	0.00	2218.54	2226.18
2	3.78	2208.38	2181.74
3	8.24	2208.08	2133.28
4	12.70	2208.03	2088.06
5	17.16	2200.02	2038.14
6	21.62	2208.01	1995.04
7	26.08	2208.01	1942.04
8	30.54	2208.01	1903.44
9	35.00	2208.01	1844.03
10	42.00	2208.01	1765.17
11	49.00	2208.01	1659.46
12	56.00	2208.01	1531.88
13	63.00	2208.01	1529.09
14	70.50	2208.01	1520.30
15	71.00	1520.30	1520.30
16	71.58	1515.46	1515.46
17	72.15	1510.59	1510.59
18	72.73	1505.02	1505.02
19	73.30	1496.79	1496.80
20	74.28	1479.79	1479.92
21	75.26	1465.02	1462.49
22	76.24	1458.58	1445.14
23	77.22	1456.67	1427.97
24	78.20	1456.05	1410.17
25	79.74	1455.74	1389.35
26	81.28	1455.57	1368.46
27	82.82	1455.45	1347.38

28	84.36	1455.3[illegible]	1324.78
29	85.90	1455.25	1299.27
30	87.77	1455.17	1256.77
31	89.63	1455.12	1218.14
32	91.50	1455.08	1182.66
33	93.05	1455.04	1151.93
34	94.60	1455.02	1120.69
35	96.15	1455.01	1089.43
36	97.70	1455.00	1060.12
37	99.75	1454.98	999.41
38	101.80	1455.00	949.73
39	102.20	949.73	949.73
40	102.73	939.23	939.23
41	103.27	928.34	928.34
42	103.80	913.94	913.94
43	105.10	887.07	887.07
44	106.40	860.86	860.86
45	107.70	841.30	841.30
46	109.00	812.65	812.65
47	109.78	798.42	798.42
48	110.56	784.34	784.34
49	111.34	769.99	769.99
50	112.12	756.31	756.31
51	112.90	741.13	741.13
52	113.25	736.29	736.29
53	113.60	731.45	731.45
54	113.95	726.62	726.62
55	114.30	721.78	721.78
56	114.65	716.95	716.95
57	115.00	712.11	712.11
58	115.35	707.28	707.28
59	115.70	702.45	702.45
60	116.05	697.63	697.63
61	116.40	692.80	692.80
62	116.75	687.97	687.97
63	117.10	683.15	683.15
64	117.45	678.33	678.33
65	117.80	673.51	673.51
66	118.15	668.69	668.69
67	118.50	663.87	663.87
68	118.85	659.05	659.05
69	119.20	654.24	654.24
70	119.55	649.42	649.42
71	119.90	644.83	644.83
72	120.44	639.49	639.49
73	120.99	634.17	634.17
74	121.53	628.87	628.87
75	122.08	623.59	623.59
76	122.62	618.34	610.34
77	123.17	613.13	613.13
78	123.71	607.95	607.95
79	124.26	602.82	602.82
80	124.80	597.75	597.75
81	125.35	592.74	592.74
82	125.89	587.83	587.83
83	126.44	583.03	583.03
84	126.98	578.42	578.42
85	127.53	574.06	574.06
86	128.07	569.98	569.98
87	128.62	566.19	566.19
88	129.16	562.63	562.63
89	129.71	559.09	559.09
90	130.25	555.11	555.11
91	130.80	549.10	549.10
92	131.68	538.76	530.76
93	132.56	528.71	528.71

94	133.47	516.85	510.05
95	134.32	508.98	508.98
96	135.20	501.12	501.12
97	136.07	494.49	494.49
98	136.94	487.96	487.96
99	137.81	481.50	481.50
100	138.69	475.10	475.10
101	139.56	468.74	468.74
102	140.43	462.38	462.38
103	141.30	455.49	455.49
104	142.65	443.72	443.72
105	144.00	430.18	430.18
106	144.46	425.18	425.18
107	144.92	420.22	420.22
108	145.38	415.28	415.28
109	145.84	410.35	410.35
110	146.30	405.41	405.41
111	146.76	400.39	400.39
112	147.22	395.21	395.21
113	147.68	389.73	389.73
114	148.14	384.29	384.29
115	148.60	378.50	378.50
116	148.86	376.00	376.00
117	149.13	373.54	373.54
118	149.39	371.11	371.11
119	149.65	368.71	368.71
120	149.91	366.34	366.34
121	150.18	364.00	364.00
122	150.44	361.68	361.68
123	150.70	359.39	359.39
124	150.96	357.13	357.13
125	151.23	354.96	354.96
126	151.49	353.00	353.00
127	151.75	351.48	351.48
128	152.01	350.52	350.52
129	152.28	350.02	350.02
130	152.54	349.77	349.77
131	152.80	349.65	349.65
142	153.13	347.93	347.93
133	153.45	345.64	345.64
134	153.78	343.32	343.32
135	154.11	340.96	340.96
136	154.43	338.57	338.57
137	154.76	336.16	336.16
138	155.09	333.72	333.72
139	155.41	331.27	331.27
140	155.74	328.80	328.80
141	156.07	326.33	326.33
142	156.39	323.86	323.86
143	156.72	321.40	321.40
144	157.05	318.95	318.95
145	157.37	316.54	316.54
146	157.70	314.18	314.18

```
TT =  0.0000          DTH =  0.0400          ITERR =   0
QU(1) =    252743.0     YU(1) =      2218.5  QU(N) =   428500.0  YU(N) =      314.18  FRDM=0.68 IFR=  1 FRM=0.00 IFM= 13

TT =  0.0000          DTH =  0.0400          ITERR =   1
QU(1) =    252743.0     YU(1) =      2218.5  QU(N) =   429697.0  YU(N) =      314.18  FRDM=0.68 IFR=  1 FRM=0.00 IFM= 13

TT =  0.0000          DTH =  0.0400          ITERR =   1
QU(1) =    252743.0     YU(1) =      2218.5  QU(N) =   429601.2  YU(N) =      314.18  FRDM=0.68 IFR=  1 FRM=0.00 IFM= 13

TT =  0.0400          DTH =  0.0400          ITERR =   1
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```
TT =    8.0000              DIH =  0.0400          ITERR =    2
QU(1) =    257611.1      YU(1) =        2225.9   QU(N) = 15266066.0   YU(N) =       377.92   FRDM=2.56 IFR= 11 FRM=0.10 IFM= 13
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KTIME=203      ALLOWABLE KTIME= 698            TT=    0.0
```

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	********	**********	*********	*********	*********
0.000	2228.27	257611	2.800	11.33	7.72	0.00	0.00
3.784	2208.40	317065	0.480	9.56	6.52	0.00	0.00
8.243	2208.09	621556	0.400	8.69	5.92	0.00	0.00
12.703	2208.03	1147668	0.600	9.99	6.81	0.00	0.00
17.162	2208.02	1910650	0.240	11.17	7.62	0.00	0.00
21.622	2208.02	2928112	0.200	12.53	8.54	0.00	0.00
26.081	2208.01	4234858	0.120	14.96	10.20	0.00	0.00
30.541	2208.02	5901427	0.280	17.47	11.91	0.00	0.00
35.000	2208.02	7958014	0.200	17.35	11.83	0.00	0.00
42.000	2208.03	12458996	0.120	18.88	12.87	0.00	0.00
49.000	2208.03	18725304	0.040	16.99	11.58	0.00	0.00
56.000	2208.02	26391248	0.000	15.35	10.46	0.00	0.00
63.000	2208.01	35471588	0.000	13.96	9.52	0.00	0.00
70.500	2208.01	42587424	0.000	62.18	42.40	0.00	0.00
1 71.000	1887.49	42587424	2.520	75.18	51.26	0.00	0.00
71.575	1862.08	42547012	2.640	62.87	42.86	0.00	0.00
72.150	1845.43	42417684	2.880	53.73	36.64	0.00	0.00
72.725	1834.87	42181500	2.960	46.34	31.59	0.00	0.00
2 73.300	1827.47	41820912	3.000	39.98	27.26	0.00	0.00
74.280	1819.31	41234012	3.040	37.01	25.23	0.00	0.00
75.260	1813.16	40452496	3.080	34.17	23.30	0.00	0.00
76.240	1808.46	39507136	3.080	30.46	20.77	0.00	0.00
77.220	1804.92	38556228	3.120	27.45	18.72	0.00	0.00
3 78.200	1802.18	37447756	3.120	24.53	16.72	0.00	0.00
79.740	1797.23	35882208	3.120	24.93	17.00	0.00	0.00
81.280	1791.10	34552812	3.160	25.66	17.50	0.00	0.00
82.820	1782.83	33866440	3.200	27.42	18.69	0.00	0.00
84.360	1770.60	33424858	3.200	31.75	21.64	0.00	0.00
4 85.900	1748.72	33102712	3.280	40.48	27.60	0.00	0.00
87.767	1727.13	32738712	3.320	40.28	27.46	0.00	0.00
89.633	1704.16	32370350	3.400	40.77	27.80	0.00	0.00
5 91.500	1678.24	31986412	3.440	41.73	28.45	0.00	0.00
93.050	1655.93	31726170	3.440	42.10	28.70	0.00	0.00
94.600	1633.45	31497282	3.480	42.38	28.89	0.00	0.00
96.150	1610.53	31329138	3.520	43.11	29.40	0.00	0.00
6 97.700	1587.09	31221118	3.520	44.03	30.02	0.00	0.00
99.750	1554.84	31140230	3.520	46.48	31.69	0.00	0.00
101.800	1486.38	31111910	3.520	60.02	40.92	0.00	0.00
102.200	1395.66	31111910	3.560	89.69	61.15	0.00	0.00

102.[illegible]	[illegible].3	[illegible]9922	3.[illegible]	[illegible]	[illegible].60	0.[illegible]	[illegible]
103.267	1287.94	31106220	3.560	79.59	54.27	0.00	0.00
103.800	1252.43	31104928	3.560	69.45	47.35	0.00	0.00
105.100	1187.22	31107104	3.600	60.15	41.01	0.00	0.00
106.400	1130.05	31095154	3.600	54.05	36.85	0.00	0.00
107.700	1075.58	31082102	3.640	50.53	34.45	0.00	0.00
109.000	976.75	31084596	3.640	65.95	44.97	0.00	0.00
109.780	960.00	31082242	3.640	50.40	39.87	0.00	0.00
110.560	942.65	31074844	3.680	53.34	36.36	0.00	0.00

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	*******	**********	*********	********	*********
111.340	925.22	31071896	3.680	49.60	33.82	0.00	0.00
112.120	907.18	31060380	3.720	47.09	32.11	0.00	0.00
112.900	887.83	31036336	3.760	45.75	31.20	0.00	0.00
113.250	882.69	31039204	3.800	45.86	31.26	0.00	0.00
113.600	877.71	31025584	3.840	45.80	31.28	0.00	0.00
113.950	072.84	31008818	3.840	45.90	31.29	0.00	0.00
114.300	860.19	30907972	3.920	45.88	31.28	0.00	0.00
114.650	863.87	30961824	4.000	45.82	31.24	0.00	0.00
115.000	859.98	30934044	4.040	45.52	31.04	0.00	0.00
115.350	856.53	30898216	4.120	45.26	30.86	0.00	0.00
115.700	853.47	30853374	4.120	44.88	30.60	0.00	0.00
116.050	050.76	30799250	4.160	44.39	30.27	0.00	0.00
116.400	848.33	30736224	4.200	43.79	29.86	0.00	0.00
116.750	846.19	30665176	4.200	43.09	29.38	0.00	0.00
117.100	844.26	30593378	4.200	41.99	28.63	0.00	0.00
117.450	842.51	30517732	4.200	41.18	28.08	0.00	0.00
117.800	840.94	30437978	4.240	40.35	27.51	0.00	0.00
110.150	839.51	30355102	4.240	39.52	26.94	0.00	0.00
118.500	838.20	30278678	4.240	38.40	26.18	0.00	0.00
118.850	837.00	30201376	4.240	37.61	25.64	0.00	0.00
119.200	835.88	30123054	4.240	36.85	25.13	0.00	0.00
119.550	834.84	30051962	4.240	35.89	24.47	0.00	0.00
119.900	833.86	29982134	4.240	35.21	24.00	0.00	0.00
120.445	831.86	29876980	4.240	35.12	23.95	0.00	0.00
120.990	829.83	29780804	4.240	35.29	24.06	0.00	0.00
121.535	827.75	29690360	4.240	35.29	24.06	0.00	0.00
122.080	825.61	29606382	4.240	35.52	24.22	0.00	0.00
122.625	823.41	29530492	4.240	35.63	24.29	0.00	0.00
123.170	821.14	29458908	4.280	35.95	24.51	0.00	0.00
123.715	810.78	29396984	4.280	36.17	24.66	0.00	0.00
124.260	816.33	29337450	4.280	36.58	24.94	0.00	0.00
124.805	813.76	29287806	4.280	36.94	25.19	0.00	0.00
125.350	811.05	29239658	4.280	37.40	25.55	0.00	0.00
125.895	808.19	29200138	4.280	37.99	25.90	0.00	0.00
126.440	805.13	29162536	4.280	38.69	26.38	0.00	0.00
126.985	801.84	29130766	4.280	39.40	26.86	0.00	0.00
127.530	798.28	29102700	4.280	40.31	27.48	0.00	0.00
128.075	794.38	29076104	4.280	41.30	28.16	0.00	0.00
128.620	790.05	29056406	4.320	42.53	28.99	0.00	0.00

129.165	786.15	29036486	4.320	45.78	24.99	0.00	0.00
129.710	779.40	29019456	4.320	45.69	31.15	0.00	0.00
130.255	772.67	29005960	4.320	47.92	32.67	0.00	0.00
12 130.000	763.96	28991260	4.320	50.92	34.72	0.00	0.00
131.600	755.87	28976520	4.360	51.05	34.80	0.00	0.00
132.560	747.25	28958014	4.360	51.39	35.04	0.00	0.00
133.440	737.67	28943216	4.360	52.02	35.47	0.00	0.00
134.320	726.25	28934120	4.360	53.37	36.39	0.00	0.00
13 135.200	683.12	28928538	4.320	69.14	47.14	0.00	0.00

PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	********	**********	*********	*********	*********
136.071	669.67	28926830	4.400	66.87	45.59	0.00	0.00
136.943	656.67	28919314	4.400	64.88	44.24	0.00	0.00
137.814	644.88	28910270	4.400	62.74	42.78	0.00	0.00
138.606	633.24	28906220	4.440	60.97	41.57	0.00	0.00
139.557	623.08	28892542	4.520	59.01	40.23	0.00	0.00
140.429	615.04	28063044	4.560	55.99	38.17	0.00	0.00
14 141.300	610.74	28831564	4.560	52.52	35.81	0.00	0.00
142.650	608.88	28801742	4.520	44.87	30.59	0.00	0.00
15 144.000	524.68	28794788	4.480	70.99	53.86	0.00	0.00
144.460	516.52	28796170	4.520	63.18	43.07	0.00	0.00
144.920	507.73	28796878	4.520	54.09	36.88	0.00	0.00
145.380	499.24	28796654	4.520	48.03	32.75	0.00	0.00
145.840	491.16	28795200	4.520	43.65	29.76	0.00	0.00
146.300	483.44	28793432	4.560	40.33	27.50	0.00	0.00
146.760	475.98	28793992	4.560	37.76	25.75	0.00	0.00
147.220	468.65	28793024	4.560	35.78	24.39	0.00	0.00
147.680	461.27	28790268	4.600	34.34	23.41	0.00	0.00
148.140	453.49	28788042	4.600	33.57	22.89	0.00	0.00
16 148.600	444.43	28786938	4.600	34.12	23.26	0.00	0.00
148.863	441.21	28784756	4.640	33.16	22.61	0.00	0.00
149.125	438.11	28779588	4.760	32.25	21.99	0.00	0.00
149.388	435.71	28765746	5.000	31.28	21.33	0.00	0.00
149.650	434.07	28733768	5.120	30.10	20.52	0.00	0.00
149.913	432.89	28675600	5.120	28.59	19.49	0.00	0.00
150.175	432.04	28593888	5.160	26.59	18.13	0.00	0.00
150.438	431.42	28492502	5.160	24.71	16.85	0.00	0.00
150.700	430.96	28377526	5.160	22.63	15.43	0.00	0.00
150.963	430.61	28259338	5.160	20.88	14.24	0.00	0.00
151.225	430.35	28142144	5.160	19.09	13.02	0.00	0.00
151.488	430.15	28027826	5.160	17.49	11.92	0.00	0.00
151.750	430.00	27917800	5.160	16.05	10.94	0.00	0.00
152.013	429.88	27812836	5.160	14.76	10.06	0.00	0.00
152.275	429.79	27717316	5.160	13.67	9.32	0.00	0.00
152.538	429.72	27630332	5.160	12.62	8.60	0.00	0.00
17 152.800	429.66	27553452	5.160	11.60	7.96	0.00	0.00
153.127	427.85	27699442	5.160	11.98	8.17	0.00	0.00
153.453	426.03	27632398	5.160	12.19	8.31	0.00	0.00
153.780	424.14	27578476	5.200	12.42	8.47	0.00	0.00
154.107	422.19	27535142	5.200	12.66	8.63	0.00	0.00

154.[illegible]	[illegible].15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
154.760	418.01	27474650	5.200	13.21	9.01	0.00	0.00
155.087	415.76	27457812	5.200	13.52	9.22	0.00	0.00
155.413	413.38	27444142	5.200	13.87	9.46	0.00	0.00
155.740	410.83	27438440	5.240	14.27	9.73	0.00	0.00
156.067	408.06	27435156	5.240	14.72	10.04	0.00	0.00
156.393	405.02	27439010	5.200	15.27	10.41	0.00	0.00
156.720	401.58	27444002	5.200	15.95	10.87	0.00	0.00
157.047	397.53	27456694	5.200	16.87	11.50	0.00	0.00

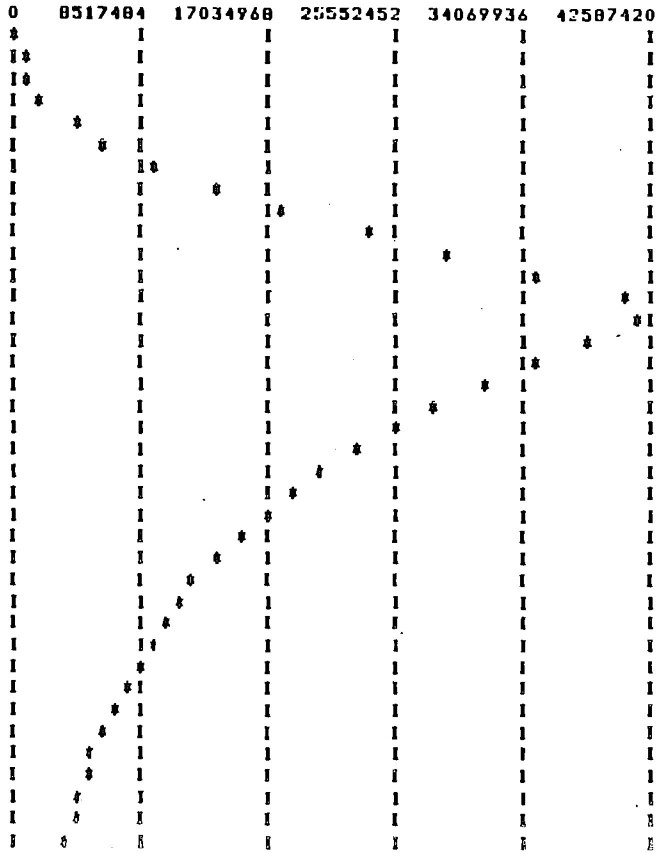
PROFILE OF CRESTS AND TIMES FOR SUSITNA RIVER
BELOW MULTIPLE FAILURES

RVR MILE FROM DAM	MAX ELEV (FT)	MAX FLOW (CFS)	TIME MAX ELEV(HR)	MAX VEL (FT/SEC)	MAX VEL (MI/HR)	FLOOD ELEV (FT)	TIME FLOOD ELEV (HR)
**********	*********	**********	********	**********	*********	*********	*********
157.373	392.45	27475192	5.120	18.25	12.45	0.00	0.00
157.700	385.06	27507370	4.960	21.11	14.39	0.00	0.00

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 15
BELOW MULTIPLE FAILURES AT MILE 71.00

GAGE ZERO = 1455.00 MAX ELEVATION REACHED BY FLOOD WAVE = 1887.49
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 432.49 AT TIME = 2.52 HOURS
MAX FLOW = 42587424 AT TIME = 2.52 HOURS

HR	STAGE	FLOW
0.0	65.3	361093
0.2	70.3	479953
0.4	91.2	1014876
0.6	124.3	2129368
0.8	161.5	3849966
1.0	200.9	6297127
1.2	238.9	9499439
1.4	273.5	13504259
1.6	306.5	18198556
1.8	337.9	23442124
2.0	368.0	29068926
2.2	396.2	34866756
2.4	421.9	40518904
2.6	431.5	41523176
2.8	427.0	38338640
3.0	420.7	34890164
3.2	411.8	31496268
3.4	400.9	28290108
3.6	388.5	25361062
3.8	375.4	22753804
4.0	361.9	20450612
4.2	348.2	18440220
4.4	334.6	16667837
4.6	321.3	15074528
4.8	308.1	13624444
5.0	295.1	12305652
5.2	282.3	11107820
5.4	269.8	10021558
5.6	257.7	9041072
5.8	246.0	8153188
6.0	234.8	7358992
6.2	223.6	6625690
6.4	212.8	5958229
6.6	203.5	5437003
6.8	194.9	4974215
7.0	186.3	4509882
7.2	177.7	4061652
7.4	169.4	3653440
7.6	161.6	3293037



$V_{hydrograph} \approx 4.369 \times 10^{11}\ ft^3$

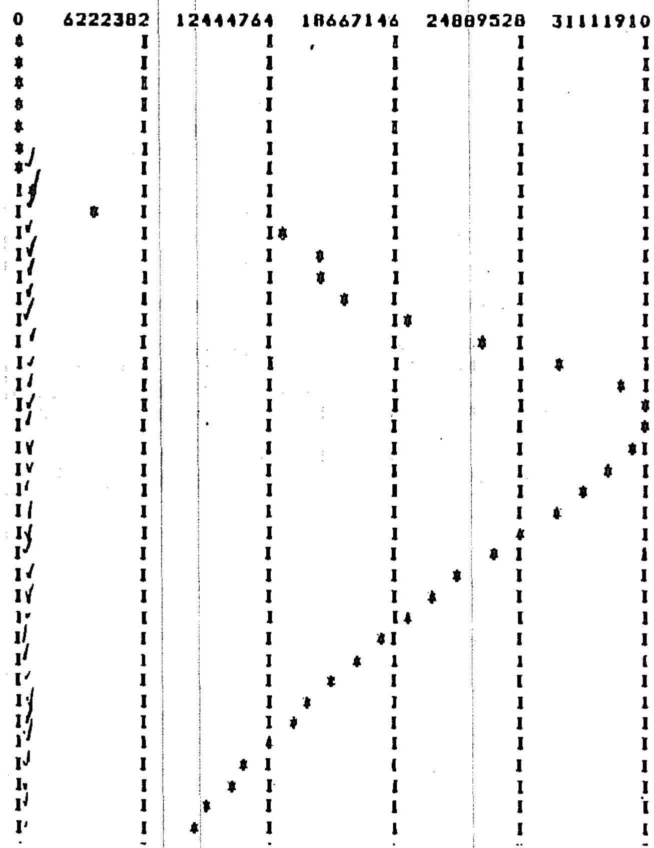
$V_{reservoir} \simeq 4.517 \times 10^{11}\ ft^3$

7.8 154.3 2968915

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 38 *DEVIL CANYON*
BELOW MULTIPLE FAILURES AT MILE 101.80

GAGE ZERO = 907.00 MAX ELEVATION REACHED BY FLOOD WAVE = 1486.38
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 579.38 AT TIME = 3.52 HOURS
MAX FLOW = 31111912 AT TIME = 3.52 HOURS

HR	STAGE	FLOW
0.0	548.0	160500
0.2	553.0	160500
0.4	554.9	160500
0.6	556.6	160500
0.8	558.1	160567
1.0	559.4	167277
1.2	560.7	179916
1.4	567.9	325063
1.6	571.0	3607777
1.8	504.1	13280243
2.0	440.8	14664711
2.2	440.6	14701547
2.4	457.8	16307810
2.6	486.7	19167628
2.8	522.1	23000854
3.0	553.8	26976634
3.2	571.2	29638658
3.4	578.3	30913356
3.6	579.1	31058122
3.8	576.0	30433892
4.0	570.0	29337148
4.2	561.7	27978732
4.4	551.6	26490338
4.6	540.3	24958996
4.8	528.2	23452606
5.0	515.5	22018078
5.2	502.6	20672402
5.4	489.7	19329332
5.6	476.8	18009714
5.8	464.2	16791272
6.0	451.8	15658334
6.2	439.6	14561401
6.4	427.0	13491602
6.6	413.5	12424975
6.8	399.7	11423067
7.0	386.0	10408404
7.2	373.0	9620321
7.4	360.4	8831875
7.6	*347.9*	*8099503*



D.C. failure e 568.9

7.8 335.6 7423592

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 51 *INDIAN CREEK*
BELOW MULTIPLE FAILURES AT MILE 112.90

GAGE ZERO = 730.00 MAX ELEVATION REACHED BY FLOOD WAVE = 887.83
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 157.83 AT TIME = 3.76 HOURS
MAX FLOW = 31036338 AT TIME = 3.72 HOURS

HR	STAGE	FLOW
0.0	11.1	174500
0.2	11.1	174501
0.4	11.2	175231
0.6	11.2	175589
0.8	11.2	175686
1.0	11.2	175706
1.2	11.2	175707
1.4	11.2	175728
1.6	11.2	175595
1.8	11.1	175501
2.0	68.4	7558429
2.2	103.7	14112761
2.4	108.6	14704284
2.6	114.2	16309481
2.8	123.2	19299470
3.0	134.8	23357660
3.2	145.6	27204840
3.4	153.1	29777102
3.6	156.9	30909888
3.8	157.8	30944184
4.0	156.8	30258800
4.2	154.7	29143764
4.4	151.9	27799204
4.6	148.4	26352440
4.8	144.5	24861506
5.0	140.2	23362042
5.2	136.0	21962082
5.4	131.8	20650026
5.6	127.5	19331254
5.8	123.1	18054620
6.0	119.0	16866352
6.2	115.0	15757381
6.4	111.1	14695907
6.6	107.2	13655168
6.8	103.3	12627906
7.0	99.3	11651947
7.2	95.5	10742678
7.4	91.8	9892706
7.6	*88.3*	*9113359*

Plot scale (FLOW): 0 — 6207267 — 12414534 — 18621801 — 24829068 — 31036335

7.8	85.0	8392901

DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 91 *CURRY*
BELOW MULTIPLE FAILURES AT MILE 130.80

GAGE ZERO = 523.00 MAX ELEVATION REACHED BY FLOOD WAVE = 763.96
FLOOD STAGE NOT AVAILABLE
MAX STAGE = 240.96 AT TIME = 4.32 HOURS
MAX FLOW = 28991270 AT TIME = 4.24 HOURS

HR	STAGE	FLOW	0 5798254 11596508 17394762 23193016 28991270
0.0	26.1	188500	
0.2	26.1	188500	
0.4	26.1	188500	
0.6	26.1	188500	
0.8	26.1	188500	
1.0	26.1	188500	
1.2	26.1	188500	
1.4	26.1	188500	
1.6	26.1	188500	
1.8	26.1	188500	
2.0	26.1	188685	
2.2	26.1	188949	
2.4	26.2	189275	
2.6	88.4	4348701	
2.8	140.1	10439139	
3.0	163.4	13660586	
3.2	184.3	17227870	
3.4	203.7	21317502	
3.6	219.7	24800390	
3.8	230.8	27177342	
4.0	237.4	28489240	
4.2	240.4	28973620	
4.4	240.9	28849276	
4.6	239.5	28291464	
4.8	236.7	27438192	
5.0	233.0	26384570	
5.2	228.6	25197396	
5.4	223.7	23968042	
5.6	218.7	22740702	
5.8	213.5	21511230	
6.0	208.1	20276976	
6.2	202.7	19081808	
6.4	197.3	17938606	
6.6	191.9	16846116	
6.8	186.6	15788913	
7.0	181.2	14763081	
7.2	175.9	13769617	
7.4	170.5	12826947	

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7.6  [illegible]
7.8   159.7 11088517  I         I        *I         I         I         I
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DISCHARGE HYDROGRAPH FOR SUSITNA RIVER ... STATION NUMBER 131 Talkeetna

BELOW MULTIPLE FAILURES AT MILE 152.80

GAGE ZERO = 333.00 MAX ELEVATION REACHED BY FLOOD WAVE = 429.66

FLOOD STAGE NOT AVAILABLE

MAX STAGE = 96.66 AT TIME = 5.16 HOURS

MAX FLOW = 27553454 AT TIME = 4.92 HOURS

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HR   STAGE      FLOW  0   5510690  11021380  16532070  22042760  27553450
0.0    16.6   200500  *         I         I         I         I         I
0.2    16.6   200500  *         I         I         I         I         I
0.4    16.7   201047  *         I         I         I         I         I
0.6    16.7   201657  *         I         I         I         I         I
0.8    16.7   202016  *         I         I         I         I         I
1.0    16.7   202222  *         I         I         I         I         I
1.2    16.7   202338  *         I         I         I         I         I
1.4    16.7   202407  *         I         I         I         I         I
1.6    16.7   202450  *         I         I         I         I         I
1.8    16.7   202479  *         I         I         I         I         I
2.0    16.7   202497  *         I         I         I         I         I
2.2    16.7   202508  *         I         I         I         I         I
2.4    16.7   202517  *         I         I         I         I         I
2.6    16.7   202521  *         I         I         I         I         I
2.8    16.7   202524  *         I         I         I         I         I
3.0    16.7   202526  *         I         I         I         I         I
3.2    16.7   202528  *         I         I         I         I         I
3.4    17.1   259199  *         I         I         I         I         I
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6.6    87.6 20243614  I         I         I         I      *  I         I
6.8    85.9 19145956  I         I         I         I    *    I         I
7.0    84.1 18083444  I         I         I         I  *      I         I
7.2    82.4 17053882  I         I         I         I*        I         I
7.4    80.6 16055884  I         I         I        *I         I         I
7.6    78.9 15090451
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ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): C. 72, I. 87

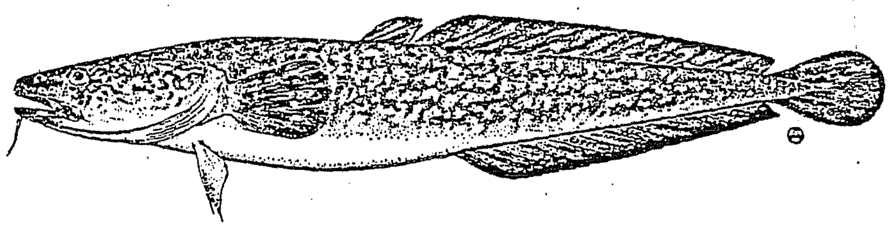
Key to Species

1 Two dorsal fins, base of first short, length of base of second 6 or more times that of the first; 1 anal fin ....BURBOT, *Lota lota* (p. 641)

Three dorsal fins, bases of near equal length; 2 anal fins .... ATLANTIC TOMCOD, *Microgadus tomcod* (p. 646)

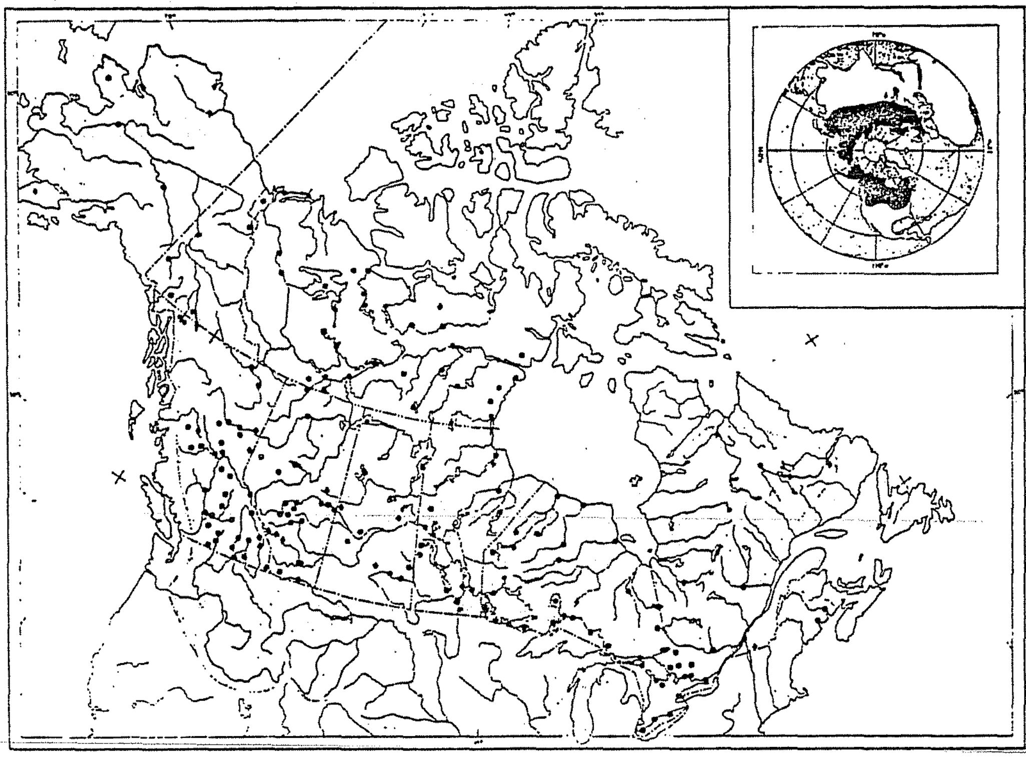
BURBOT

Lota lota (Linnaeus)



Description Body elongate, robust, average length about 15 inches (381 mm); anterior to anus it is nearly round in cross section, the body width to body depth ratio about 1:1, sometimes wider than deep for large adults; posterior to anus body distinctly compressed laterally. Head triangular, broad, depressed, its length 19.2–19.9% of total length; eye small, its diameter 11.2–16.4% of head length; snout projecting, of moderate length 27.5–32.5% of head length; one tube or barbel-like extension for each nostril opening, each about ½ the length of chin barbel; interorbital broad, its width 27.9–31.9% of head length; mouth rather large, slightly subterminal, maxillary extending to below orbit; teeth in jaws and vomer slender, and in many rows, no teeth on tongue or maxillaries; a slender barbel on tip of chin, its length 12.5–29.9% of head length, higher values for large fish. Gill rakers 7–12. Branchiostegal rays 7, rarely 8. Fins: dorsals 2; first dorsal low, short, rays 8–16; second dorsal low, base long, extending onto caudal peduncle and joined to caudal fin, rays 60–79; height of first dorsal and second dorsal about 25% of head length; caudal rounded, joined to second dorsal and anal fins, a deep notch separating fins, but there is no free caudal peduncle; anal long and low, lower than dorsals, rays 59–76; pelvic fins jugular, inserted in advance of pectorals, rays 5–8, second ray prolonged; pectoral fins rounded, short, paddle-like, rays 17–21. Scales cycloid, small, embedded, 27–29 between second dorsal and lateral line, embedded scales on integument on base of fins; lateral line complete. Pyloric caeca 31–150. Vertebrae 50–66.

Colour In the lower Great Lakes region overall colouration of adults yellow, light brown, or tan, becoming darker northward; the background colour is overlaid by a



lacelike pattern of dark brown or black; at times, especially in inland lakes, adults may be uniformly dark brown or black. On young fish, 1.6–3.6 inches (40–90 mm), the speckled pattern is conspicuous and a dark pigmented margin may occur on the posterior portion of the second dorsal and sometimes on the anal, whereas on the caudal the pigmentation does not extend to the outer margin of the fin.

Systematic notes Hubbs and Schultz (1941), in a study of northwestern North American fishes, described *Lota lota leptura* as a new subspecies, found in northwestern North America and western Siberia, distinct from *Lota lota lota* of Eurasia and *Lota lota maculosa* of eastern North America. Subsequently, the name *L. l. maculosa* was reversed to *L. l. lacustris* (Speirs 1952). Studies by Lindsey (1956), Lawler (1963), and McPhail and Lindsey (1970) have shown some evidence of clinal variation. Hence, in the present state of our knowledge, the recognition of subspecies seems unwarranted.

Distribution The burbot is generally distributed, in all suitable habitats, in the fresh waters of continental Eurasia and North America, southward to about 40°N. It is absent from the Kamchatka Peninsula of eastern USSR, from Scotland, Ireland, and most islands, and from the west coast of Norway. It is present in southern England and on Kodiak Island, Alaska.

In Canada this species occurs in New Brunswick, Labrador, Quebec, throughout Ontario, Manitoba, Saskatchewan, Alberta, and the continental portion of the Northwest and Yukon territories, exclusive of the northernmost tips, to central and eastern British Columbia. It is absent from Nova Scotia and the Atlantic islands.

Biology The burbot is one of the few Canadian freshwater fishes that spawns in

midwinter, under
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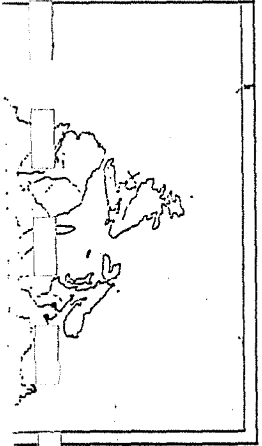

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midwinter, under the ice. It spawns from November to May over the whole of its world distribution, but mainly from January to March in Canada. There is circumstantial evidence that burbot spawn in deep water in some areas but the spawning site is usually in 1–4 feet of water over sand or gravel bottom in shallow bays, or on gravel shoals 5–10 feet deep. Although they usually spawn in the lake they are also known to move into rivers to spawn. Male burbot arrive on the spawning grounds first, followed in 3 or 4 days by the females. The actual spawning activity is said to take place in a writhing ball about 2 feet in diameter, which moves over the bottom and is made up of 10–12 intertwined and constantly moving individuals. This activity takes place only at night and the grounds are deserted in the daytime. Surface temperature of the water during the spawning period is usually 33°–35° F (0.6°–1.7° C); no nest is built by this species and no care is given the young. Average diameter for the semipelagic eggs of burbot has been recorded as 0.5 mm in Manitoba (before extrusion) but 1.25 mm in Minnesota and 1.77 mm in Ontario. Egg number (calculated) increases from about 45,600, in a 343-mm female, to 1,362,077, for a 643-mm female weighing 6.1 pounds. Eggs hatch in 30 days at 43° F and the young, therefore, appear from late February to June.

Growth in the first 4 years of the burbot's life is relatively rapid but after that time there is a gradual decrease in length increment and increase in weight. The young attain a length of 3.0–8.25 inches (76–210 mm) by the end of the first growing season. At age 5 (by otoliths) burbot in Lake Simcoe, Ont., average about 21.5 inches (546 mm) long and weigh 2–3 pounds. The maximum size in that lake was a 13-year-old female, 32.9 inches (838 mm) total length and 9.5 pounds. There is a growth differential between the sexes and at 4 years of age females become significantly longer than males; this condition prevails. The length–weight relation in Manitoba is log W=2.52+3.164 log L, where W=weight in ounces and L=total length in inches. Sexual maturity in the burbot is usually attained during the third or fourth year between 11.0 and 18.9 inches (280–480 mm), but males often mature at a smaller size.

The following comparison of age–length relations reveals that growth rate for the species increases from Manitoba through Ontario to its highest in Lake Erie.

	Heming L., Man. (Lawler 1963)	L. Simcoe, Ont. (McCrimmon & Devitt 1954)	L. Erie, Ont. (Clemens 1951b)
Age	Avg TL (*mm*)	Avg TL (*mm*)	Avg SL (*mm*)
1	147	165	210.0
2	246	305	322.7
3	279	432	376.5
4	323	483	424.0
5	366	546	492.1
6	399	572	539.9
7	429	635	557.8
8	465	673	579.1
9	–	737	590.6
10	–	762	616.0
11	–	787	–
12	–	812	–
13	–	837	–

It would appear that the maximum size known for burbot in Canada is 38.3 inches (937 mm) fork length and 18.5 pounds from Great Slave Lake. Elsewhere in the world, the species is reported to attain lengths in excess of 46 inches (1200 mm) and a weight of 75 pounds. Maximum age in Canada is probably between 10 and 15 years.

In central and southern Canada the burbot is usually a resident of the deep waters of lakes whereas in northern Canada it is also present in large, cool rivers. It has been taken as deep as 700 feet and throughout the summer is restricted to the hypolimnion. Optimum temperature for this species is 60°–65° F (15.6°–18.3° C) and 74° F (23.3° C) would appear to be its upper limit. Burbot move into shallower water during summer nights when they are active and in certain areas they definitely move into shallower water to spawn. Also, there is often a post-spawning movement into tributary rivers during late winter and early spring. During this period of concentration they are sometimes readily caught in large numbers. In the north, summer habitat is often in the river channels of lakes and young-of-the-year and yearling burbot are frequently found along rocky shores and sometimes in weedy areas of tributary streams. All movement seems to cease by July and the large fish penetrate to the deep water where adult burbot share the hypolimnic habitat with lake trout, whitefishes, and sculpins.

The burbot is a voracious predator and night feeder. Small burbot, 2–12 inches (51–305 mm) in length, in streams feed on *Gammarus*, mayfly nymphs, and crayfish. The diet of young burbot, to approximately 19.7 inches (500 mm) in length, consists mainly of immature aquatic insects, crayfish, molluscs, and other deepwater invertebrates, especially *Mysis relicta*, but relatively few fishes. Burbot over 19.7 inches (500 mm) long feed almost exclusively on fishes such as ciscoes, yellow walleye, yellow perch, alewife, kokanee, smelt, sculpins, trout-perch, sticklebacks, freshwater drum, logperch, and white bass, depending on what species are available. In summer large burbot sometimes feed exclusively on *M. relicta* in rivers, and the winter food of adults consists of invertebrates browsed from the bottom, even though (presumably) fish are as available as in the summer. Burbot captured on cisco spawning grounds are often gorged with cisco eggs. The literature contains many detailed analyses of the food of burbot (Van Oosten and Deason 1938; Clemens 1951a; McCrimmon and Devitt 1954).

Since the burbot shares the hypolimnion with such commercially important species as lake trout and the whitefishes, since it eats the same food, and since individual burbot have been reported to consume as many as 179 fish, it is an important direct competitor of these species. Of the deepwater fauna it would appear that the burbot is a predator only on eggs and young of the cisco. In the Susquehanna River, of the northeastern United States, where burbot occur with large numbers of brown and brook trout, it was considered a negligible predator of these sport fishes. In their turn young burbot are known to be part of the food of smelt, yellow perch, and other fishes.

In general, burbot harbour a wide variety of parasites including protozoans, trematodes, cestodes, nematodes, acanthocephalans, leeches, molluscs, and crustaceans. The burbot, throughout its range of distribution, is one of the important second intermediate hosts of *Triaenophorus nodulosus*. Detailed accounts of the parasites found in or on burbot from various parts of Canada have been published by Bangham and his co-workers: for Lake Erie by Bangham and Hunter (1939), for Algonquin Park lakes by Bangham (1941), Lake Huron and Manitoulin Island by Bangham (1955), and from British Columbia by Bangham and Adams (1954).

For a summary of parasites of this species in North America, *see* Hoffman (1967).

Relation to man In Canada the burbot populations are not exploited commercially and the species is almost universally regarded as a coarse fish by management agencies and fishermen alike. Records of commercial catches are not usually entered in statistical summaries (except in Ontario) and thus current or potential yields are difficult to assess. The species may occur in considerable numbers in inland waters but not in the Great Lakes where conditions have changed drastically in recent years. The writings of Dymond (1926), Dymond et al. (1929), and Kolbe (1944), among others attested to the former abundance of the burbot and also that it was once considered to constitute a serious nuisance to the commercial fishery in the Great Lakes. In other Canadian lakes it is sometimes thought to be a serious predator of more valuable species and to compete with such species for food.

Provincial agencies engaged in coarse fish removal programs occasionally harvest burbot from inland lakes during the winter months. One such operation in Manitoba (Anon. 1964), using trapnets, yielded 50,000 pounds of burbot in 3 days' fishing, indicating that high yields may be obtained if the fish are harvested during the winter months, when concentrated because of spawning activities.

Although the white, flaky flesh is palatable and nutritious it is not highly esteemed in most parts of Canada and even early reports concerning its palatability are often contradictory. As early as 1836, Richardson stated that the "flesh was eaten only in times of great

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Nomenclature

Lota lota
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Gadus lacustris
Gadus maculosus
Gadus (Lota) ma
Lota maculosa (L
Lota lota maculos
Lota lota (Linnae
Lota lota lacustri

Etymology

Common name
(Saskatchewan,
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scarcity . . . ," although Melvill (1915) noted that along the east coast of James Bay the flesh was considered to be excellent for food purposes by both Europeans and Indians. In Wyoming it was said by Bjorn (1940) to have long been regarded as a source of food. Nevertheless, attempts to encourage public acceptance of the burbot in Canada as a quality food fish or processed for industrial use have not been very encouraging to date.

When available in sufficient quantities burbot may be used for animal food on fur ranches and in the production of fish meal and oil. The vitamin A potency of burbot liver oil is stated to be about 500 units or more per gram and analyses of the Vitamin D potency of the oil obtained from the large liver have shown it to be as good as that obtained from cod liver (Branion 1930). When the burbot was abundant in Lake Erie, poundnet fishermen, who regularly handled tar-soaked netting, sometimes used the liver oil on their hands as a protection against the ravages of the tar. Burbot livers are eagerly sought in many European (especially Scandinavian) countries and are a valuable commodity when smoked and canned. Heavy infections of *T. nodulosus* in the liver however often prohibits this use. The Fisheries Research Board of Canada has experimentally canned Canadian burbot livers and the product is considered to be of high quality especially for such use as the making of canapes.

In Canada the burbot is caught incidentally by anglers while "ice-fishing" for lake trout. In recent years fishing through the ice for burbot has become a popular sport in some areas of British Columbia and in the state of Wyoming (Simon 1946), and in the latter case a closed season has been established. In parts of Europe and Asia the subspecies *L. l. lota* is a recognized food fish and is commercially exploited.

Nomenclature

Lota lota	— Linnaeus 1758: 255 (type locality Europe)
Gadus Lota Linn.	— Forster 1773: 152
Gadus lacustris	— Walbaum 1792: 144
Gadus maculosus	— LeSueur 1817b: 83
Gadus (Lota) maculosus (Cuvier)	— Richardson 1836: 248
Lota maculosa (LeSueur)	— Jordan and Evermann 1896–1900: 2550
Lota lota maculosa (LeSueur)	— Hinks 1943: 85
Lota lota (Linnaeus)	— Dymond 1947: 32
Lota lota lacustris (Walbaum)	— Speirs 1952: 100

Etymology *Lota* — the ancient name used by Rondelet.

Common names Burbot, American burbot, ling, eelpout, loche, freshwater cod, maria (Saskatchewan, Manitoba, northern Ontario), methy (northern Canada), lush (Alaska), lawyer (Great Lakes states). French common name: *lotte*.

ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION; REFERENCE TO COMMENT(S): C.90

SUMMARY OF BOTANICAL RESOURCES SECTION
EXHIBIT E, CHAPTER 3 OF THE
SUSITNA HYDROELECTRIC PROJECT
FERC LICENSE APPLICATION

BASELINE DESCRIPTION

Threatened or Endangered Plants

The Susitna River watershed upstream from Gold Creek was surveyed at selected habitat sites for plant taxa under consideration for threatened or endangered status. Access routes, borrow areas, and the intertie corridor were also surveyed for the presence of these taxa. No candidate threatened or endangered plants were found. Further endangered plant surveys will be made in the Healy-to-Fairbanks and Willow-to-Anchorage transmission corridors during the detailed design phase of project development.

Plant Communities

A diversity of plant communities occurs within the areas potentially affected by the project. The types of plant communities encountered and their areal coverage within a 20 mile (32km) wide area spanning the Susitna River between Gold Creek and the Maclaren River, include: Coniferous forest (351,640 ac), consisting of woodland, open and closed spruce (black and white spruce); mixed open and closed conifer-deciduous (56,500 ac); deciduous forest (10,860 ac), consisting of open and closed birch, and closed balsam poplar vegetation types; tundra (283,490 ac), consisting of wet sedge-grass, sedge scrub, herbaceous alpine, and mat and cushion vegetation types; shrubland (438,020 ac) consisting of open and closed tall shrub, and birch, willow, and mixed low shrub vegetation types; herbaceous (44 ac), and grassland (2,670 ac) communities.

Wetlands

Wetlands within the Susitna project area primarily include locations within riparian zones, ponds and lakes and adjacent areas on upland plateaus, wet black spruce woodland, and wet tundra. Concentrations of wetlands occur in the vicinity of upper Brushkana Creek and Tsusena Creek, the area between lower Deadman Creek and Tsusena Creek, the Fog Lakes area, the Stephan Lake area, Swimming Bear Lake, Jack Long Creek, in and near the many lakes of the Watana watershed, and along the transmission line corridors between Willow and Knik Arm and in the Tanana Flats area.

IMPACTS

This section summarizes botanical resource impacts that are of sufficient magnitude to influence mitigation planning. Impacts are grouped into one of three categories (direct loss; indirect loss; and alteration of communities), based on resource vulnerability, the probability of the impact occurring, and the duration of the impact. Direct losses of vegetation are judged most important because of the certainty and permanence of the impact. Plant community alterations are judged to be less important than vegetation losses. These impacts are less predictable and often of shorter duration than vegetation losses.

Direct Loss of Vegetation

Direct losses for the Watana project include 31,300 acres (12,667 ha) of vegetation for the dam, impoundment, and spillway. An additional 4300 acres (1742 ha) have been designated for use as camp, village, airstrip, and borrow areas. These potential losses account for 1 percent of all vegetation in the middle Susitna basin, and 3.6 percent of the vegetation present in a 20 mile (32 km) wide area spanning the Susitna River from the mouth of the Maclaren River to Gold Creek. More importantly, substantial losses of certain vegetation types will be sustained during construction of the Watana Dam. Losses of forested areas may total 8.3 percent of the 20 mile (32 km) wide area. Losses of open and closed birch forest will be greater than 20 percent for the 20 mile (32 km) wide area.

Direct losses for the Devil Canyon project will include 5871 acres (2376 ha) of forests, tundra and shrubland. Negligible amounts of tundra and shrubland (less than .05 percent) will be lost, but 0.7 percent of all forested lands in the middle basin (1.8 percent of the 20 mile (32 km) wide area) will be affected. Because of the steepness of Devil Canyon, these losses are relatively small compared to the Watana site and are comparatively less important for wildlife. However, 18.6 percent of the closed birch forest within the 20 mile (32 km) area will be eliminated.

The Watana access road will result in a loss of approximately 568 acres (230 ha) of mixed tundra vegetation types. Additional losses of about 494 acres (200 ha) for access roads and 193 acres (78 ha) for rail will be produced by the Devil Canyon facility. Direct losses within transmission corridors will occur from construction of access tails, tower sites, and substations.

Indirect Loss of Vegetation

Additional losses of vegetation may occur due to erosion, permafrost melting and subsequent land slides and slumpage, ORV use, blowdown of trees, and other causes. While some of these losses will be short-term with typical vegetation succession ensuing, or with shifts to new vegetation types for that area, long-term vegetational losses enduring for 30 to more than 100 years may occur on sites of continual erosion, land slumpage, or ORV use. The amounts that will be lost because of these factors are small compared to amounts inundated by the reservoirs.

Indirect losses of vegetation are projected to be greatest at the Watana site, where large areas on the south side of the impoundment are underlain by 200 to 300 feet (60 to 90 m) of permafrost at near melting temperature. Also, because of the large size of the reservoir, other erosional processes such as wind erosion, together with effects of dust, may cause very localized vegetation loss, especially in wind-exposed areas. The smaller, steeper nature of Devil Canyon will limit indirect losses of vegetation. Except for the possibility of one massive flow near River Mile 175, rock slides occurring above the impoundment represent the greatest threats and these will result in only small scale losses.

Some indirect loss of vegetation is expected due to erosion caused by changes in drainaage patterns and dust deposition along the access road edges. Increased utlilization by ORVs along access roads and road maintenance may damage adjacent areas. Little indirect loss in transmission line corridors is likely as a result of clearing or construction, but uncontrolled ORV access could affect vegetation on and adjacent to corridors.

Alteration of Vegetation Types

Alteration of vegetation types will be caused by changes in drainage patterns, altered river flows, and fire. In many instances, natural succession of cleared or disturbed areas not subject to inundation, will result in vegetation type changes. For example, primary herbaceous and weedy vegetation and secondary shrub growth may follow clearing of sites. There may be development of algal species and aquatic vegetation in shallow areas of the impoundments.

The most important change to existing conditions that will result from the Watana and Devil Canyon dams will be in the downstream floodplain between Gold Creek and Talkeetna, where annual spring and summer flooding and scour by ice jams will be reduced. As a result, some of the previously pulse-stabilized communities will mature. The willow and balsam poplar shrub will eventually change to mature balsam poplar and then to spruce. Within the license period, new vegetation on the newly exposed banks and island will develop into medium and tall shurubs.

Potentially significant impacts may occur to the vegetation surrounding the Watana Reservoir. Disturbance may cause warming of the soil, melting of the permafrost, and deepening of the active layer. In well-drained areas, this may result in increased growth and productivity by the existing plant community, but in waterlogged areas a shift to bog vegetation is likely. If the organic layer is lost during disturbance, long term losses of vegetation may result. Most forest and shrub areas disturbed near the reservoir will recover naturally. The ensuing patterns of vegetational succession will be enhanced if the organic layer is retained, and if root suckers or seed of vegetation remain.

Outside the actual impoundment and dam site, very few alterations of vegetation types are anticipated at Devil Canyon. Forest types will be subject to minor alterations, primarily near borrow sites G and K, and near camp and village sites. Likewise, changes in drainage, waterlogging of soil or permafrost melting, will be highly localized because the soil is generally very rocky and well drained, with only sporadic occurrences of permafrost. The smaller, steeper character of Devil Canyon will also act to limit microclimatic and mesoclimatic alterations.

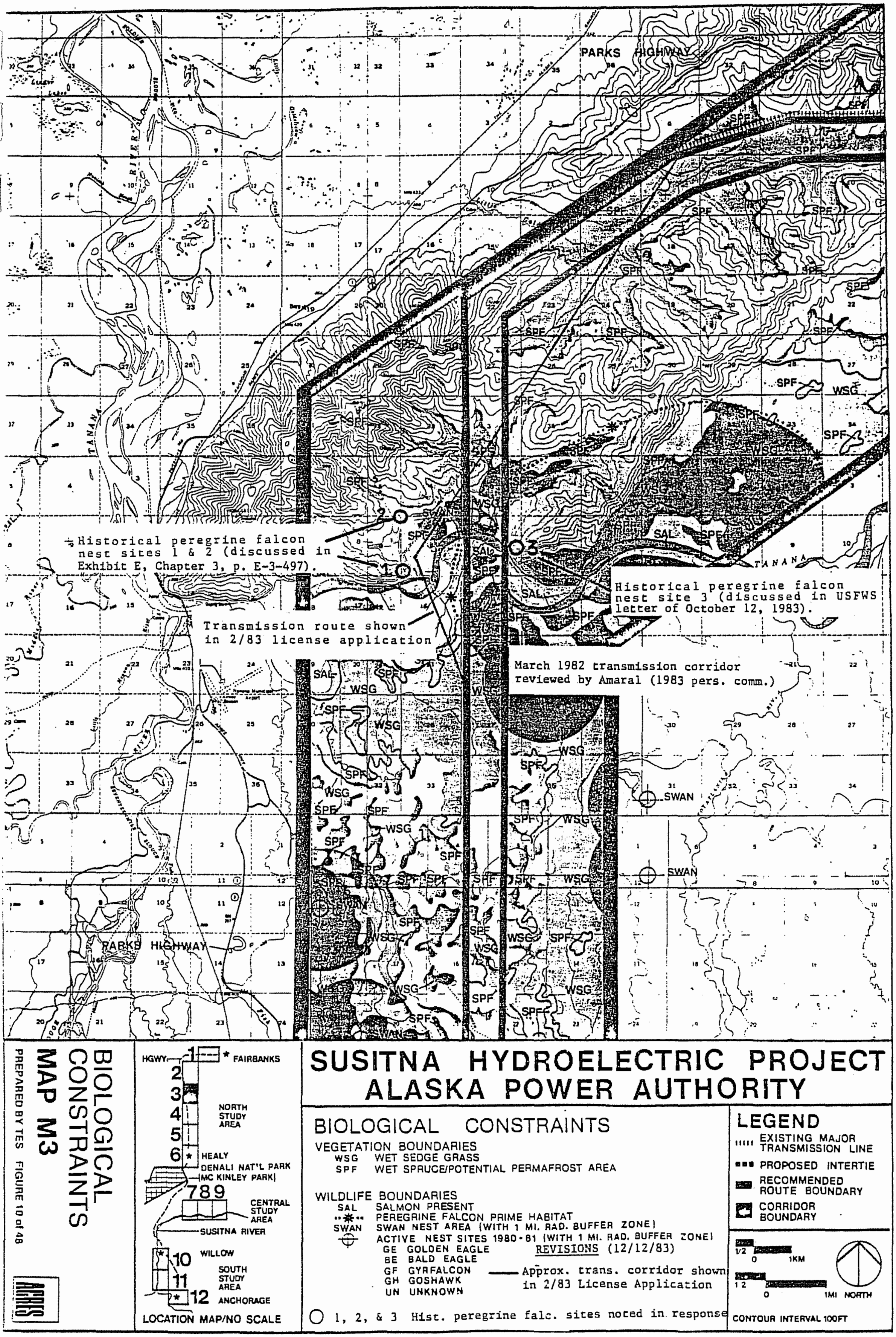
The access roads between the Devil Canyon and Watana sites, and between Watana and the Denali Highway, as well as rail construction between Devil Canyon and Gold Creek, will alter surface drainage patterns and may induce dust-related alterations in vegetation at roadsides. Selective clearing or top-cutting of tall vegetation for transmission line corridors will result in local shifts in plant types from trees to shrubs. Wet and moist tundra areas and their peripheries will be more susceptible to water logging due to vehicular traffic, with subsequent development of bog species and/or black spruce in place of cottongrass and shrub species.

Mitigation Summary

Mitigation plans for botanical resources have been developed primarily to support the wildlife mitigation program. Listed below is a brief synopsis of the mitigation plan elements:

1. Minimize facility dimensions.
2. Consolidate structures.
3. Site facilities in areas of low biomass.
4. Site facilities to minimize clearing of less abundant vegetation types.
5. Site facilities to minimize clearing of vegetation types productive as wildlife habitat components.
6. Minimize volume requirements for borrow extraction.
7. Dispose of spoil within the impoundments or previously excavated areas.
8. Design transmission corridors to allow selective cutting of trees and to accomodate uncleared low shrub and tundra vegetation within rights-of-way.

9. Dismantle nonessential structures as soon as they are vacated.
10. Develop a comprehensive site rehabilitation plan.
11. Monitor progress of rehabilitation to identify locations requiring further attention.
12. Acquire replacement lands for implementation of habitat enhancement measures.
13. Plan and develop an environmental briefings program for all field personnel.
14. Avoid the Prairie Creek, Stephan Lake, Fog Lakes, and Indian River areas by access routing.
15. Restrict public access during construction by gating the access road.
16. Use signs and possibly establish regulatory designation and measures to discourage use of ORVs and ATVs.
17. Phase implementation of the project Recreation Plan with interagency review and concurrence.
18. Site and align all facilities to avoid wetlands to the maximum extent feasible.
19. Involve agency coordination and participation in detailed engineering design and construction planning of civil engineering measures to minimize potential wetlands impacts.
20. Conduct high-resolution mapping of wetland vegetation within the project area, in coordination with COE and USFWS representatives (scheduled for 1983).



ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION: REFERENCE TO COMMENT(S): D. 1

HOMING OF TRANSPLANTED ALASKAN BROWN BEARS

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Abstract: Forty-seven brown bears (*Ursus arctos*) were captured and transplanted in Alaska in 1979. Post-release data were adequate to evaluate the survival and homing movements for 20 adults and 9 young. At least 12 adults (60%) successfully returned from an average transplant distance of 198 km. Age (for males) and distance transplanted (sexes combined) were directly related to observed incidence of return ($P < 0.05$). Sex or reproductive status did not appear to be related to observed incidence of return. Initial post-release movements of non-homing as well as homing bears indicated that most bears were aware of the correct homing direction. None of the transplanted females was known to have produced young in the year following transplanting. Six of 9 cubs or yearlings transplanted with their mothers were lost. Transplanting nuisance brown bears does not appear to be a reliable management procedure.

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Wildlife biologists frequently are requested to resolve conflicts between bears and man by transplanting the bears away from the area of conflict. Most biologists recognize this approach as ineffective because the bear may become a problem elsewhere or because it returns to the site of capture. This general premise is, however, supported by relatively few published data, a situation which led Cowan (1972) to recommend careful documentation and publication of transplant records. Homing of transplanted nuisance brown or grizzly bears has been reported by Craighead and Craighead (1972), Cole (1972), Pearson (1972), Craighead (1976), and Meagher and Phillips (in press). Typically, these bears were transplanted distances of less than 100 km and high frequencies of homing were observed. As part of a study on the impacts of brown bear predation on moose (*Alces alces*) populations (Ballard et al. 1981; Ballard et al., unpubl. rep., Alaska Dep. Fish and Game Fed. Aid Proj. W-17-9, W-17-10, W-17-11, and W-21-1, 1980), brown bear densities were artificially reduced in a portion of south central Alaska. This reduction was accomplished by capturing and transplanting as many bears as could be found within a well-defined experimental area. This paper reports on the rates and frequency of return of the transplanted brown bears.

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STUDY AREA AND METHODS

Bears were captured in the headwaters of the Susitna River in south central Alaska. The area was bordered on the north by the Alaska Range, on the east by the Clearwater Mountains, on the south by Butte Creek, and on the west by Well's Creek. Topography, vegetation, and climate of the area have been described elsewhere (Skoog 1968). Bear densities in this area were considered equivalent to that in the areas of south central Alaska where captured bears were released.

Bears were captured from 22 May through 22 June 1979. They were initially located from fixed-wing aircraft, immobilized from a helicopter (Bell 206B), and transported to a nearby highway where they were weighed and measured, specimens were collected (teeth, hair, and blood), and bears were marked with lip tattoos, ear tags, and ear flags. Radio collars (Telonics, Mesa, Ariz.) were placed on bears estimated to have completed 80% of their growth. Reproductive status of females was determined by examination of the vulva. Immobilized bears were transported by an open pickup truck either to their release sites or to an airport where they were further transported with fixed-wing aircraft (Cessna 206) to remote airstrips. Ages of the bears were estimated from counts of tooth cementum lines in a premolar (Mundy and Fuller 1964).

Thirty-six bears were immobilized initially with phencyclidine hydrochloride (Sernylan, BioCeutic Laboratories, St. Joseph, Mo.) at doses of 0.5 mg/kg of estimated body weight. Sernylan was also used to maintain immobilization during transport for all but 6 bears at doses of 0.2–0.5 mg/kg. Bears not immobilized ($N = 9$) or maintained ($N = 6$) with Sernylan were given a mixture of ketamine hydrochloride (Vetalar, Parke-Davis and Co., Detroit, Mich.) and xylazine (Rompun, Cutter Laboratories, Inc., Shawnee, Kans.) (Hebert and McFetridge 1979) at doses of 2.3 mg/kg of estimated body weight for initial immobilization and 1.3–2.3 mg/kg of measured weight for maintenance. Ketamine hydrochloride/xylazine mixtures were discontinued for immobilization maintenance because recovery was unpredictable and thus constituted a hazard for handlers. Two cubs were transported in cages and were not immoblized during either capture or transportation.

Bears transported by truck were observed until mobility was regained. Twenty-four bears remained immobile from 6.4 to 26.2 hours ($\bar{x} = 14.4$ hours) from the time of initial capture. Recovery was not observed for bears transported by aircraft ($N = 13$), but all release sites were checked to verify that bears had recovered and moved away.

Bears were transplanted in easterly directions to several places in the vicinity of Mentasta Pass, in southeasterly directions into the Wrangell Mountains or along the Copper River in the foothills of the Chugach Mountains, and in southwesterly directions along the lower Susitna River (Fig. 1).

Twelve fixed-wing aircraft flights were made to relocate radio-marked transplanted bears in 1979 (1 in May, 4 in Jun, 3 in Jul, 2 in Aug, 1 in Sep, and 1 in Oct). Other location data were collected from miscellaneous radiolocations and hunter kills in 1979–81. Locations were plotted on U.S. Geological Survey maps (scale = 1:250,000). Distance transplanted and distance between subsequent sightings were measured as a straight line without regard to topographic or hydrographic features. Rates of movement were calculated by dividing the distance between consecutive sightings by the number of days between sightings. The direction of movement was defined as homing if the direction taken from the previous sighting was within 35 degrees of the direction required to return to the capture site.

The criteria used in making a determination on when a particular bear had returned were subjective in some cases.

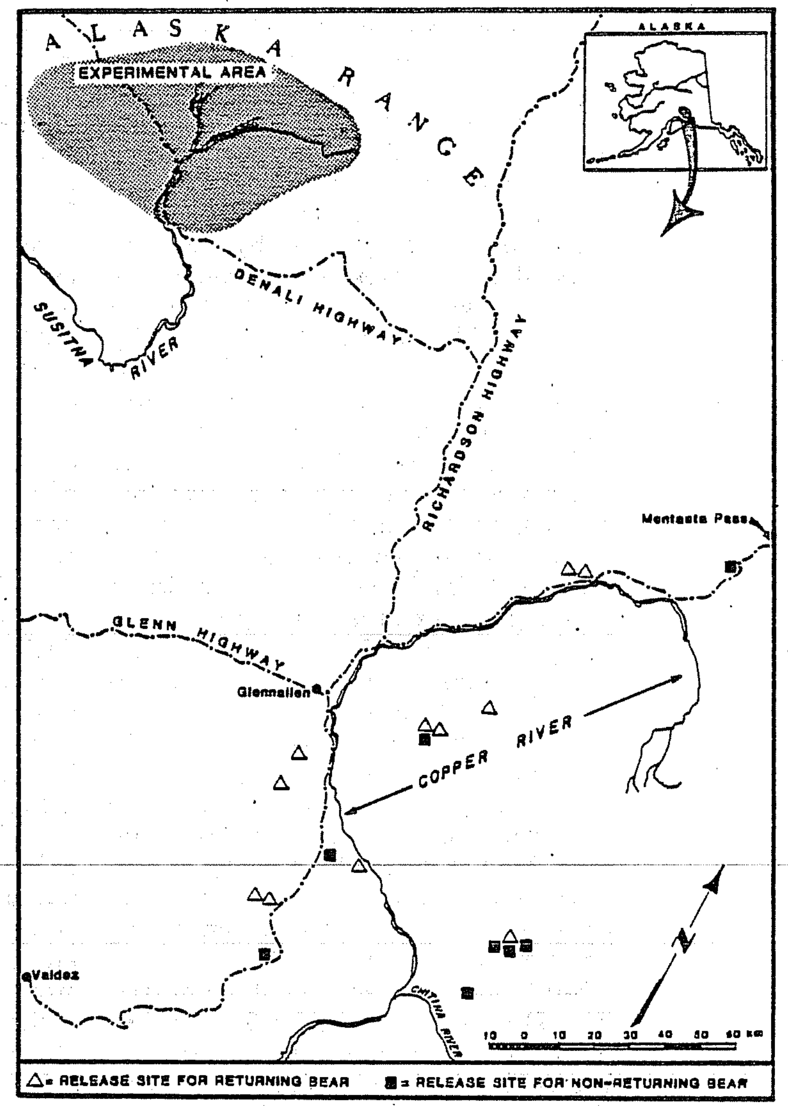

Fig. 1. Release sites of brown bears transplanted from an experimental area of south central Alaska.

Previous studies in this area (Ballard et al. 1982) indicated a mean adult home range of 572 km² using minimum home range polygons (Mohr 1947). A home range of this area, if circular, would have an average home range diameter (AHRD) of 27 km. All bears classified as returned were within 1.2 AHRD of their capture sites except for 2 bears. Bears #244 and #273 were 3.8 and 2.3 AHRD, respectively, from their capture sites when classified as having returned on the basis of

Table 1. Movement data for transplanted brown bears known to have returned to capture areas in south central Alaska.

Bear #	Age (yr) (reproductive status)	Direct distance transplanted from capture site		Direct distance returned (km)	Distance from capture site when classified returned		No. relocations		No. young lost	No. days from release until return verified
		km	AHRD[a]		km	AHRD[a]	Pre-return	Post-return		
Males										
237										
[b]	10.5	145	5.4	145	18	0.7	1	4		19
[b]		215	8.0	215	33	1.2	0	5		13
272	9.5	209	7.7	209	13	0.5	2	3		39
218[c]	5.5	230	8.5	215	23	0.9	0	1		
268[c]	4.5	255	9.4	258	14	0.6	0	1		
$\bar{x}$	7.5	211	7.8	208	20	0.7				24
Females										
213	11.5 (2 cubs)	173	6.4	173	14	0.5	7	2	2	74
236	5.5 (estrus)	145	5.4	145	6	0.2	5	7		43
240	5.5 (2 yrlgs)	207	7.7	208			3	3	?	92
251	10.5 (2 yrlgs)	211	7.8	211	13	0.5	3	14	2	33
269	16.5 (2 yrlgs)	199	7.4	199	12	0.4	3	4	0	69
244	6.5 (1 yrlg)	201	7.4	106	103	3.8	3	4	1	82
273	3.5 (estrus)	188	7.0	135	61	2.6	3	3		133
$\bar{x}$	8.5	189	7.0	168	35	1.3				72
All bears										
$\bar{x}$	8.2	198	7.3	173	28	1.0				58

[a] Average home range diameter = 27 km.
[b] This bear was transplanted twice.
[c] No radio collar, bear shot by hunter.

nondirectional movements which suggested they were in familiar territory. Differences between means were examined with Student's *t* test.

RESULTS AND DISCUSSION

Forty-seven brown bears were captured and successfully released. This included 2 releases for 1 male (#237), which was transplanted twice. Homing data were available for 34 of the releases. The homing data were derived from relocations of radio-collared adults ($N = 20$), from young accompanying radio-collared females ($N = 11$), or from hunter kills of marked but nonradio-collared bears ($N = 3$). In 1979 and 1980, 127 relocations were obtained for the transplanted bears (excluding cubs and yearlings) (Tables 1, 2). The fates of 13 transplanted bears (including 3 yearlings) were not determined. These animals were too small for radio collars and did not appear in the hunter harvest.

At least 5 of 9 adult males and 7 of 11 adult females returned to their capture areas (Table 1). There were no differences ($P > 0.10$) between the mean distances that returning males and females were transplanted (Table 1). The time from release until return was verified and was much greater for returning females than for males (Table 1). However, bears actually returned more quickly than indicated (Table 1) because of delays in verification of date of return. This delay resulted from infrequent monitoring flights. For example, the mean number of days from the previous sighting until the

Table 2. Movement data for nonreturning brown bears transplanted in south central Alaska.

Bear #	Age (yr) (reproductive status)	Direct distance transplanted		Dates under observation	No. locations after release	Direct distance from capture site to last location		No. young lost
		km	AHRD[a]			km	AHRD[a]	
Males								
211	5.5	268	9.9	31 May–12 Sep 1979	5	185	6.9	
265	4.5	268	9.9	4 Jun 1979–10 May 1980 (shot)	6	303	11.2	
246	4.5[b]	211	7.8	25 May–23 Sep 1979 (shot)	1	218	8.1	
230	10.5	256	9.5	1 Jun 1979–24 May 1980 (shot)	2	105	3.9	
216[c]	11.5	178	6.6	22 May–15 Jun 1979	4	166	6.2	
247[c]	8.5	240	8.9	26 May–31 May 1979	1	201	7.4	
258[c]	21.5	286	10.7	30 May–27 Jul 1979	1	305	11.3	
$\bar{x}$	6.2	251	9.3		3.5	202	7.5	
Females								
209	5.5 (estrus)	260	9.6	4 Jun 1979–8 Sep 1981 (shot)	8	298	11.0	
215	3.5 (anestrus)	168	6.2	24 May 1979–15 Aug 1980	8	113	4.2	
248	4.5 (estrus)	249	9.2	26 May–30 Sep 1979	6	190	7.0	
261	7.5 (2 yrlgs)	184	6.8	1 Jun 1979–6 Jun 1980	4	210	7.8	1
$\bar{x}$	5.3	215	8.0		6.5	202	7.5	
All bears								
$\bar{x}$	5.8	233	8.6		5.0	202	7.5	

[a] Average home range diameter = 27 km.
[b] No radio.
[c] Insufficient data, not included in calculations of means.

time a bear was verified as having returned was 33 days but ranged from 11 to 84 days. The sum of the distances between sightings until return for 10 radio-collared bears averaged 107% of the direct distance back (61–130%). This suggests that returning bears moved back with a minimum of nondirected movements.

Eight adults did not return to their capture areas (Table 2). For these bears, the mean distance from capture site to the location last observed was 87% (41–115%) of the distance transplanted. Nonreturning bears were transplanted farther than returning bears (Tables 1, 2); this difference was significant ($P < 0.05$) only when data for both sexes were pooled.

There were no differences in mean ages of returning and nonreturning bears of either sex ($P > 0.10$) (Tables 1, 2). These data may be biased by inclusion of hunter-killed bears as hunters may select for larger (older) bears. When hunter-killed bears are excluded, the mean age of returning males (10.0 years) was different ($P < 0.005$) than that of nonreturning males (4.8 years). No females were shot by hunters in 1979 or 1980. Excluding hunter-killed bears and combining sexes, there was a difference ($P < 0.05$) in age between returning ($\bar{x} = 8.8$ years, $N = 9$) and nonreturning bears ($\bar{x} = 5.3$ years, $N = 5$).

Both returning and nonreturning bears included females in estrus and females with offspring. Reproductive status therefore did not appear to be a determinant of whether a female returned.

Daily movement rates of returning bears were compared with those for nonreturning bears and with those of returned bears. Returning bears had greater ($P < 0.01$) movement rates ($\bar{x} = 3.6$ km/

day) while traveling back than following their return ($\bar{x}$ = 0.6 km/day). Returning bears had greater ($P < 0.01$) movement rates than did nonreturning bears ($\bar{x}$ = 1.4 km/day). Nonreturning bears had greater ($P < 0.05$) daily movement rates than did returning bears subsequent to return. These results would be expected from nonreturning bears attempting to establish themselves in a new area relative to homing bears on their way back or subsequent to return. These data do not accurately reflect actual movement rates because of varying, and long, intervals between sightings. Intensive studies of 21 undisturbed brown bears in the study area indicated daily movement rates averaged 7.7 km/day (Ballard et al. 1982).

Returning bears moved in a homing direction for 87% of the distance between sightings and for 89% of the days between sightings. Nonreturning bears moved in a homing direction for only 39% of the distances between sightings and for only 27% of the days between sightings. Initial post-release movements were in a homing direction for 5 of the 10 radio-collared bears which returned and for 5 of 7 radio-collared bears which did not. This suggests that many of the nonreturning bears initially knew the proper direction to return home, but for unknown reasons did not return.

It is possible that some of the 11 bears classified as nonreturning actually returned but were not discovered due to radio failure. When last located, 6 of these bears were closer to their respective capture sites than they were at the point of release (Table 2).

Two bears classified as nonreturning in 1979 moved in homing directions in 1980. Female #209 was observed in May 1980 198 km south of her capture site. In August 1980 she was only 118 km southeast of her capture site. Subsequently, this bear traveled eastward and in fall 1981 was shot by a hunter 298 km from her capture site. Male #230 lost his radio collar 2 weeks following release at a point 249 km southeast of his capture site. This bear was shot almost a year later (May 1980) 150 km southeast of his capture site.

Travel routes followed by some transplanted bears may have been influenced by natural or man-made barriers. Five bears (#'s 209, 211, 265, 261, and 269) that originally headed directly back towards their capture areas reversed direction prior to crossing the wide and braided Copper River. Only 1 of these bears (#269) eventually crossed the river and returned to its capture area. Another (#209) eventually crossed the Copper River (by Sep 1979), but still did not return to its capture area. Two of the 5 deflected bears had yearling offspring (#'s 261 and 269). Five other radio-collared bears released east of the Copper River (#'s 258, 230, 273, 272, and the 2nd release for #237) crossed the Copper River. None of these bears had offspring.

Movements of 3 bears (all females with offspring) appeared to have been briefly influenced by highways. These 3 bears eventually returned to their capture areas. For example, female #213 (with 2 cubs) moved in a direct homing direction (northwest) following release until she encountered the Glenn Highway, 8 days and 21 km north of her release site. Nine days following release she lost her cubs; she remained within 1–8 km of the Glenn Highway for at least 2 more weeks until she crossed the highway on a direct route back. Similar short-term apparent deflections from highways were observed for females #240 and #244, both with yearling offspring.

These observations of apparent deflections or delays in homing caused by rivers and highways may indicate an aversion by some bears, especially females with young, to cross such obstacles. However, such barriers do not consistently deflect bear movements. In September 1973, a 3.8-year-old male from Cordova was transplanted 93 km by boat to Montague Island in Prince William Sound, Alaska. Within 28 days the bear had returned to the capture site (J. Reynolds, pers. commun.). Only 2 returning routes were available, both would have required swimming long distances (15.1 or 10.5 km) across strong tidal currents.

Of the 9 young transplanted with 5 radio-collared females, only 3 (2 returns and 1 nonreturn) were still with their mothers when last observed in 1979. One additional female (#240) was not observed after her return to the capture site in 1979 so the status of her 2 yearlings could not be verified. Available data are inadequate to compare the observed rate of offspring loss with that of natural populations in this area; however, we suspect the transplanted young had higher than normal losses. The time that the lost offspring survived varied from 0 to 36 days. The fate of the lost offspring was not determined; although cases of survival of lone cubs have been reported (Johnson and LeRoux 1973), we suspected that most died. It is a reasonable speculation that these offspring, released into terrain which was unfamiliar to their mothers, would have been particularly vulnerable to predation by resident male bears.

Six of 11 radio-collared adult females were observed in 1980, but none was accompanied by offspring. Two (#273 and #209) were in estrus when captured in 1979. Female #244 had a yearling in 1979 which she lost by 2 July 1979. She was observed with an adult bear on 15 September 1979 but had no offspring when seen in July 1980. Female #251 had 2 yearlings which she lost by 19 June 1979; she had no offspring when observed on 18 July 1980. Female #215 was not notably in estrus when transplanted, but was seen with an adult bear on 3 July 1979. She had no offspring when observed on 15 August 1980. Bear #269 successfully homed with both of her yearlings in 1979. She had no young with her in September 1980. This bear was shot by a hunter in fall 1981, reportedly without offspring. These observations suggest the possibility of lowered productivity by transplanted females, possibly related to trauma associated with transplanting, homing, or re-establishment in a new area.

Three transplanted males were seen with smaller, presumably female, bears subsequent to release. Trauma associated with transplant may have less effect on male breeding activity.

There were no evident differences in ability to return related to the type of drug used for immobilization or for maintenance. There were also no evident differences in homing ability related to types of transportation (truck and/or aircraft).

Homing bears were transplanted an average of 7.3 (5.4–9.4) average home range diameters from their point of capture and were probably totally unacquainted with their release sites. However, the directions of movement following release, for both returning and nonreturning bears, suggested that most transplanted bears sensed the correct homing direction and that successful homing was not dependent on random movements until familiar terrain was encountered. Lentfer (1972, 1973) suggested that polar bears (*Ursus maritimus*) inhabiting drifting pack ice are able to navigate, without physical reference points, to maintain their position or to find a seasonally recurring area of food abundance. Homing brown bears may be able to navigate in a similar fashion.

Although nonreturning bears were moved farther and were younger than homing bears, no threshold distance or age beyond which bears could or would not return was demonstrated. Undoubtedly, a threshold distance exists but our results suggest it is greater than 258 km, the longest distance returned by a transplanted bear. The average age of nonreturning bears (greater than 1.5 years old) was 5.8 years. However 5 bears equal to or younger than this average age returned to their capture areas suggesting the absence of an age threshold. Many nuisance bears are accustomed to feeding in garbage dumps; such bears may find natural habitats at transplant sites to be less desirable than such dumps. Correspondingly, transplanted nuisance bears might be expected to show even higher rates of return than demonstrated by the non-nuisance bears transplanted in this study. Although transplanting problem bears may be occasionally justifiable by social or economic factors, we conclude that such efforts have high probabilities of failure.

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LGL ALASKA

ANCHORAGE

BURNING AND BROWSING EFFECTS ON WILLOW GROWTH IN INTERIOR ALASKA[1]

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Abstract: Productivity and utilization of browsed and unbrowsed Scouler willow (*Salix scouleriana*) was measured in a 1971 burn and in an adjacent 70-year-old mature black spruce (*Picea mariana*) forest. Production of available willow browse in the burn increased from 8 kg/ha in 1973 to 22.6 kg/ha in 1974. The greatest production came from branches which had been browsed the previous winter. In the burn in 1974, an average browsed branch produced 4.0 g of new growth, whereas an unbrowsed branch produced 2.4 g. The available willow browse produced in the control in 1974 was 9.9 kg/ha, with a browsed branch producing 2.8 g and an unbrowsed branch 0.8 g. Willow shrubs are able to compensate for loss of biomass due to overwinter browsing by increased productivity of browse-damaged stems.

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During winter, moose (*Alces alces*) in Alaska feed primarily on shoots and branches of willow (*Salix* spp.), birch (*Betula papyrifera*), aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*) (LeResche and Davis 1973, Cushwa and Coady 1976). These hardwoods are frequently associated with plant communities characteristic of early successional stages after burning (LeResche et al. 1974, Viereck 1973). Browse production in early seral stage development is high, and the shoots and branches of woody browse species are numerous and within reach of mammalian herbivores (Spencer and Chatelain 1953, Leege 1968). Klein (1970) suggested that quality and digestibility of forage are as important as quantity and availability, and Cowan et al. (1950) and Leege (1969) stated that quality is related to successional stage. Trees and woody shrubs often grow out of reach in later successional stages and thus the number of small twigs and branches available as forage is reduced (LeResche et al. 1974, Spencer and Hakala 1964).

During the later 1950's, moose populations appeared to increase throughout interior Alaska (U.S. Fish & Wildlife Service unpubl. reports, Coady 1973) concurrent with an increase in seral range created by wildfires (Hardy and Franks 1963, Barney 1969). Early seral stage communities created by fire can increase the carrying capacity of winter range (Spencer and Chatelain 1953, Leege 1968, 1969).

The dominant species in mature forests of interior Alaska is either white spruce (*Picea glauca*) or black spruce (*P. mariana*), with woody shrubs present at lower densities (Viereck 1973). The biomass of forage available to moose at various successional stages has not been determined for this region of interior Alaska, though it has been done elsewhere by Bishop (1969) and Milke (1969). I compared current annual growth of browsed and unbrowsed Scouler willow on a burn and on an adjacent mature black spruce forest. The role of fire in improving winter moose habitat through increased production of woody browse was also examined. Data were collected in 1974 and 1975.

STUDY AREA

The 2 study areas were located in a 70-year-old mature black spruce stand (control) and in 50 ha of an adjacent 6,300 ha

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1971 burn. These are at the Wickersham study site of the USDA Forest Service, 50 km northwest of Fairbanks along the Elliott Highway. Prior to the wildfire, both areas were dominated by black spruce with scattered alder (*Alnus crispa*) and willow shrubs in the understory.

METHODS

Browse Utilization

Willow shrub density was estimated in 20 10×100 m plots in each area. Fecal pellet group counts (Neff 1968) were made in the same plots. A shrub was defined as a plant with a variable number of stems originating from the same root system. The biomass of forage available and consumed was estimated using the Shafer twig-count method (Shafer 1965). Available browse included all twigs less than 4 mm in diameter lying between 50 cm and 4 m above the ground. In May 1974 and 1975, the total number of browsed and unbrowsed branches was counted on 200 randomly selected willows in each area. Alder was not utilized as forage by moose and was not included in the samplings. The diameter at point of browsing (dpb) was measured on 50 browsed branches. Fifty unbrowsed twigs of the same diameter were clipped, oven-dried, and weighed for mean weight per twig. The weight per twig was multiplied by the number of branches available per shrub and the number of shrubs/ha to get the total biomass of browse available to moose/ha. The browse available was multiplied by the percentage of browsed twigs to get an estimate of browse consumed per hectare.

Browse Production

In early September 1974, current annual growth (determined by bud scale scars) was collected from 30 selected willow shrubs in each plot. Shrubs in the control had been browsed by both moose and snowshoe hares (*Lepus americanus*). Production of new growth from branches browsed and not browsed the previous winter was compared on the same shrub and between shrubs. Samples were oven-dried for 48 hours at 65 C and weighed.

Browsing Simulation

All twigs were collected from 2 unbrowsed willow shrubs in the burn in April 1974 before growth began, then in September 1974 and September 1975 after new growth ceased. This simulated 100 percent browsing with the intention of showing its effect on productivity.

RESULTS AND DISCUSSION

Browse Utilization

There were 400 ± 13.4 (burn) and 489 ± 16.3 (control) willow shrubs/ha. Willows in the burn and control averaged 17 and 9 stems/shrub, respectively (Figs. 1 and 2). The greater number of stems on willows in the burn was due to heavy browsing intensity by snowshoe hares during 1971–72 which resulted in multiple branchings at the root crown. In the burn, browse utilization was 44 percent and 45 percent in 1973 and 1974, whereas in the control it was 34 percent and 8 percent (Table 1). Browse production and utilization was not quantified in the control in 1973. Milke (1969) found the browse removed by moose from various willow species during one winter to range from 0.1 to 33.8 percent. In 8- and 15-year-old willow stands along a floodplain in interior Alaska, I recorded browse utilization of 55 and 56 percent (Wolff 1976). Spencer and Chatelain (1953) measured browse utilization in 4 areas on the Kenai from 1950–1952 and found an average utilization of 45–55 percent.

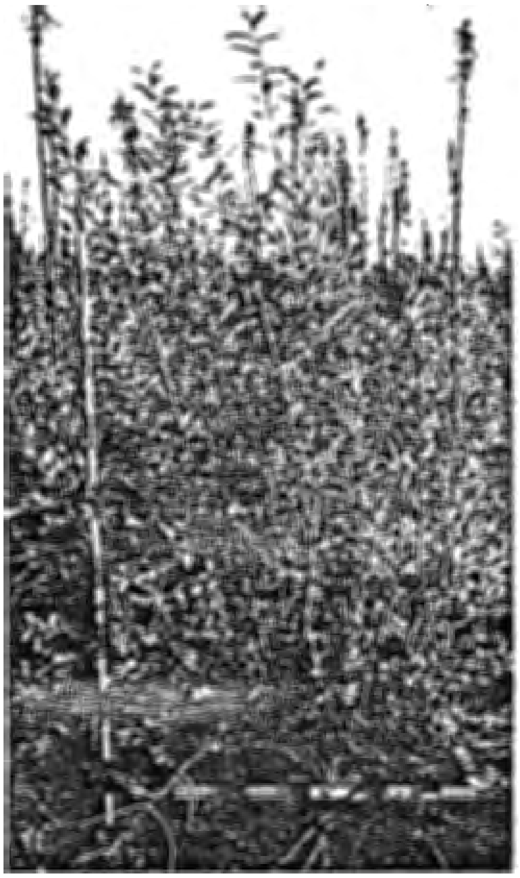

Fig. 1. Photo of a willow shrub in the burn 3 years after fire.

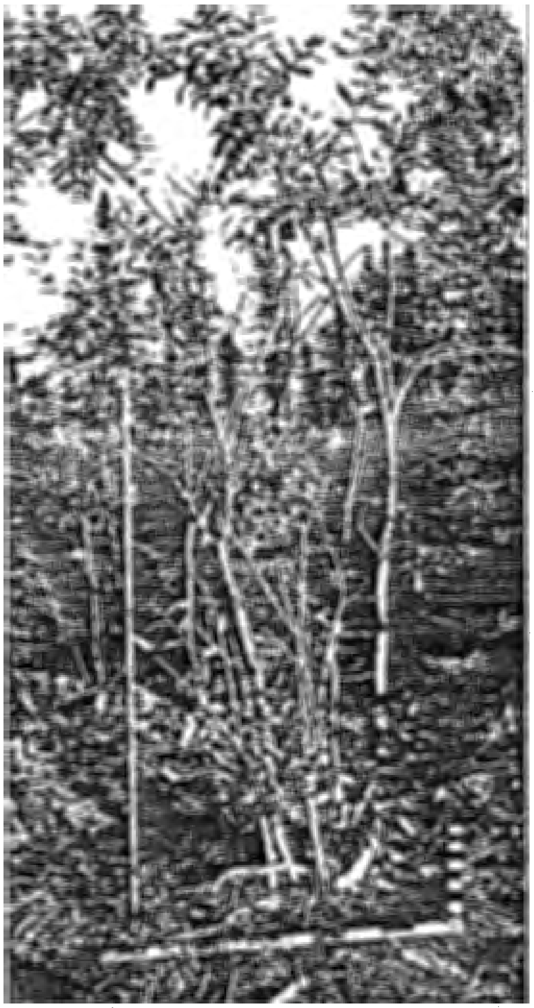

Fig. 2. Photo of a willow shrub in the 70-year-old black spruce forest.

Table 1. Production and consumption of willow browse in the burn and control study sites at Wickersham for 1973 and 1974. (±SE)

Area	Willow browse produced (kg)	Willow browse available (kg)	Total browse consumed (kg)	Browsing intensity (%)	Carrying capacity[a] (M.D./ha)
Burn 1973	11.0	8.0 ± 2.5	3.5	44	1.6 ± 0.5
Burn 1974	52.5	22.6 ± 3.2	10.2	45	4.5 ± 0.6
Control 1973[b]				34	
Control 1974	21.1	9.9 ± 2.5	0.8	8	2.0 ± 0.5

[a] Carrying capacity and utilization computed on an average daily consumption rate of 5 kg woody browse/moose/day (Gasaway and Coady 1974). Moose days/ha (M.D./ha).
[b] Production and utilization of willow browse was not quantified in the control in 1973.

In the burn, browse consumption increased from 3.5 kg/ha during the 1973–74 winter to 10.2 kg/ha during the 1974–75 winter (Table 1). This 3-fold increase coincided with a similar increase in food availability.

During the 1973–74 winter, 9 (±0.10) and 7 (±0.08) pellet groups/ha were recorded for the burn and control, respectively. At an average daily consumption

Table 2. Production of hardwood browse from browsed and unbrowsed branches in the burn and control study areas at Wickersham during the 1974 growing season. (±SE)

Area	No. of willow shrubs/ha	No. of branches/shrub	No. of browsed branches/shrub	New growth/browsed branch (g)	New growth/unbrowsed branch (g)	Total new growth/shrub (g)	Total hardwood browse/ha (kg)
Burn	400 ± 13.4	42 ± 4.15	19 ± 3.01	4.0 ± 0.35	2.4 ± 0.21	131.2 ± 17.20	52.5 ± 6.88
Control	489 ± 16.3	19 ± 2.68	14 ± 4.81[a]	2.8 ± 0.64	0.8 ± 0.05	43.2 ± 3.89	21.1 ± 3.92

[a] Branches in the control browsed by either moose or hares.

rate of 5 kg woody browse for an adult moose (Gasaway and Coady 1974), the forage available in the burn during the 1973–74 winter would have supported 1.6 moose-days/ha. However, only 3.5 kg of woody browse/ha were consumed in the burn, equivalent to 0.7 moose-days/ha. Nine pellet groups/ha were counted in the burn and at 0.7 moose-days/ha this expands to 12.9 pellet groups deposited/moose-day. A similar figure was obtained from the pellet counts in 1974–75. These results agree with the report by Julander et al. (1963) that the defecation rate for moose was 13 pellet groups/day.

Browse Production

In 1974, unbrowsed willow branches in the burn produced 2.4 g of new growth per branch (g/br), whereas a previously browsed branch produced 4.0 g/br (Table 2). Browsing intensity from the previous winter ranged from 0 to 100 percent. Production of new growth was greatest on those shrubs which had been browsed most heavily the previous winter. Krefting et al. (1966) found a similar response with mountain maple (*Acer spicatum*).

The total current annual growth of willow produced in the burn in 1974 was 52.5 kg/ha. About 25 percent of this was less than 50 cm above the ground (mean snow depth from mid November through March was 48 cm) and was not available during the 1974–75 winter. Also, the dpb never exceeded 4.4 mm ($\bar{x} = 3.75 \pm 0.03$) with a mean weight per twig of 1.3 ± 0.02 g; some new growth (32%) had a diameter greater than this and was presumably unpalatable to moose. Therefore of the 52.5 kg of woody browse produced, only 22.6 kg should be considered as usable moose forage (Table 1). In the 1973–74 winter, there was a greater portion of browse available which was less than 4 mm in diameter, consequently, the percent of total production in 1973–74 which was available was greater than in 1974–75.

Willow browse was not quantified in the control in 1973; but in 1974 there were 21.1 kg/ha produced, 9.9 of which was available to moose. Branches previously browsed by moose or hares produced 2.8 g/br and unbrowsed branches, 0.8 g/br. This may be somewhat biased, however, as the branches which were previously browsed were probably more productive and were selected by the moose. Browsed branches were closer to the ground than the unbrowsed ones, most of which were above 2 m. One possible reason for this is that branches which grow close to the ground may have a high crude protein content (Bailey 1967). The lower branches are also easier for moose to reach.

Browse Simulation

The 2 willow shrubs which were totally clipped produced 90, 289, and 693 g (April 1974, Sept. 1974, Sept. 1975) and 124, 317, and 790 g. Some of this (an estimated 25%) was greater than 4 mm in diameter and should not be considered as moose forage.

Both shrubs were browsed by moose or hares in the 2 winters prior to my experiment.

GENERAL DISCUSSION

Although browsed branches produced more than unbrowsed branches from 1973 to 1975 (Table 2), continuous browsing over several years might eventually deplete plant or soil reserves causing eventual decline in productivity (Menke 1973). Aldous (1952) reported that paper birch could withstand clipping of 50 percent of the current year's growth over a 6-year period without loss of production. Krefting et al. (1966) found that mountain maple withstood 100 percent simulated browsing for 10 years and still produced more annual browse than a non-clipped plant. They suggested that a lower browsing intensity may have better long-term effects, and several authors have suggested that 50 percent browse utilization may give maximum sustained production of hardwood browse (Krefting et al. 1966, Spencer and Chatelain 1953, Wolff 1976).

Production and utilization was assessed only in *Salix scouleriana*. There are 34 species of willow in Alaska (Viereck and Little 1972), and all species may not respond to browsing in the same way. However, personal observations of *S. alaxensis*, *S. planifolia*, and *S. interior* also indicate that browsing stimulates production. Moose seem to prefer some species over others, and the degree of utilization may differ considerably (McMillen 1953, Murie 1961, Milke 1969, Coady 1974). Though nutritive value of a plant may be a good indicator of preference (Albrecht 1945, Cook et al. 1956, Heady 1964, Hurd and Pond 1958), other inherent characteristics of individual species seem to be important in determining palatability.

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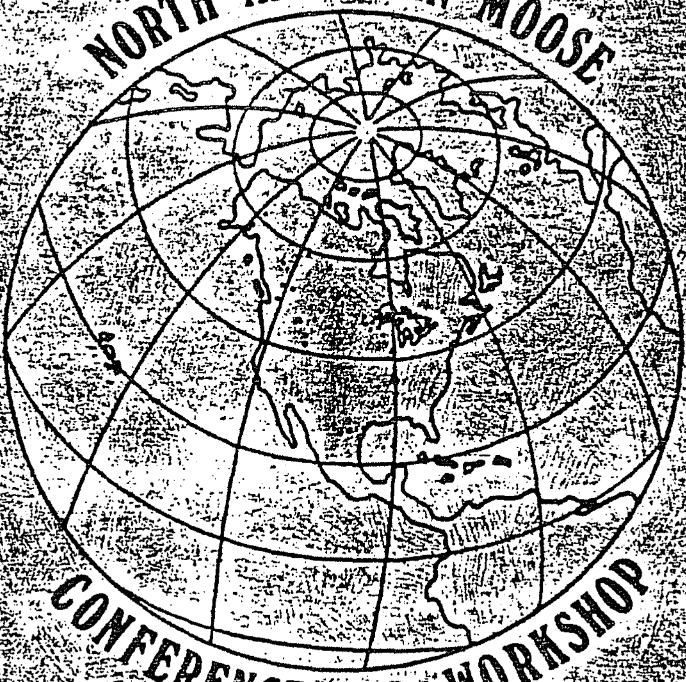
PROCEEDINGS

NORTH AMERICAN MOOSE



CONFERENCE AND WORKSHOP

NUMBER 15

SOLDOTNA—KENAI, ALASKA MARCH, 1979

GASAWAY, W.C., A.W. FRANZMANN, AND J.B. FARO. 1978. Immobilizing moose with a mixture of etrophine and xylazine hydrochloride. J. Wildl. Manage. 42:686-690.

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MOOSE HABITAT AND FOREST SUCCESSION ON THE TANANA RIVER FLOODPLAIN AND YUKON-TANANA UPLAND

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Abstract: Production, availability, and utilization of woody browse by moose in winter were recorded in stands of 16 different ages on the Tanana River floodplain and the Yukon-Tanana uplands of Alaska. These stands represented primary and secondary succession following fire, flooding, and clearing. The forage available included 198 kg/ha in a 1-year-old aspen stand, 167 kg/ha in an 11-year-old birch stand, and 66 kg/ha in a 16-year-old willow stand. Stands greater than 25 years post-disturbance had less than 10 kg of browse per hectare. Aspen stands provide the most browse 1-5 years post-disturbance, whereas birch and willow stands provide the most browse between 10 and 16 years. Browsing intensities ranged from 0% to 56% in most stands, suggesting moose are below their habitat carrying capacities. The use of browse availability and consumption rates to determine carrying capacities and moose-days of use are discussed.

During winter, moose (*Alces alces*) in Alaska feed primarily on shoots and branches of willows (*Salix* spp.), paper birch (*Betula papyrifera*), aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), and cottonwood

(P. trichocarpa) (LeResche and Davis 1973, Cushwa and Coady 1976, Wolff 1978). These hardwoods are frequently associated with plant communities characteristic of early seral stages (LeResche et al. 1974, Viereck 1973). Browse production in early seral stage development is high, and the shoots and branches of woody browse species are numerous and within reach of browsing mammals. Trees and woody shrubs often grow out of reach in later successional stages, and thus the number of twigs available is reduced (LeResche et al. 1974, Spencer and Hakala 1964). In the Tanana region these early seral-stage plant communities are created by deposition of sand bars resulting from floodplain processes, by wildfire, and to a lesser extent by logging or other man made disturbances. The predominant climax plant communities in the taiga of interior Alaska are either white or black spruce (*Picea glauca, P. mariana*).

Forest succession and rate of change are determined by a host of factors. Among these are species composition of the disturbed community, nature of disturbance, site conditions, and availability of seeds and other reproductive materials. These factors, acting in concert, produce three basic successional patterns (Lutz 1956, Viereck 1975). The first is termed autosuccession, that is, a disturbance in black spruce, white spruce, birch or aspen results in the return of the same species in relatively pure stands. Willow, alder and other shrubs are common in the early stages of this successional pattern. Second, a disturbance in white spruce results in regeneration of birch from seed or stump sprouts and/or aspen primarily from root suckers followed by white spruce. The 1- to 20-year-old aspen and birch stands are highly productive and have been well documented as providing prime moose winter range (Spencer and Hakala 1964). The third pattern is characteristic of the floodplains of Alaska's rivers, wherein willow or willow-alder stands are replaced

by poplar and white spruce. Patterns 1 and 2 are secondary succession and pattern 3 is primary succession. For variations in these patterns see Viereck (1975).

The major objective of this study was to compare browse porduction in different age communities following different types of disturbances to determine the capacity for providing moose winter range. These observations were made on the Tanana River floodplain and the adjacent Yukon-Tanana uplands.

STUDY AREAS

Table 1 presents general site and vegetation data for the areas included in this study. A further brief description of each follows:

Uplands

Wickersham (W). The Wickersham fire occurred in 1971 and covered about 6 000 ha. Wickersham-1 (W-1) is located in an area which was classified as a heavily burned, black spruce stand. Site W-3 is located in a large, unburned black spruce stand across the fire line from W-1 and is representative of the conditions in W-1 prior to the fire. Wickersham-2 (W-2) is an aspen stand burned at the same time as W-1 (willow) and located several kilometers from W-1. Wickersham-4 (W-4), the most severely disturbed site, was cleared for homesteading. Stands adjacent to the clearing are similar to WC-3. During the clearing, mineral soil was exposed placing the succession on this site somewhere between primary and secondary.

Murphy Dome (MD). Murphy Dome 1 and 2 (MD-1, MD-2) are located in a 2 000 ha area burned in 1958.

Goldstream (GS). This area burned in 1966.

Table 1. Vegetation type and description of study sites.

Site	Vegetation type	Soil type	Slope position	Elevation (m)	Aspect	Slope %	Drainage class	Type of disturbance	Year of disturbance	Stand age when sampled	Type of succession
Uplands											
Wickersham-1	closed conifer, black spruce	Fairplay silt-loam	ridgetop	468	WNW	05	well	fire	1971	3,4,5 6,7	secondary
Wickersham-2	closed deciduous aspen	Not available	middle	518	SSW	15	well	fire	1971	1,4,7	secondary
Wickersham-3	closed conifer, black spruce	Fairplay silt-loam	ridgetop	468	--	0	well	fire	1900	75,76 77,78	secondary
Wickersham-4	closed conifer, black spruce	Fairplay silt-loam	middle	450	S	10-15	well	homestead clearing	1967	11	secondary
Elliot Highway	closed deciduous, paper birch	Not available	middle		SE	20	well	fire	1927	50	secondary
Goldstream	closed conifer, black spruce	Minto silt-loam	bottom	110	N	2-5	moderate	fire	1966	11	secondary
Murphy Dome-1	closed mixed, white spruce-paper birch	Not available	bottom	770	--	0	moderate	fire	1958	16,19	secondary
Murphy Dome-2	closed mixed, white spruce-paper birch	Not available	lower	770	SE	8-10	well	fire	1958	19	secondary

Table 1. Vegetation type and description of study sites--Continued.

Site	Vegetation type	Soil type	Slope position	Elevation	Aspect	Slope %	Drainage class	Type of disturbance	Year of disturbance	Stand age when sampled	Type of succession
Uplands											
Parks Highway-1	closed deciduous, aspen	Fairbanks silt loam	middle	310	W	8-10	well	fire	1942	36	secondary
Parks Highway-2	closed deciduous, aspen	Fairbanks silt-loam	middle	110	S	10-15	well	fire	1927	60	secondary
Bonanza Creek	closed mixed, paper birch-white spruce-aspen	Fairbanks silt-loam	middle	240	SW	8-10	well	harvest	1976	1	secondary
Floodplain											
Tanana River-1	open willow	alluvial land	--	130	--	0	well	N/A	N/A	8,9,10	primary
Tanana River-2	alder-poplar	alluvial land	--	130	--	0	well	N/A	N/A	25	primary
Tanana River-3	closed willow	alluvial land	--	130	--	0	well	N/A	N/A	16,19	primary
Tanana River-4	closed mixed, balsam poplar-white spruce	Salchaket very fine sandy loam	--	130	--	0	well	N/A	N/A	80	primary

Parks Highway (P) and Elliott Highway (E). These stands are representative of sapling- and pole-sized hardwood stands which cover large areas of the Yukon-Tanana upland and were burned 30-50 years ago.

Bonanza Creek (BC). This site was a mature upland forest harvested in 1977. Stem density of the trees prior to harvesting was 323 birch, 132 white spruce, and 43 aspen per hectare.

Floodplains

Tanana River (TR). Tanana River-1,-2,-3, and -4 represent several stages of primary successional sequence on floodplains.

METHODS

The amounts of browse available to moose and their browsing intensities were measured in May of each year after snowmelt. One 10-ha plot was established in each stand, except the Bonanza Creek area which was only 1 ha. Each plot was considered representative of the stand. The densities of trees and shrubs were determined by the point-center-quarter method (Cottam and Curtis 1956) using 40 points. Four trees or shrubs (160 per site) were sampled at each point, and the number of browsed and unbrowsed twigs on each plant recorded. A shrub consisted of single or multiple stems arising from a single base. A twig was a single branch less than 4 mm in diameter, usually a portion of the current annual growth. The Shafer (1963) twig-count method was used to estimate the availability and utilization of hardwood browse. This procedure was similar to that of Joyal (1976). The mean diameter at point of browsing was determined by measuring the diameter of 25 randomly selected browsed branches of each species. Twenty-five unbrowsed twigs of the same diameter were clipped, ovendried, and

weighed in order to determine the mean weight per twig. The weight per twig was multiplied by the number of twigs per shrub and number of shrubs per hectare to provide an estimate of the total biomass of hardwood browse available to moose per hectare. The mean diameters at point of browsing (dpb) and weights per twig (Table 2) were used to compute the amount of browse available per shrub and per hectare. An estimate of browse consumed per hectare was obtained by multiplying the total browse available by the percentage of browsed twigs. Estimates of available browse included growth less than 4 mm in diameter between 50 cm and 3.5 m above the ground.

Table 2. The Diameters at Point of Browsing and Twig Weights of the Browse Plant Species Sampled.

Browse species	Diameter at point of browsing mm, (1 S.E.)	Twig Wt. g, (1 S.E.)
Scouler willow	3.6 (.02)	1.02 (.01)
Feltleaf willow	3.8 (.04)	0.84 (.02)
Sandbar willow	2.8 (.04)	0.56 (.03)
Balsam poplar	4.1 (.07)	1.32 (.07)
Cottonwood	6.0 (.14)	2.36 (.24)
Birch	3.1 (.04)	1.02 (.04)
Aspen	3.1 (.04)	0.97 (.03)
Alder	2.9 (.03)	0.68 (.04)
Highbush cranberry	3.0 (.03)	0.32 (.10)
Willows*	3.0 (.06)	0.63 (.07)

*Willows include Park willow, tall blueberry willow, Bebb willow, diamondleaf willow, and grayleaf willow.

Preference indices (P.I.) were determined for stands that had two or more browse plant species to see if moose were selecting certain plant species to the exclusion of others. The index is defined as P_{ib}/P_{is}, where

$P_{\underline{i}b}$ is the proportion of the $\underline{i}$th species in the diet, and $P_{\underline{i}s}$ is the proportion of that species in the stand. Preference indices were computed using three sets of data: number of stems, number of twigs, and biomass. These computations gave somewhat different results due to the large difference in number of twigs per stem and weights per twig.

RESULTS

Production of Available Browse

Tree and shrub densities and production of available browse are shown in Figure 1 and Table 3. These results are presented below and organized by stand type.

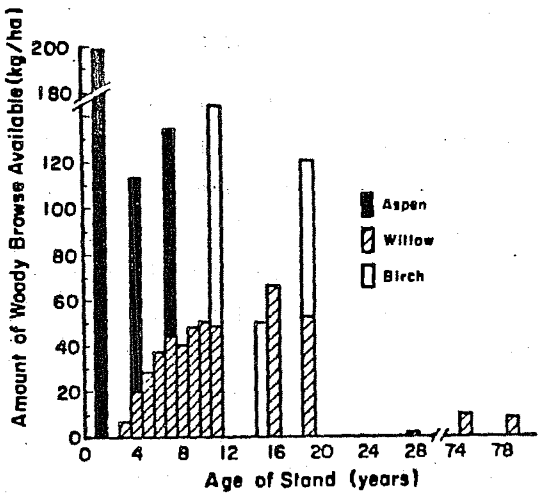

Figure 1. Amounts of woody browse available by species in stands of different age classes.

Table 3. Availability, Utilization and Browse Preferences by Species for Upland and Flood Plain Sites in the Tanana River Drainage.

Site	Age	Species	Shrubs/ ha (1 S.E.)	Twigs/ shrub (1 S.E.)	Forage available/ Shrub, g	Forage available/ ha, kg	Browse consumed ha, kg	Browsing intensity %	Frequency of occurrence	Preference index as determined by no. of: stems	twigs	biomass
Wickersham-1	+3	Scouler willow	400(13.4)	16.0(4.2)	16.3	6.5	2.9	44	74	-	-	-
	+4	Scouler willow	452(14.1)	42.0(3.7)	42.8	19.3	8.7	45	77	-	-	-
	+5	Scouler willow	638(15.0)	43.8(3.8)	44.7	22.5	7.4	26	67	-	-	-
	+6	Scouler willow	638(15.0)	57.0(3.1)	58.1	37.1	0	0	0	-	-	-
	+7	Scouler willow	638(15.0)	67.7(3.9)	69.1	44.1	8.4	19	67	-	-	-
Wickersham-2	+1	Aspen	198,375	1.0(0.0)	1.0	198.4	198.4	100(hares)	100	-	-	-
	+4	Aspen	28,948	4.0(0.2)	3.9	112.9	21.5	19	43	-	-	-
	+7	Aspen	21,645(2,769)	6.4(0.5)	6.2	134.2	0	0	0	-	-	-
Wickersham-3	+75	Scouler willow	489(16.2)	19.0(2.7)	19.4	9.5	3.2	34	53	-	-	-
	+76	Scouler willow	489(16.2)	19.0(2.7)	19.4	9.5	0.8	8	16	-	-	-
	+77	Scouler willow	489(16.2)	17.1(1.9)	17.4	8.5	0	0	0	-	-	-
	+78	Scouler willow	489(16.2)	13.2(0.8)	13.6	6.6	0	0	0	-	-	-
	+79	Scouler willow	489(16.2)	16.7(1.2)	17.0	8.3	0.8	1	9	-	-	-
Wickersham-4	+11	Birch	7,645	19.7	20.1	153.7	33.8	22	63	1.0	.09	1.0
		Scouler willow	1,330	7.4	7.5	10.0	7.9	79	91	1.3	3.2	3.2
		Alder	1,330	31.2(3.0)	30.3	40.3	1.6	4	27	0.3	0.2	0.2
		Aspen	760	4.5(1.2)	4.4	3.3	1.5	44	66	2.0	7.0	2.0
			11,065(1,065)			207.3	44.8	$\bar{x}$=22				
Murphy Dome-1	+16	Willow	10,957	3.3(0.3)	3.4	37.3	5.2	14	28	1.1	1.7	1.7
		Birch	1,895	14.8(2.1)	15.1	28.6	0.3	1	6	0.4	0.4	0.1
		Spruce	2,300	0	0	0	0	0	0			
			15,152(1,969)			65.9	5.5	$\bar{x}$=8				

Table 3. Availability, Utilization and Browse Preferences by Species for Upland and Flood Plain Sites in the Tanana River Drainage--Continued.

Site	Age	Species	Shrubs/ha (1 S.E.)	Twigs/shrub (1 S.E.)	Forage available/Shrub, g	Forage available/ha, kg	Browse consumed ha, kg	Browsing intensity %	Frequency of occurrence	Preference index as determined by no. of: stems	twigs	biomass
Murphy Dome-1	+10	Willow	11,110	6.9(0.6)	4.1	45.5	15.5	30	54	1.2	1.0	1.1
		Birch	2,037	3.3(0.7)	3.4	6.9	0	0	0	0	0	0
		Alder	2,037	5.6(0.9)	3.8	7.7	0	0	0	0	0	0
		White spruce	3,334	0	0	0	0	0	0	0	0	0
			18,518			60.1	15.5	x̄=26				
Murphy Dome-2	+10	Birch	5,000	10.3(3.5)	10.7	93.5	4.7	5	13	1.5	0.9	0.8
		Willow	6,719	4.7(0.6)	3.9	26.2	2.6	10	20	0.6	1.4	1.6
		White spruce	3,906	0	0	0	0	0	0			
			15,629(1,241)			119.7	7.3	x̄=6				
Goldstream	+11	Willow	11,757	3.3(0.3)	2.8	32.9	0	0	0	-	-	-
		Birch	396	3.0(1.5)	3.1	1.2	0	0	0	-	-	-
		Balsam poplar	1,057	1.3(0.6)	1.7	1.8	0	0	0	-	-	-
			13,210(952)			35.9						
Elliot Highway	+50	Birch	4,714	0	0	0	0	0	0	-	-	-
		Alder	1,852	0	0	0	0	0	0	-	-	-
		White spruce	1,852	0	0	0	0	0	0	-	-	-
			8,418(1,007)									
Parks Highway-1	+35	Aspen	6,618	0	0	0	0	0	0	-	-	-
		Alder	216	0	0	0	0	0	0	-	-	-
		White spruce	360	0	0	0	0	0	0	-	-	-
			7,194									
Parks Highway-2		Aspen	1,392(146)	0	0	0	0	0	0	-	-	-
	+50	Aspen	11,820(1,392)	1.0(0.0)	1.0	11.8	9.1	77	77	0.7	0.9	0.9
Bonanza Creek	+1	Birch	107(16)	39.4(3.4)	40.2	4.3	3.9	91	96	1.2	1.2	1.1
			11,927			16.1	13.0	x̄=88				

Table 3. Availability, Utilization and Browse Preferences by Species for Upland and Flood Plain Sites in the Tanana River Drainage--Continued.

Site	Age	Species	Shrubs/ha (1 S.E.)	Twigs/shrub (1 S.E.)	Forage available/Shrub, g	Forage available/ha, kg	Browse consumed ha, kg	Browsing intensity %	Frequency of occurrence	Preference index as determined by no. of: stems	twigs	biomass
Tanana River-1	+0	Feltleaf Willow	8,286	3.8(0.5)	3.2	26.5	14.6	55	64	1.1	1.0	1.0
		Sandbar willow	3,371	3.7(0.5)	2.1	7.1	4.0	57	67	0.8	0.7	1.0
		Balsam poplar	2,388	2.0(0.2)	2.6	6.2	3.8	92	74	1.0	1.9	1.0
			14,045(3,075)			39.8	22.4	x̄=56				
Tanana River-1	+9	Feltleaf willow	10,041	3.6(0.4)	3.0	30.1	0	0	0	-	-	-
		Sandbar willow	3,814	3.5(0.4)	2.0	7.6	0	0	0	-	-	-
		Balsam poplar	3,107	2.4(0.3)	3.2	9.9	0	0	0	-	-	-
			16,962(2,948)			47.6	0	0				
Tanana River-1	+10	Feltleaf willow	9,882	3.1(0.3)	2.6	25.7	4.9	19	19	0.6	1.1	1.2
		Sandbar willow	3,414	3.4(0.4)	1.9	6.5	2.6	40	73	3.0	1.6	2.6
		Balsam poplar	4,672	2.9(0.5)	3.8	17.8	.5	3	5	0.3	0.3	0.2
			17,968(1,330)			50.0	8.0	x̄=16				
Tanana River-1	+11	Feltleaf willow	11,427	3.1(6.3)	2.6	29.7	5.6	19	29	0.8	0.9	0.9
		Sandbar willow	2,770	5.0(0.7)	2.8	7.8	4.9	63	50	29	1.7	2.2
		Balsam poplar	2,770	2.9(0.6)	3.8	10.5	0	0	0	0	0	0
		Alder	346	8.7(3.6)	5.6	1.9	0	0	0			
			17,313(866)			49.9	10.5	x̄=21				
Tanana River-2	+28	Balsam poplar	1,416	0	0	0	0	0	0	-	-	-
		Alder	7,642	1.2(0.2)	0.8	6.1	0	0	0	-	-	-
		Feltleaf willow	377	0.8(0.6)	0.7	0.3	0	0	0	-	-	-
			9,434(506)			6.4	0	0	0			

Table 1. Availability, utilization and Browse Preferences by Species for Upland and Flood Plain Sites in the Tanana River Drainage--Continued.

Site	Age	Species	Shrubs/ ha (1 S.E.)	Twigs/ shrub (1 S.E.)	Forage available/ Shrub, g	Forage available/ ha, kg	Browse consumed ha, kg	Browsing intensity %	Frequency of occurrence	Preference index as determined by no. of: stems	twigs	biomass
Tanana River-3												
	+16	Feltleaf willow	30,000	2.4(0.2)	2.0	60.0	39.6	66	89	1.0	1.8	1.2
		Tall blueberry willow	27,000	2.8(0.2)	1.3	35.1	19.7	56	60	0.8	0.7	1.0
		Park willow	2,250	3.2(0.3)	1.5	3.4	0.6	18	43	0.3	0.3	0.3
		Balsam poplar	5,000	2.1(0.2)	2.8	14.0	1.8	13	18	0.4	0.5	0.3
			64,250(16,229)			112.5	61.7	$\bar{x}$=56				
Tanana River-3												
	+19	Feltleaf willow	18,182	3.5(0.3)	2.9	52.7	12.6	24	35	-	-	-
		Willows	5,289	4.1(0.7)	1.9	10.0	0.3	3	6	-	-	-
		Alder	9,587	5.4(0.5)	3.7	35.5	0.0	0	0	-	-	-
			33,058(2280)			98.2	12.9	$\bar{x}$=13				
Tanana River-4												
	+80	Balsam poplar	2,162	0	0	0	0	0	0	-	-	-
		Alder	2,378	2.6(0.7)	1.8	4.3	0	0	0	-	-	-
		White spruce	865	0	0	0	0	0	0	-	-	-
			5,405(446)			4.3	0	0				

Uplands

Wickersham: In W-1 (willow), browse production increased from 6.5 to 44.1 kg/ha, 3 to 7 years after the fire. All browse consisted exclusively of post-fire vegetative sprouts of Scouler willow. The increase in production was due to an increase in number of shrubs for the first 5 years and an increase in number of twigs per shrub for all 7 years.

Browse production in W-2 (aspen) was greatest the 1st year after fire (198 kg/ha), decreased to 113 kg/ha 4 years after fire, and increased to 134 kg/ha 7 years after the fire. The high productivity 1 year after fire was due to a large number of stems with one twig/stem, whereas at 7 years the number of stems had decreased, but the number of twigs per stem had increased to 6.4. This stand originated from root suckers.

W-3, the unburned stand of black spruce, supported 489 willow shrubs/ha. The biomass of available browse was less than 10 kg/ha for the 5-year sampling period. The number of twigs per shrub in the unburned stand varied from 13 to 19 compared to 68 twigs/shrub in the 7-year-old burn. Some of the shrubs had branches 5 m high and were out of browsing reach.

W-4 (birch clearing) had 11,065 stems/ha, 7,645 of which were birch. The mean number of twigs per birch stem was 19.7 and yielded 153.7 kg/ha of browse. Willows, aspen, and alder yielded another 53.6 kg/ha for a total of 207.3 kg/ha of browse. This stand resulted from the establishment of seedings and was the most productive of all stands sampled.

Murphy Dome: Browse production in MD-1 was 66 and 60 kg/ha, 16 and 19 years post-fire respectively. Production of willow and birch browse decreased from 66 to 52 kg/ha during the 3-year period as alder made up 8% of the woody browse in the older stand. White spruce was also becoming more predominant in the stand at 19 years attaining a density of 3,334 stems/ha and a height of 1 to 2 meters.

At MD-2, browse production was 119.7 kg/ha. The number of willow stems per hectare was greater than birch, but the larger number of twigs per stem (18.3 for birch and 4.7 for willow) resulted in a greater production of birch browse. Alder was not present in the birch stand, but white spruce density was 3,906 stems/ha. The birch stems averaged 6 m in height; consequently, about 25% of current annual growth less than 4 mm in diameter was above browsing height and was not included in the sampling. The browse at both Murphy Dome stands resulted from seed.

Goldstream: This 11-year-old willow stand had 25.9 kg/ha of browse. The majority of this was produced by three species: grayleaf (*Salix glauca*) feltleaf, and diamond leaf willow (*S. planifolia*), none of which were identifiable to species at the time of sampling. Birch and poplar were less dense in the stand. Spruce seedlings were abundant but all were less than 30 cm tall.

Bonanza Creek: This stand had 11,820 aspen stems/ha yielding 11.8 kg/ha of browse. These stems were root suckers and were about 1 m high. Birch regeneration was from stump sprouts which averaged 39.4 twigs /stump. Birch seedlings were also present but were less than 10 cm tall. All browse sampled in this 1-year-old stand was above snowline and available to moose as forage.

Elliott Highway: This 50-year-old stand of birch, alder, and white spruce had no browse within reach. The birch had a d.b.h. of 6 to 8 cm and a height of 6 to 8 m. The canopy was closed, and there were no other browse shrubs in the understory.

Parks Highway-1: This 35-year-old aspen stand had 6,618 stems/ha; however, the mean d.b.h. was 10 cm, and the nearest twigs were 5 m from the ground. The stand had grown out of reach of browsing mammals, and there were no other woody shrubs in the understory.

Parks Highway-2: Trees in this homogeneous, 70-year-old aspen stand had a d.b.h. of 20 cm; and the dominant trees were 21 m. No twigs were within browsing range of moose, and there were no woody shrubs in the stand. White spruce was present in the understory.

Floodplain

Tanana River: Browse production at the TR-1 increased from 39.8 to 49.9 kg/ha between 8 and 11 years of age. Feltleaf willow was the most common species present with sandbar willow and balsam poplar also present. Alder was also present in the stand but did not show up in the sampling until 11 years. The number of twigs per stem varied from 2.4 to 5.0 for all browse species. The number of stems per hectare and twigs per shrub had not changed from 9 to 11 years which suggests that maximum production of browse had probably been reached. Most shrubs were 2 to 3 m tall and within browsing reach; however, about 5% of the feltleaf willows were taller than 4 m and out of browsing range.

The 28-year-old alder stand, TR-2, produced only 6.4 kg/ha of browse, 6.1 of which was alder. The alder was 4 to 5 m tall, and the poplar was 9 m tall. All poplar twigs were higher than 4 m. Alder and poplar had taken over the stand which presumably was dominated by willows in its earlier succession.

The forage available at TR-3 (willow) was 112.5 and 98.2 kg/ha at ages 16 and 19 years. The number of willow stems per hectare decreased substantially between 16 and 19 years, while the number of alders increased. This suggests that annual productivity is probably declining. The method used for sampling the 16-year-old stand differed slightly from the method used for the 19-year-old stand. This may have resulted in an overestimate of the 16-year-old stand and may account for the large difference in available forage. The decrease in forage available was real however, as evidenced by a large number of decadent willow stems.

The formation of the Tanana River stands (primary succession) was a more complex process than those resulting from secondary succession on the upland sites. The majority of shrubs on floodplain sites are believed to be of seed origin; however, an unknown percentage are of vegetative origin. These have resulted from production of new plants from broken branches deposited and buried during periods of high water. Shrub origin of this type is similar to seed reproduction in that the plants must establish root systems. The other exception to seed origin is that sandbar willow and balsam poplar can expand vegetatively by root suckers. The point to be made is that shrubs and trees of seed origin do not have the advantages of sprouts which arise from established root systems with stored reserves.

In the 80-year-old poplar stand, TR-4, browse production was limited to 4.3 kg/ha of alder. The poplars were 20 m tall with a d.b.h. of 20-25 cm. No other woody browse was available in the understory.

Browsing Intensities and Selectivity

Uplands

Browsing intensities and preference indices are shown in Table 3.

Wickersham: Browsing intensities at W-1 (willow) ranged from 0% to 45% during the 5-year sampling period. The heaviest browsing intensity was at 4 years, the lowest, no browsing, was at 6 years. During the years in which browsing was recorded, 67% to 77% of the shrubs had been browsed to

some extent. Most shrubs which were browsed had less than 50% of their available twigs clipped and rarely was 100% of the twigs on a given shrub removed. This was true for all stands sampled.

Browsing intensity in W-2 (aspen) was 100% 1 year after the fire; however, this was due entirely to snowshoe hares (*Lepus americanus*). Moose browsing intensity was 19% at 4 years and 0% at 7 years.

Browsing intensity in the unburned stand, W-3, was 34% and 8% at 75 and 76 years respectively, then decreased to 0% and 1% for the next 3 years.

Browsing intensity at W-4 (birch clearing) was 23%. A preference was shown for aspen followed by Scouler willow, birch, and alder. This was the only stand in which alder was browsed.

Murphy Dome: Browsing intensities at the MD-1, 16 and 19 years, were 8% and 26% respectively. At MD-2 browsing intensity was 6%. Preference indices showed a definite preference for willows in the birch stand. Willows consisted of Scouler and feltleaf willows which were browsed at equal intensities. When using the preference index computed by number of stems, however, a preference was shown for birch in the birch stand. The differences in results are due to a larger number of twigs per stem on birch as compared with willow.

Goldstream: No browsing by moose was recorded at the 11-year-old stand at Goldstream. Browse was plentiful in this stand and within reach, but no browsing was recorded. There was no evidence of browsing during the previous two winters.

Bonanza Creek: Browsing intensity at the logged stand was 81%. This was the highest browsing intensity recorded. A slight preference was shown for birch; however, both aspen and birch were browsed at high intensities.

No browsing by moose was recorded in the adjacent unlogged 130-year-old stand.

Tanana River: Browsing intensities at TR-1 ranged from 0% at 9 years to a maximum of 56% at 8 years. Preference indices showed sandbar willow to be a preferred species; however, feltleaf willow also had a preference index greater than 1. Poplar had a low selectivity value, and alder was not eaten. No browsing by moose was recorded in TR-2.

Browsing intensities at TR-3 were 55% and 13% at 16 and 19 years, respectively. A slight preference was shown for feltleaf willow when the stand was sampled at 16 years with tall blueberry willow, park willow, and poplar consumed to a lesser extent. Sampling was conducted before budbreak at 19 years, so tall blueberry and park willow could not be differentiated.

No browsing by moose was recorded in the 80-year-old poplar stand, TR-4.

DISCUSSION

Species Response

Production and utilization of browse is determined by the interaction of prior stand density and composition, regeneration characteristics, growth rate of browse species, site conditions, nature of disturbance, and the impact of browsing on the vegetation.

Aspen. Aspen was present in three of the upland stands. It occurs on relatively warm, permafrost-free, upland sites and is uncommon on floodplains. Because of its ability to produce root suckers following death of the parent stem, substantial amounts of browse are produced the first full growing season following disturbance. Density and distribution of stems in

young aspen sucker stands is relatively uniform compared to the aggregated or clumpy nature of birch and willow stems of vegetative origin. The genetic composition of sucker stands is such that one genotype (a clone) may cover a large area. For example, clone sizes up to 40 ha have been reported in North America (Kemperman and Barnes 1976). In the other major browse species, each stem or multi-stemmed group is genetically different. These genetic patterns could have significance with regard to selection and palatability of browse. Aspen seed reproduction is common in this region, but pure stands resulting from seed are not known.

The Wickersham aspen stand (W-3) exhibited the classic response to fire. The browse available at the end of the first growing season was the greatest observed in this study. By age 7, stem density was reduced to about 10% of that at age 1, while available browse declined to only 68%. Maintenance of browse availability at higher levels is the result of the formation of lateral branches in older stems due to browsing effects. Few, if any, lateral branches are produced by 1-year-old aspen suckers. The age at which browse is no longer available depends on site quality and other variables. Observations made in 17- and 15-year-old aspen stands indicated that the lowest branches were 2 m from the ground and 75 percent of the current annual shoot growth was over 4 m above the ground. The 35- and 60-year-old aspen stands produced no available aspen browse.

In the severely disturbed homestead clearing, W-4, aspen occurred as widely spaced single stems suggesting that they were of seed origin. Observations made in this study do not allow a comparison between browse production in seedling and sucker stands, however, our observations elsewhere in this region suggest that seedling growth is much slower than sucker growth and that 3 to 5 years or more are required before seedlings are tall enough to provide winter browse. The result of slower growth would be to offset the productive period by this number of years. Relative rates of browse production by seed and vegetative growth are summarized in Fig. 2.

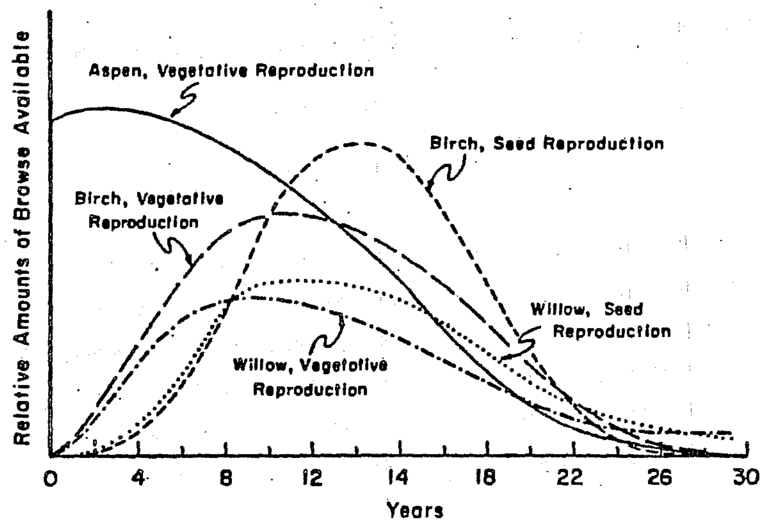

Figure 2. Rates and relative amounts of browse produced by aspen, willows, and birch by seed and vegetative growth in different aged stands.

Birch: Birch, which occurs primarily on upland sites, was a major component in six of the stands examined. It is also found to a limited extent in older successional floodplain stands. Birch has a wider tolerance than aspen in that it occurs on the same sites plus somewhat colder sites (Gregory and Haack 1965).

Regeneration of birch occurs from seed and stump sprouts. Stems resulting from vegetative reproduction of birch are fast growing and produce moose browse at the end of the first full growing season (e.g.

stand BC, Table 3 and Fig. 2). The structure of the stand is one of multi-stemmed clumps arising from the stumps of earlier mature trees. The capacity of mature birch to produce post-disturbance sprouts decreases after 40-60 years, and by age 100 only about one-half of the cut trees appear to produce basal sprouts (J. Zasada, unpubl).

In order to obtain stands with a structure and density similar to aspen, it is necessary for seed reproduction to fill in the gaps between the multi-stemmed groups. Birch produces vast quantities of seed at frequent intervals (Zasada and Gregory 1972). Establishment of seedlings is greatest on mineral soil but can occur on disturbed organic matter. Growth of seedlings is slower than sprouts. Unpublished data collected at Bonanza Creek Experimental Forest indicated that average seedling height in clearcuts was about 70 cm and maximum height about 1.2 m at age 5. Birch sprouts in the same area averaged 3-4 m.

Available moose browse varied from 4 kg/ha at the 1-year-old BC stand to 154 kg/ha at W-4. No birch browse was available in the 50-year-old birch stand. With the exception of stand W-4, browse production was mostly produced by sprouts. At W-4, the most productive in terms of available birch browse, the stand was composed entirely of stems resulting from seed regeneration. J. Oldemeyer (pers. communication) recorded an annual production of from 79 to 151 kg/ha of browse in 25-year-old birch stands on the Kenai National Moose Range.

Willow: Willows are primary forage species following disturbance in black spruce communities on uplands and on newly formed sandbars of flood plains. Although there is some overlap in species composition between uplands and lowlands, the sites in this study had only feltleaf willow occurring on both general types. Willow stand formation on uplands following fire tends to be predominantly from sprouting. Sprouts can attain heights of 50 to 80 cm in 1 year, while seedlings take at least 3 years to attain this height. Stand formation on floodplains is a mixture of stems formed from seed and buried branches. In the case of sandbar willow, additional stems are produced by root suckering.

On upland sites, where Scouler willow predominated, stems were available above snowline the first 2 years after fire, but these were completely consumed by snowshoes hares (Wolff 1977). Four years after the fire, browse production was twice as great in the burn as in the unburned stand; 7 years after the fire, it was five times greater. Willow browse at MD-1 (birch) was less than at W-1 (willow) and probably reached peak production between 15 and 19 years post-fire. It is projected that browse production in W-1 will peak between 10 and 15 years after the fire and decrease by 20 years.

At TR 1, a flooplain site, browse production increased from 8 to 11 years, and it appeared to peak between 10 and 11 years. In the adjacent 28-year-old alder stand, TR-2, willow production was negligible, and alder was dominant. Alder was invading the 11-year-old stand, and it is projected that TR-1 will be dominated by alder and balsam poplar by 20-25 years.

A similar pattern of production and succession was evident at TR-3. Production declined between ages 16 and 19. Alder was beginning to invade this stand; according to the predicted successional pattern for the flood plain, it will dominate the stand along with poplar in the next 10 to 15 years (Viereck 1970).

In unpublished work we assessed sprouting capacity (rate of secondary succession) of floodplain willows by conducting a cutting study at TR-1. All willow stems were cut from four, 100-m^2 plots. Stem density and browse

production were determined in May 1975 (before cutting), May 1976 (1 year after cutting), and May 1978 (3 years after cutting).

Cutting resulted in a 36% reduction in the number of willow stems per plot after 3 years. The number of shoots per shrub increased by 29 and 56% 1 and 3 years respectively after cutting. Browse production was 82% of predisturbance condition after 1 year and slightly greater 3 years after clipping (Table 4). These results indicated that the species on this floodplain site respond in a manner similar to that of willow on uplands.

Table 4. Response of Willows at Tanana River-1 Site to Removal of Above Ground Stems. N=4

Years since cutting	Stems per plot	Twigs per shrub	Browse per plot[1/]
Before cutting	253(42)[2/]	1.9(.3)	.37(.02)
1	154(24)	2.4(.4)	.30(.04)
3	161(27)	3.1(.5)	.40(.05)

[1/] Multiply by 100 for kg/ha.

[2/] Standard error of the mean of parentheses.

Browse Preference: Browsing preferences were difficult to obtain because of homogeneity of stands. Over the 4-year sampling period at TR-1, a preference was shown for sandbar willow followed by feltleaf willow and balsam poplar. At TR-3, feltleaf willow was preferred over tall blueberry willow, park willow, and balsam poplar (Table 3). Willows were preferred to birch in the mixed stand at MD-2 and W-4. In Quebec, Joyal (1976) also found willow to be preferred over aspen and birch. In the one instance where aspen occurred in mixture (W-4), it was preferred to birch. Oldemeyer et al. (1977) found that alder and birch supply higher winter levels of protein, but willow is more digestible; because of variation in nutrients, trace elements, and digestibility among species, they suggest that variety is important in the diet of moose.

Preference for a species was dependent in part by its abundance in the stand. When willow had a low frequency of occurrence, it had a higher selective value than when it occurred in higher densities (Figure 3a). Preference indices using number of stems, branches, or biomass gave a similar result. The same pattern did not, however, hold for birch (Figure 3b). Small sample size prevented statistical analysis of these differences.

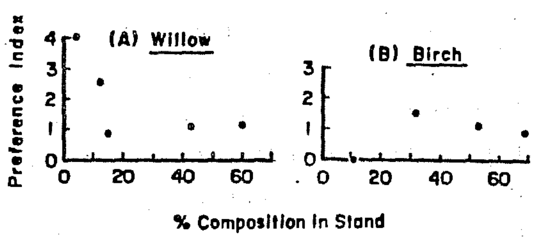

Figure 3. The relationship between percent composition in the stand of willows (A) and birch (B) and moose preference indices.

Due to low browsing intensities in most stands throughout this study, it was difficult to obtain a quantitative measure of browse preferences or even stand-type preferences. Browsing intensities were high at Bonanza Creek, but this was a small stand, and stands within 200 m

experienced lower browsing intensities. In larger stands such as the Murphy Dome or Wickersham sites, moose had unlimited forage and could be more selective. In fact in W-2 (willow) browsing by moose was not recorded at 7 years, but browsing in W-1 (willow) was 19%. On the Kenai National Moose Range where moose populations are high and food is limited, all browse plant species are consumed at high levels (Oldemeyer et al. 1977). Similar observations were made in McKinley National Park from 1975 to 1978 where a high moose population has been browsing over 80% of preferred willow species (J. Wolff, unpubl).

Using data in this study and unpublished observations, we have attempted to list the browse species preferences. Sandbar willow is the preferred species followed by other willow species, birch, aspen, cottonwood, poplar, highbush cranberry, and alder. Willow species, which are common in interior Alaska and are used extensively by moose, include *S. alaxensis*, *S. planifolia*, and *S. arbusculoides* (Milke 1969, Machida 1979). Alder was reported consumed by moose along the Colville River on the North Slope of Alaska (Coady 1974).

In this study, no attempt has been made to determine palatability of individual shrubs other than developing a preference index for each species. Nonrandom browsing by moose on individuals within a species has been suggested by LeReseche and Davis (1971) and was quantified by Machida (1979). The nutrient content, digestibility, and inhibitory compounds which are present in different concentrations in different species and between shrubs within a species have an effect on palatability (Cowan et al. 1950, Oldemeyer et al. 1977). Shrubs which have been browsed for several consecutive years may contain inhibitory compounds which reduce palatability and inhibit further browsing; however, Machida

(1979) found that moose may select the same shrub for at least 3 consecutive years to the exclusion of others. Therefore, only a portion of the biomass of browse available in a stand may be palatable to moose.

Carrying capacity and utilization of browse in a stand was computed using an average daily consumption rate of 5 kg browse/moose/day (Gasaway and Coady 1974) and recorded in moose days per hectare (M.D./ha) (Wolff 1978). Carrying capacities and utilization for all stands which produced woody browse are shown in Figure 4 and Table 5. Maximum carrying capacity is based on a daily consumption rate of 5 kg/moose assuming *all* browse available is palatable. In this study, a maximum browsing intensity of 56% was recorded. On the Kenai National Moose Range, J. Oldemeyer (pers. communication) found that moose which were taking 85% of the available browse were starving and were undergoing high over-winter mortality. In McKinley National Park, I recorded a browsing intensity of between 80% and 90%; calf production and winter calf survival there were low (S. Buskirk, National Park Service, McKinley National Park, Alaska, pers. comm.). Therefore, at a browsing intensity of between 60% and 85%, moose are probably reaching the carrying capacity of palatable browse. Based on these figures and observations, we have adjusted the carrying capacity of palatable browse to 75% of total browse available which probably represents the critical threshold in most stands below which moose can still select palatable browse. After 75% of the browse has been consumed, the remaining browse is not only less nutritious but more scattered and energetically more costly for the moose to locate and consume the remaining 25%. The maximum sustained browsing intensity which a shrub can withstand is probably between 50% and 75% (Krefting et al. 1966, Wolff 1978). The 75% adjusted carrying capacity must be

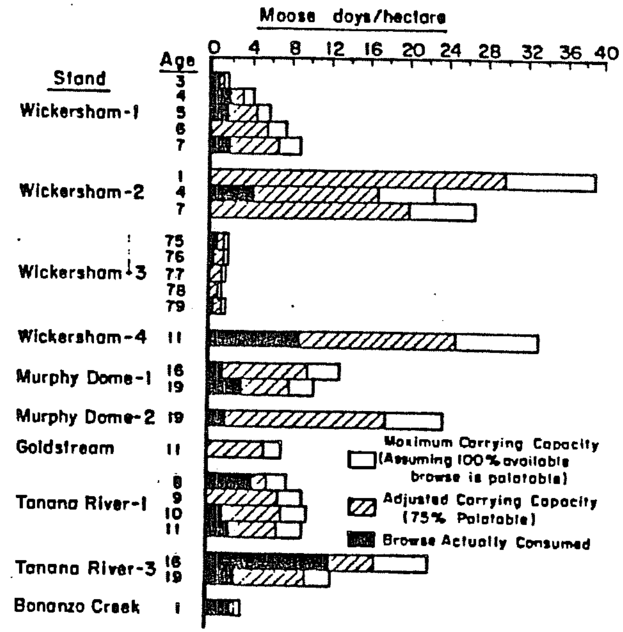

Figure 4. Maximum and adjusted carrying capacities and amounts of browse consumed by moose in each study area.

considered a generalization and should be further adjusted to specific stand conditions.

Moose population densities during the period of this study (1972-1978) were not measured for the study sites. However, during this period populations were generally considered very low (Coady 1976). The implications of these low populations to browse utilization are two-fold. The most obvious is the relatively low level of browse utilized. During the course of this study, all areas observed had been browsed to some degree during at least 1 year. With several exceptions, however,

Table 5. Carrying Capacity and Browse Utilization for Selected Upland and Flood Plain Stands in the Tanana River Drainage.

Stand	Age	Browse available Kg/ha	Maximum carrying capacity M.D./ha	Adjusted carrying capacity M.D./ha	Total browse consumed Kg/ha	Actual utilization M.D./ha
Wickersham-1	+3	6.5	1.3	1.0	2.9	0.6
	+4	19.3	3.9	2.9	8.7	1.7
	+5	28.5	5.7	4.3	7.4	1.5
	+6	37.1	7.4	5.6	0	0
	+7	44.1	8.8	6.6	8.4	1.7
Wickersham-2	+1	198.4	39.7	29.8	0	0
	+4	112.9	22.6	17.0	21.5	4.3
	+7	134.2	26.8	20.1	0	0
Wickersham-3	+7	9.5	1.9	1.4	3.2	0.6
	+76	9.5	1.9	1.4	0.8	0.2
	+77	8.5	1.7	1.3	0	0
	+78	6.6	1.3	1.0	0	0
	+79	8.3	1.7	1.3	0.8	0.2
Wickersham-4	+11	167.0	33.4	25.1	44.8	9.0
Murphy Dome-1	+16	65.9	13.2	9.9	5.5	1.1
	+19	52.4	10.5	7.9	15.5	3.1
Murphy Dome-2	+19	119.7	23.9	17.9	7.3	1.5
Goldstream	+11	35.9	7.2	5.4	0	0
Tanana River-1	+8	39.8	8.0	6.0	22.4	4.5
	+9	47.6	9.5	7.1	0	0
	+10	50.0	10.0	7.5	8.0	1.6
	+11	48.0	9.6	7.2	10.5	2.1
Tanana River-3	+16	112.5	22.5	16.9	61.7	12.3
	+19	62.7	12.5	9.9	12.9	2.6
Bonanza Creek	+1	1 16.1	3.2	2.4	13.0	2.6

browsing intensities were generally less than 50 percent; and in four stands no browsing was observed. Although carrying capacity is not known for large areas within this region, the data suggest that moose have not been food-limited, and much winter range is not being exploited.

Secondly, moderate browsing intensities on trees and woody shrubs in young stands may actually increase the amount of browse in future years (Spencer and Chatelain 1953, Krefting et al. 1966). Wolff (1978) observed that browsing has a pruning effect in that browsed branches produced more vegetative growth the following growing season than unbrowsed branches. This is true for young and old stands but has a greater positive effect on young shrubs or trees. Multiple stems and lateral branching of main stems of willows at Wickersham are the result of heavy browsing by hares and moose the first 3 years after fire. The large number of twigs per stem of birch at W-4 and Murphy Dome are likewise the result of a brooming effect following several consecutive years of browsing on terminal shoots. Browsing had not occurred at the Goldstream site for several years, and current annual growth on willows was less than 0.7 g/twig. Current annual growth in browsed stands was greater than 1.0 g/twig; Wolff (1978) reported current annual growth of browsed twigs at W-1 to be 4.0 g/twig. Heavy browsing intensity near 100% for several years may, however, lower current annual growth and in some cases kill the plant.

SUMMARY AND CONCLUSIONS

1. Seral communities important to moose winter range production result from both primary and secondary succession. The most common cause of the latter is wildfire; however, forest harvesting and land clearing also fall into this category. Primary succession occurs on newly deposited sandbars along the Tanana River and its tributaries.

2. The dominant trees and shrubs in these seral communities are several species of willow, birch, aspen, balsam poplar and alder. All of these species, but particularly aspen, are capable of producing some browse within one growing season after disturbance, provided that vegetative regeneration is possible. If they must regenerate from seed, a minimum of 3-5 years is required before browse production begins.

3. The time of maximum production varies with species, site conditions, and severity of disturbance. Aspen sucker stands are most productive up to 10 years old. Willow sprout stands reach maximum production between 10 and 16 years with a marked decline after 20 years. Birch is similar to willow.

4. During peak production, aspen stands appear to produce more biomass followed by birch and willow, in that order. This is probably due to the dense aspen stands formed by root suckers.

5. One or more willow species are preferred to birch, aspen, balsam poplar, and alder.

6. The realized carrying capacity of a stand may be only 75 percent of total browse available.

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AN EXPERIMENTAL MOOSE HUNT ON HECLA ISLAND, MANITOBA

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Abstract: Evidence suggesting that the moose herd on Hecla Island, located in Lake Winnipeg, had surpassed the carrying capacity of the Island resulted in the implementation of a controlled moose hunt in the fall of 1978. Two seasons were held, an early fall season limited to 150 bow hunters and a winter season restricted to 100 hunters. All licences were obtained *via* a draw. Bow hunters harvested 3 bull moose while rifle hunters took 37 moose (18 bulls, 15 cows and 4 calves). The lungs, heart, liver, kidneys, female reproductive tract, stomach sample, jaw, front leg bone and blood samples were obtained from most animals. In addition, live and/or dressed weights were obtained from most animals. A summary of the analysis of the biological material collected is reported. An economic analysis of the hunt showed that 101 rifle hunters spent a total of $9,774.78 of which $8,338.56 was injected into the local economy. 139 bow hunters spent a total of $13,910.30 of which $4,815.50 was spent in the local area. This hunt, although designed to reduce the moose population closer to the Island's present carrying capacity, did little other than remove a number comparable to the number of calves in the population in early December. A post season survey revealed 177 moose and the population is estimated to be 221.

Hecla Island, the largest island in Lake Winnipeg located in the south central portion of Manitoba encompasses about 161 Km^2 and is considered unique in the province because of its Icelandic history and its present day large moose population. The latter is presently est-

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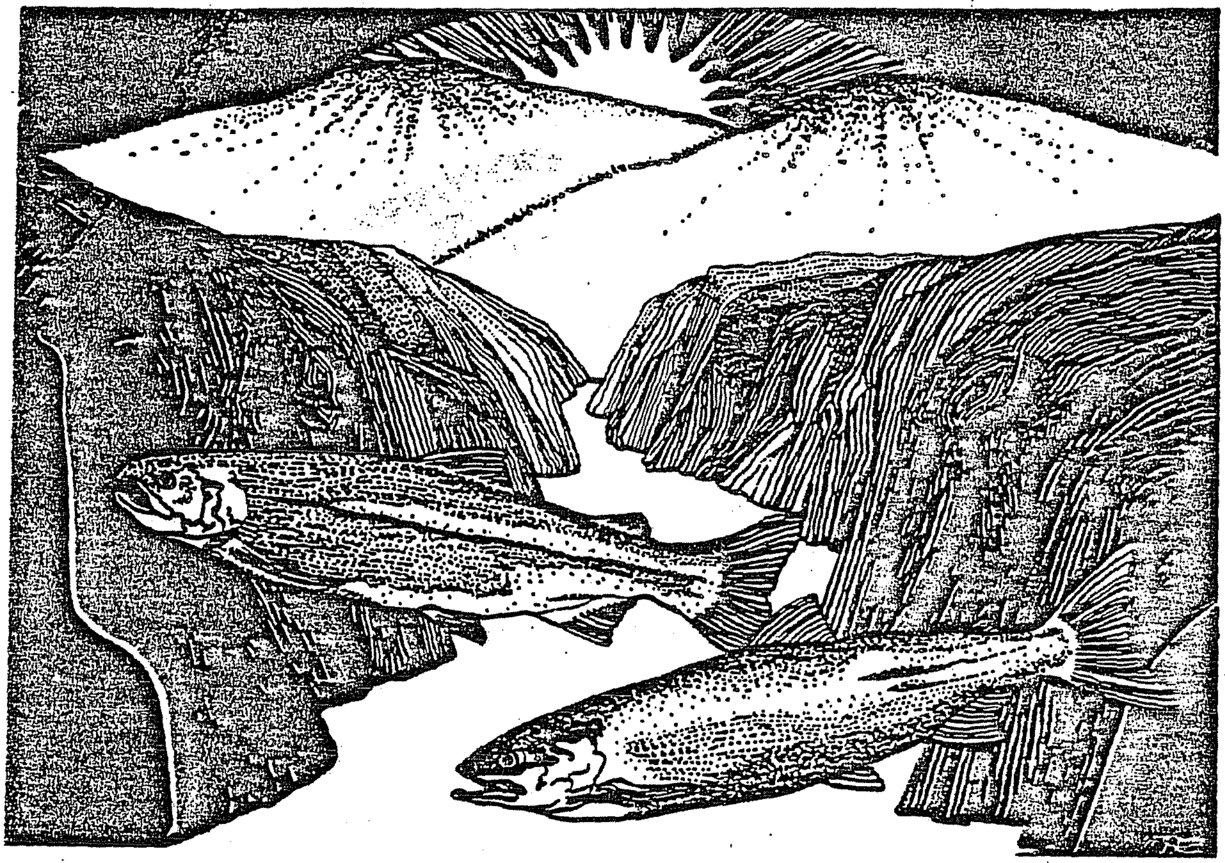

Subtask 7.10
Phase 1 Final Draft
Stock Separation
Feasibility Report
Adult Anadromous Fisheries Project
ADF&G / Su Hydro 1982

ALASKA
DEPARTMENT OF FISH AND GAME

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

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1. SUMMARY

Five species of Pacific salmon return to freshwater systems, including the Susitna River, in Upper Cook Inlet. The Upper Cook Inlet commercial fishery harvests mixed stocks and species migrating north of Anchor Point, with a long term average catch of 2.8 million fish, worth approximately 17.9 million dollars.

The commercial sockeye salmon harvest has averaged 1.2 million fish the past ten years. This species is economically the most valuable species, receiving greatest emphasis in management and research. A stock identification program using scale pattern analysis has been developed to estimate stock contribution of major river systems to the commercial harvest. Estimates for the 1979 and 1980 fisheries show stock contribution by the Susitna River was 22.7% and 19.2% respectively.

The Upper Cook Inlet chum salmon catch has averaged 707,000 fish the past ten years. Though available escapement data identify the Susitna River as the major producer, river systems on the west side of Cook Inlet are known to support chum salmon populations. Evaluation of west side production is necessary to determine the need for a stock separation program. Electrophoresis and scale pattern analysis are two options for stock identification, should a program prove necessary.

The Upper Cook Inlet coho catch has averaged 204,000 fish the past ten years. Though the Susitna River appears to be the single largest producing system in

Upper Cook Inlet, contribution of west side river systems must be addressed. Previous stock identification has been attempted with positive results using fish weight and scale pattern analysis. However, prior to implementing a stock identification program, major Upper Cook Inlet systems must be confirmed to estimate Susitna River contribution.

The ten year average catch for Upper Cook Inlet pink salmon is 146,000 and 1.7 million fish for odd and even years respectively. Two leading pink salmon producers are the Kenai and Susitna river drainages. However, production of west shore systems is unknown. When major producing river systems have been defined, electrophoresis and length-weight data should be examined as stock identification techniques.

Because migration timing relative to 25 June commercial season opening, Susitna River chinook salmon currently are not significantly exploited in the Upper Cook Inlet fishery; a stock separation program is not necessary at this time.

2. INTRODUCTION

The Susitna River drainage is the largest watershed in the Cook Inlet basin. Though considered the highest salmon producing system in Upper Cook Inlet, quantitative contribution of the Susitna River to the commercial fishery is unknown due to the high number of intra-drainage spawning and rearing areas, the paucity of data on other known and suspected salmon producing systems in Upper Cook Inlet and the overlap in migration timing of mixed stocks and species in Cook Inlet harvest areas.

This report focuses on the feasibility of assessing the Susitna River contribution to the commercial salmon fishery in Upper Cook Inlet through a stock identification program and is intended to serve as a planning document. In preparing this report, fishery harvest data was examined and a literature review was conducted centering on stock identification techniques and escapement investigations in Upper Cook Inlet.

This study is part of the Fish Ecology (Subtask 7.10) Phase I investigations of the Susitna Hydroelectric Project.

The primary objectives of the fish ecology studies relative to Susitna Hydroelectric Project are to: (1) describe the fisheries resources of the Susitna River, (2) assess the impacts of development and operation of the Susitna Hydroelectric Project on these fisheries resources, and (3) propose the mitigation measures to minimize adverse impacts (Alaska Power Authority Susitna Hydroelectric Project, Environmental Studies Procedures Manual, Subtask 7.10, Fish Ecology Impact Assessment and mitigation planning, prepared by Terrestrial Environmental Specialists August 1981). The task of meeting the first of these study objectives is the responsibility of the Alaska Department of Fish and Game (ADF&G) under a reimbursable services agreement (RSA) with the Alaska Power Authority (APA) and the second and third are the responsibility of Terrestrial Environmental Specialists (TES).

3. OBJECTIVE

The purpose of this project was to identify and determine methods, means and feasibility of estimating Susitna River salmon stock contribution to the Upper Cook Inlet commercial fishery.

4. METHODS

Accomplishing the stated objective required examination of salmon harvest data for the Cook Inlet commercial fishery, and review of literature regarding the Upper Cook Inlet fishery programs and stock identification techniques.

To determine the contribution of Susitna River salmon to the Cook Inlet commercial fishery, assessment of salmon production in remaining Cook Inlet river systems is required. Therefore, salmon abundance data in freshwater systems was researched for chinook, sockeye, coho, pink and chum salmon. Whereas the term escapement in literature refers to the total number of adult salmon which have achieved spawning migration into freshwater, the terminology "escapement enumeration or counts" used in this text and appendices refers to sonar, weir or tower escapement monitoring. Reference to "survey counts" or "peak survey counts" is aerial or stream survey data. Aerial ground survey and escapement monitoring data were provided by the Alaska Department of Fish and Game (ADF&G) Division of Commercial Fisheries, Fisheries Rehabilitation and Enhancement Division and Division of Sport Fish, Cook Inlet Aquaculture Association, Dowl Engineers, and Woodward-Clyde Consultants. Biologists from ADF&G Division of Sport Fish, Cook Inlet Aquaculture Association and Woodward-Clyde

Consultants were interviewed regarding observations of fish in areas which had been surveyed but as yet, not documented. Additional observations were provided by Dowl Engineers. Sport fish harvest data (Mills 1980) was included as an indicator of species presence, particularly where escapement or survey data was not available. The abundance data is tabled in the appendices by geographical area and listed by river system in alphabetical order.

5. RESULTS AND DISCUSSION

5.1 The Cook Inlet Commercial Fishery

Cook Inlet is divided into two management areas. The region north of the latitude of Anchor Point is Upper Cook Inlet and the area between the latitudes of Anchor Point and Cape Fairfield on the Kenai Peninsula is defined as Lower Cook Inlet. Commercial fisheries in Lower Cook Inlet are primarily terminal, occurring in small bays. Therefore, few salmon migrating to Upper Cook Inlet are intercepted in the lower inlet area (Middleton 1980). Upper Cook Inlet fisheries harvest stocks bound for river systems north of Anchor Point. These systems account for 78% of the salmon produced in the Cook Inlet area.

To regulate commercial catch and effort, Upper Cook Inlet is divided into two management sections, the Central and Northern districts. These districts in turn are broken into subdistricts (Figure E.5.1) and again into statistical areas. Both set and drift gill nets are fished in the Central District, and only set nets are legal in the Northern District. Five salmon species are harvested in Upper Cook Inlet fisheries. Most of the catch occurs in the

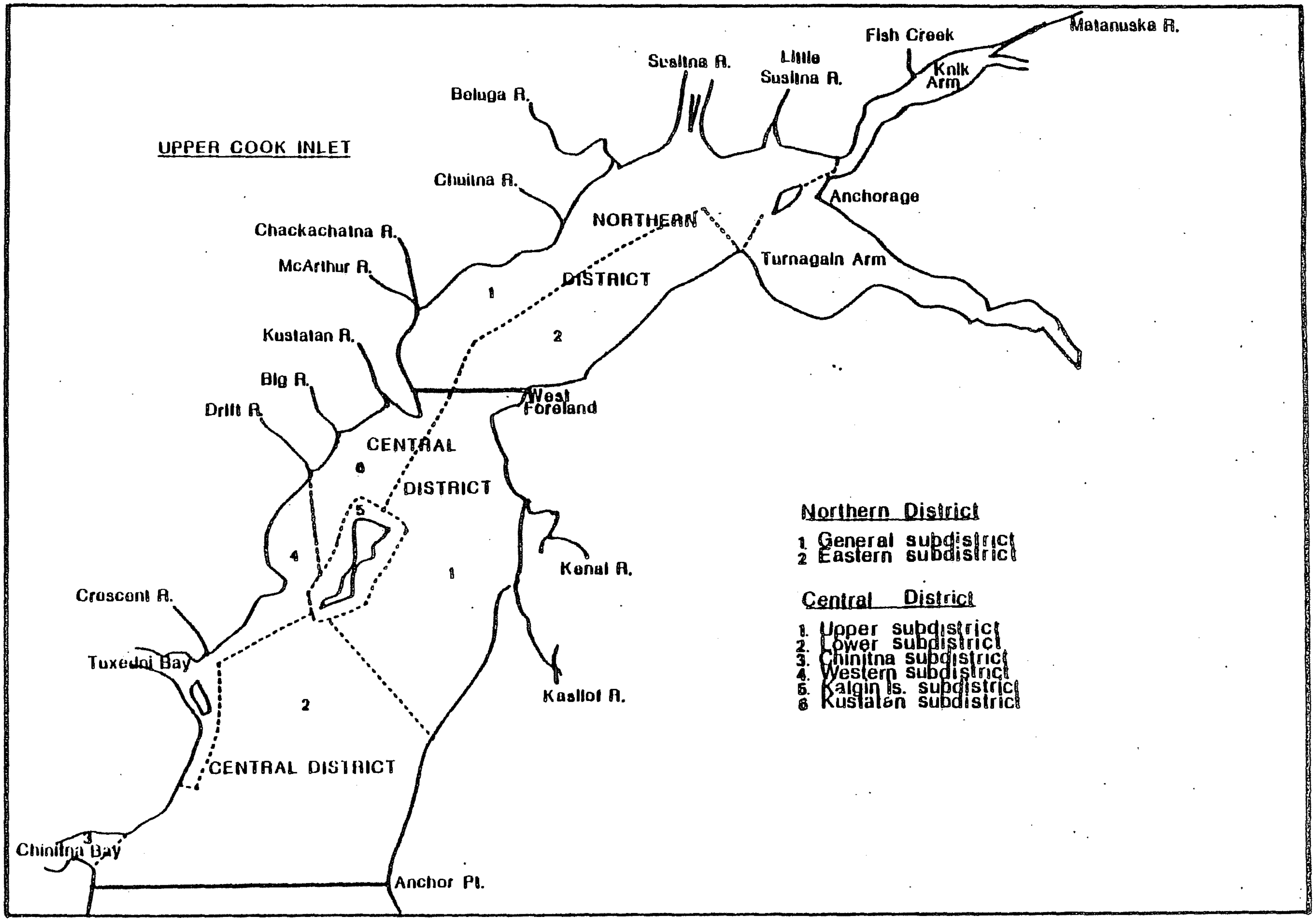

Figure E.5.1. Upper Cook Inlet Management Area, Adult Anadromous Investigations, 1982.

Central District (Tables E.5.1 - E.5.3). The commercial catch has averaged 2.8 million fish between 1970 and 1980, with an ex-vessel value of 17.9 million dollars.

5.2 Sockeye Salmon (Oncorhynchus nerka)

Sockeye salmon is the species of highest value in the commercial fishery, receiving greatest attention in management and research by the Alaska Department of Fish and Game (ADF&G). The commercial catch of sockeye salmon has averaged 1.2 million fish, the past ten years, with an ex-vessel value 6.9 million dollars (Table E.5.1). In 1981, about 1.4 million fish were harvested of which 43% were taken by the drift fleet in the Central District. The fishing season opens by regulation 25 June, except for the Western Subdistrict which opens 16 June. Fishing periods are scheduled Monday and Friday of each week, and are regulated by emergency order, depending on catch and escapement levels.

Major river systems in Upper Cook Inlet are glacially turbid, preventing visual monitoring of escapement. Consequently, hydroacoustic techniques are primarily employed. Side scan sonar counters are used to monitor escapement in the Kenai, Crescent, Kasilof, and Susitna rivers by ADF&G, Division of Commercial Fisheries. Escapement is enumerated by weirs in Fish and Cottonwood creeks by ADF&G Fisheries Rehabilitation and Enhancement Division (F.R.E.D.), and Packers and Wolverine creeks by Cook Inlet Aquaculture Association (C.I.A.A.).

Table E.5.1. Commercial catch of upper Cook Inlet salmon in numbers of fish by species, 1960-1981, Adult Anadromous Investigations, Su Hydro Studies, 1982.

Year	Chinook	Sockeye	Coho	Pink	Chum	Total
1960	27,512	923,314	311,461	1,411,605	659,597	3,333,889
1961	19.737	1,162,303	117,778	34,017	349,628	1,683,463
1962	20,210	1,147,573	350,324	2,711,689	970,582	5,200,378
1963	17,536	942,980	197,140	30,436	387,027	1,575,119
1964	4,531	970,055	452,654	3,231,961	1,079,084	5.738,285
1965	9,741	1,412.350	153,619	23,963	316,444	1,916,117
1966	9,541	1,851,990	289,690	2,006,580	531,825	4,689,626
1967	7,859	1,380,062	177,729	32,229	296,837	1,894,716
1968	4,536	1,104.904	470,450	2,278,197	1,119,114	4,977,201
1969	12,398	692,254	100,952	33,422	269.855	1,108,881
1970	8,348	731,214	275,296	813,895	775.167	2,603,920
1971	19.765	636,303	100,636	35,624	327,029	1,119.357
1972	16,086	879,824	80,933	628,580	630,148	2,235,571
1973	5,194	670,025	104,420	326,184	667,573	1,773,396
1974	6,596	497,185	200,125	483,730	396,840	1,584,476
1975	4,790	684.818	227,372	336,359	951,796	2,205,135
1976	10,867	1,664.150	208,710	1,256,744	469.807	3,610,278
1977	14.972	2,054,020	192,975	554,184	1,233,733	4.049,704
1978	17,308	2,622,487	219,234	1,687,092	571,925	5.118,041
1979	13,713	920,780	259,956	74,318	654,462	1,923,229
1980	12,497	1,584,392	283,623	1,871,058	387,078	4,138,648
1981	11,548	1,443,294	494,294	127,857	842,849	2,919.621

1979-1981; Preliminary data.

Table E.5.2. Commercial catch of Central District salmon in numbers of fish by species, 1960-1981, Adult Anadromous Investigations, Su Hydro Studies, 1982.

Year	Chinook	Sockeye	Coho	Pink	Chum	Total
1960	19,294	775,067	167,084	969,420	541,043	2,471,908
1961	11,982	1,084,929	76,803	23,252	288,525	1,485,491
1962	10,425	1,013,993	177,441	2,431,246	826,549	4,459,654
1963	10,191	833,517	133,600	21,496	343,333	1,342,137
1964	4,363	809,791	284,726	2,645,575	952,126	4,696,581
1965	9,441	1,380,775	131,717	19,049	299,538	1,840,520
1966	8,119	1,720,885	209,122	1,633,913	496,188	4,068,227
1967	7,675	1,261,997	133,875	23,769	258,453	1,685,769
1968	4,065	964,329	313,802	1,743,358	1,060,660	4,086,214
1969	9,494	654,189	80,527	25,802	258,019	1,028,031
1970	6,887	664,795	192,767	640,201	752,674	2,257,324
1971	10,167	595,770	78,542	27,201	310,426	1,022,106
1972	11,174	794,087	61,587	537,750	610,368	2,014,966
1973	5,024	624,411	80,469	188,934	636,722	1,535,560
1974	6,427	455,622	153,087	440,854	360,350	1,416,340
1975	4,661	619,292	194,321	245,406	921,009	1,984,689
1976	10,466	1,594,585	171,564	1,108,126	455,510	3,340,251
1977	14,277	1,950,605	172,892	444,881	1,208,336	3,790,991
1978	16,634	2,570,863	171,978	1,359,822	534,594	4,653,891
1979	12,128	816,090	208,303	25,515	644,400	1,706,436
1980	11,440	1,473,168	180,842	1,371,754	368,597	3,405,801
1981	10,790	1,193,826	360,992	74,556	796,766	2,436,930

1979-1981; Preliminary Data

Table E.5.3. Commercial catch of Northern District salmon in numbers of fish by species, 1960-1981, Adult Anadromous Investigations, Su Hydro Studies, 1982.

Year	Chinook	Sockeye	Coho	Pink	Chum	Total
1960	8,218	148,247	144,377	442,185	118,954	861,981
1961	7,755	77,374	40,975	10,765	61,103	197,972
1962	9,785	133,580	172,883	280,443	144,033	740,724
1963	7,345	109.463	63,540	8,940	43,694	232,982
1964	168	160,264	167,928	586,386	126,958	1,041,704
1965	300	31,575	21,902	4,914	16,906	75,597
1966	1,422	131,105	80,568	372,667	35,637	621,399
1967	184	118,065	43,854	8,460	38,384	208,947
1968	471	140,575	156,648	534,839	58,454	890,987
1969	2,904	38,065	20,425	7,620	11,836	80,850
1970	1,461	66,419	82,529	173,694	22,493	346,596
1971	9,598	40,533	22,094	8,423	16,603	97,251
1972	4,912	85,737	19,346	90,830	19,780	220,605
1973	170	45,614	23,951	137,250	30,851	237,836
1974	169	41,563	47,038	42,876	36,490	168,136
1975	129	65,526	33,051	90,953	30,787	220,446
1976	401	69,565	37,146	148,618	14,297	270,027
1977	515	103,415	20,083	109.303	25,397	258,713
1978	669	51,624	47,256	327,270	37,331	464.150
1979	1,585	104,690	51,653	48,803	10,062	216,793
1980	1,057	111,224	102,781	499,304	18,481	732,847
1981	758	249,468	133,081	53,301	46,083	482,691

1979-1981; Preliminary Data

The Kasilof, Kenai, Susitna and Crescent rivers, and Fish Creek (Big Lake) are considered principle sockeye salmon producing systems in the Upper Cook Inlet fishery. Run timing of these major stocks overlap (Figure E.5.2) requiring a method to assess individual stock contribution to the commercial fishery.

Stock separation using scale pattern analysis has been used in the sockeye salmon fishery since 1978 (Bethe and Krasnowski 1979; Bethe, et al. 1980; Cross et al. 1981). This tool provides an inseason estimate of stock composition of the commercial catch by fishing period and assists in regulating fishery openings and closures. In addition, the catch allocation provided by stock identification combined with escapement data, estimates the season's return to each major river system.

Scale measurements, length and weight data have been used as variables for stock delineation with linear discriminant function analysis. Stock identification models are built from measurements representing fish of known origin, i.e. escapements. Measurements from unknown fish (catch samples) are then classified with the models to their river of origin. Systems currently included in the analysis are the Kasilof, Kenai, Susitna, and Crescent rivers and Fish Creek (Big Lake). In 1979, about 22.7% of the sockeye run to Cook Inlet was from the Susitna drainage and about 26.7% and 36.0% of the run was produced by the Kasilof and Kenai rivers, respectively (Cross 1981). The 1980 run composition by river system was 19.2% Susitna, 38.3% Kenai and 31.3% Kasilof (Cross 1981).

Success of the sockeye identification program varies each season and confidence intervals for these limits are wide. One problem is continual mis-

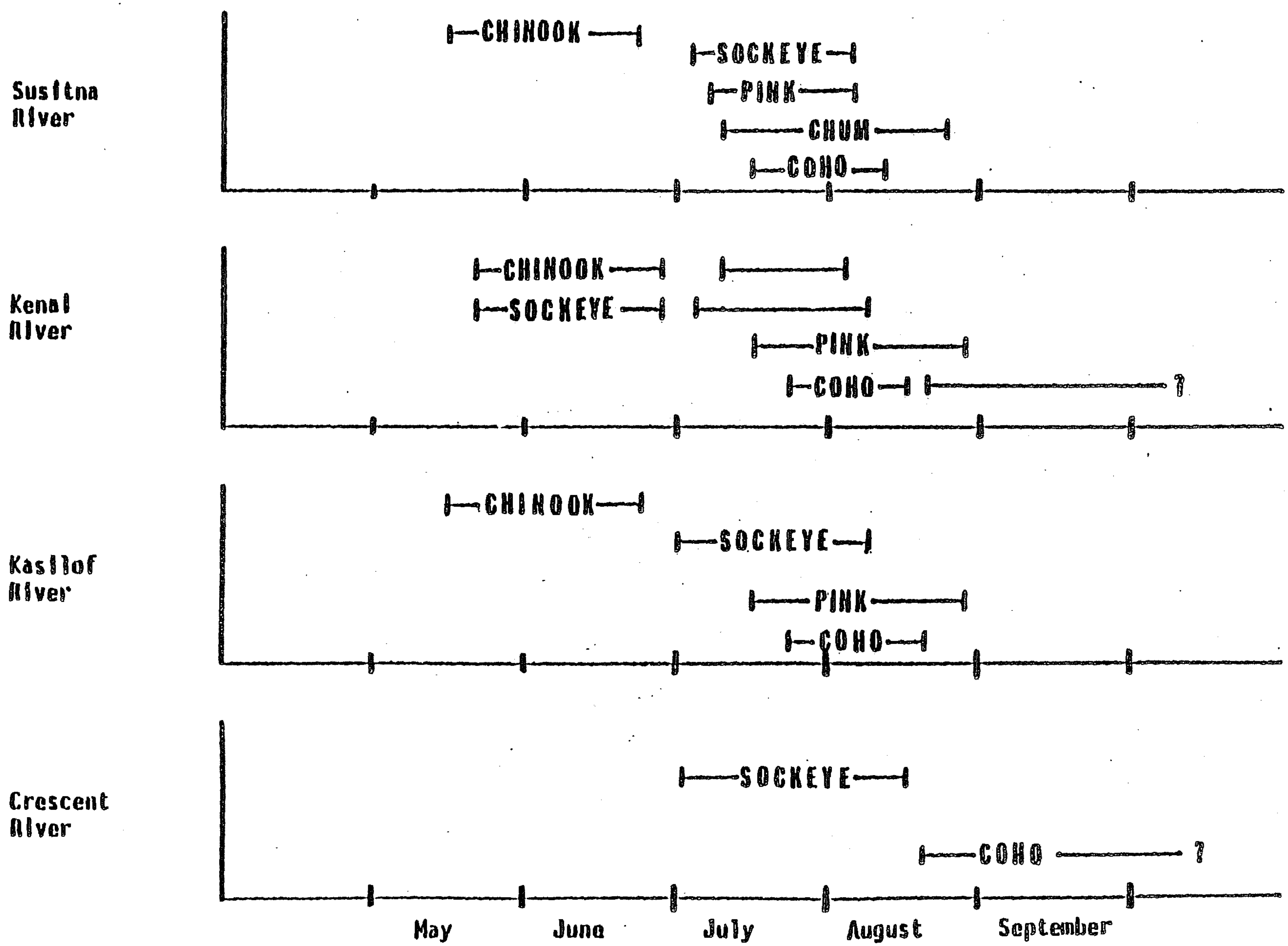

Figure E.5.2. Timing of sockeye, pink, coho and chinook returns into the Kenai, Kasilof, Crescent and Susitna Rivers, Adult Anadromous Investigations, Su Hydro Studies, 1982.

classification of Susitna River sockeye to either the Kenai or Kasilof rivers. Clarification of the model could be addressed by possibly identifying sub-stocks within the Susitna River drainage or refining pattern measurement techniques.

5.3 Chum Salmon (Oncorhynchus keta)

The commercial chum salmon catch has averaged 707,000 fish the past ten years. Chum salmon are second to sockeye salmon in economic value averaging 2.3 million dollars, ex-vessel. The 1981 fishery produced a catch of 842,000 chum salmon (Table E.5.1). Approximately 90% of the catch was taken by the Central District drift net fleet. During the 1981 season, the drift net fleet was harvesting substantial numbers of chum salmon by 27 June, continuing through mid-August. Chum salmon catches occur coincidentally with sockeye salmon in the fishery. At this time, the best data available regarding chum salmon and a good indicator of run strength for each area are twenty years of commercial catch statistics collected by statistical area and day. This data, however, has yet to be analyzed.

Survey and escapement data regarding chum salmon is limited (Appendices EA-EE). Production areas for chum salmon have been identified as Chinitna Bay, west shore river systems of Upper Cook Inlet, and the Susitna River. Escapement has been indexed into the Susitna River by sonar and tag/recapture operations, and into the Chinitna Bay by aerial survey. Though the Susitna River has been identified as the largest chum salmon producer, contribution by west shore systems is virtually unknown and may be significant. If it is determined that the contribution of systems other than the Susitna River is insignificant, then a stock separation project is not necessary. However, should major chum salmon systems be identified, a stock separation program should be initiated.

In Bristol Bay, catch allocation of sockeye salmon stocks has been attempted where percent age composition of adult returns differs for each river system (Meacham and Nelson 1980). The possibility that salmon in west side systems may differ from Susitna River fish and may be distinquished by age composition should not be overlooked. Calculation of age and length data for chum salmon in the commercial catch has been non-existent, and for escapements, limited.

Both electrophoresis and scale pattern analysis have been used to distinguish between chum salmon populations. Electrophoresis is a biochemical method for detecting genetic differences in proteins. Because protein genotypes for individual fish can be identified, the same genetic characteristics may portray traits of a specific population. A basis for distinquishing between groups of populations of fish is then provided. Electrophoresis has proven successful in distinquishing between mature and immature chum salmon and identifying chum stocks to river of origin in a mixed stock situation (Okazaki 1979). Differences in chum salmon from western Alaska, central Alaska, and British Columbia have also been discerned by electrophoresis (Okazaki 1981).

Chum salmon caught in the north Pacific Ocean have been identified to continent of origin based on scale pattern analysis (Tanaka 1969). In addition, the ADF&G stock separation program has examined the feasibility of identifying chum salmon stocks in Southeastern Alaska. This study has resulted in development and support of a project on chum salmon in that area (Cross, personal communication). Therefore, potential stock separation of Upper Cook Inlet chums by scale patterns warrants further investigation should several major producing systems be identified. Scale collection is a relatively simple process, compared to collection of electrophoresis tissue samples which require freezing within 24 hours of removal from the fish. Implementing a stock identification program by either scale pattern analysis or electrophoresis requires primary assessment of major production areas, run timing and collection of age-weight-length data from escapements. This information would assist in evaluating the necessity of a stock separation program and which approach to implement.

5.4 Coho Salmon (Oncorhynchus kisutch)

Upper Cook Inlet coho salmon rank third in commercial value. Since 1960, the commercial catch has averaged 240,000 fish. The 1981 season produced the best harvest since statehood of 494,070 coho salmon (Table E.5.1). Distribution of the catch has gradually shifted with increased gear efficiency and drift net fleet participation. In the early 1950's, 50% of the Upper Cook Inlet catch was taken by Northern District set nets with the drift net fleet accounting for 10% of the harvest. Comparatively, in 1981, the Northern District set net and Central District drift net fishery provided 27% and 48% of the harvest, respectively. Coho salmon catches have usually peaked in the Northern District set net fishery 25 July and in the Central drift net fleet, Kalgin Island and west side set net fisheries about 21 July.

Based on run timing and fish weight, major coho salmon stocks have been identified as Kenai, Kasilof or Susitna River fish (Middleton 1980). The problem with this stock definition is the term Susitna refers to all systems in the Northern District. Significant numbers of coho salmon have been documented in the Northern District by aerial and ground surveys, escapement enumeration and sport fish harvest. These systems include Fish Creek (Big Lake), Little Susitna River, Susitna River, Cottonwood Creek and systems on the west side of the Inlet. In the Central District, coho salmon are known to return to the Kenai, Kasilof, and Crescent rivers, Packers Creek (Kalgin Island) and west side systems. Run strength information is documented only for the Kenai River, Susitna River, Fish Creek, Cottonwood Creek and Packers Creek. Run magnitude and contribution to the commercial fishery of coho salmon returns to remaining areas is unknown (Appendices EA-EE).

The Susitna River coho salmon run begins in early July and is coincidental to the Fish Creek, Kasilof River and early Kenai River runs in the commercial fishery. Timing of late run Kenai River fish appears distinct from these other stocks (Figure E.5.2). Crescent River returns begin in mid-August and continue into fall. Late coho salmon returns to other west side rivers have also been reported, but abundance and run timing are unknown. Should run timing of any of these populations be distinct from the Susitna River returns, they need not be considered for a stock identification model, thereby simplifying the design of the program. However, these run characteristics must be examined before any system can be eliminated from such a study.

Identification of coho salmon stocks exploited by the commercial fishery has been attempted using fish weight (Wadman 1976). Coho salmon from Northern

District rivers vary in weight between systems yet overall are significantly smaller than fish from the early Kenai and Kasilof river returns. Apportioning the commercial catch to system of origin was also attempted, using fish weight as criteria. Results indicated that prior to 23 July, the drift net fleet harvested mostly small coho salmon, or fish migrating to the Northern District (Larry Engel, Personal Communication). Commercial catch data has not been analyzed for stock identification of coho salmon since the 1976 study.

A feasibility study performed by Robertson (1979) examined classification of Cook Inlet coho salmon populations by scale patterns. Scales from adult salmon captured in the Kenai and Susitna rivers were used for known samples and overall, self-classification was high (89.0% and 72.2% respectively). Stock composition estimates of the fishery indicated, with one exception, that most fish captured on the western side of the Inlet were bound for the Susitna River and catches in east side fisheries were from the Kenai River. Analysis however, of the Central District west side set net fishery showed an extremely high proportion of Kenai River fish in the stock composition estimate. These results may have been misleading due to presence of unknown stocks in the catch that were not included in the model as known samples. Scale characteristics of these unknown samples were similar to Kenai River fish, least comparable to Susitna River fish and classified accordingly. The weakness of the analysis was attributed to not having representative samples from all major systems.

It is possible to include additional variables other than scale information to the linear discriminant model. Because fish weight appears to differ significantly between groups, the addition of this variable to the analysis may provide a key to a successful classification model.

The feasibility of a coho stock identification study based on scale pattern analysis and fish weight should be examined, once production of west side streams and run timing of west side coho returns has been determined.

5.5 Pink Salmon (Oncorhynchus gorbuscha)

Upper Cook Inlet pink salmon returns exhibit even year run strength. The catch since 1960 has averaged 146,000 in odd years and 1,671,000 for even years. About 127,900 pink salmon were harvested in 1981 (Table E.5.1). Approximately 42% and 43% of the catch was taken by the Northern set net and Central District drift net fisheries, respectively. Though the Kasilof River supports a small run, the Kenai and Susitna river systems are considered primary producers of pink salmon in the Upper Inlet. Pink salmon have also been documented in the west side river systems (Appendices EA-EE). As with the other salmon species, the importance of west side production is unknown and needs to be addressed.

Pink salmon escapement into the Susitna River peaks about 20 July, whereas Kenai River fish peak about two weeks later (Figure E.5.2). Kenai Peninsula pink salmon migrate close to the eastern shore and are caught primarily by the east side set net fishery. Pink salmon moving into the Northern District are harvested by the drift net fleet, when more valuable species become less abundant (Middleton 1980). The best source of information concerning run strength and timing, as with chum salmon, is historical catch data, yet to be analyzed. With exception of that for the Susitna River, escapement and available weight and length data is minimal for pink salmon.

Absence of a freshwater growth zone and small differences found in marine growth patterns appear to limit application of scale pattern analysis as a stock separation tool for pink salmon. Therefore, scale pattern analysis is usually bypassed. Scale pattern analysis of British Columbian and Alaskan fish distinguished between even and odd year returns, but correctly classified samples only to region and not river or origin (Bilton 1971). A feasibility study of Southeastern Alaskan pink salmon showed little potential for using scale characteristics as a means for stock identification (Robertson 1978). Therefore, scale pattern analysis is a technique that should be disregarded for Upper Cook Inlet.

Stock identification of pink salmon has been accomplished using electrophoresis with varying degrees of success. The major drawback with this technique is that frequently differences between stocks occur only over wide geographical regions larger than the Upper Cook Inlet area (Johnson 1979). In contrast, however, studies in Prince William Sound were able to differentiate between stocks of several streams and subpopulations within one stream (Nickerson 1979). In the same paper, Nickerson noted that differences in length-weight data for pink salmon were useful in differentiating between populations.

Electrophoresis appears to be the best option for pink salmon stock identification. Assessing the contribution of west side pink salmon stocks to the commercial fishery, confirming the differences in run timing, and sampling systems that will be classified as major producing systems for length, weight and tissue samples are necessary for preliminary investigation of any stock specific characteristics.

5.6 Chinook Salmon (*Oncorhynchus tschwyatscha*)

Three Upper Cook Inlet stocks of chinook salmon have been tentatively identified as Kenai, Kasilof and Susitna river fish. Abundance data for chinook salmon has been limited mainly to aerial surveys conducted by ADF&G, and catch statistics of the freshwater sport fishery (Mills 1980). Chinook salmon have also been documented in the Little Susitna River and in many east and west side streams (Appendices EA-EE). However, abundance information is not complete because many river systems have not been completely surveyed (Appendices EA-EE).

The Susitna River chinook salmon run begins in late May and peaks in mid-June. Therefore Susitna River fish have mostly passed through the area in which they would be subject to the commercial fishery prior to the season opening 25 June. In 1964, the continued depressed condition of Susitna chinook salmon stocks resulted in changing the opening date of the commercial fishery from mid-May to the end of June. Commercial catches of chinook salmon in the Upper Cook Inlet fishery since that time have primarily been Kenai and Kasilof river fish.

About 11,500 chinook salmon were caught in the 1981 commercial fishery. Of this total, only 364 fish were caught in the Western Subdistrict prior to 25 June opening for the remainder of the Upper Cook Inlet fisheries. Therefore, assuming these fish are the end of the Susitna River run, commercial exploitation is minimal. Though commercial effort is much less for chinook salmon than other species, the subsistence and recreational harvests are substantial. In 1980, about 2,270 and 16,650 fish were taken in the subsistence and sport fisheries, respectively (Mills 1980).

Positive results have been attained in feasibility analysis of using scale patterns to differentiate between chinook salmon populations. Preliminary studies on the Yukon River resulted in high self-classification of upper, middle, and lower river fish (McBride 1981). This program is being expanded to refine the classification estimates by spawning population and to apportion commercial catches. Feasibility analysis of Upper Cook Inlet chinook has also been examined (Bethe 1978). Escapement samples from Susitna, Kenai, Ninilchik and Anchor rivers were collected and analyzed. Separability was high for all two-way comparisons, (range 72.0% to 73.3%) and for Susitna River fish versus combined samples from Kenai, Anchor and Ninilchik rivers (range 71.0% to 83.2%).

Because Susitna River chinook salmon presently are not exploited by the commercial fishery, a stock identification program is not necessary at this time. Even if a program were attempted, the number of fish currently harvested commercially is too small to obtain adequate numbers of samples for analysis. Should commercial catch levels again become substantial, escapement assessment for all systems, an inventory of the west side populations, and consideration of use of scale pattern analysis or electrophoresis for stock separation should be examined.

6. RECOMMENDATIONS

To pursue a program that will assess the contribution of Susitna River salmon stocks to the Upper Cook Inlet commercial fishery, the following are first year recommendations:

1. Develop an inventory system to determine characteristics (timing, length, weight, age) of salmon runs to west side systems of Upper Cook Inlet. This data will help to determine the feasibility of pursuing a stock identification program. The accuracy of any stock identification program is also dependent on the entirety of the known samples used to build the model. Should the west side systems not be considered, the actual contribution by the Susitna River drainage will be misrepresented.

2. Escapement sampling for age-weight-length information currently implemented in major sockeye salmon producing systems should be expanded to include chum and coho salmon. Length-weight data and tissue samples for electrophoresis should also be collected from pink salmon. This data combined with run timing and information regarding west side systems will provide the basis for determining if stock specific characteristics are present for each species by which a stock separation program may be developed.

7. ACKNOWLEDGEMENTS

The commercial catch and stream survey data tabled in this report were primarily from information compiled by the ADF&G Division of Commercial Fisheries, Cook Inlet staff. ADF&G escapement and survey data were also provided by Bob Chlupach of Fisheries Rehabilitation and Enhancement Division and Larry Engel, Steve Hammerstrom, Kelly Hepler and Stan Kubik of the Sport Fish Division. Tom Mears (Cook Inlet Aquaculture Association), Mike Joyce (Woodward-Clyde Consultants), and Ron Dagan (Dowl Engineers) also provided abundance estimates. Appreciation is extended to the ADF&G Cook Inlet commercial fisheries staff for their support and report review.

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APPENDIX EA

SALMON ABUNDANCE DATA FOR UPPER COOK INLET

WEST SIDE SYSTEMS

Appendix Table EA-1. Salmon abundance data for Upper Cook Inlet west side river systems, compiled from escapement enumeration programs[1], sportfish harvest data[2] and aerial ground survey data[1,3], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Bachatna Creek	1981	7/20		100				Tom Mears, Cook Inlet Aquaculture Ass'n (T.M.,CIAA
Bear Creek	1981	7/21	0	0	0	0	0	T.M., CIAA
Beluga River System								
Beluga Lake	Before 1970							Max. count 50 sockeye (1957); large numbers chinook and coho (1946)
	1970	9/01		10				
Beluga River	Before 1970							No fish observed (1953-57)
	1978	8/24			520		1,500	Upper River
	1980	10/30						T.M., CIAA, large numbers of salmon, species unknown
Bishop Creek	1976		12					
	1977		468					
	1979		30					
	1980	6/27	0	0	0	0	0	T.M., CIAA
	1981		174					
	1981	7/16	10					T.M., CIAA
	Personal Comm.			Present			Present	Stan Kubik, ADF&G Div. Sport Fish (S.K.,SF) Abundance estimate from several years observations
Bishop Lake	Before 1970							Max. count 81 chinook (1964)
	1981	7/16	0	0	0	0		T.M., CIAA
Capps Creek	Before 1970							Max. count 2,000 sockeye (1950); 5 pinks, 8 chums (1958)
	1980	6/27	0	0	0	0	0	T.M., CIAA
Chichantna River	Before 1970							No fish observed
	1980	6/27	0	0	0	0		T.M., CIAA
	1981	7/16	0	0	0	0		T.M., CIAA
Coal Creek	Before 1970							Max. count 2,000 sockeye (1950); 25 pinks, 25 chums (1965)
	1972			1,250				Peak survey count
	1973		31					
	1975	8/29	0	0	0	0	0	
	1976		17					
	1977	8/25		47				
	1977	9/01		151				
	1978	8/09		2,200				
	1978	8/24		75				

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED); Cook Inlet Aquaculture Association (CIAA); Woodward-Clyde Consultants (WCC); Dowling Engineers Consulting Firm (DE).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-I Mills, Michael J. 1980. Statewide Harvest Study - 1980 Data. Alaksa Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-IC.

3/ All entries are aerial or ground stream survey data unless otherwise designated.

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Coal Creek	1978		1,551	2,313				Peak survey count
	1979	8/22	0	0	0	0	0	
	1979	9/19		500	5			
	1979		178					
	1980	6/29	0	0	0	0	0	T.M., CIAA
	1980	8/22		500				
	1980	9/11		700				
	1981		223					
	Personal Comm.				Present		Present	S.K., SF
Coal Creek Lake	Before 1970							Max. count less than 300 sockeye (1958-59)
	1972	9/01		1,700	150			Includes west fork
	1977			51				Peak survey count
	1978			75				Peak survey count
	1979			300				
	1981	9/04		1,100				Includes west fork
Drill Creek	1976		11					
	1978		77					
	1979		11					
	1980	6/27	0	0	0	0	0	T.M., CIAA
	Personal Comm.			1,000			5,000	S.K., SF
Lone King Creek	Before 1970							Max. count 2,000 sockeye (1950); chums, pinks, chinook observed
	Personal Comm.			5,000			Present	S.K., SF, west end of lake
	1981	7/15	25					T.M., CIAA
Mouth Creek	Personal Comm.		Present				Present	S.K., SF
Olson Creek	Before 1970							Max. count 3 chinook (1958)
	1973		2					
	1974	7/13	Present				0	
	1976		247					
	1977		1,229					
	1978		94					
	1979		17					
	1980							T.M., CIAA
	1981		116					
	Personal Comm.		Present				Signif.	Thousands of pinks, S.K.,SF
Pretty Creek	Before 1970							Max. count 10 chinook, 1,153 pinks (1958)
	1980	6/27	0	0	0	0	0	T.M., CIAA
	Personal Comm.		100				1,000	S.K., SF
Scarp Creek	Personal Comm.		1,000	Present				S.K., SF
West Fork	Personal Comm.			1,000				S.K., SF
Big River System	Before 1970*							Max. count 3,275 sockeye (1960); good coho run, some pinks (1961)
	1970	9/01		1,200				
	1980	7/02	0	0	0	0	0	T.M., CIAA
	1980	8/29		5,000				T.M., CIAA
	1981	6/11		20,000				T.M., CIAA, upper and lower river

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
North Fork	1976	8/19		35				
	1980	7/08		10,000				
	1980	8/01		840				
	1980	9/19		3,750	1,250			
	1981	7/13	0	0	0	0	0	
Wolverine Creek	Before 1970							Coho present
	1981	7/13	0	0	0	0	0	
	1981	9/30		900	400			
	1981			17522				Escapement count (weir), T.M., CIAA
Buchitna Creek	1981	7/07	0	0	0	0	0	T.M., CIAA
Cannery Slough	1981	7/13	0	0	0	0	0	T.M., CIAA
	Personal Comm.			Present	Signif.		Present	S.K., SF
Chakachamna River System								
Chakachatna Lake	Before 1970							Max. count 590 sockeye (1955)
	1980	9/02			50			T.M., CIAA
	1981	9/14	Present	Present	Present	Present	5,000	Mike Joyce, Woodward and Clyde Consultants (M.J., WWC)
Chilligan River	Before 1970							Max. count 2,000 sockeye (1952)
	1981	9/14		10,000				M.J., WWC
	Personal Comm.		12	1,000				S.K., SF
Kenibuna Lake	Before 1970							Few sockeye observed (1952)
McArthur River	Before 1970							Good run of sockeye in West Creek (1961)
	1980	9/14	Present	Present	Present		5,000	M.J., WWC
	1981	7/15		40				
	Personal Comm.				Present			S.K., SF
Middle River	Before 1970							A few coho reported (1961)
	1980	9/02	0	0	0	0	0	T.M., CIAA
	1981	9/14	Present		Present			M.J., WWC
	Personal Comm.				Present		Present	S.K., SF
Neacola River	1981	9/14		Present				M.J., WWC
	Personal Comm.						Present	S.K., SF
Noaukta Slough	Personal Comm.			5,000		Present	Present	S.K., SF
	1981							Large numbers of fry, M.J. WWC
Snodgrass Creek	Before 1970							Sockeye and coho present (1961)
Straight Creek	1973		5					
	1975		9					
	1976		59					
	1977		24					
	1978		100					
	1981		126					
	1981	9/14		3,000		Present	Present	M.J., WWC
	Personal Comm.		100			Present	5,000	S.K., SF

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Chinitna Bay	Before 1970							Max. count 7,000-8,000 chums (1959-60)
Chinitna River	1980	9/10			200	100		T.M., CIAA
	1981	8/03				1,000		
	1981	8/05				760		
	1981	8/15				2,200		
Clearwater Creek	1971	8/15				5,000		
	1973	8/18				8,450		
	1974	8/22				1,800		
	1975	8/17				4,400		
	1976	8/11				12,500		
	1977	8/21				12,700		
	1978	8/12				6,500		
	1979	8/21				1,350		
	1980	8/25				2,250		
	1980	9/10				5,000		T.M., CIAA
	1981	8/03				1,000		
	1981	8/15				6,150		
East Glacier Creek	1980	9/10				25		T.M., CIAA
Fritz Creek	Before 1970							Max. count 11,000 chums (1966)
	1978	8/12				800		
	1979	8/21				700		
	1980	8/22				1,000		
	1980	9/10			200	100		T.M., CIAA
	1981	8/03				200	50	
	1981	8/15				500		
Inishin River	Before 1970							43 chum (1965)
Johnson River	Before 1970							Max. count 500 coho, 50 pinks (1955)
	1980	9/10			600	300		T.M., CIAA
Marsh Creek	Before 1970							Max. count 35,000 chums (1963)
	1981						810	
Middle Glacier Creek	1980	9/10				200		T.M., CIAA
Portage Creek	Before 1970							Max. count 5 chums (1965)
Red River	1980	9/10	0	0	0	0	0	T.M., CIAA
Silver Salmon Creek	Before 1970							Fair sockeye and chum runs; Max. count 60 coho, 200 pinks (1961)
West Glacier Creek	1980	9/10			400	200		T.M., CIAA
Chuitna River	Before 1970							Max. count 17 chinook, 40 coho, 20 chums and 600-700 pinks (1950)
	1973		149					
	1974		171					
	1975		629					
	1976		1,904					
	1977		1,901					
	1978		1,130					
	1979		1,246					

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Chuitna River	1981	7/14	165					Ron Dagan, Dowling Engineers (R.D.,DE)
	1981	7/16	40					T.M., CIAA
	1981	8/03	375					R.D., DE
	1981	8/04	35		2			R.D., DE
	1981	8/05	Present		4	1	1	R.D., DE
	1981	8/06	6		5	1		R.D., DE
	1981	8/24	1		80	22		R.D., DE
	1981	8/25			9			R.D., DE
	1981	9/24			269			R.D., DE
	1981	9/25			27			R.D., DE
	1981	9/26			12			R.D., DE
	1981	9/27			63			R.D., DE
	1981	9/28			23			R.D., DE
	Personal Comm.			Present	1,000	Present		S.K., SF
Congahbuna Lake	1981	7/15	0	0	0	0	0	T.M., CIAA
Old Tyonek Creek	Before 1970							Sockeye, coho, and pinks present (1961)
Crescent River System								
Crescent Lake (Grecian Lake)	Before 1970							Max. count 132 sockeye (1954); chums, pinks and chinook present (1961)
	1970	9/15		Present				
	1972			10,000				
	1974	9/16 9/17		69				
	1975	8/16		Signif.				
Stream #1	Before 1970							Max. count 2,500 sockeye (1952)
	1981	9/01		Present				
Stream #2	Before 1970							Max. count 1,000 sockeye (1952)
	1974	8/15		0				
	1981			Present				Sockeye present in September
Stream #3	Before 1970							Max. count 6 sockeye (1954)
Stream #4	Before 1970			Present				Max. count 250 sockeye (1952)
Crescent River	Before 1970							Max. count 2,000 sockeye (1952)
	1979			87,000				Escapement count (sonar)
	1980			91,000				Escapement count (sonar)
	1981			41,213				Escapement count (sonar); cohos present in mid-August
Dog Creek	Before 1970							Thousands of chums (1959-1961)
Drift River	Before 1970							Cohos present in fall (1961)
	1980	9/10	0	0	0	0	0	T.M., CIAA

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Elling Lake (Blue Lake)	1970	7/24		1,200				
	1972	8/31		1,000				
	1972	10/31		1,000				
	1980	8/07			100			T.M., CIAA
	1980	8/27		5,000				T.M., CIAA
Falls Creek	1981				Present	Present		
Harriet Creek	Before 1970							No fish observed (1952)
	1981	7/21	0	0	0	0	0	T.M., CIAA
Bear Lake	1981	7/21	0	0	0	0	0	T.M., CIAA
Indian Creek	Before 1970							Sockeye before 1932, coho and pinks present (1961)
Island Creek	Before 1970							Sockeye, coho, and chums present (1961)
Ivan Creek	Before 1970		0	0	0	0	0	No fish observed (1965)
	1980	7/06	0	0	0	0	0	T.M., CIAA
Kustatan River	Before 1970							No fish observed (1958)
	1981	7/15	0	0	0	0	0	T.M., CIAA
Blacksand Creek	1981		0	0	0	0	0	T.M., CIAA
Jenson Creek	Before 1970							Sockeye and chums present (1961)
	1981	6/10		2,000	Present			
Lewis River	Before 1970							Max. count 67 chinook (1962)
	1970		12					
	1972		7					
	1973		173					
	1974		135					
	1975		75					
	1976		380					
	1977		454					
	1978		561					
	1979		546					
	1980	7/06	0	0	0	0	0	T.M., CIAA
	1981		560					
	Personal Comm.				1,000		5,000	S.K., SF
Montana Bill Creek	1981	7/02	0	0	0	0	0	T.M., CIAA
Moose Creek	1981	5/28	0	0	0	0	0	
Nikolai Creek	Before 1970							Max. count 1 chinook and some pinks (1961); Few suitable spawning areas
	1977		143					
	1981	7/15	0	0	0	0	0	T.M., CIAA
	Personal Comm.		100		500		10,000	S.K., SF

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Nigishlamna River	1980	9/02	0	0	0	0	0	T.M., CIAA
Packers Lake (Kalgin Is.)	Before 1970							Max. count 100,000 sockeye (1926); 5,600 coho (1952)
	1970	9/01		500				
	1971	8/10		507				
	1971	9/10		3,356				
	1972	7/20		200				
	1972	10/09		298				
	1972			3,700				
	1974			1,454				
	1980			16,400			Present	T.M., CIAA
	1981			13,000	2,000			T.M., CIAA
	1981			7,100			2,040	
	1981			13,024	2,440			Escapement count (weir), T.M. CIAA
Polly Creek	Before 1970							Max. counts 2,000 coho; pinks and chums present (1961)
	1980	8/29				10,000		T.M., CIAA
Redoubt Creek	Before 1970							Cohos present (1961)
	1981	7/21	0	0	0	0	0	T.M., CIAA
South Fork Creeks	1981			2,000				T.M., CIAA
Theodore River	Before 1970							Max. count 67 chinook (1962)
	1970		36					
	1971		0					
	1972		79					
	1973		205					
	1974		205					
	1975		95					
	1976		1,032					
	1977	7/23	2,263					
	1978		547					
	1979		512					
	1980	7/06	0	0	0	0	0	T.M., CIAA
	1981		535					
	Personal Comm.				1,000		5,000	S.K., SF
Three Mile Creek	1980	6/27	0	0	0	0	0	T.M., CIAA
	Personal Comm.			1,000			5,000	S.K., SF
Tuxedni Bay								
Bear Creek	1980	9/20	0	0	0	0	0	T.M., CIAA
Difficult Creek	1980	9/16	0	0	0	0	0	T.M., CIAA
Hungryman Creek	1980	9/16	0	0	0	0	0	T.M., CIAA
Open Creek	1980	9/16	0	0	0	0	0	T.M., CIAA
Tuxedni River	1980	9/16		50	60			T.M., CIAA
Unnamed Tux. Streams	1980	9/16	0	0	0	0	0	T.M., CIAA

Appendix Table EA-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Waddell Lake	1980	8/25		500				T.M., CIAA
	1981	7/21	0	0	0	0	0	T.M., CIAA
	1981	Aug.		1,200				T.M., CIAA
	1981	9/11		1,200				T.M., CIAA
Westforeland Lakes	1981	7/07	0	0	0	0	0	
Whiskey Jack Slough	Before 1970							Cohos present (1961)
#13 Creek	Before 1970							Cohos present in fall (1961-69)
	1970				Present			
#14 Creek	Before 1970							Cohos present in fall (1961-69)
	1970				Present			
#23 Creek	Before 1970							Pinks present (1960)
#24 Creek	Before 1970							Pinks present (1960)
#25 Creek	Before 1970							Cohos and pinks present (1961)

APPENDIX EB

SALMON ABUNDANCE DATA FOR TURNAGAIN ARM RIVER SYSTEMS

Appendix Table EB-1. Salmon abundance data for Turnagain Arm river systems, compiled from escapement enumeration programs 1/, sport fish harvest data 2/, and aerial/ground surveys 1,3/, Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Bird Creek	Before 1970							Max. count 6 chinook (1957), 6,000 pinks (1964)
	1973		2					
	1974		3					
	1976		6					
	1976	8/25	6			7	906	
	1977	9/01	3			56	647	
	1979						654	Sport fish harvest
	1980				26		2,127	Sport fish harvest
	Personal Comm.		Present		Present	Present	5,000	Stan Kubik, ADF&G Div. of Sport Fish (S.K., SF) Max. abundance estimate from several years observations
California Creek	1976	8/21					155	
	1976	8/25	2	1	4	6	516	
	1978	8/10	4		5		59	
	1978	9/01		1			919	
Campbell Creek	Before 1970							Max. count 187 chinook (1964); 1,000 pinks (1958)
	1973		201					
	1974		79					
	1976		210					
	1977		349					
	Personal Comm.			Present	300		5,000	S.K., SF
Chikaloon	Before 1970							Max. count 20,000 sockeye (1947); 75,000 pinks (1960)
	1976	8/19		1,543				
	1981	5/28	0	0	0	0	0	
	Personal Comm.				Present	Present	Present	S.K., SF
Indian Creek	Before 1970							Max. count 8 sockeye (1962); 238 pinks (1958)
	1976	8/25					102	
	1977	9/01					63	
	1978	9/01					232	
Ingram Creek	Before 1970							Max. count 217 pinks (1958)
	1976	8/21					489	
McHugh Creek	Personal Comm.						Present	S.K., SF

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED); Cook Inlet Aquaculture Association (CIAA); Woodward-Clyde Consultants (WCC); Dowling Engineers Consulting Firm (DE).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-I
Mills, Michael J. 1980. Statewide Harvest Study - 1980 Data. Alaksa Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-IC.

3/ All entries are aerial or ground stream survey data unless otherwise designated.

Appendix Table EB-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Portage Creek	Personal Comm.			500		500	5000	S.K., SF
Gravel Pit Area	Before 1970							Max. count 350 chinook (1950); 650 sockeye (1952); 1 pink (1954); 1 chum (1953)
	Personal Comm.		500		200		1,000	S.K., SF
Williwaw Creek	Before 1970							Max. count 291 sockeye, 13 chums (1928)
	1974	9/11		48				
	1974	9/25		17				
	1975	8/22		42				
	1975	8/30		47				
	1975	9/06		51				
	1975	9/15		47				
	1976	8/11	0	0	0	0	0	
	1976	8/21		264				
	1976	8/25		76				
	1976	9/03		81				
	1977	8/24		244				
	1977	9/01		441		42		
	1978	8/10		44				
	1978	8/30		195				
	1978	9/19		142				
Potter Creek	Personal Comm.						Present	S.K., SF
Rabbit Creek	Personal Comm.				100		500	S.K., SF
Resurrection Creek	Before 1970							Max. count 80,000 pinks (1960); 35 chums (1958)
	1976	8/11					840	
	1976	8/21			20		6,000	
Seattle Creek	1976	8/21			Present		600	
Six Mile Creek	Before 1970							Max. count 896 pinks (1958)
	1976	8/21					800	
	1978	8/23					1,200	
Skookum Creek	Personal Comm.				Present			S.K., SF
Three Mile Creek and Lake	Before 1970							Max. count 49 sockeye (1954); 896 pinks (1958)
Twenty Mile Creek	1979			204	362		36	Twenty Mile River sport fish harvest
	1980			146	439	43	43	Twenty Mile River sport fish harvest
Carmen Lake	1976	8/20		2				
	1976	8/21					9	
	1978	8/23		603		10		
	1981			29	20		30	

APPENDIX EC

SALMON ABUNDANCE DATA FOR KNIK ARM

RIVER SYSTEMS

Appendix Table EC-1. Salmon abundance data for Knik Arm river systems, compiled from escapement enumeration programs[1], sport fish harvest data[2], and aerial/ground surveys[1,3], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Chester Creek	Personal Comm				100	Present		Stan Kubik, ADF&G Div. of Sport Fish (S.K., SF) Max. abundance estimate from several years observervations
Cottonwood Creek	Before 1970							Max. sockeye count 8-10,000 (1936); 1,161 coho (1960)
	1970	9/22			5			
	1971	8/18		253				
	1971	9/17			29			
	1972	8/22		10	Present			
	1972	9/01		38				
	1972	9/08		1,199				
	1972	9/21			21			
	1973	9/24			18			
	1974	9/23			20			
	1974	9/25			6			
	1974	9/26			1			
	1974	9/27			9			
	1974	10/02			11			
	1974				21			
	1975	9/22			108			
	1975	9/24			128			
	1976				204			
	1976	9/20			104			
	1976	9/22			100			
	1977				264			
	1980				530			
	1979			1,525	1,198			Sport fish harvest
	1980			2,660	3,375			Sport fish harvest
	1981			25,180	2,436			Escapement count (weir)
Cottonwood Lake	Before 1970							Max. count 500 fish (1951)
	1972	8/22		225				
Meadow Creek	Before 1970							Max. count 5,000 sockeye (1952-1969); 175 coho (1960)
	1970	9/21		43	49			
	1970	9/29			25			
	1971	9/20			9			
	1971	9/28			2			
	1972	8/22		290				
	1972	9/25			27			
	1979	8/10		1,879				
Neklason Lake	Before 1970							Max. count 256 sockeye (1956)
	1972	8/22		110				

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED); Cook Inlet Aquaculture Association (CIAA); Woodward-Clyde Consultants (WCC); Dowling Engineers Consulting Firm (DE).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1 Mills, Michael J. 1900. Statewide Harvest Study - 1980 Data. Alaksa Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1C.

3/ All entries are aerial or ground stream survey data unless otherwise designated.

Appendix Table EC-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Eagle River	Before 1970							Chinook present (1966-1969); Max. count 3,000 pinks (1963)
	1970		81					
	1973		61					
	1976		81					
	1977		313					
	1977		31					South fork
	1978		102					
	Personal Comm.			Present	Present	Present	Present	S.K., SF
Eklutna River	Personal Comm.				Present	Present	Present	S.K., SF
Fire Creek	Personal Comm.		Present		Present			S.K., SF
Fish Creek (Big Lake)	Before 1970							Max. count 306,982 sockeye (1940); 19,417 coho (1938); 699 pinks (1950)
	1970			31,470	1,048		3,940	Escapement count (weir)
	1970	9/30			176			
	1971			31,900	583			Escapement count (weir)
	1971	8/24		4,250				
	1971	9/30			141			
	1972			6,981	709		57	Escapement count (weir)
	1972	9/08		572				
	1973			2,705	210		6	Escapement count (weir)
	1974			16,225	1,154			Escapement count (weir)
	1975			29,080	1,601			Escapement count (weir)
	1975	8/21		34				
	1975	8/26		318	1			
	1975	8/29		487	1			
	1975	9/05		1,192	1			
	1975	9/23		968				
	1975	9/29		194		1		
	1976			14,032	765			Escapement count (weir)
	1977	9/01		372				
	1977			5,183	970		109	Escapement count (weir)
	1978			3,555	3,121			Escapement count (weir)
	1979			68,739	3,000			Escapement count (weir)
	1979			157				Big Lake sport fish harvest
	1980			43				Big Lake sport fish harvest
	1981			50,479	2,261			Escapement count (weir) FRED
Blodgett Lakes	Before 1970							Max. count 15-20,000 sockeye
	1972	8/22		53				
Kern Creek	Personal Comm.						Present	S.K., SF
Knik River	Personal Comm.			6,000				Larry Engel, ADF&G Div. of Sport Fish (L.E., SF) Max. abundance estimate from several years observations
	Personal Comm.			4,000		50		Tom Mears, Cook Inlet Aquaculture Ass'n (T.M., CIAA) Observ. from Aug-Sep., 1979-81
Jim Lake	Personal Comm.				Signif.			L.E., SF
	1981				Present			T.M., CIAA
	1981				35			Test fish catch

Appendix Table EC-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Little Susitna River	1973		374					
	1979		800	1,478	3,382	364	618	Sport fish harvest
	1980		646	2,127	6,302	465	3,918	Sport fish harvest
Horseshoe Lake	Before 1970							Max. count 45,000 pinks (1964), 2 chinook (1958)
Matanuska River	Before 1970							Chinook present
	Personal Comm.			2,500	150	2,500		T.N., CIAA, Kings River confluence 1981 observations
Bodenburg Slough	1972			464				Peak survey count
	1973	8/21		57				
	1973	8/24		162				
	1973	8/27		200				
	1973	8/30		237				
	1973	9/04		252				
	1973	9/16		199				
	1974	8/23		88				
	1974	8/29		135				
	1974	9/04		141				
	1974	9/12		171				
	1974	9/16		147				
	1975	8/21		138				
	1975	8/26		130				
	1975	8/29		164				
	1975	9/05		160				
	1975	9/23		109				
	1976	8/23		48				
	1976	8/27		84				
	1976	9/02		108				
	1976	9/07		107				
	1976	9/12		111				
	1977	8/22		146				
	1977	8/30		174				
	1977	9/06		164				
	1977	9/15		140				
	1978	8/22		270				
	1978	9/11		81				
	1978			505				Peak survey count
Granite Creek	Before 1970							Max. count sockeye 116 (1959), chum 61 (1957)
Moose Creek	1970	7/24		120				
	1971	7/28		22				
	1971	7/29		40				
	1972	7/28		15				
	1972	7/31		6				
	1973	8/01		36				
	1974	8/01		32				
	1975	8/01		55				
	1976	7/28		101				
Mud Lake	Before 1970							Max. count 90 sockeye (1957)
Nancy Lake	Before 1970							Max. count 7,000 sockeye (1954)
	1972	8/15		5,000				
	1972	9/07		530				
	1972	9/11		1,979				
	1972			1,731				Peak survey count
	1973			283				Peak survey count

Appendix Table EC-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Nancy Lake	1974			140				Peak survey count
	1975			84				Peak survey count
	1975	8/21		31				
	1975	8/24		56				
	1975	8/26		74				
	1975	9/05		60				
	1975	9/23		42				
	1976	8/23		47				
	1976	8/27		230				
	1976	9/02		284				
	1976	9/07		267				
	1976	9/12		282				
	1977			4,801	3			Escapement count (weir)
	1977	8/23		170				
	1977	8/30		844				
	1977	9/06		573				
	1978			2,050				Escapement count (weir)
	1979			3,831				Escapement count (weir)
	1979	9/07		800				
	1980			69				Sport fish harvest
Lake Creek	Before 1970							Max. count 60 chinook (1967); 200 sockeye (1958)
	1970			1				
	1971			2				
	1972			14				
	1974			535				
	1975			281				
	1976			3,375				
Nancy Creek	Before 1970							Max. count 142 sockeye (1954)
	1975	8/26		8				
	1975	8/29		11				
	1975	9/05		9				
Palmer Creek	Before 1970							Max. count 144 sockeye (1957); 20 chums (1950)
	1978	8/22		83				
	1978	9/11		505				
	1978	9/21		351				
Peter's Creek	Before 1970							Max. count 101 chinook (1965)
	Personal Comm.				Present	Present	Present	S.K., SF
Petersen Creek	Personal Comm.						Present	S.K., SF
Ship Creek	Before 1970							Max. count chinook 1,764 (1964); chums 600 (1953); pinks 1,250 (1952)
	1970		1,746					
	1971		221					
	1972		121					
	1973		165					
	1974		146					
	1975		120					

Appendix Table EC-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Ship Creek	1976		006					
	1977		1,011					
	1978		867					
	1979		124					
	1979				512		91	Sport fish harvest
	1980				301	• 9	405	Sport fish harvest
	1981		1,000					
	Personal Comm.			Present		Present		S.K., SF
Six Mile Creek	1980			300		100		T.M., CIAA, 1980 observations
Six Mile Lake	Personal Comm.			200	200			S.K., SF
Wasilla Creek	1970	9/25			101			
	1970	9/28			94			
	1971				104			
	1972	9/21			19			
	1973				28			
	1974				30			
	1975				158			
	1976				162			
	1978				158			
	1979				187			
	1979				1,211	45	136	Sport fish harvest
	1980				3,555	9	210	Sport fish harvest
Wasilla Lake	Before 1970							Max. count 3,581 sockeye (1960) 1,161 coho (1960)
	1972	8/22		660				

EC-5

APPENDIX ED

SALMON ABUNDANCE DATA FOR KENAI PENINSULA RIVER SYSTEMS

Appendix Table ED-1. Salmon abundance data for Kenai Peninsula river systems, compiled from escapement enumeration programs[1], sport fish harvest data[2], and aerial surveys[1,3], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Bishop Creek	Before 1970							Max. count 23,000 sockeye (1958)
	1974	9/19		24				
	1976	8/20		154				
	1977	7/22		7,000				
	1981	Aug.		2,000				Tom Mears, Cook Inlet Aquaculture Association (T.M., CIAA)
Bishop Lake	1981	9/03		170				T.M., CIAA
Daniels Lake & Creek	1981	9/03		2,000				T.M., CIAA
Parsons Lake & Creek	1981	9/03	0	0	0	0	0	T.M., CIAA
Timberlost Lake & Creek	1981	9/03		2				T.M., CIAA
Deep Creek	Before 1970							Max. count 3,600 chinook (1951); 13 coho (1958); 72 pink (1959)
	1972		530					
	1973		220					
	1974		740					
	1975		610					
	1976		1,680					
	1977		990					
	1978		1,010					
	1979		4,773	1,006	749		91	Sport fish harvest
	1980		1,818	878	883		795	Sport fish harvest
Tustamena Drainage								
Kasilof River	Before 1970							Max. count 89,000 sockeye 1968
	1970			38,000				Escapement count (sonar)
	1971			90,000				Escapement estimate (partial survey & sonar counts)
	1972			113,000				Escapement count (sonar)
	1973			40,000				Escapement count (sonar)
	1974			70,000				Escapement count (sonar)
	1975			48,000				Escapement count (sonar)
	1976			139,000				Escapement count (sonar)
	1977			152,000				Escapement count (sonar)
	1978			116,000				Escapement count (sonar)
	1979			144,000				Escapement count (sonar)
	1980			184,000				Escapement count (sonar)
	1981			256,625				Escapement count (sonar)

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED); Cook Inlet Aquaculture Association (CIAA); Woodward-Clyde Consultants (WWC); Dowling Engineers Consulting Firm (DE).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1
Mills, Michael J. 1980. Statewide Harvest Study - 1980 Data. Alaksa Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1C.

3/ All entries are aerial or ground stream survey data unless otherwise designated.

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Bear Creek	Before 1970							Max. count 22,000 sockeye (1950); 37 pinks (1952); 1 coho (1957)
	1970	8/08		3,521				
	1970	8/16		6,652				
	1970			6,900				Peak survey count
	1971			12,645				
	1972			27,736				Peak survey count
	1972	7/20		80				
	1972	7/27		350				
	1972	8/01		684			2	
	1972	8/06		5,592			2	
	1972	8/11		10,261			7	
	1972	8/15		27,736			5	
	1972	8/23		14,846			2	
	1972	8/30		9,000				
	1973			9,463				Peak survey count
	1974			1,454				Peak survey count
	1975	8/14		15,000			39	
	1975	8/20		15,595				
	1975			16,616				Peak survey count
	1976	8/07		6,000			1	
	1976	8/22		31,000			4	
	1977	8/01		11,000				
	1977	8/13		27,000			50	
	1977	8/26		34,784			24	
	1978	8/10		17,507				
	1978			40,000				Peak survey count
	1979	8/11		22,081			15	
	1981	7/01		0	0	0	0	
	1981	7/28		10,000				T.M., CIAA
Clear Creek	1970			553				Peak survey count
	1971			1,203				Peak survey count
	1972			300				
	1972			198	1	1		Peak survey count
	1972	9/01		162		1	3	
	1973			166				Peak survey count
	1974			130				Peak survey count
	1975	8/13		101		1	13	
	1975	8/15		326		4	3	
	1975	8/22		281		1	5	
	1975			328				Peak survey count
	1976	8/09		155			1	
	1977	8/06		319			14	
	1977	8/11		1,432			32	
	1977	8/18		1,621			28	
	1977	8/27		1,017			2	
	1978	8/13		181		1	13	
	1979	8/10		360			2	
	1980	7/30		200			1	
	1981	7/01		1,500				
	1981	7/28		200				T.M., CIAA
	1981	8/17		2,478				
Cliff House Creek	Before 1970							Max. count 7,000 sockeye (1949); 3 chums (1953); 7 pinks (1958)
Coal Creek	1979	8/30		0	0	0	0	T.M., CIAA

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Crooked Creek	1979		868					Escapement count (weir)
	1980		2,460					Escapement count (weir)
Crystal Creek	1971			569				Peak survey count
	1971			1,002				
	1972	8/05		286	1		1	
	1972	8/09		531				
	1972	8/12		582			1	
	1972	8/26		816				
	1972	9/01		90				
	1972	9/05		59				
	1972			1,144				
	1975	8/15		441				
	1975	8/22		89				
	1976	8/09		345				
	1976	9/18		806			1	
	1977	8/06		0	0	0	0	
	1977	8/13		163				
	1977	8/18		589				
	1977	8/27		479				
	1979	8/10		499			2	
	1981	7/01	0	0	0	0	0	
	1981	8/17		860				
Glacier Flats Creek	Before 1970							Max. counts 10,500 sockeye (1968); 120 pinks (1962)
	1970			5,124				Peak survey count
	1971			26,266				
	1972	8/16		24,843			1	Max. count 7 pinks (1958)
	1972	8/21		29,859		1		
	1972	8/27		39,048		1		
	1972	9/03		20,352				
	1972	9/07		11,361				
	1972	9/15		2,436				
	1972			52,175				Peak survey count
	1973			10,623				Peak survey count
	1974			11,240				Peak survey count
	1975			14,355				Peak survey count
	1976	8/09		1,483				
	1976	8/18		2,252				
	1976	8/22		2,968				
	1976			7,122				Peak survey count
	1977	8/05		2,781			4	
	1977	8/16		3,866				
	1977	8/26		5,763				
	1977			5,835				Peak survey count
	1978			6,144				Peak survey count

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Glacier Flats Creek	1979	8/10		3,593				
	1981	7/01	0	0	0	0	0	
	1981	7/28		10,000				T.M., CIAA
	1981	8/08		20,000				
	1981	8/19		800				Partial escapement count (weir)
Indian Creek	Before 1970							Max. count 12 sockeye (1962); 98 pinks (1954)
	1981	7/28	0	0	0	0	0	T.M., CIAA
Moose creek	Before 1970							Max. count 18,000 sockeye (1968); 52 pinks (1957)
	1970			2,800				Peak survey count
	1971			9,439				
	1972	7/20		138				
	1972	7/27		100				
	1972	7/29		7,553			4	
	1972	8/08		7,743			10	
	1972	8/14		14,323		1	15	
	1972	8/22		11,341		1	10	
	1972			15,971				
	1973			290				Peak survey count
	1974			4,444				Peak survey count
	1975	8/13		3,116		1	17	
	1975			2,747				Peak survey count
	1976	8/08		7,300		1	3	
	1976	8/19		12,364			21	
	1976			12,000				Peak survey count
	1977	8/04		11,210			39	
	1977	8/14	6	11,503			4	
	1977	8/25		13,857				
	1977			14,565				Peak survey count
	1978	8/01		15,899				
	1979	8/09		8,000			23	
	1980	7/31		2,910				
	1980	8/13		15,645			2	
	1981	7/01		100				
	1981	7/28		10,000				T.M., CIAA
	1981	8/19		8,415			Present	
Nikolai Creek	Before 1970							Max. count 20,000 sockeye (1946); 96 pinks (1966); 1 chum (1955)
	1971			2,231				
	1972	8/13		3,921		1	20	
	1972			13,760				Peak survey count
	1975	8/11		2,552		1	161	
	1975	8/19		698	4		35	
	1976	8/05		6,500				
	1977	7/30	3	10,851		2	97	
	1977	8/10		5,200			58	
	1978	8/09		4,890		1	22	
	1979	8/08	5	6,838			18	
	1980	8/22		5,100				
	1981	7/01	0	0	0	0	0	
	1981	7/30		34,722				
	1981	7/28		10,000				T.M., CIAA
Olsen Creek	Before 1970							Max. count 34 sockeye (1954)
	1975	8/20		4				

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Kenai River System								
Kenai River	Before 1970							Max. count 88,000 sockeye (1951)
	1970			73,000				Escapement count (sonar)
	1971			278,000				Estimates partially survey and sonar counts
	1972			318,000				Escapement count (sonar)
	1973			367,000				Escapement count (sonar)
	1974			161,000				Escapement count (sonar)
	1975			142,000				Escapement count (sonar)
	1976			380,000				Escapement count (sonar)
	1977			707,000				Escapement count (sonar)
	1978			399,000				Escapement count (sonar)
	1979			285,000				Escapement count (sonar)
	1980			464,000				Escapement count (sonar)
	1981			407,638				Escapement count (sonar)
Beaver Creek	Before 1970							Cohos and pinks present (1967)
	1980	6/28	0	0	0	0	0	T.M., CIAA
Carter Creek	Before 1970							Max. count 250 sockeye (1967)
Cooper Creek	Before 1970							Max. count 300 sockeye, 35 chinook (1950), some coho (1936)
Cottonwood & Pipe Creeks	1981	8/03	0	0	0	0	0	T.M., CIAA
Crescent Creek	Before 1970							Max. count 250 sockeye (1946); 500 chinook (1947)
	1979	7/25	141					
Funny River	Before 1970							Max. Count 7 pinks (1952)
	1980	9/11	0	0	0	0	0	T.M., CIAA
Grant Creek & Lake	Before 1970							Max. count 76 chinook (1963); 324 sockeye (1962)
	1977	8/11	0	0	0	0	0	
	1977	8/24		4				
	1978	8/12	5					
	1979	8/07	42					
	1980	8/01	5					
Hidden Creek	Before 1970							Max. count 3,194 sockeye (1965); 6 coho (1953)
	1970	8/28		112				
	1970	9/12		158				
	1970	9/22		323				
	1971	8/18		32				
	1971	8/28		112				
	1971			1,958				Escapement count (weir)
	1972	8/28		1,000				

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Hidden Lake	Before 1970							Max. count 3,700 sockeye (1963)
	1970			323				Escapement count (weir)
	1971			1,958				Escapement count (weir)
	1972			4,956				Escapement count (weir)
	1973			690				Escapement count (weir)
	1974			1,150				Escapement count (weir)
	1975			1,375				Escapement count (weir)
	1976			4,860				Escapement count (weir)
	1977			1,055				Escapement count (weir)
	1978			4,647				Escapement count (weir)
	1979			5,762				Escapement count (weir)
	1980			8,421	307			Escapement count (weir)
Jean Creek & Lake	Before 1970							Max. count 1,200 sockeye (1947)
	1974	8/28		526				
	1974			26,880	2,389			Escapement count (weir)
	1975	8/07		20				
	1976	8/09		78				
	1976	8/18		250				
	1977	8/09		68				
	1977	8/22		119				
	1977	8/23		129				
	1978	8/09		63				
	1980	9/18		1,091				T.M., CIAA
	1981	8/03		60				T.M., CIAA
Johnson Creek	Before 1970							Max. count 625 Sockeye (1969)
	1970			626				Peak survey count
	1971			160				Peak survey count
	1972			150				Peak survey count
	1973			713				Peak survey count
	1974	8/27		19				
	1974			46				Peak survey count
	1975	8/10		105				
	1975	8/20		63				
	1976	8/07	0	0	0	0	0	
	1976	8/09	0	0	0	0	0	
	1976	8/17	0	0	0	0	0	
	1977	8/02		25				
	1977	8/11		271				
	1977			450				Peak survey count
	1978	8/08	0	0	0	0	0	
	1978	8/13		769	21			
	1978	8/24		252	98			
	1978			780				Peak survey count
	1979	8/01		588				
	1980	8/05		253				
Juneau Creek & Lake	Before 1970							Max. count 72 chinook (1957); large numbers of sockeye (1936)
	1976	8/08	0	0	0	0	0	
	1977	8/09	18	2				
	1977	8/23	5	15				
	1978	8/09	42	7			1	
	1979	7/12	90					

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Killey River	Before 1970							Max. count 100 pinks (1960)
King County Creek	Before 1970							No fish observed
	1981	8/03	0	0	0	0	0	T.M., CIAA
Moose Creek	Before 1970							Max. count 1,061 sockeye; 3 chum (1953); 3 pink (19
	1970			348				Peak survey count
	1971			3,201				
	1972			3,400				Peak survey count
	1973			660				Peak survey count
	1974	8/21		942				
	1974	8/27		939				
	1975	8/11		686				
	1975	8/26		602				
	1975			1,278				Peak survey count
	1976	8/05		3,191				
	1976	8/17		5,558				
	1977	8/01		6,329				
	1977	8/10		6,515			1	
	1977	8/25		5,578				
	1978	8/10		1,919	14		2	
	1978	8/29		1,055	27			
	1978			1,933				Peak survey count
	1979	7/25		3,986				
Morning Slough	1978	8/11		320				
	1978	8/23		281				
Mud Lake	Before 1970							Max. count 100 chinook (1949); 1,000 sockeye (1948)
	1970			561				Peak survey count
	1971			1,370				
	1972			1,200				Peak survey count
	1973			1,731				Peak survey count
	1974	8/09		1,216				
	1974	8/20		1,214				
	1974	8/29	0	0	0	0	0	
	1975	8/14		652				
	1975	8/25		910				
	1975	8/25		657				
	1975	8/25		1,010				
	1975			1,214				Peak survey count
	1976	8/05		802				
	1976	8/18		1,548				
	1977	8/03		1,740				
	1977	8/12		1,840				
	1977	8/26		2,230				
	1978	8/09		1				
	1978	8/22		825				
	1980	8/12	9	1			1	Dave's Creek
	1980	8/19	3	4	15			Dave's Creek

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Pipe Creek	1975	8/12		6				
	1976	8/08		136				
	1976	8/23		55				
	1977	8/02		500			2	
	1977	8/11		210				
	1977	8/23		207				
	1978	8/11		202			2	
	1979	8/09		160			2	
Ptarmigan Creek	Before 1970							Max. count 3,000 sockeye (1947); 300 chinook (1948)
	1970	8/18	7					
	1971	8/02	9	45				
	1972	8/08	0	0	0	0	0	
	1973			1,041				Peak survey count
	1974	8/24	13	550				
	1974	8/27	9	506				
	1975	8/11	0	0	0	0	0	
	1975	8/19		32				
	1975			186				Peak survey count
	1976	8/06	0	0	0	0	0	
	1976	8/16	0	0	0	0	0	
	1976	8/30	11	505				
	1977	7/31	0	0	0	0	0	
	1977	8/12		3				
	1977			1,513				Peak survey count
	1978	8/13	1					
	1978	8/25	3,529					
	1979	8/20	25	532				
	1900	9/05	8					
Quartz Creek	Before 1970							Max. count 15 chinook (1952); 1,456 sockeye; 1 pink and 10 chum (1954)
	1970			200				Peak survey count
	1971			800				Peak survey count
	1973			3,173				Peak survey count
	1974	8/20	33	255		1		
	1974	8/26		153				
	1975	8/11	7	1,068				
	1975	8/21	27	908				
	1976	8/09	5	3,372				
	1976	8/19	7	1,086				
	1977	8/01	2					
	1977	8/09	11	127				
	1977	8/26	4	143				
	1977	8/27	5	3 037				
	1978	8/12	44	10,627				
	1978	8/23		9,176	4	1	1	
Railroad Creek	Before 1970							Max. count 275 sockeye (1967)
	1970			99				Peak survey count
	1971			194				Peak survey count
	1972			700				Peak survey count
	1973			521				Peak survey count
	1974	8/21		3				
	1975	8/10		573				
	1975	8/20		192				

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Railroad Creek	1976	8/07		1,032				
	1976	8/17		679				
	1977	8/02		1,175				
	1977	8/11		1,239				
	1977	8/24		732				
	1977			1,262				Peak survey count
	1978			1,749				Peak survey count
	1980	8/05		1,259				
	1980	8/13		1,749				
Rocky Creek	1981			163				
Russian River (Upper)	Before 1970							Max. count 2,100 chinook (1958); 62,000 sockeye (1968); 18 coho (1956); 25 chum (1960); 100 pinks (1958)
	1970	9/01		33,000	87	77		Escapement count, sockeye (weir); other species estimates from surveys
	1970			227				Peak survey count
	1971			67,000				Escapement count (weir)
	1971			11,442				Peak survey count
	1972			94,000				Escapement count (weir)
	1972			7,113				Peak survey count
	1973			45,000				Escapement count (weir)
	1973			8,571				Peak survey count
	1974			40,000				Escapement count (weir)
	1974			2,909				Peak survey count
	1975			39,000				Escapement count (weir)
	1975			866				Peak survey count
	1976			4,813				Peak survey count
	1976	8/18	88	40,000	7		2	Escapement count, sockeye (weir); other species estimates from surveys
	1977			38,982				Peak survey count
	1977			56,000				Escapement count (weir)
	1978			87,000				Escapement count (weir)
	1978			26,885				Peak survey count
	1979			112,000	1,098			Escapement count, sockeye (weir); Sport fish harvest, coho
	1980			116,000	1,025			Escapement count, sockeye; Sport fish harvest, coho
Seepage Creek	Before 1970							Max. count 25,000 sockeye (1946)
	1971			2,292				
	1972	8/26		34		1	5	
	1972			3,872				Peak survey count
	1975	8/15		2,000				
	1975	8/22		3,416				
	1976	8/09		179				
	1976	8/18		223				
	1977	8/05		612				
	1977	8/12		3,376				
	1977	8?16		840				
	1977	8/26		587				

Appendix Table ED-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Seepage Creek	1978	8/12		1,055				
	1979	8/10		788				
	1980	7/30		800				
	1980	8/12		1,811				
	1981	7/01	0	0	0	0	0	
	1981	7/28						Approx. 1,000 fish, species unknown, (T.M.,CIAA)
	1981	8/08		3,376				
Ship Creek	Before 1970							Max. count 650 pinks (1951)
Skilak River	1981	8/03	0	0	0	0	0	T.M., CIAA
Slikok Creek (Lake)	Before 1970							Max. count 5 pinks (1957)
	1980		0	0	0	0	0	T.M., CIAA
	1981	8/03	0	0	0	0	0	T.M., CIAA
Snow River	Before 1970							No fish observed (1952)
Soldotna Creek	Before 1970							No fish observed (1957)
Tern Creek	1979	7/21		1,693				
Trail Creek (Upper)	1977	8/02		124				See Morning Slough for additional counts
	1977	8/27		196				
Trail Lake	Before 1970							No fish observed (1952)
Trail River	Before 1970							Peak count 10,000 sockeye (1977)
	1976	8/17		78				
	1977	8/02		124				
	1977	8/11		106				
	1977	8/24		35				
	1978	8/13		71				
Swanson River	Before 1970							Max. count 2,043 coho (1965)

APPENDIX EE

SALMON ABUNDANCE DATA FOR THE SUSITNA RIVER

Appendix Table EE-1. Salmon abundance data for Susitna River Mainstream and main stream tributaries, compiled from escapement enumeration programs[1], sport fish harvest data[2], and aerial surveys[1,3], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Mainstem								
Susitna Station (system-wide estimates)	1970			38,000				
	1971							
	1972			113,000				
	1973		15,000	40,000				Chinook estimate from aerial surveys, includes sport harvest
	1974		15,000	70,000				Chinook estimate from aerial surveys, includes sport harvest
	1975		11,500	108,000				Chinook estimate from aerial surveys, includes sport harvest
	1976		71,200	111,000			933,000	Escapement-population estimate; chinook estimate from aerial surveys, includes sport harvest
	1977		118,100	238,000	50,000	105,000	1,490,000	Escapement-population estimate; chinook estimate from aerial surveys, includes sport harvest
	1978		81,100	94,000	100,800	148,000	2,478,100	Escapement count (sonar); chinook estimate from aerial surveys, includes sport harvest
	1979		77,200	157,000		125,000		Escapement count (sonar); chinook estimate from aerial surveys, includes sport harvest
	1980			191,000		7,939	2,047,000	Escapement count (sonar); chinook estimate from aerial surveys, includes sport harvest
	1981		60-70,000	340,232	33,470	46,461	113,349	Escapement count (sonar); chinook estimate from aerial surveys
Sunshine Station	1981			89,906	22,793	59,630	72,945	Abundance estimate (sonar)
	1981			133,489	19,841	262,851	49,501	Mark/recapture estimate
Talkeetna Station	1981			3,464	3,522	10,036	2,529	Abundance estimate (sonar)
	1981			4,809	3,306	20,835	2,335	Mark/recapture estimate
Curry Station	1981			2,804	1,146	13,068	1,041	Mark/recapture estimate
Tributaries								
Alexander Creek	Before 1970							Max. count 1,868 chinook (1953), sockeye present (1964), 2,000 coho (1963), 100,000 pinks (1964); 500 chum (1963)
	1970	7/26	280	2,720 sockeye and coho				
	1970		491					
	1972		202					
	1973		875					
	1974		2,193					
	1975		1,878					

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED), and Cook Inlet Aquaculture Association (CIAA).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1B
Mills, Michael J. 1980. Statewide Harvest Study -1980 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1C.

3/ All entries are aerial or ground stream survey data, unless otherwise designated.

Appendix Table EE-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Alexander Creek	1976		5,412					
	1977	7/26	2,504					
	1977		13,385					
	1978		5,854					
	1979		6,215					
	1979		712	79	1,560	45	236	Sport fish harvest
	1980		1,438	52	999	121	809	Sport fish harvest
	Personal Comm.			5,000			250,000	Stan Kubik, ADF&G Div. Sport Fish (S.K.,SF)
								Max. abundance estimate from several years observations
Sucker Creek	Before 1970							Max.count 20 chinook (1964); 1,000,000 pinks (1966)
Wolverine Creek	Before 1970							Max. count 14 chinook (1964)
Birch Creek	Before 1970							Large numbers of sockeye observed 1953; few coho some chums; 75,000 pinks (1969)
	1970	9/17			201			
	1970	9/23			206			
	1971	9/27			138			
	1972	8/18		107	15	10	3,051	
	1972	9/28			69			
	1973	8/31		16				
	1973	9/07		1				
	1973	9/16		4				
	1973	9/26			106			
	1974	8/23	0	0	0	0	0	
	1974	8/29	0	0	0	0	0	
	1974	9/04		2	8			
	1974	9/16	0	0	0	0	0	
	1974	9/26			49			
	1975	8/21		55			2	
	1975	8/26		8				
	1975	8/29		11	10			
	1975	9/05		1	15		1	
	1975	9/23	0	0	0	0	0	
	1976	8/24		49			19	
	1976	8/27		25	11		7	
	1976				40			
	1978	9/11		299	146			
	1979	8/28		100	25			
	1981	8/25		150	10	10		
Fish Lakes (Birch Creek)	Before 1970							Max. counts 500 sockeye (1953)
	1972	8/18		107				
	1973	8/21		251				
	1973	8/31		205				
	1973	9/07		158				
	1973	9/16		158				
	1974	8/23		43				
	1974	8/29		95				
	1974	9/04		67				
	1974	9/16		67				
	1975	8/21		70				
	1975	8/26		93				
	1975	8/29		113				
	1975	9/05		132				
	1975	9/23		46				
	1975			187				Peak survey count

Appendix Table EE-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Fish Lakes (Birch Creek)	1976	8/24		82	17		48	
	1976	8/27		25	11		26	
	1976	9/03		47			7	
	1976	9/07		23			14	
	1977			611				Peak survey count
	1978	8/22		79			42	
	1978	9/25		242	28			
	1978			299				Peak survey count
	1980	8/18		2,100				
Fourth of July Creek	1974	9/11			26	594		
	1974	8/16					159	
Goose Creek	Before 1970							Chinook, chum present, max. count 5,000 pinks (1969), 177 coho (1968)
	1970	9/16				2		
	1974	7/26	41					
	1975	8/03	13					
	1976	7/15	160					
	1976	7/23	104					
	1977		133					
	1978		283					
	1981		262					
Indian River	Before 1970							Max. count 1,002 chinook (1957)
	1972	7/30	35					
	1973	7/26	110					
	1973	7/29	122					
	1974	7/25	102					
	1974	8/19					577	
	1974	9/10			64			
	1975	8/04	31					
	1975		35					
	1976	7/23	537					
	1977		393					
	1978		114					
	1979	10/29				150		Cook Inlet Aquaculture Ass'n (CIAA)
	1979		285					
	1981		422					
Kashwitna River-North Fork	Before 1970							Chinook present, max count 10,000 pinks (1966)
	1971		1					
	1972		31					
	1973		183					
	1974		103					
	1975		33					
	1976		203					
	1977		336					
	1978		362					
	1979		457					
	1981		557					

Appendix Table EE-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Kroto Creek	Before 1970							Max. count chinook 3,000 (1954); 86 sockeye (1950); 300,000 pinks (1954)
	1970		579					Sport fish harvest
	1970		1,417					West Fork only
	1971		434					Sport fish harvest
	1972		275					Sport fish harvest
	1972		1,780					
	1973		2,381					
	1974		5,279					
	1975		4,737					
	1976		21,693					
	1977		39,642					Entire Deshka River System
	1978		24,639					
	1979		27,385					
	1979		3,685		2,290		689	Sport fish harvest
	1980		2,811		973		109	Sport fish harvest
	Personal Comm.			500	10,000		500,000	S.K., SF (entire Deshka River System)
Lane Creek	Before 1970							Chinook present
	1974	8/9/74					74	
	1975					3	106	Peak survey count
	1981		40		3	76	291	Peak survey count
Little Willow Creek	Before 1970							Max. count 278 chinook (1969); 35,000 pinks
	1970	7/28	45					
	1972	8/01	99					
	1976		833					
	1977		598					
	1978		436					
	1979			141	262	118	745	Sport fish harvest
	1979		324					
	1980		32	77	494	270	6,420	Sport fish harvest,
	1981		459					
Montana Creek	Before 1970							Chinook present, max. count 30,000 pinks (1966); 450 coho (1951)
	1970		161					
	1970	7/27	260					
	1970	7/28	21					
	1971	8/03	20					
	1971	8/05	24					
	1972	7/25	211					
	1972	7/26	106					
	1973		527					
	1974	7/24	280					
	1975	7/29	229					
	1976	7/26	1,445					
	1977		1,443					
	1978		881					
	1979		1,094					
	1979		312	346	1,735	745	2,472	Sport fish harvest
	1980		559	257	2,684	571	8,230	Sport fish harvest
	1981		814					

Appendix Table EE-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Moose Creek	1970		126					
	1971		40					
	1972		21					
	1973		36					
	1974		32					
	1975		55					
	1976		116					
	1977		153					
	1978		237					
	1979		253					
	1981		239					
Portage Creek	1972	7/30	68					
	1973	7/26	153					
	1973	7/29	174					
	1974	7/27	260					
	1974	8/18			150	276	218	
	1975	8/04	32					
	1976	7/23	702					
	1977		374					
	1978		140					
	1979		190					
	1981		659					
Question Creek and Lake	Before 1970							Max. count 5,970 sockeye (1957)
	1973	9/28			59			
	1974				3			
	1975	9/23			111			
	1976	9/28			126			
	1977				87			
	1978				45			
	1979				384			
	1980				321			
Rabideaux Creek	Before 1970							Chinook present
	1975	9/26				67		
	1976	9/29				91		
	1977		99					
	1978					88		
	Personal Comm.		Present		Present		Present	S.K., SF
Red Shirt Creek	Before 1970							Max. counts, 2,600 sockeye (1952); 380 coho (1952)
	1972	8/29		160	100			
	1973	8/17		35				
	1973	9/14		47				
	1974	8/26		0	0	0	0	
	1974	9/09		0	0	0	0	
	1974	10/03		1				
	1974			160				Peak survey count
	1975	8/29		135				
	1976	8/17		66				
	1976	8/26		92				

Appendix Table EE-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Red Shirt Creek	1976	9/14		117				
	1976	9/16		130				
	1977	8/24		43				
	1977	9/01		4				
	1978	8/29		13				
	1979	9/07		645	92			
	1980	9/11		650				
	1981	8/25		600				
Role Jo Lake	Before 1970							Sockeye and coho present
	1972	8/16		40				
	1972	8/29		160				
	1973	8/17	0	0	0	0	0	
	1973	9/04		47				
	1974		0	0	0	0	0	
	1975	8/29		24				
	1976	9/26		25				
	1976			35				Peak survey count
	1977	8/24		43				
	1977	9/01		4				
Sheep Creek	Before 1970							Max count 768 chinook (1958); 20,000 pinks (1958); chums present
	1972	6/06	Present		Present	Present	Present	Memo from Div. of Sport Fish
	1972	8/01	101					
	1973	7/24	444					
	1973	7/26	402					
	1974	7/26	202					
	1975	8/03	42					
	1976		455					
	1977		630					
	1978		1,209					
	1979		778					
	1979		10	31	462	682	2,412	Sport fish harvest
	1980		45	0	430	648	6,362	Sport fish harvest
	1981		1,013					
Sloughs 6,9,11,14,16,17,19,20,21	1974	8/28-9/18		103		1,352		
Sunshine Creek	Before 1970							Max. count 25 chinook (1963); 1,000 pinks (1962)
	1979		10	157	774	55	700	Sport fish harvest
	1980		13	116	1,534	225	2,408	Sport fish harvest
Trapper Creek	Before 1970							Max. count 234 chinook (1964)
Willow Creek	Before 1970							Max. count 4,500 chinook (1947); 2,000 coho (1950); 20,000 chum (1950); 40,000 pink (1950); 60 sockeye (1957)
	1970		640					
	1971		165					
	1972		370					
	1972		11					Sport fish harvest

Appendix Table EE-1. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Willow Creek	1973	7/24	678					
	1973	7/25	981					
	1973		1,074					
	1974	7/26	402					
	1975	8/04	177					
	1976	7/15	1,660					
	1977		1,065					
	1979		459	94	402	582	3,445	Sport fish harvest
	1980		289	83	1,207	989	23,638	Sport fish harvest
	1981		1,357					
	Personal Comm.					7,000	250,000	Larry Engel, ADF&G Div. of Sport Fish (L.E., SF) Max. abundance estimate from several years observations

Appendix Table EE-2. Salmon abundance data for the Yentna River subdrainage of the Susitna River, compiled from escapement enumeration programs[1], sport fish harvest data[2], and aerial surveys[1,3], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Bear Creek	Personal Comm.		100				5,000	Stan Kubik, ADF&G Div. of Sport Fish (S.K., SF) Max. abundance estimate from several years observations
Cache Creek	Personal Comm.		100				Present	S.K., SF
Camp Creek	Before 1970							Max. count 101 chinook (1965)
Canyon Creek	1974		10					
	1975		2					
	1976		44					
	1977		135					
	Personal Comm.						Present	S.K., SF
Chelatna Lake	1975	8/29		50				
	1980	8/29		4,120				
	1981	8/27		14,900				
Spring Creek	Before 1970							Max. count 142 sockeye (1954)
	1972	8/29		33				
	1973	9/06		11				
	1974	9/06	0	0	0	0	0	
	1975	9/01		4				
Christmas Tree Creek								
	Before 1970							Sockeye present
	1972	8/29		50				
	1973	8/17		0				
	1973	8/28		29				
	1973	9/11		40				
	1973	9/12		Present				
	1974	8/26		49				
	1974	9/09		56				
	1974	9/18		80				
	1975	8/24		84				
	1975	9/03		55				
	1976	8/26		56				
	1976	9/09		54				
	1978	8/28		30				
	1980	8/22		0				
	1980	9/11		50				
Clearwater Creek	1977		47					
	Personal Comm.		100				5,000	S.K., SF

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED), and Cook Inlet Aquaculture Association (CIAA).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-I
Mills, Michael J. 1980. Statewide Harvest Study -1980 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1C.

3/ All entries are aerial or ground stream survey data, unless otherwise designated.

Appendix Table EE-2. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Coffee Creek	Before 1970							Sockeye present
	1972	8/29		254				
	1972	8/30		24				
	1973	9/06	0	0	0	0	0	
	1975	8/30		70				
	1975	9/01		7				
	1977	8/27		231				
	1978	8/27		18				Coffee Creek and Snowslide Creek
Contact Creek	Personal Comm.		100			Present	1,000	S.K., SF
Cripple Creek	1975	8/23		427				
	1975	8/30		48				
	1976	8/23		438				
	1976	9/02	24	428				
	1977	9/12	0	0	0	0	0	
	1979	8/26	0	0	0	0	0	
Crystal Creek	1972	8/29		33				
	1972	9/06		11				
Deception Creek	1978		49					
	1979		239					
	1981		366					
Dickason Creek	Personal Comm.		Present				Present	S.K., SF
Donkey Creek	Personal Comm.		100	1,000			5,000	S.K., SF
Fish Lakes	Before 1970							Sockeye escapements exceeding 1,000 (1950)
	1974			1,048				Escapement count (weir)
	1981		200		500			S.K., SF
Flag Creek	Personal Comm.						Present	S.K., SF
Friday Creek	1980	7/26	82					
Gagnan Creek	1981		Present				Present	S.K., SF
Grayling Creek	Before 1970							Chinook, coho present in 1953, 5313 pinks (1954), 322 chums (1952)
	1975	8/29				2		

Appendix Table EE-2. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Hewitt Lake	Before 1970							Max. count 3060 sockeye (1956)
	1972	8/23		990				
	1972	8/29		290				
	1973	8/29		134				
	1973	9/12		453				
	1973	8/18		69				
	1974	8/27		151				
	1974	9/10		204				
	1974	9/18		288				
	1975	8/25		113				
	1975	9/04		247				
	1976	8/26		419				
	1976	9/10		1,984				
	1976			2,017				Peak survey count
	1977	8/29		729			1	
	1978	8/23		225				
	1978			1,594				Peak survey count
	1979	8/26		275				
	1979	9/07		415				
	1980	8/22		1,200				
	1980	9/11		1,100				
	1981	9/04		3,215				Hewitt and Whiskey Lakes combined
	1981			9,850				Hewitt and Whiskey Lakes combined
Hewitt Creek	Before 1970							Sockeye, pink, chinook present, max. count 312 coho (1954)
	1972	8/23		137				
	1973	8/18		29				
	1973	8/29		49				
	1973	9/12		67				
	1974	8/27		94				
	1974	9/09		78				
	1974	9/18		32				
	1975	8/25		30				
	1975	9/03		30				
	1976	8/26		17				
	1976	9/19		236				Combined with Whiskey Lake
	1977	8/28		14			17	
	1978	8/29		93				
	1979	9/07		40				
	1979	8/26		20				
	1980	8/22		50				
	1980	9/11		50	50			
	Personal Comm.		Present					Present S.K., SF
Happy River	Personal Comm.		Present					Present S.K., SF
Huckleberry Creek								
	Before 1970							Max. count 434 sockeye (1953)
	1972	8/23	1					
	1973	8/17		110				
	1973	8/28		389				
	1973	9/11		511				
	1972	8/23	1					
	1973	8/17		110				
	1973	8/28		389				
	1973	9/11		511				
	1974	8/27		79				
	1974	9/18		129				
	1974	9/19		369				
	1975	8/29	328					

Appendix Table EE-2. Continued

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Huckleberry Creek	1975	9/03		263				
	1976			182				Peak survey count
	1977			8				Peak survey count
	1978	8/29	311					Combined with Whiskey Lake count
	1979	8/26	500					
	1980	8/22	1,000					
	1980	9/11	1,750					
Hungryman Creek	Personal Comm.		100	5,000				S.K., SF
Indian Creek	Personal Comm.		Present			Present		S.K., SF
Johnson Creek	Personal Comm.		Present		Present	Present		S.K., SF
Kichatna	1977		120					
	Personal Comm.		1,000		10,000		10,000	S.K., SF
Lake Creek	Before 1970							Max. count 770 chinook (1969), 559 sockeye (1956)
	1970	7/26	189				700	
	1971		119					
	1972		920					
	1972	8/30	114	112				
	1973		761					
	1974		535					
	1975		281					
	1976	7/26	3,735					
	1977		7,391					
	1978		8,931					
	1979		4,196					
	1979		1,796	440	2,671	136	882	Sport fish harvest
	1980		775	267	2,351	69	2,101	Sport fish harvest
	Personal Comm.		6,000	5,000	2,500	15,000	500,000	S.K., SF
Martin Creek	Before 1970							Chinook present
	1974		23					
	1975		6					
	1976		791					
	1977		1,061					
Moose Creek	Personal Comm.		present	600				S.K., SF
Nakochna River	Personal Comm		100				1,000	S.K., SF
Peters Creek	1974		124					
	1975		8					
	1976		1,489					
	1977		3,042					
	Personal Comm .		4,000		1,000		10,000	S.K., SF
Pickle Creek	Personal Comm.		100				5,000	S.K., SF

Appendix Table EE-2. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Puntella Lake	1977	8/24		2,100				
	1978	8/24		1,105				
	1979	8/26		90				
	1980	8/22		550				
Quartz Creek	1973	9/14		250				
	1976	8/17		60			35	
	1976			150				Peak survey count
	1977			450				Peak survey count
	1978			125				Peak survey count
	1979	8/26	5	480				
	1981	9/04		1,210	50			
	Personal Comm.						Present	S.K., SF
Red Creek	Before 1970							Chinook present
	1977		1,511					
	1978	8/24	0	0	0	0	0	
	1978		385					
	1981		749					
	Personal Comm.						5,100	S.K., SF
Red Salmon Lake	1973	9/14		250				Peak survey count
	1974	9/09		160				Peak survey count
	1975	8/29		142				Peak survey count
	1976	9/02		376	40			
	1976	9/14		35				
	1977	8/24		150	1			
	1977			372				Peak survey count
	1978	8/09		200				
	1978	8/24		235	230			
	1980	8/22		1,100			900	
Rich Creek	Personal Comm.						few	S.K., SF
Shell Creek	Before 1970							Signif. numbers of sockeye
	1972	7/28		5,000			5	
	1972	8/10		0	0	0	0	
	1972	8/18		0	0	0	0	
	1972	8/29		50				
	1973	9/14		200				
	1973			295				Peak survey count
	1974	8/26		35	15			
	1974	9/09		64	20			
	1974	10/03		0	0	0	0	
	1974			956	1		3	Escapement count (weir)
	1975	8/29		0	0	0	0	
	1975			2,027		2	76	Escapement count (weir)
	1976	8/17		900			20	
	1976	8/26		170	55			
	1976	9/14		120				
	1976			344				Peak survey count
	1977	8/24		127				
	1979	9/07		1,000	200			
	1981	9/04		5,100				

Appendix Table EE-2. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Shell Lake	Before 1970							Signif. number of sockeye
	1972	7/28		0	0	0	0	
	1972	8/29		640				
	1973	9/04		115				
	1973	9/14		95				
	1974	8/26		0	0	0	0	
	1974	9/09		20				
	1974	10/03		5				
	1975	8/29		251				
	1976	8/26		194	55			
	1976	9/14		309				
	1977	8/24		172				
	1977	8/26		194				
	1977	9/01		247				
	1978	8/24		127				
	1979	9/07		480				
	1979			94				Sport fish harvest
	1980	8/22		4,800				Includes outlet
	1980	9/11		5,500				Includes outlet
	1980			198				Sport fish harvest
	1981	9/08		6,050				
	1981	10/02		3,500				
Skwentna River	Before 1970							Max. count 75 sockeye (1953)
	1976	8/26		150	20	1	140	
	1977	9/01		450				
	1978	8/29		308				
Snowslide Creek	1972			33				
	1973			11				
	1974		0	0	0	0	0	
	1975			4				
	1976		0	0	0	0	0	
	1977			171				
Sunflower Creek	Before 1970							Max. count 151 chinook (1964), 1 pink (1953)
Talachulitna River System	1972			6,501				Peak survey count
	1972		405	15,730	458	12,783	202,915	Escapement count (tower)
	1973			12,362				Peak survey count
	1973		291	19,727	8	707	92,496	Escapement count (tower)
	1974			6,106				Peak survey count
	1974		303	15,976	193	415	50,496	Escapement count (tower)
	1975			5,105				Peak survey count
	1976		1,319					
	1976	8/17		10,249			30,000	
	1976	8/26		10,553				
	1976	9/14		13,210				
	1977		1,856					
	1977	9/01		25,935				
	1978		1,375					
	1978	8/24		12,570			500,000	
	1978	9/6-9/7		14,308			6,783	
	1979	8/22		9,295				
	1979		1,648					

Appendix Table EE-2. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Talachulitna River System	1979			220				Sport fish harvest
	1980			267				Sport fish harvest
	1980	8/22		15,000			135,000	
	1980	9/11		21,125				
	1980	10/02		17,150	25		5,800	
	1981	9/08		10,000			100	
	1981	10/02		4,660	125			
	1981		2,025					
	Personal Comm.				2,000	10,000	500,000	S.K., SF
Judd Lake	Before 1970							Max. counts 100,000 sockeye (1966), 10,062 pinks (1952), 56 chinooks (1963) and 370 chums (1952)
	1970	9/01		600				
	1972	9/16		4,900				
	1973	8/17		5,350				
	1973	9/05		10,364				
	1973	9/28		4,225				
	1974	8/28		4,050				
	1974	9/10		5,675				
	1975	8/29		4,720				
	1979			220				Sport fish harvest
	1980			267				Sport fish harvest
Judd Springs #2	Before 1970							Max. count 2,858 sockeye (1956)
	1972	9/16		180				
	1973	8/17	0	0	0	0	0	
	1973	9/05		335				
	1973	9/28		75				
	1974	8/29	0	0	0	0	0	
	1974	9/10		82				
	1975	8/29	0	0	0	0	0	
Talachulitna Creek	Before 1970							Max. count 1,199 sockeye (1956)
	1972	9/16		390				
	1973	8/17		270				
	1973	9/05		960				
	1973	9/28		1,350				
	1974	8/28		74				
	1974	9/10		205				
	1975	8/29		86				
Talachulitna River	Before 1970							Max. count 52,900 sockeye (1962); 30,000 coho (1952); 1,522 chums (1956); 1,000,000 pinks (1960)
	1972	9/16		30				Upper river
	1972		405					
	1973	7/05		78				Upper river
	1973	7/05		231				Talachulitna Lake
	1973	7/17		26				Talachulitna Lake
	1973	8/17		510				Upper river
	1973	9/05		78				Upper river
	1973	9/05		390				Talachulitna Lake
	1973	9/28		65	6	10		Upper river

Appendix Table EE-2. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Talachulitna River	1973		333					
	1974	8/28		55				
	1974	9/10		102				
	1974		303					
	1975	8/06		86				
	1975	8/29		95				
	1975	8/29		150				Upper river
	1975		120					
	1976	8/17		10,249			30,000	
	1976	8/25		20,550				Includes Talachulitna Lake and Judd Spring 82
	1976	8/26		10,553				Included Judd Lake
	1976	9/14		13,210				
	1976		1,319					
	1977	9/01		29,935				
	1977		1,856					
	1979	8/31		2,699				
	1979		293	47	125	55	100	Sport fish harvest
	1980		121	112	491	17	276	Sport fish harvest
Trinity Lakes	Before 1970							Max. counts 417 sockeye (1957), 6,000 pinks (1962)
	1972	8/18		350				
	1973	9/14		75				
	1976	9/14		42				
	1977	8/25		148				
	1977	9/01		186				
	1978	8/26		140	20			
	1978			150				Peak survey count
	1979	9/07		195				
	1980	8/22		50				
	1980	9/11		200				
Whiskey Lake	Before 1970							Max. count 1,000 sockeye (1953)
	1972	8/29		20				
	1973	9/11		1				
	1974	8/26		49				
	1974	9/09		216				
	1974	9/18		118				
	1975	9/03		62				
	1976	8/26		150				
	1976			17				
	1978	8/28		8				
	1978	9/28		192	2			
	1979			221				Peak survey count
	1979	8/26		190				
	1979	9/07		110				
	1979			252				Sport fish harvest
	1980	8/22		425				
	1980	9/11		300				Sport fish harvest

Appendix Table EE-3. Salmon abundance data for the Talkeetna River subdrainage of the Susitna River, compiled from escapement enumeration programs[1], sport fish harvest data[2], and aerial/ground surveys[1,3], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Chunilna Creek (Clear Creek)	Before 1970							Max. counts 349 chinook (1964), coho present, 10,000 chums (1953), 75,000 pinks (1954)
	1970		72	7,000				
	1970		58					
	1971		5					
	1972	7/30	91					
	1973	7/25	245					
	1973	7/28	292					
	1974	7/27	236					
	1974	7/31	283					
	1974		823					
	1975	7/28	101					
	1976	7/16	1,220					
	1976	7/23	1,237					
	1977		769					
	1979		312	31	1,248	355	645	Sport fish harvest
	1980		172	6	661	385	622	Sport fish harvest
Mama and Papa Bear Lakes	1976	8/23		30	100		7,700	
	1977	9/12		75	23			
	1978	8/29		310	250		20,250	
	1980	8/18		300			10,000	
	1981	8/25		450			100	
Larson Lake	Before 1970							Sockeye, coho, pinks and chums present
	1972	9/07		300				
	1973	9/06		20				Max. count 559 sockeye (1956)
	1974	9/09		19				
	1975	8/30		32				
	1975	7/06		63				
	1975	9/13		47				
	1976	8/23		485				
	1976	9/02		327				
	1977			330				
	1977	8/05		50				Entire System
	1977	8/10		150				Entire system
	1977	8/16		1,300				Entire system
	1977	8/29		2,500				Entire system
	1977	9/12		1,655				Entire system
	1978			117				Peak survey count
	1979	8/28		160				
	1981	8/25		5,500				

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED), and Cook Inlet Aquaculture Association (CIAA).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1B
Mills, Michael J. 1980. Statewide Harvest Study -1980 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1C.

3/ All entries are aerial or ground stream survey data, unless otherwise designated.

Appendix Table EE-3. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Prairie Creek	Before 1970							Max. count 275 chinook (1963) sockeye present
	1970	7/29	675					
	1970		820					
	1971		40					
	1972		630					
	1972	8/22		202				
	1973	7/29	3,286					
	1973	8/23		21				
	1973	9/06		21				
	1973	9/17		7				
	1973		4,190					
	1974	7/26	1,498					
	1974	8/25		37				
	1974	9/05		12				
	1974	9/17		2				
	1975	8/04	369					
	1975	8/23		36				
	1975	9/02		49	44			
	1975	9/26		5	12			
	1976	7/20	6,513					
	1976	8/25		81	2			
	1976	9/03		80	36			
	1976	9/10		60	11			
	1976		339					
	1977		5,790					
	1977	8/27	9	120				
	1978		5,154	120				Peak survey count
	1981		1,900					
Stephan Lake	Before 1970							Max. count 6,500 sockeye (1951)
	1972	8/21		38				
	1972	9/07	0	0	0	0	0	
	1972			166				Peak survey count
	1973	8/23		85				
	1973	9/06		106				
	1973	9/17		128				
	1973			234				Peak survey count
	1974	8/25		51				
	1974	9/05		48				
	1974	9/17		40				
	1974			79				Peak survey count
	1975	8/24		124				
	1975	9/03		155				
	1975	9/27		136				
	1975			212				Peak survey count
	1976	8/25		197				
	1976	9/10		346	11			
	1976			381				Peak survey count
	1977	8/27		419				Peak survey count
	1978	9/12		1,022	2			
	1980	8/18		220				
	1981	8/25		475				
Talkeetna River	Before 1970							Large number chums (1953)
	1976	8/23				410		Larry Engel, ADF&G Div. of Sport Fish (L.E., SF)
	Personal Comm.		Signif.					Abundance estimate from several years observation
Twenty Mile Creek	Before 1970							Max. count 2,705 chinook (1965)

Appendix Table EE-4. Salmon abundance data for the Chulitna River subdrainage of the Susitna River, compiled from escapement enumeration programs[1/], sport fish harvest data[2/], and aerial/ground surveys[1,3/], Adult Anadromous Investigations, Su Hydro Studies, 1982.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Bunco Creek								
	1973	8/02	34					
	1976	7/23	112					
	1977		136					
Bunco Lake								
	Before 1970							Good escapement of pinks in 1964
Byers Creek	Before 1970							Few chinook, 1,200 sockeye (1964), good pink escapement (1964)
	1971	8/29	2					
	1971	9/08			35	1,100		
	1972	7/30	7					
	1973	7/26	1					
	1973	9/26			49			
	1974	7/25	0	0	0	0	0	
	1976	7/23	53					
	1976	8/23		50			39	
	1977		69					Peak survey count
	1977	8/04	1					
	1977	8/05	2	300				
	1977	8/10		200				
	1977	8/16		100				
	1977	9/12		6	314			
	1979	10/29		1,000	500	0		Cook Inlet Aquaculture Ass'n (CIAA)
Byers Lake	1977			300				Peak survey count
	1981	8/27		275	100		200	
Chulitna River, East Fork	Before 1970							Chinook present, max. count sockeye 500 (1964)
	1973		42					
	1973	8/02	41					
	1974	7/25	41					
	1975	8/04	7					
	1976	7/23	112					
	1977		168					
	1978		59					
Chulitna River, Mainstream	Before 1970							Chinook, coho, pinks and chinook present (1958)
	1976	7/23	124					
	1977		229					
	1978		62					
	Personal Comm.							Larry Engel, ADF&G Div. of Sport Fish (L.E., SF) Max. abundance estimate from several years observations

1/ Courtesy of Alaska Department of Fish and Game Div. of Commercial Fisheries, Div. of Sport Fish, and Fisheries Rehabilitation and Enhancement Div. (FRED), and Cook Inlet Aquaculture Association (CIAA).

2/ Mills, Michael J. 1980. Statewide Harvest Study - 1979 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1B
Mills, Michael J. 1980. Statewide Harvest Study -1980 Data. Alaska Department of Fish and Game Div. of Sport Fish, Federal Aid Report, Vol. 22 Study SW-1C.

3/ All entries are aerial or ground stream survey data, unless otherwise designated.

Appendix Table EE-4. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
Chulitna River, Middle Fork	1973		219					
	1973	8/02	206					
	1974	7/25	159					
	1974	8/04	55					
	1976	7/23	1,870					
	1977		1,782					
	1978		900					
Coal Creek	Before 1970							Chinook, pinks present
	1976	8/17	0	0	0	0	0	
	1976	8/26	0	0	0	0	0	
	1976	9/14	0	0	0	0	0	
Honolulu Creek	1973	7/26	17					
	1973	7/29	8					
	1974	7/25	12					
	1976	7/23	24					
	1977		36					
Parker Creek	Before 1970							Max. count 200 sockeye (1965)
Slim Creek	Before 1970							Max. count 150 sockeye (1954)
	1970	8/24		516				
	1972	8/25		63				
	1973	8/22	0	0	0	0	0	
	1973	9/05		53				
	1973	9/18		168				
	1973			195				Peak survey count
	1974	8/24	0	0	0	0	0	
	1974	9/06		83				
	1974	9/17		195				
	1975			176				Peak survey count
	1975	9/25		50				
	1975	8/30		50				
	1975	9/26		75				
	1976	8/24		69				
	1976	9/08		64				
	1977	8/24		755	3			
	1977	9/12-9/13		739				
	1978			263				Peak survey count
	1979	8/28		40				
Spink Creek	Before 1970							Max. count 60 chinook (1958)
Swan Lake	Before 1970							Max. count 150 sockeye (1954)
	1975	8/22		229				
	1975	8/30		239				
	1975	9/25		90				
	1978	8/25-8/26		734				
	1978	9/14		263				
	1978	9/21-9/22		234				
	1980	8/18		1				
	1981	8/25		350				

Appendix Table EE-4. Continued.

Area	Year	Date	Chinook	Sockeye	Coho	Chum	Pink	Comments
T-Creek	Before 1970							Max. count 400 sockeye (1954)
	1972	8/26		182				
	1972			239				Peak survey count
	1973	8/22		35				
	1973	9/05		88				
	1973	9/18		78				
	1973			115				Peak survey count
	1974	8/24		176				
	1974	9/05		163				
	1974	9/17		82				
	1974			191				Peak survey count
	1975	8/22		229				
	1975	8/30		223				
	1975			289				Peak survey count
	1976	8/24		447				
	1976	9/08		39	50			
	1977			745		Present	Present	Peak survey count
Tokositna River	Before 1970							Max. count 97 sockeye (1954)
	1981			Present	Present			
Troublesome Creek	Before 1970							Max. count 100 chinook (1958)
	1971	7/21	5					
	1971	7/27	5					
	1971	9/08	5			70		
	1972	7/30	5					
	1972	8/26		182				
	1973	7/26	7					
	1973	9/05		141				
	1973	9/26			5			
	1974	7/25	0	0	0	0	0	
	1976	7/23	92					
	1977		95					
	1979	10/29				100		CIAA

ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION; REFERENCE TO COMMENT(S): I. 75

Attachment Table 1. Summary of preliminary plans for FY84 Aquatic Studies Program activities by habitat type and river mile.

This table, prepared by Aquatic Habitat and Instream Flow personnel, presents the various study programs conducted by project personnel at FY84 study sites. Study sites are presented in order of ascending river mile by habitat catagory.

TABLE LEGEND

AH = Aquatic Habitat Investigations

- FHS = Fish Habitat Studies
- A = Availability data
- U = Utilization data
- M = Modelling A+U (IFG type)
- X = Cross Section
- I = Incubation
- V = Vibert Boxes
- Th = Thalweg

IFE = Instream Flow Evaluations

- S = Staff gage
- Q = Discharge
- T = Ryan (TRM)
- DIS = Datapod intragravel & surface temp.
- DST = Datapod stage and temp.
- DG = Datapod dissolved gas.
- WQ = Water Quality
- X = Cross Section

RJ = Resident Juvenile Investigations

- JH = Juvenile Habitat Study
  - IFG -4 Model
  - Habitat Model
  - WSP Model
- JP = Juvenile Preference Sites
- JC = Coded Wire Tag
- RT = Radio Telemetrs Tagging Site
- RH = Resident Fish Habitat Study
- RP = Resident Fish Population Estimate
- EF = Electrofishing Site
- JV = Juvenile Vibert Box Study

AA = Adult Anadromous Investigations

- SS = Stream Survey
- E = Escapement Estimate (Petersen)
- SO = Escapement Estimate (Sonar)
- Ma = Fish use maping

USGS & RM Investigations

- St = Stage Recorder - RM
- Qu = Discharge - USGS
- Qr = Discharge - RM

* Tributary River Mile

** Tributaries to the Chulitna River RM corresponds to Susitna River/ Talkeetna River confluence

Attachment Table 1: Continued

STUDY SITE	RIVER MILE	AH FHS	AH IFE	RJ	AA	USGS R & M
Slough						
Rabideaux Cr. Slough	83.1			ES		
Slough 1	99.6			ES	SS,EG	
Slough 2	100.2					
Whiskers Creek Slough	101.2	Th	S,Q,WQ,X	JH,RH,ES,JP	SS,Ma,EG	
Slough 3B	101.4			JP	SS,EG	
Slough 3A	101.9				SS,EG	
Slough 4	105.2				SS,EG	
Slough 5	107.6			JH,JP	SS,EG	
Slough 6	108.2				SS,EG	
Slough 6A	112.3	Th	S,Q,WQ,X	JH,RH,ES,JP	SS,Ma,EG	
Slough 7	113.2				SS,EG	
Slough 8	113.7		S,Q,WQ,X	JH,JP	SS,Ma,EG	
Slough 8D	121.8				SS,Ma,EG	
Slough 8C	121.9				SS,Ma,EG	
Slough 8B	122.2				SS,Ma,EG	
Moose Slough	123.5			RT,ES	SS,Ma,EG	
Slough A'	124.6			ES	SS,EG	
Slough A	124.7				SS,EG	
Slough 8A	125.1	M,I	DIS,S,Q,WQ,X	RP,JH,JC,RT,ES,JP	SS,Ma,EG	St
Slough B	126.3				SS,Ma,EG	
Slough 9	128.3	M,I	DIS,S,Q,WQ,X	JH,JC,JP	SS,Ma,EG	St
Slough 9B	129.2				SS,EG	
Slough 9A	133.8				SS,Ma,EG	
Slough 10	133.8	M,I,V,Th		JP	SS,Ma,EG	
Slough 11	135.3	I,V,U,X	T,S,Q	JC,JH,JP	SS,Ma,EG	
Slough 12	135.4				SS,EG	
Slough 13	135.9				SS,EG	
Slough 14	135.9				SS,EG	
Slough 15	137.2			ES	SS,Ma,EG	
Slough 16B	137.3	Th		ES	SS,EG	
Slough 17	138.9				SS,Ma,EG	
Slough 18	139.1				SS,EG	
Slough 19	139.7		T,S,Q,WQ,X	ES,JP	SS,Ma,EG	
Slough 20	140.0	X,Th	S,Q,WQ,X	JP,RH	SS,Ma,EG	
Slough 21	141.1	M,I,V	T,S,Q,WQ,X	JC,JH,ES,JP	SS,Ma,EG	
Slough 21A	144.3				SS,EG	
Slough 22	144.3	Th	S,Q	JH,JP	SS,EG	
Tributary						
Yentna River	30.1		T(4.0)*		E(4.0)*	
Answer Creek	84.1				SS	
Question Creek	84.1				SS	
Birch Creek	88.4				SS	
Fish Creek	97.2				SS	
Talkeetna River	97.2		T(1.5)*,WQ		SS	

Attachment Table 1: Continued.

STUDY SITE	RIVER MILE	AH FHS	AH IFE	RJ	AA	USGS R & M
Byers Creek **	98.6				SS	
Troublesome Creek **	98.6				SS	
Swan Lake **	98.6				SS	
Chulitna River	98.6		T(0.6)*,WQ		SS	
Whiskers Creek	101.4		S,Q	RT,JP,ES	SS	
Chase Creek	106.4			JP,ES	SS	
Slash Creek	111.5				SS	
Gash Creek	111.6				SS	
Lane Creek	113.6	U	S,Q	JV,RT,JP,RH,ES	SS	
Lower McKenzie Cr.	116.2			JP	SS	
Upper MeKenzie Cr.				JP		
McKenzie Creek	116.7				SS	
Little Portage Cr.	117.7				SS	
Dead Horse Creek	120.9			ES	SS	
Fifth of July Creek	123.7				SS	
Skull Creek	124.7			RT,ES	SS	
Sherman Creek	130.8			ES	SS	
Fourth of July Cr.	131.1	U,I,V	S,Q	RS,RT,JP,RH	SS	
Gold Creek	136.7		S,DST,Q		SS	
Indian River	138.6	U	S,DST,Q	ES,RT,JP,JV,RH	SS	
Indian River Hello	10.1*			JP		
Jack Long Creek	144.5			RP,ES,RT,JP,RH	SS	
Portage Creek	148.9	U	S,DST,Q	ES,RT,JP,RH,RP	SS	
Portage Creek Helio	4.2*			JP	SS	
Portage Creek Helio	8.0*			JP	SS	
Portage Creek Helio	10.2*			JP	SS	
Cheechako Creek	152.4				SS	
Chinook Creek	157.0				SS	
Devil Creek	161.0				SS	
Fog Creek	176.7					
Tsusena Creek	181.3		T(0.1)*	RT		
Deadman Creek	186.7		T(0.1)*			
Watana Creek	194.1		T(0.1)*			
Kosina Creek	206.8		T(0.1)*			
Jay Creek	208.5					
Goose Creek	231.3		T(0.1)*			
Oshetna River	233.4		T(0.1)*			
Tributary Mouth						
Portage Creek	148.8			JP		
Lane Creek	113.6	A,U	S	JP		
Fourth of July Cr.	131.1	A,U	S	JP		
Indian River	138.6			JP		
Whiskers Creek	101.4			JP		

Attachment Table 1: Continued.

STUDY SITE	RIVER MILE	AH FHS	AH IFE	RJ	AA	USGS R & M
Mainstem						
Flathorn MS	18.2		T			
MS at Susitna Sta.	25.5		T			
MS above Deshka	40.9		T			
Sunshine Station	80.0				E,SO	
MS at Parks Hwy. Br.	83.9		T,WQ			
MS at Whiskers Creek Slough mouth	101.2		S			
MS at Whiskers Creek Slough head	101.5		S	JP		
Mainstem below Talk. Camp	102.5			ES		
Talkeetna Station	103.0		S,T,WQ	JC	E,SO	
LRX 9	103.2		T			
LRX 10.2	105.9		S			
LRX 10.3	106.4		S			
LRX 11	106.7		S			
LRX 12	108.4		S			
Oxbow I	110.2			JP		
LRX 16	112.4		S			
MS above Slough 6A	112.3			JP		
LRX 18	113.0		S			
MS below Lane Cr. Mo.	113.4		S			
MS above Lane Cr. Mo.	113.7		S			
MS above Mainstem II NW Side Channel	115.6		S			
MS above Mainstem II NE Side Channel	115.9		S			
Mainstem - Curry	119.5			ES		
Curry Station	120.0		T		E,SO	
LRX 24	120.7		S,WQ			
LRX 28	124.4		S			
LRX 29	126.1		S,T,WQ			
MS above Slough 8A	127.2		S			
LRX 31	128.7		S			
LRX 32	129.8		S			
LRX 33	130.1		S			

Attachment Table 1: Continued

STUDY SITE	RIVER MILE	AH: FHS	AH: IFE	RJ	AA	USGS R & M
LRX 34	130.6		S			
LRX 35	130.9		S			
MS at Fourth of July Creek	131.1		S	JP		
LRX 37	131.8		S			
LRX 40	134.3		S	—		
Side Channel below Mouth of Sl. 11	135.3		S	JP,JH		
Side Channel above Mouth of Sl. 11	135.3		S	JP,JH		
Cliff below Gold Cr. Creek Bridge	135.8		DG,T			Qu
LRX 44 Side Channel Slough 11	136.5		S			
Gold Creek Bridge	136.7		S,T			
MS above Gold Creek	136.8		T,WQ			
MS at mouth of Slough 16B	137.9		S			
MS at head of Slough 16B	138.3		S			
LRX 49	138.3		S	RH,ES		
LRX 50	138.5		S			
LRX 51	138.9		S			
MS at Slough 19	139.8		S			
LRX 53	140.1		S			
MS at mouth of Slough 21 Side Channel	140.6		S			
LRX 54	140.8		S			
LRX 55	141.5		S			
LRX 56	142.1		S	ES		
LRX 57	142.3		S,T,WQ			
MS at Slough 22 head	144.7		S			
Fat Canoe Island	147.0			RT,ES,RP,RH		
LRX 61	148.7		S			
LRX 62	148.9		S			
Canyon Back Eddy	150.0		T	RT,ES		
MS above Tsusena Cr.	181.5		T			
MS above Oshetna R.	234.4		T			
<u>Side Channels</u>						
Mainstem II	114.4	Th	S,Q,WQ,T	JP		
Slough 10 Side Ch.	133.7	M,Th	S,Q,W,QT	JP,JH		
Above Slough 11	136.1	M,Th	T,S,Q	JP,JH		C
Below Slough 11	135.3	X	S	JP JH		
Slough 21 Side Ch.	140.5	M,Th	S,Q,WQ,T	JP		
Side Channel 10A	132.1			JH		
Oxbow One	110.2			JP		
Side Channel	117.8			JP		
Curry				JP		

DEPARTMENT OF THE ARMY
ALASKA DISTRICT, CORPS OF ENGINEERS
POUCH 898
ANCHORAGE, ALASKA 99506

November 9, 1983

REPLY TO
ATTENTION OF:
Regulatory Functions Branch
Permit Processing Section

Mr. Raymond Benish
Alaska Power Authority
334 West 5th Avenue, Second Floor
Anchorage, Alaska 99501

Dear Mr. Benish:

Enclosed is the signed Department of the Army permit, file number 071-OYD-4-830374, Susitna River 9 authorizing the placement of fill material in wetlands to construct an airstrip in Matanuska-Susitna Borough, Alaska. Also, enclosed is a Notice of Authorization which should be posted in a prominent location near the authorized work.

If changes in the location or plans of the work are necessary for any reason, plans should be submitted to this office promptly. If the changes are unobjectionable, the approval required by law before construction is begun will be issued without delay.

Sincerely,

David B. Barrows
Chief, Regulatory Functions Branch

Enclosures

The following Special Conditions will be applicable when appropriate:

STRUCTURES IN OR AFFECTING NAVIGABLE WATERS OF THE UNITED STATES:

a. That this permit does not authorize the interference with any existing or proposed Federal project and that the permittee shall not be entitled to compensation for damage or injury to the structures or work authorized herein which may be caused by or result from existing or future operations undertaken by the United States in the public interest.

b. That no attempt shall be made by the permittee to prevent the full and free use by the public of all navigable waters at or adjacent to the activity authorized by this permit.

c. That if the display of lights and signals on any structure or work authorized herein is not otherwise provided for by law, such lights and signals as may be prescribed by the United States Coast Guard shall be installed and maintained by and at the expense of the permittee.

d. That the permittee, upon receipt of a notice of revocation of this permit or upon its expiration before completion of the authorized structure or work, shall, without expense to the United States and in such time and manner as the Secretary of the Army or his authorized representative may direct, restore the waterway to its former conditions. If the permittee fails to comply with the direction of the Secretary of the Army or his authorized representative, the Secretary or his designee may restore the waterway to its former condition, by contract or otherwise, and recover the cost thereof from the permittee.

e. Structures for Small Boats: That permittee hereby recognizes the possibility that the structure permitted herein may be subject to damage by wave wash from passing vessels. The issuance of this permit does not relieve the permittee from taking all proper steps to insure the integrity of the structure permitted herein and the safety of boats moored thereto from damage by wave wash and the permittee shall not hold the United States liable for any such damage.

MAINTENANCE DREDGING:

a. That when the work authorized herein includes periodic maintenance dredging, it may be performed under this permit for ______________________ years from the date of issuance of this permit (*ten years unless otherwise indicated*);

b. That the permittee will advise the District Engineer in writing at least two weeks before he intends to undertake any maintenance dredging.

DISCHARGES OF DREDGED OR FILL MATERIAL INTO WATERS OF THE UNITED STATES:

a. That the discharge will be carried out in conformity with the goals and objectives of the EPA Guidelines established pursuant to Section 404(b) of the Clean Water Act and published in 40 CFR 230;

b. That the discharge will consist of suitable material free from toxic pollutants in toxic amounts.

c. That the fill created by the discharge will be properly maintained to prevent erosion and other non-point sources of pollution.

DISPOSAL OF DREDGED MATERIAL INTO OCEAN WATERS:

a. That the disposal will be carried out in conformity with the goals, objectives, and requirements of the EPA criteria established pursuant to Section 102 of the Marine Protection, Research and Sanctuaries Act of 1972, published in 40 CFR 220-228.

b. That the permittee shall place a copy of this permit in a conspicuous place in the vessel to be used for the transportation and/or disposal of the dredged material as authorized herein.

This permit shall become effective on the date of the District Engineer's signature.

Permittee hereby accepts and agrees to comply with the terms and conditions of this permit.

[signature] (Acting Exec Dir.)　　　　11-1-1983

PERMITTEE & TITLE　　　　DATE

BY AUTHORITY OF THE SECRETARY OF THE ARMY:

______________________________　　　　______________

David B. Barrows　　　　DATE

Chief, Regulatory Functions Branch

FOR: DISTRICT ENGINEER,

U.S. ARMY, CORPS OF ENGINEERS　Colonel Neil E. Saling

Transferee hereby agrees to comply with the terms and conditions of this permit.

______________________________　　　　______________

TRANSFEREE　　　　DATE

U.S. GOVERNMENT PRINTING OFFICE : 1983 O - 431-536

s. That there shall be no unreasonable interference with navigation by the existence or use of the activity authorized herein.

t. That this permit may not be transferred to a third party without prior written notice to the District Engineer, either by the transferee's written agreement to comply with all terms and conditions of this permit or by the transferree subscribing to this permit in the space provided below and thereby agreeing to comply with all terms and conditions of this permit. In addition, if the permittee transfers the interests authorized herein by conveyance of realty, the deed shall reference this permit and the terms and conditions specified herein and this permit shall be recorded along with the deed with the Register of Deeds or other appropriate official.

u. That if the permittee during prosecution of the work authorized herein, encounters a previously unidentified archeological or other cultural resource within the area subject to Department of the Army jurisdiction that might be eligible for listing in the National Register of Historic Places, he shall immediately notify the district engineer.

II. Special Conditions: *(Here list conditions relating specifically to the proposed structure or work authorized by this permit)*:

071-OYD-4-830374

Application No.

Name of Applicant Alaska Power Authority

Effective Date NOV 9 1983

Expiration Date (*If applicable*)

File No. Susitna River 9

DEPARTMENT OF THE ARMY PERMIT

Referring to written request dated July 5, 1983 for a permit to:

( ) Perform work in or affecting navigable waters of the United States, upon the recommendation of the Chief of Engineers, pursuant to Section 10 of the Rivers and Harbors Act of March 3, 1899 (*33 U.S.C. 403*);

(X) Discharge dredged or fill material into waters of the United States upon the issuance of a permit from the Secretary of the Army acting through the Chief of Engineers pursuant to Section 404 of the Clean Water Act (*33 U.S.C. 1344*);

( ) Transport dredged material for the purpose of dumping it into ocean waters upon the issuance of a permit from the Secretary of the Army acting through the Chief of Engineers pursuant to Section 103 of the Marine Protection, Research and Sanctuaries Act of 1972 (*86 Stat. 1052; P.L. 92-532*);

Alaska Power Authority
334 West 5th Avenue, 2nd Floor
Anchorage, Alaska 99501

is hereby authorized by the Secretary of the Army:

to place approximately 4,620 cubic yards (cy) of fill material by grading within the project area to construct an airstrip. Approximately 2 feet of peat will be removed and stockpiled along the edge of the runway. The dimensions of the runway will be approximately 2,500' long and 50' wide.

in wetlands adjacent to the Susitna River, sections 27 and 28, T. 32 N., R. 5 E., S.M.

at Matanuska-Susitna Borough, Alaska

in accordance with the plans and drawings attached hereto which are incorporated in and made a part of this permit (*on drawings, give file number or other definite identification marks.*)

"PROPOSED: WATANA AIRSTRIP; SUSITNA HYDROELECTRIC PROJECT; IN: WETLANDS ADJACENT TO THE SUSITNA RIVER; AT: MATANUSKA-SUSITNA BOROUGH, ALASKA; APPLICATION SUBMITTED BY: ALASKA POWER AUTHORITY; DATED: JULY 1983; 1 SHEET"

subject to the following conditions:

I. General Conditions:

a. That all activities identified and authorized herein shall be consistent with the terms and conditions of this permit; and that any activities not specifically identified and authorized herein shall constitute a violation of the terms and conditions of this permit which may result in the modification, suspension or revocation of this permit, in whole or in part, as set forth more specifically in General Conditions j or k hereto, and in the institution of such legal proceedings as the United States Government may consider appropriate, whether or not this permit has been previously modified, suspended or revoked in whole or in part.

ENG FORM 1721, Sep 82 EDITION OF 1 JUL 77 IS OBSOLETE (ER 1145-2-303)

b. That all activities authorized herein shall, if they involve, during their construction or operation, any discharge of pollutants into waters of the United States or ocean waters, be at all times consistent with applicable water quality standards, effluent limitations and standards of performance, prohibitions, pretreatment standards and management practices established pursuant to the Clean Water Act (*33 U.S.C. 1344*), the Marine Protection, Research and Sanctuaries Act of 1972 (*P.L. 92-532, 86 Stat. 1052*), or pursuant to applicable State and local law.

c. That when the activity authorized herein involves a discharge during its construction or operation, or any pollutant (*including dredged or fill material*), into waters of the United States, the authorized activity shall, if applicable water quality standards are revised or modified during the term of this permit, be modified, if necessary, to conform with such revised or modified water quality standards within 6 months of the effective date of any revision or modification of water quality standards, or as directed by an implementation plan contained in such revised or modified standards, or within such longer period of time as the District Engineer, in consultation with the Regional Administrator of the Environmental Protection Agency, may determine to be reasonable under the circumstances.

d. That the discharge will not destroy a threatened or endangered species as identified under the Endangered Species Act, or endanger the critical habitat of such species.

e. That the permittee agrees to make every reasonable effort to prosecute the construction or operation of the work authorized herein in a manner so as to minimize any adverse impact on fish, wildlife, and natural environmental values.

f. That the permittee agrees that he will prosecute the construction or work authorized herein in a manner so as to minimize any degradation of water quality.

g. That the permittee shall allow the District Engineer or his authorized representative(s) or designee(s) to make periodic inspections at any time deemed necessary in order to assure that the activity being performed under authority of this permit is in accordance with the terms and conditions prescribed herein.

h. That the permittee shall maintain the structure or work authorized herein in good condition and in reasonable accordance with the plans and drawings attached hereto.

i. That this permit does not convey any property rights, either in real estate or material, or any exclusive privileges; and that it does not authorize any injury to property or invasion of rights or any infringement of Federal, State, or local laws or regulations.

j. That this permit does not obviate the requirement to obtain state or local assent required by law for the activity authorized herein.

k. That this permit may be either modified, suspended or revoked in whole or in part pursuant to the policies and procedures of 33 CFR 325.7.

l. That in issuing this permit, the Government has relied on the information and data which the permittee has provided in connection with his permit application. If, subsequent to the issuance of this permit, such information and data prove to be materially false, materially incomplete or inaccurate, this permit may be modified, suspended or revoked, in whole or in part, and/or the Government may, in addition, institute appropriate legal proceedings.

m. That any modification, suspension, or revocation of this permit shall not be the basis for any claim for damages against the United States.

n. That the permittee shall notify the District Engineer at what time the activity authorized herein will be commenced, as far in advance of the time of commencement as the District Engineer may specify, and of any suspension of work, if for a period of more than one week, resumption of work and its completion.

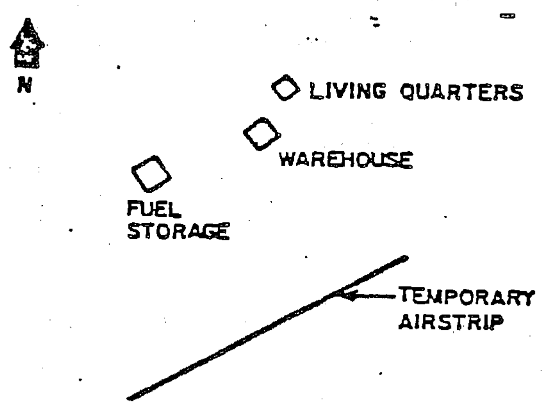
o. That if the activity authorized herein is not completed on or before ________ day of ________ , 19 ________ , (*three years from the date of issuance of this permit unless otherwise specified*) this permit, if not previously revoked or specifically extended, shall automatically expire.

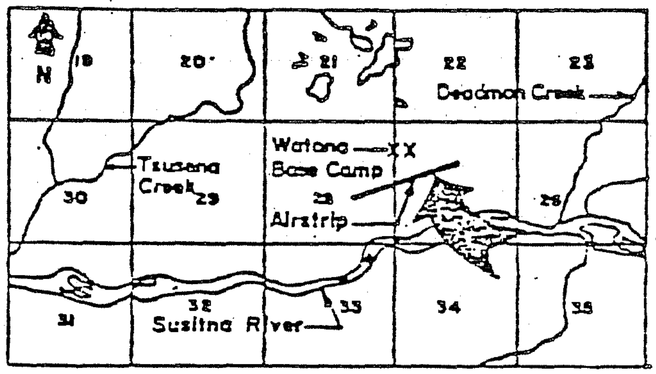
p. That this permit does not authorize or approve the construction of particular structures, the authorization or approval of which may require authorization by the Congress or other agencies of the Federal Government.

q. That if and when the permittee desires to abandon the activity authorized herein, unless such abandonment is part of a transfer procedure by which the permittee is transferring his interests herein to a third party pursuant to General Condition t hereof, he must restore the area to a condition satisfactory to the District Engineer.

r. That if the recording of this permit is possible under applicable State or local law, the permittee shall take such action as may be necessary to record this permit with the Register of Deeds or other appropriate official charged with the responsibility for maintaining records of title to and interests in real property.

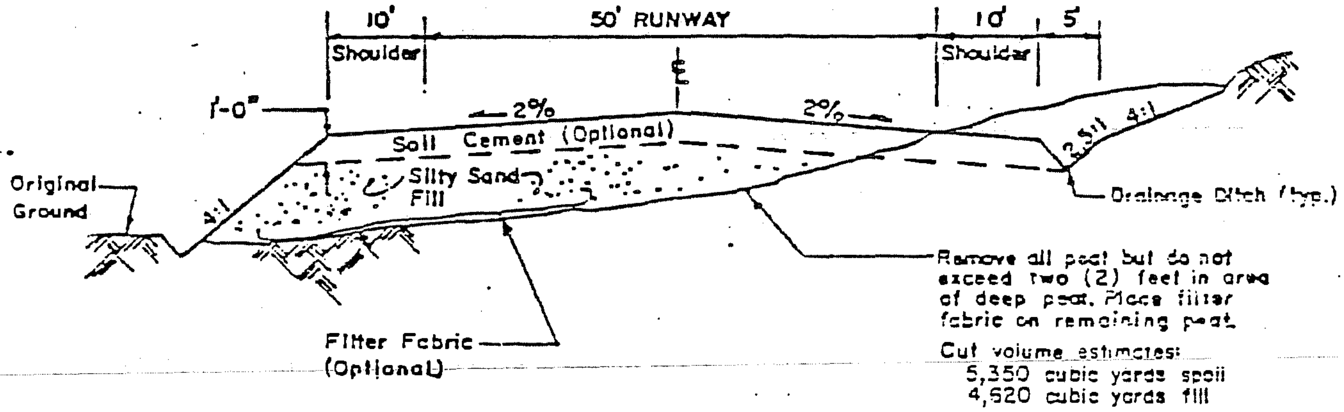
Frank Moolin & Associates, Inc.





VICINITY MAP: Talkeetna Mts. USGS Quad D-3 & D-4
T 32N, R5E, Seward Meridian
N.T.S.

LOCATION MAP
WATANA BASE CAMP
N.T.S.



TYPICAL RUNWAY SECTION
N.T.S.

NOTES:

1. Temporary airstrip will be 2500 feet long with a centerline grade as close to 2% as possible.
2. A minimum of two feet of peat will be removed and stockpiled along the edge of the runway for use during restoration upon airstrip closure.
3. Materials during construction will balance out and no additional borrow material is required. Filter fabric will be used as required.
4. Natural drainage is toward Tsusena Creek located over a mile to the west.
5. Watana Base Camp is located just north of the proposed site.
6. Construction is proposed for August 1983.

LAND OWNERSHIP:

1. Section 27, T32N, R5E, S.M. is owned by Knikatnu, Inc., Box 2130, Wasilla, Alaska 99645.
2. Section 28, T32N, R5E, S.M. is held in interim conveyance for Knikatnu, Inc., by Cook Inlet Region, Inc., 2525 C Street, Anchorage, Alaska 99503.

SUSITNA
RIVER 9

PROPOSED WATANA AIRSTRIP
SUSITNA HYDROELECTRIC PROJECT

Submitted by
ALASKA POWER AUTHORITY

STATE OF ALASKA

DEPARTMENT OF ENVIRONMENTAL CONSERVATION

CERTIFICATE OF REASONABLE ASSURANCE

A Certificate of Reasonable Assurance, as required by Section 401 of the Clean Water Act, has been requested by the Alaska Power Authority, 334 West 5th Avenue, 2nd Floor, Anchorage, Alaska 99501, for the construction of a 2,500' long, 50' wide airstrip within a wetland. Approximately 2' of peat [5,350 cubic yards (cy)] will be removed and stockpiled along the edge of the runway to be used during rehabilitation of the area after the project use. Approximately 4,620 cy of fill material will placed by grading within the project area. No additional fill material will be brought to the site. Filter fabric will be used as required to stabilize the foundation and facilitate drainage. No refueling facilities or structures will be erected.

The proposed activity is located in Sections 27 and 28, T32N, R5E, Seward Meridian, adjacent to the Susitna Hydroelectric Project Watana Base Camp near Talkeetna, Alaska.

Public notice of the application for this certification has been made in accordance with 18 AAC 15.180.

Water Quality Certification is required for the proposed activity because the activity will be authorized by a Corps of Engineers permit identified as Susitna River 9, NPACO No. 071-OYD-4-830374, and a discharge may result from the proposed activity.

Having reviewed the application and comments received in response to the public notice, the Alaska Department of Environmental Conservation certifies that there is reasonable assurance that the proposed activity, as well as any discharge which may result, is in compliance with the requirements of Section 401 of the Clean Water Act which includes the Alaska Water Quality Standards, 18 AAC 70, and the Standards of the Alaska Coastal Management Program, 6 AAC 80, provided that:

1) If any petroleum products are stored on the site or if the site is used as a fueling facility, materials such as sorbent pads must be available on-site to contain and cleanup any spilled fuel. This stipulation is necessary to protect against the destruction of important habitat by the accidental discharge of a toxic material. (6 AAC 80.130 Habitat).

Oct. 7, 1983
Date

Bob Martin
Bob Martin
Regional Supervisor

STATE OF ALASKA

DIVISION OF GOVERNMENTAL COORDINATION

CONSISTENCY DETERMINATION WITH THE

ALASKA COASTAL MANAGEMENT PROGRAM

A determination of consistency with the Alaska Coastal Management Program, as required by 6 AAC 80, has been requested by the Alaska Power Authority, 334 West Fifth Avenue, Second Floor, Anchorage, Alaska 99501. The applicant proposes to construct an airstrip by grading onsite material. Approximately 2' of peat [5,350 cubic yards (cy)] would be removed and stockpiled along the edge of the runway to be used during rehabilitation of the area after the project use. Approximately 4,620 cy of fill materials would be placed by grading within the project area. No additional fill material would be brought to the site. A filter fabric would be used as required to stabilize the foundation and facilitate drainage. The airstrip would be approximately 2,500' long, and 50' wide, with 2-foot-wide shoulders and a centerline grade close to 2% to utilize natural topography and would support field activities and collection of data during the Watana Dam Detailed Design Phase of the Susitna Hydroelectric Project. The proposed activity is located at T. 32 N., R. 5 E., S.M., Section 27 and 28 near the Susitna River, Alaska.

This proposed activity, identified as Susitna River 9 (State I.D. No. AK830824-56; COE No. 071-OYD-4-830374), requires an authorization from the U.S. Army Corps of Engineers and is therefore subject to review for consistency with the Alaska Coastal Management Program, in accordance with Section 307(c)(3)(A) of the Federal Coastal Zone Management Act.

Having reviewed the application, the Division of Governmental Coordination determines that the proposed activity is consistent with the Guidelines and Standards of the ACMP, 6 AAC 80, provided that the applicant complies with the following stipulation(s):

> If any petroleum products are stored at the site or if the facility is used as a fueling facility, materials such as sorbent pads shall be available on-site to contain and cleanup spilled fuel. (This

stipulation is intended to protect water quality by preventing discharge of toxic substances in water sources.) 6 AAC 80.140 AIR, LAND, AND WATER QUALITY

Adherence to the above stipulation(s) will ensure that this project will be consistent with the ACMP standard(s) 6 AAC 80.140 AIR, LAND, AND WATER QUALITY as follows:

6 AAC 80.140. AIR, LAND, AND WATER QUALITY. Notwithstanding any other provision of this chapter, the statutes pertaining to and the regulations and procedures of the Alaska Department of Environmental Conservation with respect to the protection of air, land, and water quality are incorporated into the Alaska coastal management program and, as administered by that agency, constitute the components of the coastal management program with respect to those purposes.

Authority: AS 44.19.893
AS 46.40.040

Public Law 88-29
88th Congress, S.20
May 28, 1963

An Act

To promote the coordination and development of effective programs relating to outdoor recreation, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Congress finds and declares it to be desirable that all American people of present and future generations be assured adequate outdoor recreation resources, and that it is desirable for all levels of government and private interests to take prompt and coordinated action to the extent practicable without diminishing or affecting their respective powers and functions to conserve, develop, and utilize such resources for the benefit and enjoyment of the American people.

Recreation programs. Coordination & development.

SEC. 2. In order to carry out the purposes of this Act, the Secretary of the Interior is authorized to perform the following functions and activities:

Functions and activities.

(a) INVENTORY.—Prepare and maintain a continuing inventory and evaluation of outdoor recreation needs and resources of the United States.

(b) CLASSIFICATION.—Prepare a system for classification of outdoor recreation resources to assist in the effective and beneficial use and management of such resources.

(c) NATIONWIDE PLAN.—Formulate and maintain a comprehensive nationwide outdoor recreation plan, taking into consideration the plans of the various Federal agencies, States, and their political subdivisions. The plan shall set forth the needs and demands of the public for outdoor recreation and the current and foreseeable availability in the future of outdoor recreation resources to meet those needs. The plan shall identify critical outdoor recreation problems, recommend solutions, and recommend desirable actions to be taken at each level of government and by private interests. The Secretary shall transmit the initial plan, which shall be prepared as soon as practicable within five years hereafter, to the President for transmittal to the Congress. Future revisions of the plan shall be similarly transmitted at succeeding five-year intervals. When a plan or revision is transmitted to the Congress, the Secretary shall transmit copies to the Governors of the several States.

(d) TECHNICAL ASSISTANCE.—Provide technical assistance and advice to and cooperate with States, political subdivisions, and private interests, including nonprofit organizations, with respect to outdoor recreation.

(e) REGIONAL COOPERATION.—Encourage interstate and regional cooperation in the planning, acquisition, and development of outdoor recreation resources.

77 STAT. 49.
77 STAT. 50.

(f) RESEARCH AND EDUCATION.—(1) Sponsor, engage in, and assist in research relating to outdoor recreation, directly or by contract or cooperative agreements, and make payments for such purposes without regard to the limitations of section 3648 of the Revised Statutes (31 U.S.C. 529) concerning advances of funds when he considers such action in the public interest, (2) undertake studies and assemble information concerning outdoor recreation, directly or by contract or cooperative agreement, and disseminate such information without regard to the provisions of section 4154, title 39, United States Code, and (3) cooperate with educational institutions and others in order to assist in establishing education programs and activities and to encourage public use and benefits from outdoor recreation.

74 Stat. 661.

77 STAT. 50.

(g) INTERDEPARTMENTAL COOPERATION.—(1) Cooperate with and provide technical assistance to Federal departments and agencies and obtain from them information, data, reports, advice, and assistance that are needed and can reasonably be furnished in carrying out the purposes of this Act, and (2) promote coordination of Federal plans and activities generally relating to outdoor recreation. Any department or agency furnishing advice or assistance hereunder may expend its own funds for such purposes, with or without reimbursement, as may be agreed to by that agency.

(h) DONATIONS.—Accept and use donations of money, property, personal services, or facilities for the purposes of this Act.

SEC. 3. In order further to carry out the policy declared in section 1 of this Act, the heads of Federal departments and independent agencies having administrative responsibility over activities or resources the conduct or use of which is pertinent to fulfillment of that policy shall, either individually or as a group, (a) consult with and be consulted by the Secretary from time to time both with respect to their conduct of those activities and their use of those resources and with respect to the activities which the Secretary of the Interior carries on under authority of this Act which are pertinent to their work, and (b) carry out such responsibilities in general conformance with the nationwide plan authorized under section 2(c) of this Act.

Definitions.

SEC. 4. As used in this Act, the term "United States" shall include the District of Columbia and the terms "United States" and "States" may, to the extent practicable, include the Commonwealth of Puerto Rico, the Virgin Islands, Guam, and American Samoa.

Approved May 28, 1963, 10:13 a.m.

LEGISLATIVE HISTORY:

HOUSE REPORTS: No. 150 accompanying H. R. 1762 (Interior and Insular Affairs Comm.); 303 (Conference Comm.).
SENATE REPORT No. 11 (Interior and Insular Affairs Comm.).
CONGRESSIONAL RECORD, Vol. 109:
Mar. 7, 8, 1963: Considered in Senate.
Mar. 11, 1963: Considered and passed Senate.
Apr. 29, 1963: Considered and passed House amended (in lieu of H. R. 1762).
May 1, 1963: Senate disagrees to House amendments and requests conference.
May 15, 1963: Conference report agreed to in House.
May 15, 1963: Conference report agreed to in Senate.

GPO 85139

ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION; REFERENCE TO COMMENT(S): I. 105

(Foz Do Areia) NEIDERT OTA Feb. 1982

Aeration at high velocity flows

(Parts 1&2)

By N. L. de S. Pinto*, S. H. Neidert and J. J. Ota

PART ONE

The results of laboratory and prototype experiments on aeration at high velocity flows are presented. The research relates to the spillway of the 160 m-high Foz do Areia dam in Brazil, which has now been operating for about 18 months. The air discharge entrained by the various flow conditions was measured on the prototype, and model studies were made before and after this to compare results, and to optimize the design of the structure.

SPILLWAY CHUTES under high velocity flows may be subjected to cavitation damage even when the chute surface is essentially smooth and the flow of water apparently uniform. Cavitation occurrence seems to be correlated not only to high velocities, but to discharge concentration as well.

For high specific discharges, nowadays usual in large schemes, air entrainment from the water surface caused by the development of the turbulent boundary layer does not always reach the region near the bottom of the channel. In the absence of the protection provided by water-air emulsion, any surface irregularity capable of reducing pressure locally to the vaporization level becomes important.

The higher the water velocities, the more critical the cavitation problem becomes. For velocities of around 40 m/s or more, the pressure field is particularly sensitive, as shown in the pressure-velocity comparison analysis of Fig. 1. For that velocity range, local increases of 5-10 per cent are enough to cause corresponding pressure reductions of about 10 m of water column.

As shown by recent events at the Karun spillway[1] in Iran, it is very difficult (in fact, practically impossible) to finish the concrete lining to the standard of smoothness required to prevent cavitation at such high water velocities.

In those cases, steps or ramps may be used to promote air admission under the nappe near the concrete surface to be protected. The Foz do Areia spillway, on the Iguaçu river in Brazil, is a recent example of the successful use of such a system.

Many aspects related to cavitation in high velocity flows and to the importance and benefits of aeration were presented in a previous article[2].

This article deals essentially with the phenomenon of air entrainment. Based on a general analysis of the air entrainment mechanism and of the data from prototype and laboratory tests, an analytical treatment of the

*CEHPAR, Universidade Federal do Paraná, Caixa Postal 1.309, 80 000 Curitiba, Paraná, Brazil.

Water Power & Dam Construction
February 1982
pages 34-38

Fig. 1. Local pressure reduction as related to the velocity variation.

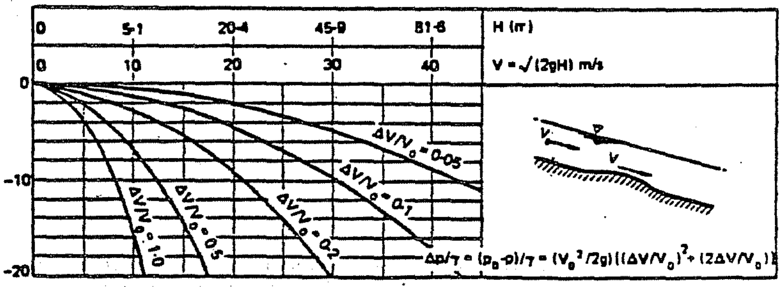


Table I—Cavitation index values

n	$\sigma_i = H\text{-}H_v/V^2/2g$	
5	0.62	
10	0.50	$H = h + p_a/\gamma$
20	0.35	H_v = steam pressure
40	0.25	V = mean velocity of flow

problem is developed, setting a basis for predicting the performance of aeration devices from hydraulic model studies.

Designing an aeration system requires the answer to three main questions:

- At what velocity should first aeration be provided?
- What is the volume of air entrained at the aerator? and,
- What is the spacing between aerators to maintain a given protection level?

The answer to the first item is related to the concept of aeration as a cavitation-preventing system. Care taken during concrete placing and finishing certainly contributes to reducing surface irregularities and, consequently, cavitation risks. Table I presents some values of the incipient cavitation index, which indicate the effect of surface quality. Quality improvement is naturally related to a cost increment because of the difficulties of working the surface to more strict tolerance levels.

One of the basic ideas underlying aeration systems is the reduction in cost resulting from less stringent specifications for the concrete surface finishing. An adequate evaluation of the critical cavitation index for the irregularities that may be expected in the works, and economical considerations, should influence the design decision as to the placement of the initial aerator.

Available information about aeration effects[3,4] indicates that an air concentration of 5-10 per cent near the surface to be protected, $C = (v_a/V_a + V_w)$, almost eliminates cavitation risks. Therefore, an adequate design of aeration systems depends on: the correct evaluation of the quantity of air to be entrained at the aerator and also the development of air concentration near the surface to be protected. Additional aerators are to be provided at sections in which the concentration falls below the minimum required level.

Aerator geometry

Ramps or steps inserted on the chute surface are the simplest and most practical devices used to cause natural aeration of water flow near a solid boundary. The sudden discontinuity in the bottom alignment creates an air-water interface along which the high velocity water drags air in an intense mixture process, Fig. 2 (a, b).

A transverse gallery or a recess can be added to any of the systems to improve conditions for air admission to the cavity below the jet, and to improve aerator effectiveness, Fig. 2 (c, d).

As indicated on Fig. 2 (e, f), a combination of the various systems is possible.

For air admission to the space downstream of the step or ramp, special ducts, wall slots, recesses, or lateral wedges are used according to specific design conditions. On Fig. 3 various possible methods are shown. A particular case of the lateral recess type of aeration is the solution used in the Bratsk spillway in Siberia[5]. The ramp is built near the end of the spillway pier and air is drawn in through the openings naturally formed in the separation zone downstream of the piers.

Defining of the ideal proportions of the different parts of the aeration device constitutes one of the fundamental design problems. There are several options to be considered and it is difficult to evaluate the influence of each dimension on the aerator performance.

Air entraining mechanism

The initial air drag mechanism is characterised by the tangential stress between water and air at the interface just downstream of the separation point at the step or ramp. Flow turbulence is responsible for the roughness of the liquid surface which tends to increase along the jet, intensifying the drag. Once surface tension effects are overcome, the air-water interface changes into a spray

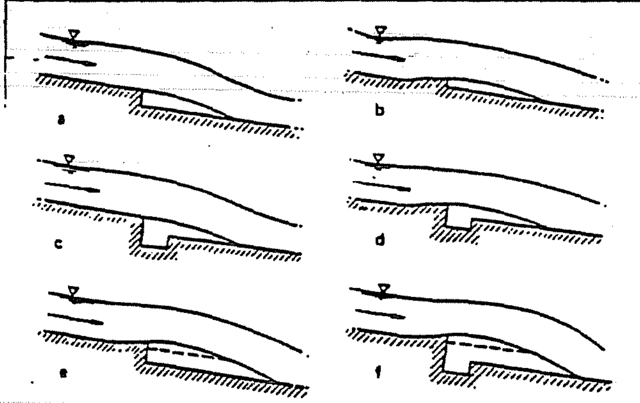


Fig. 2. Main types of aerator devices.

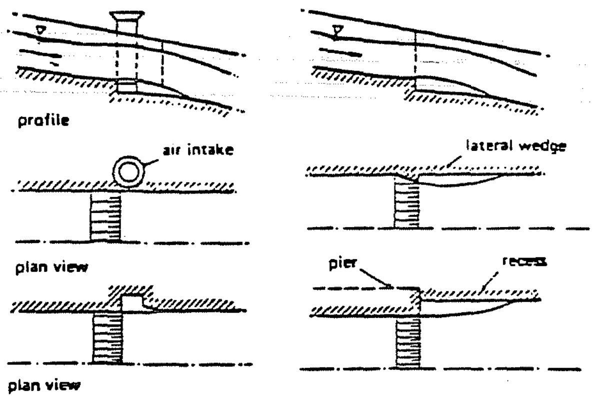


Fig. 3. Main solutions for air admission.

Notations

α	= Angle to the horizontal of the channel bottom plane
ϕ	= Angle of the ramp to channel bottom plane
t	= Ramp height (m)
d	= Step height (m)
V	= Mean velocity of water (m/s)
h	= Depth of flow normal to the bottom (m)
L	= Water jet length (m)
Δp	= Air pressure difference between regions above and below the water jet (kg/m^2)
g	= Acceleration of gravity (m/s^2)
ρ	= Water density (kg m^{-4}.s^2)
μ	= Dynamic viscosity of water (kg m^{-2}s)
σ	= Water surface tension coefficient (kg m^{-1})
C	= Dimensionless coefficient
Q_a	= Air flow entrained by water (m^3/s)
A	= Sectional area of the air jet at the exit of the duct (m^2)
ρ_a	= Air density (kg m^{-4}s^2)
F_r	defines the flow conditions
E_e	measures the influence of the difference of pressure above and below the water jet
L/h	defines the jet geometry
t/h, d/h, $tg\,\alpha$, $tg\,\phi$	define the aerator geometry

which has considerably higher efficiency as an air entraining mechanism. In prototype structures the spray effect is by far the preponderant mechanism of air entrainment.

When the water hits the bottom of the channel, the flow will have entrained a volume of air which will be moved downstream as an air-water mixture. The behaviour of the mixture presents some analogy with that of sediment suspensions in turbulent flow. The air bubbles tend to rise from the bottom, while turbulence tends to maintain the mixture within the turbulent boundary layer. Air concentration near the bottom reaches its maximum immediately after the impact point of the jet, gradually diminishing downstream until an equilibrium condition is attained, after an eventual interaction with the air dragged from the upper free surface.

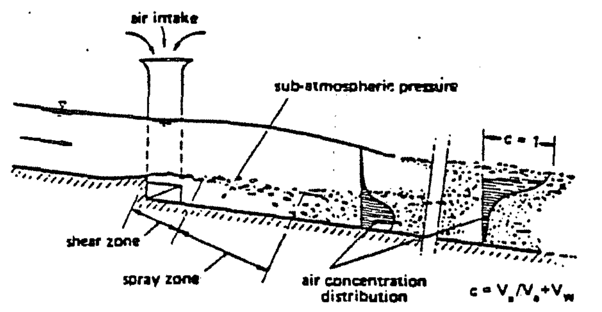


Fig. 4. The air-entraining mechanism.

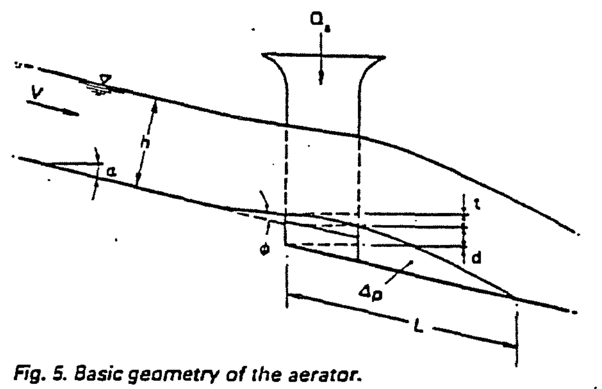


Fig. 5. Basic geometry of the aerator.

Air concentration at a fair distance from the jump will naturally tend to be very similar to that observed in high velocity flows aerated from the free surface alone, as reported by Straub and Anderson[6]. In fact, it seems logical that the final air concentration curve would be independent of the air entraining system. The main aspects of the drag mechanism and mixture process are schematically shown in Fig. 4.

The continuity of the process, of course, requires a continuous air supply to the space created under the jet. In that region, pressures will always be sub-atmospheric because of the velocity of the air flow and the head losses through the aeration ducts. The pressure difference will cause a deflection of the water jet trajectory in relation to the normal free-fall parabola to be reflected on the length of the jet, certainly an important parameter as far as the amount of entrained air is concerned.

Dimensional analysis

Dimensional analysis of flow over a step or a ramp is more easily carried out if aeration phenomena are ignored initially. The problem is maintained within the framework of classical hydraulics, the more complex biphase flow question is avoided, and the analytical procedure becomes considerably simpler.

Analytical treatment of the phenomenon is made for an ideal aerator as shown in Fig. 5, assuming a two-dimensional flow and limiting the aerator geometry to the step-ramp combination.

Referring to Fig. 5, it is possible to define the following main variables to be considered in the study of the phenomenon of air entrainment by running water (see Notations).

The phenomenon may be described by a function of 12 parameters:

$$f(\alpha, \phi, t, d, V, h, L, \Delta p, g, \rho, \mu, \sigma) = 0 \quad \ldots \quad (1)$$

which may be reduced to nine dimensionless groups:

$$f'(F_r, R_e, E_e, W_e, L/h, t/h, d/h, tg, \alpha, tg\,\phi) = 0 \quad \ldots \quad (2)$$

where:

$$F_r = V/\sqrt{(gh)};\ R_e = \rho VL/\mu;\ E_e = V/\sqrt{(\Delta p/\rho)};\ W_e = V\,(\sqrt{(\sigma/\rho L)}$$

For the size of the hydraulic structures being considered in this study, the effects of R_e and W_e may be disregarded, and Eq. (2) may be written as:

$$f''(F_r, E_e, L/h, t/h, d/h, tg\,\alpha, tg\,\phi) = 0 \quad \ldots \quad (3)$$

The general configuration of the flow is related to the aeration phenomenon by the parameter E_e, which depends essentially on the conditions in which air is admitted to the void below the jet.

Referring to Fig. 6, where an air intake is schematically represented, it may be written:

$$Q_a = C\,A\,\sqrt{(\Delta p/\rho_a)} \quad \ldots \quad (4)$$

Eq. (4) may still be written in terms of E_e:

$$Q_a = CA\,\sqrt{(\rho/\rho_a)}\,V/E_e \quad \ldots \quad (5)$$

The analytical treatment up to this point does not take into account the physical nature of the air entrainment phenomenon itself. For the complete solution of the problem, an additional equation is required to relate water and air flow parameters.

The nature of such a relationship may be guessed by a

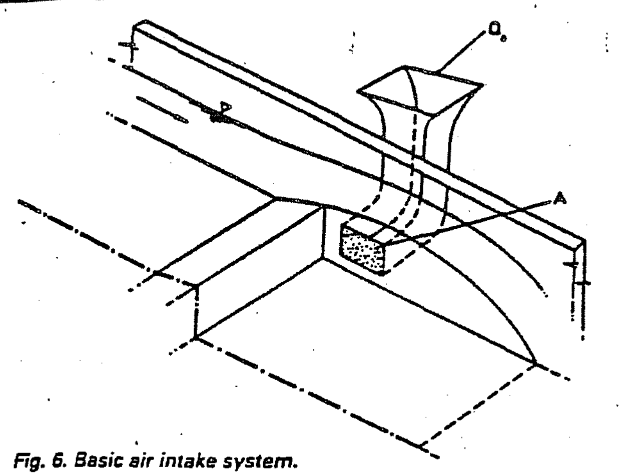


Fig. 6. Basic air intake system.

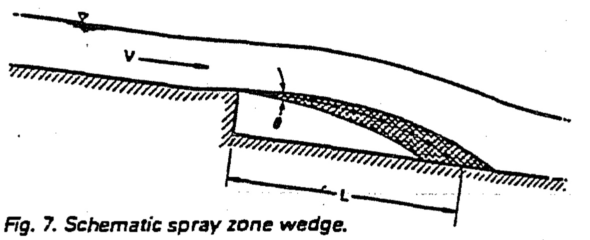


Fig. 7. Schematic spray zone wedge.

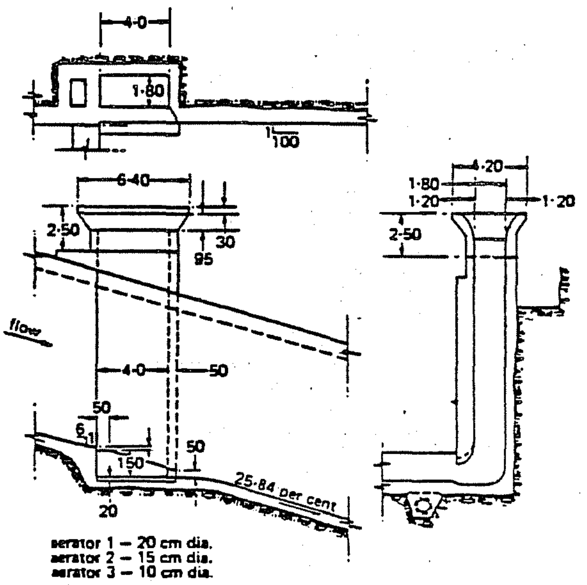


Fig. 8. Aeration system of the Foz do Areia spillway.

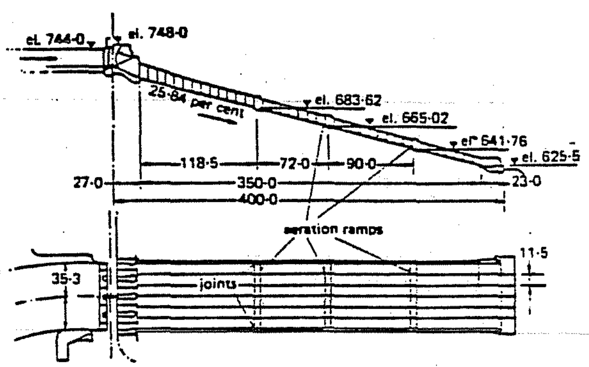


Fig. 9. Main dimensions of the Foz do Areia spillway.

simplified interpretation of the spray dragging mechanism. Referring to Fig. 7 and considering the spray zone limited to the dashed wedge, it seems acceptable to write:

$$q_a = K_1\,(L\,tg\,\phi\,V)/2 \qquad \text{... (6)}$$

or simply:

$$q_a = K\,L\,V \qquad \text{... (7)}$$

where q_a is the air discharge per metre of width of the chute.

If $q = Vh$ is the specific water discharge, Eq. (7) may be written in a dimensionless form:

$$q_a/q = \beta = K\,(L/h) \qquad \text{... (8)}$$

Simulating air entrainment phenomena in the laboratory is known to be difficult because of the unknown scale effects. Prototype tests would be ideal for checking the nature of Eq. (8). Operation of the Foz do Areia spillway has provided a very convenient opportunity for that experiment.

Prototype results

This study is based on tests performed at the Foz do Areia spillway, on the Iguaçu river in Brazil.

Foz do Areia is a 160 m-high concrete face rockfill dam with a volume of 14 × 10^6 m^3 of rock which creates a net reservoir of 4.10^9 m^3 for a 2500 MW hydroelectric powerplant at the right abutment, Fig. 8.

The spillway, on the left abutment, with a capacity of 11 000 m^3/s, consists of a classic ogee crest, with four sector gates of 14.5 × 18.5 m, followed by a 70.6 m-wide, 400-m-long chute, at a slope of 25.84 per cent to the flip bucket deflector, at an elevation 118.5 m below the reservoir maximum water level, Fig. 9.

The main characteristics of the aeration system are shown in Fig. 10.

During the initial phase of spillway operation, measurements of air flow entrained at each aerator for

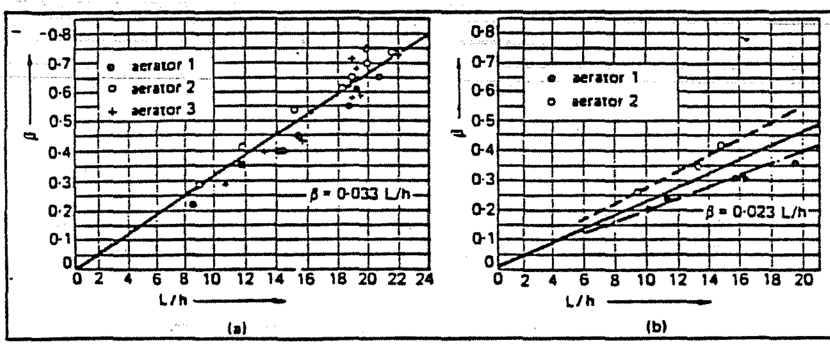


Fig. 10. β = f(L/h) as estimated from prototype results.

Table II—Results of tests performed

Test	Reservoir el. (m)	Q (m^3/s)	Aerator 1 h (m)	Aerator 1 $\Delta p/\gamma$ (m)	Aerator 1 L (m)	Aerator 1 Q_a (m^3/s)	Aerator 2 h (m)	Aerator 2 $\Delta p/\gamma$ (m)	Aerator 2 L (m)	Aerator 2 Q_a (m^3/s)	Aerator 3 h (m)	Aerator 3 $\Delta p/\gamma$ (m)	Aerator 3 L (m)	Aerator 3 Q_a (m^3/s)
01	731.5	1470	0.81	0.22	12.6	666	0.74	0.34	11.5	786	0.71	0.34	11.9	775
02	731.5	1000	0.59	0.16	11.1	554	0.55	0.21	10.5	613	0.54	0.22	11.0	587
03	731.5	850	0.52	0.14	10.1	515	0.50	0.17	9.9	549	0.49	0.18	9.7	546
04	731.5	690	0.46	0.11	9.5	453	0.44	0.13	9.0	485	0.44	0.15	8.7	476
05	731.5	535	0.38	0.08	8.2	395	0.38	0.08	7.8	399	0.38	0.10	7.4	386
06	735.3	2090	1.08	0.25	12.8	732	0.97	0.42	11.9	861	0.90	0.39	12.5	846
07	735.3	3300	1.64	0.23	14.0	730	1.43	0.52	13.3	941	1.29	0.49	14.3	932
08	738.4	538	0.39	0.15	7.6	195	0.38	0.15	7.25	228	0.38	0.10	8.6	395
09	738.4	1027	0.59	0.32	9.5	312	0.56	0.45	7.8	352	0.55	0.22	11.0	604
10	738.4	1804	0.94	0.54	10.7	412	0.85	0.80	8.4	463	0.80	0.38	13.1	791
11	738.4	2060	1.06	0.58	10.7	437	0.95	0.90	7.7	496	0.88	0.42	13.3	832
12	738.6	1032	0.60	0.34	9.5	319	0.56	0.43	7.8	348	0.56	0.22	11.0	602
13	738.6	2078	1.06	0.58	10.7	432	0.96	0.87	7.7	495	0.89	0.40	13.3	832

different water discharges from 500 to 3300 m^3/s were made. The water discharges were determined from spillway rating curves obtained in a 1:100 scale hydraulic model.

Air discharges were calculated from pressures measured at the walls of the aeration towers, used as Venturi meters. Besides the air inflow, the pressure distribution under the jet along the step wall of the aerator was measured. Fig. 11 shows the typical configuration of the pressure distribution below the nappe across the chute.

The results of all the tests performed are summarized in Table II. The aerators are identified by numbers 1 to 3 from upstream. Flow depth and jet lengths are also included in the Table. Flow depths were analytically computed by the direct step method without taking into account the aeration effects in the development and structure of the boundary layer. The length of the jet was obtained in a sectional hydraulic model of 1:50 scale, where the pressure under the nappe could be varied in a way so that the length value corresponding to the average pressure measured on the prototype could be obtained.

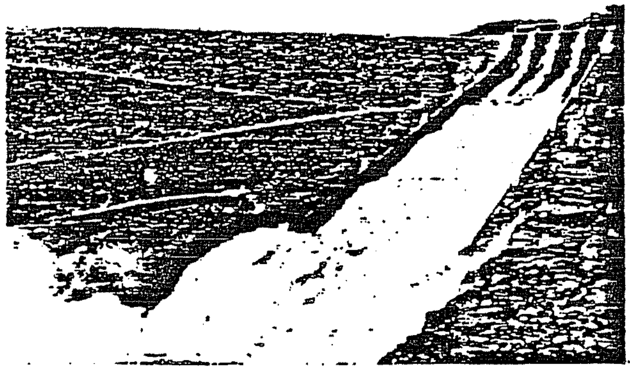
Tests 1 to 7 correspond to normal spillway operation. To obtain a wider range of values and to explore the sensitivity of the aerator devices, tests 8 to 13 were performed, with the right-side air intake towers of aerators 1 and 2 closed. The supply of air at only one of the extremities in those two aerators resulted in a noticeably modified picture of pressure distribution under the jet, as indicated in Fig. 12, and, consequently, in the length of the jet and in the air discharge as well.

Plotting the experimental values in a graph of $\beta = q_a/q$ against L/h (Fig. 10) seems to confirm the reasoning underlying expression (8), at least as a first approximation.

The straight-line equation arbitrarily chosen to represent the phenomenon is obviously an over-simplification. It is apparent in Fig. 10 (a) that the curve of best fit would indicate β tending to zero for a finite value of L/h. Also, from the non-symmetrical air flow tests, it seems that two different equations would better represent the experimental data, Fig. 10 (b).

Limitations of experimental conditions are also to be taken into account. Air discharges do not include air being entrained laterally through the space left by a 10 cm recess in the lateral walls. Also, in the non-symmetrical tests, plugs at the air intakes were not absolutely air-tight. Furthermore, estimating the length of the water jet, even in controlled laboratory conditions, is a somewhat subjective process.

(To be concluded.)



Foz do Areia dam spillway discharging 2500 m^3/s.

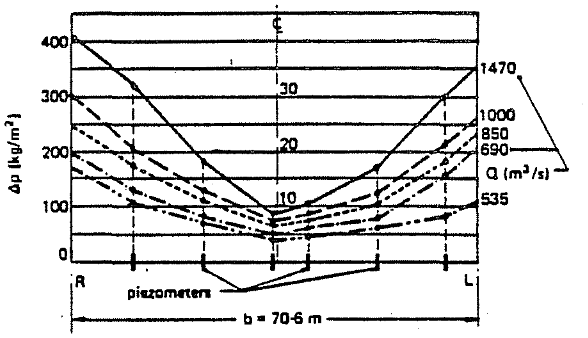


Fig. 11. Pressure distribution below the water jet. Symmetrical air flow conditions.

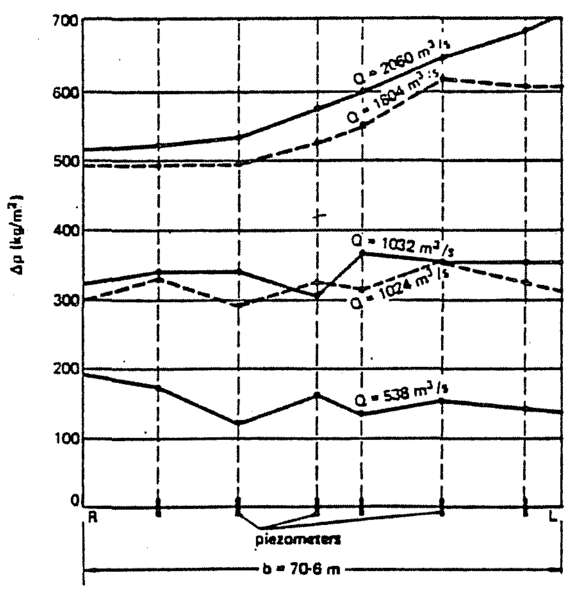


Fig. 12. Pressure distribution below the water jet. Asymmetrical air flow conditions.

Aeration at high velocity flows

By N. L. de S. Pinto*, S. H. Neidert and J. J. Ota

PART TWO

The development of suitable physical modelling to assess the behaviour and characteristics of aeration in spillways is verified by comparing model tests with the Foz do Areia dam's spillway in Brazil. The optimum spacing of areators for spillways is also discussed.

THE LIMITATIONS imposed by the scale of the model were discussed last month, along with the test results, presented in tabular form. The relationship of these tests to the prototype spillway aeration system are now examined.

Model and prototype conformity?

The Foz do Areia spillway aeration system design was supported by hydraulic model studies on a 1:50 scale sectional model.

As a true representation of the aeration mechanism could not be expected at that reduced scale, tests were aimed essentially at optimising the shape and proportions of the ramps and steps. However, entrained air flow was measured and the results are shown in Fig. 13, together with prototype observations, to point out the considerable scale effect, if the Froude law of similarity is admitted.

At the 1:50 scale, surface tension effects prevent a true reproduction of prototype conditions as far as the aeration process is concerned. However, hydraulic conditions of the flow are very well simulated. It is possible, for example, to explore the nature of Eq. (3), as is illustrated in Fig. 14.

The model reproduces a constant aerator geometry, and different flow conditions are caused by different discharges and the variation of the pressure under the nappe, artificially produced by a throttling device at the air intake section. Parameters ($d/h = 0$), $tg\ \alpha$, $tg\ \phi$ remain constant.

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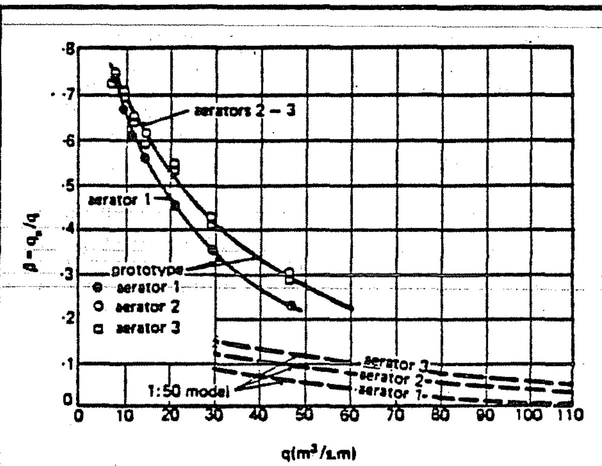


Fig. 13. Efficacy of air entrainment; model and prototype results.

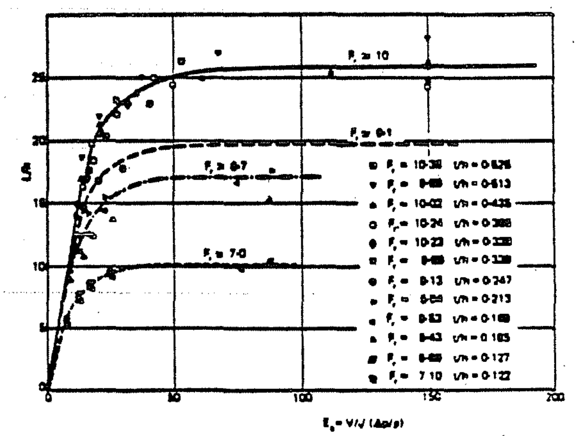


Fig. 14. Nature of the function $f(F_r, E_e, L/h, t/h) = 0$ as measured on the 1:50 scale model for aerator no. 1.

It may be observed that parameter E_e does not influence the geometry of the water jet for values above 50. For that region the water nappe can be considered as an essentially free jet, not influenced by the slight negative pressure underneath. For values of E_e less than 50, the importance of the air throttling effect upon the geometry of the flow is noticeable.

The influence of the Froude number and of the parameter t/h are not readily distinguishable because of the nature of the tests. However, close examination of some tests in which the Froude number can be considered to be essentially the same, clearly reveals the isolated effect of parameter t/h.

Results presented in Fig. 14 for aerator no. 1 were confirmed on aerators 2 and 3, which showed exactly the same tendencies.

Air entrainment, as observed on the 1:50 scale model, is essentially caused by a surface dragging mechanism. Spray phenomena are practically non-existent, as surface tension effects maintain the integrity of the lower nappe.

Surface tension effects may be evaluated by comparing the Weber number $W_e = V/(\sqrt{(\sigma/\rho L)})$ in model and prototype. Whereas in the latter it reaches values of the order of 10 000, in the model the corresponding numbers are normally below 300.

It is apparent that for convenient modelling of the air entraining process and reproduction of the spray mechanisms observed in the prototype, higher Weber numbers should be attained in the model.

The maximum head available in the CEHPAR laboratory, of the order of 10 m, set the limits for a 1:8 scale model of aerator no. 1, built in a 0.15 m-wide glass-walled flume. Water was conveyed through a 0.30 m-diameter vertical pipe where a Venturi meter and a control valve were installed. The pipe ended in a rectangular section where a slide gate, immediately upstream from the test section, could regulate the water depth of the flow over the aerator. Air admission was through a vertical conduit, 0.10 × 0.10 m square, as illustrated in Fig. 6, in which wall pressures could be measured and air flow evaluated by the Venturi principle. The air jet area (A) could be changed by a slide gate, to produce different pressure conditions under the water jet.

Flow discharges observed in the prototype were reproduced in the model according to the Froude law. Fig. 15 presents the results measured in the model.

Air discharges (Q_{am}) are plotted against the average pressure below the water jet $(\Delta p/\gamma)_m$ for different opening conditions of the air outlet orifice, from 1 × 10 cm to complete opening (curves 1-5). Constant water discharge curves from 535 to 3300 m³/s (prototype) are also represented in the Fig. 15. Curves A and B represent the relationship between the average pressure below the nappe and the air discharge as actually measured in the prototype, for aerator no. 1. As can be seen, their nature is for all practical purposes well described by Eq. (4). It is to be noted that for plotting curves A and B, the Froude law was again accepted, so that values in the graph were computed from the following relations:

$$Q_{am} = Q_{ap}\,(1/8)^{5/2}\,(1.2/70.6)\,10^3$$

$$(\Delta p/\gamma)_m = (\Delta p/\gamma)_p\,(1/8)\,10^3$$

where Q_{ap} is the total air flow measured in the prototype (m³/s), and $(\Delta p/\gamma)_p$, the prototype average pressure under the water jet, in metres of water column.

Therefore, curves A and B in Fig. 15 represent prototype conditions. They could have been obtained in the model by a convenient setting of air inlet conditions. For instance a 5 × 10 cm orifice reproduces very well the conditions described by curve B.

The results may be better evaluated in Fig. 16, in which air discharge is plotted against water flow, both for model and prototype data.

Model results are taken from Fig. 19, accepting as already known the relation $\Delta p = f(Q_a)$ given by curves A and B. The agreement between model and prototype data is excellent, especially for discharges below 2000 m³/s.

Tests on the 1:8 scale model have also provided an opportunity to study the nature of Eq. (8) as affected by the throttling of the air inlet. Results shown in Fig. 15 include data for air inlet dimensions of 1 × 10 cm to the complete duct opening. Conditions for $\Delta p = 0$ were inferred by extrapolation.

As measuring the water jet length in the 1:8 scale model was difficult because of the intense spray formation, the corresponding values of L were measured in the 1:50 scale model in which the same flow conditions were reproduced. Results shown in Fig. 17 clearly demonstrate the throttling effect. It is to be noted that, to minimise scale effects, only tests with Weber number above 1000 were plotted.

Despite the limited number of tests, a tendency for the relation $\beta = f(L/h)$ to depart from the straight line through the origin is well characterized, more so for the less restricted air inlets. That seems to be in accordance with the rule of thumb, which recommends the ratio L/h to be above 4 or 5 for satisfactory behaviour of aeration ramps.

The experimental study seems to have demonstrated the feasibility of modelling the aeration phenomena on hydraulic structures. The surface tension effect has been clearly detected and evidence as to the limits of its influence was gathered. Indications are that surface tension effects may be disregarded for W_e above 1000.

The influence of throttling air admission to the lower nappe was demonstrated. It became clear that it is important to know the relationship $Q_a = f(\Delta p)$ in any project. The air pressure is related to the air velocity head at the inlet section, and to the evolution of the air flow as it moves transversally to the water current while being entrained by it. Head losses at the air must also be added.

Many points remain to be clarified before the problem of air entrainment by high velocity flows and its reproduction in hydraulic models may be considered to be understood completely. The effects are to be analysed further of different geometries, such as: the slope of the

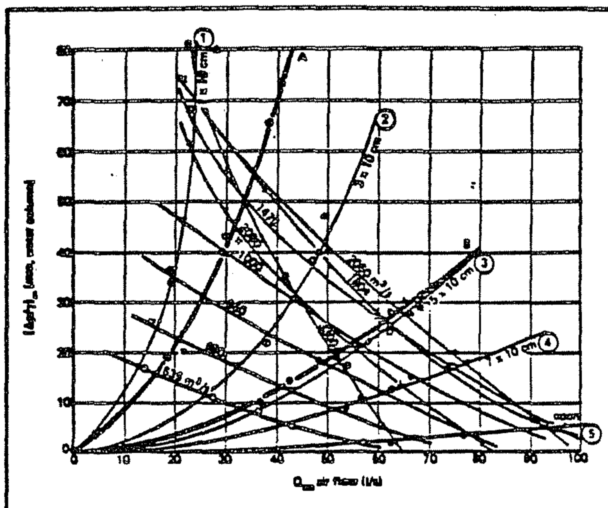
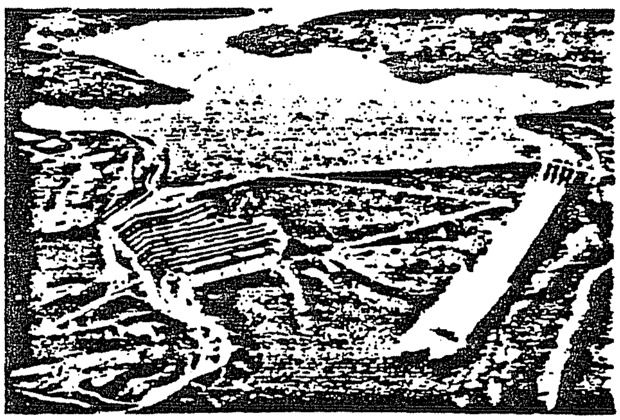


Fig. 15. Performance of aerator no. 1.



Aerial view of Foz do Areia.

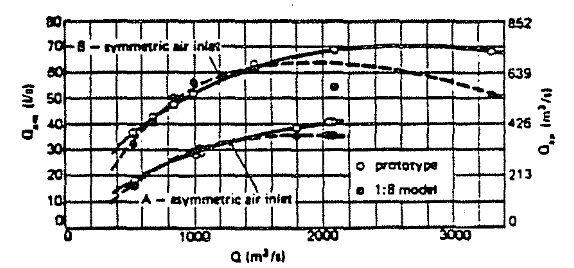


Fig. 16. Entrained air flow against water discharge; model and prototype results.

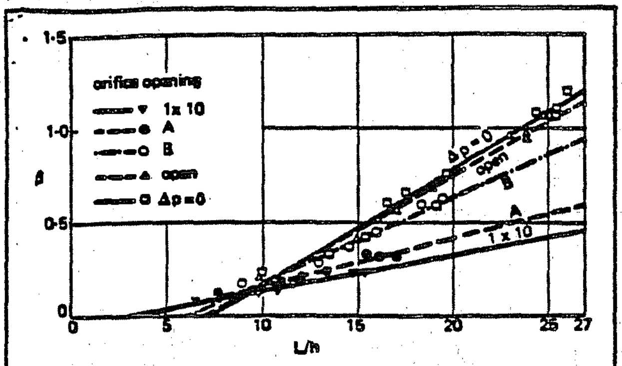


Fig. 17. The relationship β = f(L/h) as related to air opening conditions.

ramps or of the chute itself on the air entrainment process; the nature of air flow through the aeration conduits and specially along the lower nappe and its relation with the evolution of pressures; the degree of generalization of the conclusions on surface tension effects and the meaning of Weber number as defined in the text.

Unfortunately, spillways in general do not operate very frequently, and prototype and model measurements are scarce. A complete understanding of the aeration phenomenon can only be expected after a considerable amount of prototype data, duly confirmed by laboratory tests, become available. Meanwhile, the desirability of further observation, analysis and publication of results cannot be too strongly emphasised.

Spacing of the aerators

As mentioned previously, the concentration of air at the bottom of the chute is reduced along the flow because of the effects of gravity. The protective effect on the lining will diminish correspondingly until it becomes insufficient, determining the need for a new aerator.

Unfortunately, no defined criteria exist for evaluating the rate of change of air concentration and of its protection effectiveness. The designer is therefore expected to orient himself from existing information on practical experience and previous project decisions.

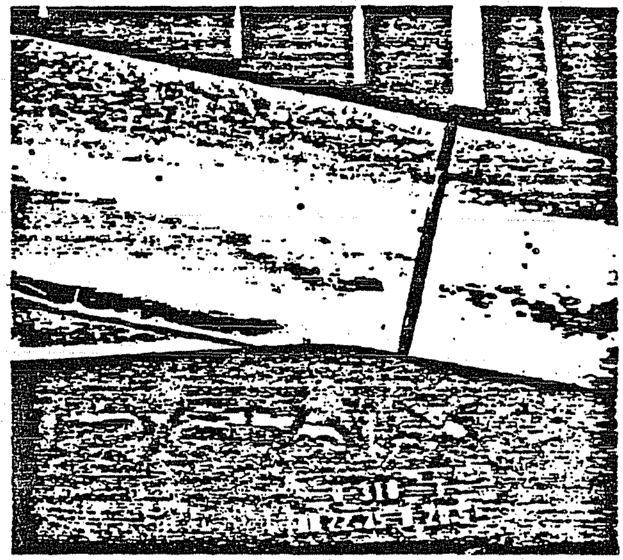
Semenkov and Lentjaev[8] mention the experiments carried out on the Bratsk spillway, where average air concentration of the flow was observed to decrease at a rate of 0.5 per cent per metre of chute length. At a 1 cm-thick layer closest to the bottom, the loss rate was from 1.5 to 2.0 times greater. At the Bratsk gravity dam with a downstream slope of 0.8:1, a second aerator, initially planned for 40 m downstream along the spillway face was considered unnecessary. The 100 m-long chute is protected by a single aerator between the crest piles.

At the Nurek spillway seven aerators were used, which were formed by 40 cm steps spaced every 20 m. It is known that aeration was considered to be excessive, and some aerators have been eliminated.

At the Foz do Areia spillway, aerators were spaced at 72 m and 90 m, as shown in Fig. 8. Operation seems to be adequate, although it is not possible to conclude whether two aerators would have been enough.

For the Emborcação spillway, a project similar to Foz do Areia, under construction, the chute of which is 330 m long with an 18 per cent slope, two aerators 103 m apart were planned, the second one being approximately 100 m upstream from the flip bucket.

The raising of the Guri spillway in Venezuela involves extensive use of aeration devices. Chute lengths downstream from aerators vary from 5 to 150 m for different parts and phases of the works.



A 1:8 scale model reproducing a water discharge of 3300 m³/s over aerator no. 1; W_e = 1300.

Bottom slope and curvature should be taken into consideration in spacing aeration devices. Flatter slopes make upward air movement more rapid, determining a faster reduction of air concentration along the bottom. Centrifugal effects in concave curves, such as flip buckets, increased the upward air bubble velocity considerably.

Assessing the need for increased aeration can be helped by an evaluation of self aeration conditions of the flow, as studied by Straub and Anderson[6].

The need for more research on the evolution of air concentration along the flow and protection from the phenomenon is evident. Meanwhile, it seems reasonable to consider that a well designed aerator should be able to protect a stretch of chute of about 50 to 100 m. □

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ALASKA POWER AUTHORITY

334 WEST 5th AVENUE - ANCHORAGE, ALASKA 99501

ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION; REFERENCE TO COMMENT(S): I.251

August 23, 1983

Susitna Joint Venture

Mr. Rodney Schulling
Matanuska - Susitna Borough
631 South Valley Way
P.O. Box B
Palmer, Alaska 99647

Mr. Chris Beck
Department of Natural Resources
Land & Resource Planning Section
555 Cordova St.
Pouch 7-005
Anchorage, Alaska 99501

SUBJECT: Comments on the Susitna Area Plan

Dear Mr. Schulling & Mr. Beck:

The Alaska Power Authority would like to bring to your attention a number of actual or potential actions on the part of the Power Authority that may influence decisions on the Susitna Area Plan; and reciprocally, action of the plan which may impact the Power Authority's Susitna Hydroelectric Project. Needless to say, the Power Authority would seek to develop projects in conformity to any stated land use plan, and thus we await with interest, the publication of the Susitna Area Plan. In the same manner, the Power Authority would also seek to comply with other management plans as stated by other agencies, for example, the Alaska Department of Fish & Game. The Federal Energy Regulatory Commission (FERC) will encourage the Power Authority to seek accommodations between agencies and the Power Authority when conflicts arise over management objectives. The Susitna Area Plan offers an opportunity to develop a balanced project and thus reduce the potential for conflicting resource plans.

Listed below are a number of points which the Power Authority feels should be addressed by your Team in developing the Susitna Area Plan.

1. Land Acquisitions

Project lands are described in the Application for License - Exhibit G, a copy of which you have. Exhibit G plates show project lands required for facilities including; dam, powerhouse, service facilities, permanent village, the impoundment area, including a buffer zone around the perimeter, access roads, and the transmission corridors. Timely acquisition of these lands is critical to the project schedule. The Susitna Area Plan should anticipate project development, facilitate the process of acquisition, and minimize conflicts or confusion with adjacent landowners or potential owners by incorporating the project features as proposed. Also, some flexibility should be built into the plan to accommodate a limited number of potential project modifications that remain under active review.

2. Land Status

Ownership of lands in the project area is in a state of flux as federal lands are transferred to the State and the Native Corporations and State lands are transferred to the borough and to private ownership. Expeditious resolution of land status is a prerequisite to the timely acquisition of project lands.

3. Land Exchange

There is the potential for the exchange of lands between the State and Native Corporations. If this mechanism is acceptable, the plan should identify lands that the State considers likely for exchange. As mentioned in the previous point, the State must be prepared to act in a timely manner regarding acquisition of project lands. The plan should address the potential shift of lands from private to public ownership.

4. Temporary Land Use

Some lands would be used only during construction stages of the project. Management guidelines should permit flexibility in arranging for the diverse kinds of temporary users that may arise. In addition, the State should retain title of State lands until project related uses have been completed.

5. Project Induced Growth

While project induced growth may account for only a small portion of growth in the Matanuska-Susitna Borough, some of the growth would be located along the Parks Highway in areas that otherwise might develop much more slowly. It is likely that demand for commercial and residential land in the area of Cantwell and Trapper Creek may press on available supplies. The Susitna Area Plan should accommodate a pattern of growth somewhat different than a without - project baseline condition.

6. Rights-of-Way

Transmission line, road and railroad rights-of-way would be required for project development and operation. Proposed access plans and transmission corridors have been identified in the License Application. When disposing of land, these proposed rights-of-way should be retained by the State to assure that the Power Authority does not have to buy back what was earlier State land. Persons seeking lands, especially remote parcels, should be apprised of project related developments that may be approximate to the lands they are considering.

The development of both the road system, electrical transmission systems and other utility alignments should proceed along a plan of integrated utility corridors. Adequate space should be provided in these corridors for future utility development. Identification of utility corridors should involve participation of the Power Authority as well as local utilities.

Major policy issues remain to be solved with respect to public access to the project roads at the conclusion of the construction phase of the project. The License Application addresses both recreation planning and fish and wildlife mitigation with public access being permitted following construction. Open access also conforms to the desires of the Native Corporations who will be the adjacent landowners. Open access would provide a "worst case" scenario in the impact assessment/mitigation plan because such access would require the largest investments in a recreation plan and the greatest mitigation effort in the fish and wildlife plan. As we have stated, this is a "worst case" analysis in the absence of a single, coherent management plan for the lands in the middle of Watana Basin. The Susitna Area Plan provides an opportune forum for the enunciation of a single management plan. Such a plan would provide a balance among the many conflicting goals for this area. The Power Authority looks forward to working with your team in developing a set of management criteria for the lands and waters of the Susitna project area.

Current federal policy tolerates All Terrain Vehicles (ATV) access to federal lands in the area of the Susitna project. An understanding of the policy for the use of ATV's on State lands would affect recreation planning.

7. Wildlife Mitigation

While the analysis of project impacts and mitigation plans is ongoing, a preliminary Wildlife Mitigation Plan is outlined in the License Application. The details of the plan will be refined in cooperation with resource agencies as information improves, and as guidance becomes more focused. Nevertheless, at this time we can state some attributes of mitigations lands, the extent and location of such lands.

A. Moose and Bear Mitigation Land

The License Application states that compensation for loss and alteration of habitat for moose, brown bear, and black bear will be provided through habitat enhancement measures to be conducted on lands to be selected for this purpose. The locations of these lands have not been identified. The Power Authority wishes to ensure that selection of habitat enhancement lands is consistent with land use designations provided for in the Susitna Area Plan and other State and Federal agency planning documents. To this end, discussions have been initiated with the Alaska Department of Fish & Game. We look forward to the close involvement of your team in assisting the Power Authority to identify lands which are optimal for habitat enhancement and consistent with intended land uses.

Several attributes of lands suitable for moose and bear habitat enhancement have been identified on a provisional basis. Approximately 20,000 acres of public lands will be required for this purpose. Enhancement measures will potentially include controlled burning, logging, vegetation crushing, and land clearing. Selection of lands with relatively low-productivity vegetation types, such as woodland black spruce or mature cottonwood forest, will allow the greatest increase in habitat suitability and help to limit the total number of acres required for enhancement. Access and topography will be important considerations in allowing habitat enhancement measures to be implemented. Suitable compensation lands will have varied terrain consisting of moderate slopes and elevation gradients, with a high appropriation of relatively low, flat areas suitable as moose winter range. Proximity of compensation lands to areas utilized by recreational and subsistence hunters may also be desirable. We anticipate that more precise criteria will be developed with the participation of your team, the Department of Fish & Game, and other agencies.

B. Caribou Compensation

The proposed access road from the Denali Highway to Watana Dam Site has been relocated west to minimize its effects upon the Nelchina caribou herd. The road will be constructed on a minimum berm to minimize interference with the movement of caribou. Nevertheless, there may be some unavoidable impacts to the caribou herd related to the access road, construction activity and/or the proposed reservoir. Some compensating action may be required to assure the continued well being of the Nelchina caribou herd. The Power Authority will work with resource management agencies to identify and effect measures to maintain the Nelchina caribou herd. One measure which deserves serious consideration is the establishment of the Nelchina Special Use Area as proposed by the Alaska Department of Fish and Game. This area would have as its northern boundary the southern bank of the Watana Reservoir. The management objectives for this portion of the proposed lands could address these lands being within the Special Use Area.

8. Fisheries

The primary objective of the aquatic mitigation program is to maintain natural or semi-natural production in the aquatic habitat. This would be accomplished by means of appropriate flow release schedules and various kinds of modifications to the side channels and sloughs. It is critical that the integrity of aquatic ecosystems be maintained if aquatic production is to be retained. It is likely, therefore, that the Power Authority would request Mineral Closing Orders to protect productive and or modified reaches. It may be necessary to acquire Land Use or Special Land Use Permits to support the aquatic mitigation program.

The Power Authority anticipates that water quality in the mainstream, sloughs, and tributaries will be maintained by using your land use measures to protect these waters.

9. Recreation

The interplay of alternate options for resource development is particularly clear in the area of recreation. Most recreation activity would be directed at the harvest of sport fish and game. To increase access and recreation opportunities would place additional demands on existing fish and game populations. This, by its nature, is usually considered an adverse impact for the population. In addition, new users would compete with existing users. The Susitna Area Plan should state clear guidelines for recreation activities in the area. The plans should support regional recreation plans, the necessity to maintain healthy populations of sports fish and wildlife, and the interests of landowners and land managers. The Susitna project recreation plan can then be brought into line with the area plan.

We appreciate your effort towards integrating our concerns with respect to Susitna Hydroelectric Project with the Susitna area planning effort. Please keep us informed regarding the status of the Plan and do not hesitate to contact us if we can participate more fully.

Sincerely,

Thomas J Arminski

for Richard S. Fleming
Deputy Project Manager, Environment

RF:ms

cc: Commissioner Richard Lyon, DCED, Juneau
Commissioner Esther Wunnicke, DNR, Juneau
Susitna Area Plan Study Team Members
Mr. Carl Yanagawa, ADF&G, Anchorage
Mr. Jeff Smith, DC&RA, Anchorage
Mr. Ned Farquhar, DNR, Juneau
Mr. Dwight Glasscock, H-E, Anchorage
Ms. D. Jane Drennan, PM&S, Washington, D.C.

9795/045

ALASKA POWER AUTHORITY RESPONSE
TO AGENCY COMMENTS ON LICENSE
APPLICATION; REFERENCE TO
COMMENT(S): I. 321

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

ENVIRONMENTAL STUDIES - SUBTASK 7.12

1982 PLANT ECOLOGY STUDIES

FINAL REPORT

APRIL, 1983

By

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LGL ALASKA RESEARCH ASSOCIATES, INC.

1 - SUMMARY

The range ecology group of the University of Alaska, Agricultural Experiment Station, was responsible for conducting browse inventory and plant phenology studies in the middle Susitna River Basin and a pre-burn inventory and assessment study in the Alphabet Hills of southcentral Alaska.

A total of 47 sites were sampled from 27 July to 20 August, 1982, to measure canopy cover, shrub stem density, browse utilization, browse availability, and current annual growth biomass in the browse inventory study. The 47 sites were classified and grouped into 10 Level IV vegetation types based on Viereck et al.'s (1982) vegetation classification system. Five of the sampled vegetation types were forest: Open White Spruce, Open Black Spruce, Woodland Spruce, Open Birch Forest, and Open Spruce-Birch Forest. Five of the sampled vegetation types were scrub: Dwarf Birch, Dwarf Birch-Willow, Open Ericaceous Shrub Tundra, Ericaceous Shrub-Sphagnum Bog, and Low Willow Tundra.

Picea glauca was the dominant overstory tree in the Open White Spruce and Woodland Spruce vegetation types while *Picea mariana* dominated the tree canopy in the Open Black Spruce vegetation type. In these 3 needleleaf forest types, *Alnus sinuata* was the only tall shrub, *Betula glandulosa* and *Salix pulchra* were the dominant low shrubs, and *Vaccinium uliginosum*, *V. vitis-idaea*, and *Empetrum nigrum* were the dwarf shrubs with the highest average canopy cover. *Petasites frigidus* and *Cornus canadensis* were the predominant forbs. Moss cover averaged 46% in the needleleaf forest types. *Alnus sinuata*, *B. glandulosa*, and *S. pulchra* were the dominant shrubs producing leaf and twig current annual growth biomass and gross available twig biomass in the 3 needleleaf forest vegetation types. Percent utilization of these shrub species ranged from 2% to 30% in the needleleaf forest. *Betula papyrifera*

and mixed Picea glauca - B. papyrifera stands were the dominant overstory cover in the Open Birch Forest and Open Spruce-Birch forest vegetation types, respectively. Alnus sinuata was the dominant tall shrub in these deciduous forest types. Dryopteris spp., Epilobium angustifolium, and Linnaea borealis were the predominant forbs.

Betula glandulosa had both the highest canopy cover, stem density, current annual growth biomass, and gross available twig biomass in the Dwarf Birch vegetation type of all vegetation types sampled. Percent utilization of twigs, however, was only 3%. Salix pulchra had low canopy cover and scattered distribution in the Dwarf Birch Type, but still averaged 14 kg/ha current annual twig growth biomass with 9% utilization. The Dwarf Birch-Willow vegetation type was only 1 of 2 types sampled where the low shrub S. pulchra had canopy cover estimates approximately equal to or greater than B. glandulosa, although stem density estimates remained lower. Current annual growth biomass of both leaves and twigs of B. glandulosa remained much higher than for S. pulchra. The ericaceous shrubs Vaccinium uliginosum, V. vitis-idaea, Empetrum nigrum, and Ledum groenlandicum were dominant low-growing shrubs in the Open Ericaceous Shrub Tundra and Ericaceous Shrub-Sphagnum Bog vegetation types. Salix pulchra in the Low Willow Tundra vegetation type had both the greatest canopy cover and stem density in the vegetation types sampled.

The phenology study was initiated to evaluate forage availability for cow moose during parturition along the canyon slopes above the middle Susitna River. If critical spring forage were found only in the potential impoundment area, then moose survival and reproduction may be impacted by the reservoir. Exclosures were erected in late May at 4 elevations along 4 transects (3 at 1 transect) on south-facing slopes to protect plants from grazing. The exclosures were sampled and the corresponding north-facing slopes were observed at 7-day intervals for phenological development of the vegetation and evidence of utilization by moose. These observations were made from 31 May to 2 July 1982. Some general observations were made on a reconnaissance survey on 15 and 16 May. Samples were also obtained at the end of the growing season from 31 August to 3 September 1982.

Elevation within transect and transect location had a significant effect on soil temperature, plant canopy cover, and current growth biomass during the spring period. However, the effects of elevation were not consistent among transects. On some transects vegetation matured faster at the bottom-elevation site while on others it matured faster at the middle-slope or at the highest elevations. Vegetation along one of the transects matured much later than along any other transect. Timing of vegetation development resulted from an interaction of climate, topography, and site history. Some plant maturation differed among species at the same site. Most early-developing sites that were studied were above the level of the potential impoundment, but could be influenced by mesoclimatic changes created by the reservoir.

Twenty-five sites were sampled for cover of shrubs, herbaceous plants, lichens, and bryophytes in the Alphabet Hills study area. The density of trees as well as tall and low shrubs was estimated at each site. Biomass and utilization of major tall and low shrub twigs were also estimated. The sites examined were classified into 5 vegetation types: Open White Spruce, Open Black Spruce, Woodland White Spruce, Dwarf Birch, and Dwarf Birch-Willow. *Picea glauca* and *P. mariana* were the major tree species present in the study area. *Betula glandulosa*, *Salix pulchra*, and *Salix glauca* were the most abundant low shrubs. Utilization was greatest for *S. pulchra* twigs.

Vaccinium spp. and *Empetrum nigrum* were the most abundant dwarf shrubs. *Equisetum* spp., *Cornus canadensis*, and *Petasites frigidus* were the most abundant forbs. *Carex* spp. were also abundant, as well as bryophytes and lichens.

Vegetation type names were indicative of the relative abundance of trees and/or shrubs in each type. Cover of herbaceous vascular plants was inversely related to shrub density in the study area. Fire may increase the potential of Open White Spruce, Open Black Spruce, and Woodland White Spruce types as moose habitat. Shrubs that are major foods of moose in Alaska exist in these types. In addition, the Dwarf Birch-Willow sites had the greatest density of those important shrub species, presumably due to a relatively recent history of fire.

ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION; REFERENCE TO COMMENT(S): I. 348

Notes on

ICE JAMS

by

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INTRODUCTION

Without doubt the most dramatic event on a northern river is the formation of a large ice jam. This can cause water levels that far exceed even the largest summer, or open water, flood levels, with obvious consequences for riverside communities and engineering structures. Figure 1(a) compares breakup and summer flood levels for Fort Vermilion on the Peace River in Alberta. The location is shown in Figures 1 and 2 of Appendix II. The dominance of the breakup water levels is obvious. The view from the front door of one of the riverside homes in the town during the fourth highest flood is shown in Figure 1(b). Bridge superstructures must obviously be placed well above such levels to avoid the problems shown in Figures 2 and 3, and development located to avoid the problems shown in Figures 4 and 5.

The sudden failure of ice jams can cause high velocity flow and the movement down river of large ice floes at high water levels. It is noteworthy that each pier of the bridge recently constructed at Fort Vermilion was designed to resist the full ice load of 7 MN applied at the highest breakup stage shown in Figure 1(a). Ice jams can also cause unusual scour both of the bed and banks, the latter more by the flow of water in unexpected locations rather than the physical abrasion of the ice.

Ice jams are therefore an extremely important feature of river engineering in cold regions*. Yet, in comparison with summer floods, their characteristics are poorly known.

Ice jams can be very local and very brief; yet very damaging. In unpopulated regions they are also unrecorded. These features make it desirable that the mechanics of ice jam formation and behaviour be understood because statistical records of breakup water levels are few and, more importantly, unlike summer flood records, those few cannot be transposed to other locations along even the same river.

ICE JAM TYPES AND CHARACTERISTICS

Ice jams can be broadly classified on the basis of the season in which they form - freeze-up, winter and breakup - and of their type - floating and grounded.

Freeze-up Jams

These form when the stream becomes gorged with frazil ice, as shown in Figure 6, or when the down-river passage of pancake ice becomes obstructed and a jam forms.

Winter Jams

These form when a mid-winter thaw causes breakup. By definition such a breakup does not extend over a long length of the stream. The supply of

* When defining the geographical limits of cold regions it is well to recall events such as the ice jam in 1899 on the Mississippi River at New Orleans! (Gerdel, 1969).

ice floes is therefore limited and the increase in discharge is of short duration. These two features generally limit the magnitude of the water level increases. The major significance of such jams is that they refreeze forming a formidable obstruction for the subsequent spring breakup. This is also a danger with freeze-up jams (for example, see Frankenstein and Assur, 1972).

Breakup Jams

Generally these are of most concern and form during the general spring ice run.

After initiation an ice jam can develop into a floating or grounded ice jam.

Floating Jam

This type of jam maintains a relatively unobstructed flow of water under its full length, except perhaps for a short section near the toe (downstream end) of the jam. It seems to be the most common type of jam and is sketched in Figure 7(a).

Grounded (or Dry) Jam

In this jam type the ice accumulation extends to the stream bed over a considerable portion of the length of the jam. The jam then behaves much like a rockfill dam, as shown in Figure 7(b), with the character of the flow being that of flow through porous media. High water levels can therefore be expected.

The discussion that follows deals with breakup jams. Such jams will obviously depend heavily on the time and manner of breakup. This is briefly reviewed first.

BREAKUP AND ITS PREDICTION

First, it is important to realise that there are some rivers in cold regions which rarely, if ever, experience a well-defined ice run. Such streams are generally braided and shallow with large expanses of ice frozen to the bed, such as the Delta River shown in Figure 8 (which is nowhere near a delta). Such streams are very common in N.W. North America. However for streams in which an ice run is a regular feature, the nature of breakup at a given location depends on:

(i) snow melt (magnitude and rate of rise of water level);
(ii) thickness and strength of the ice cover;
(iii) water level at freeze-up;
(iv) quantity of ice moving down from upstream and, last, but definitely not least;
(v) morphology of the river.

Breakup can progress upstream or downstream depending on the orientation of the river and its tributaries relative to the spring isotherms and the occurrence of snowmelt and/or spring rains. In many instances breakup occurs first along the central portions of a stream because of the breakup of a major tributary. However, no matter in which direction breakup progresses, it is a progression only in a very general sense; there are many local perturbations, these often taking the form of major ice jams.

Breakup is instigated by changes in one or both of two features: water level and ice sheet strength. The ice can become so weak that a low flow is sufficient to fragment and move the ice out. In this case the ice run will be minor. At the other extreme the water level and flow can increase sufficiently to float a strong ice sheet free of the bed and banks and to fragment the ice sheet. For a competent ice cover it would seem breakup can only occur in an intermittent fashion, with ice jams forming, however briefly, to build up water levels and release surges. Such a surge will move ahead of the fragmented ice to keep the breakup front moving. As will be discussed later, the celerity of such surges can be very high.

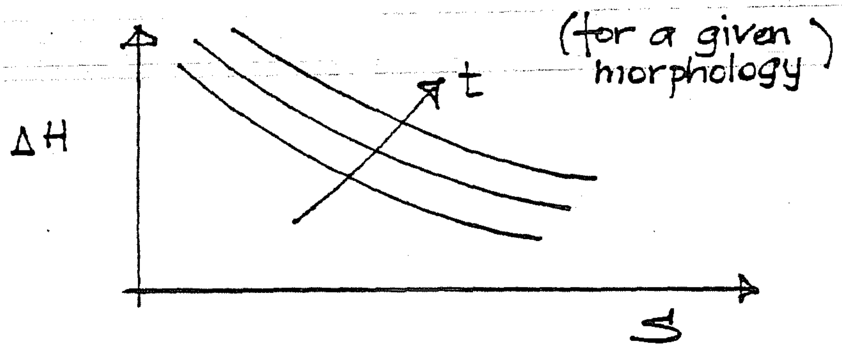
From the above discussion it would seem the three most pertinent parameters governing the moment and manner of breakup at a given location are:

(i) the difference in water level from that just after the formation of a stable ice cover during freeze-up, ΔH;
(ii) ice thickness, t_i;
(iii) the number of degree days of thaw, S, which provides a measure of the ice strength.

That item (i) is relevant is supported by the graphs shown in Figure 9, taken from Shuliakovskii (1963). Item (iii) is supported by the other graph shown.

If item (iii) is important there is little doubt that ice thickness should also be a parameter, although it may vary little from year to year at a given site. However, it should be remembered that the natural ice thickness can be modified by the formation of a freeze-up jam, winter jam or aufeis.

Presumably, for a given river morphology, the relation between breakup and these parameters will have the form:



Unfortunately no systematic evaluation of such a function has been reported in North America. About all that can be said at present is that breakup will not occur until about 30°C days have accumulated and the water level has increased somewhat beyond that at freeze-up.

The required increase in water level can be caused by snowmelt (or rain) or by an ice jam failure upstream. Either of these can occur on the mainstream or an upstream tributary.

To give some idea of the way breakup progresses Figure 10 shows a summary of the average breakup dates for the major streams in Alberta, Canada. There are several features of interest. As mentioned above, several streams breakup in their central reaches first, the breakup generally being triggered by breakup in a major tributary. This role of tributaries in causing breakup on the mainstream can be an important consideration. If the relative discharges of tributary and mainstream are changed (for example, by regulation or diversion) this will change the influence of the tributary on breakup in the mainstream, and, consequently, may change the frequency of ice jams at and near the confluence.

Also of interest in Figure 10 is the concentration of the isochrones at the Wabasca - Peace confluence near Ft. Vermilion. This is probably indicative of ice jams at the confluence and suggests that, unlike the Smoky River near Peace River town, breakup on the Wabasca is not strong enough to cause breakup on the Peace River.

In addition to being important in the spring, the risk of inducing breakup imposes important constraints on the allowable range of discharges from hydro-plants (Burgi et al., 1971; Pentland, 1973).

Some field observations of breakup have been reported (eg. MacKay, 1965; Newbury, 1967; Johnson and Kistner, 1967; Nuttall, 1970; Slaughter and Samide, 1971; Sampson, 1973; McFadden and Collins, 1977); and Michel and Abdelnour (1975) have done some preliminary studies in the laboratory using simulated ice, but in general much of engineering significance remains to be learned about the common event called breakup.

INITIATION OF ICE JAMS

The initiation of ice jams during breakup will probably be a function of the same variables as breakup. Hence ice jams can be expected with large ice thickness, heavy snow accumulation and a large and rapid increase in temperature above freezing. On the other hand, ice jams are less likely if there has been little snow or there is a gradual onset of spring. If an ice jam forms its severity will be a function of the rate of rise of water level (and the associated velocity), the amount of ice travelling with the breakup front, and the nature of the obstacle that initiates the jam.

Obviously with all these parameters fixed, the probability of a jam at a particular location will depend on the river morphology. This can at least be roughly analysed. Using a simple analysis Nuttall (1973) has shown that locations of large mean depth, relative of the average for the stream, cause an increase in concentration of floating ice and hence constitute an hydraulic obstruction to the passage of ice and increase the chance of jam initiation. Such locations will correspond to bends and narrows. At these locations, the plan form of the stream provides a further impediment to the passage of ice. The headwaters of reservoirs provide other examples and these are indeed a common location of ice jams. Sudden changes in slope from steep to flat also seem to be prime ice jam locations. This is presumably related to the deepening of the flow and the decrease in velocity.

Such high ice concentrations can also be caused by physical obstructions such as islands and bars. A very common physical obstruction is the ice sheet on the river, particularly if it is thick or more shore - or bottom - fast than normal (eg. because of freeze-up of winter jams, aufeis, or hanging dams). The mainstream ice cover is a frequent cause of ice jams at the mouth of tributaries.

The Athabasca River at Fort McMurray, Alberta, (see Figure 10), is an example of a location where both hydraulic (sudden decrease in slope and increase in depth and width) and physical obstructions (islands, bars, bend, wide ice sheet) exist. Not surprisingly, therefore, it is a location where ice jams form almost annually.

FLOATING ICE JAMS

Ice jam initiation has been briefly discussed. After initiation the future characteristics of a breakup jam depend on a series of hydraulic and structural constraints.

A general analytical framework for determining the major characteristics of floating ice jams was established over a decade ago by Pariset and Hausser (1961), Michel (1965) and Pariset, Hausser and Gagnon (1966). The analysis reflected that of an earlier investigation of the mechanics of log jams by Kennedy (1958). Some refinements to the analysis were added by Uzuner and Kennedy (1976) but, as pointed out by Beltaos (1978), the essentials remained unchanged. The latter investigator applied the analysis to two natural ice jams on the Smoky and Wapiti Rivers in Alberta with encouraging results. Another successful application is reported by Macdonald and Hopper (1972). Although further confirmation under field conditions is obviously desirable, the approach seems viable. It should therefore be possible to determine reasonable values for the maximum breakup water levels at a site caused by steady floating ice jams, using records of past breakup discharges. The latter are generally both transposable and available.

Hydraulic Constraints

If the surface velocity is low enough ice floes will simply accumulate against the solid ice cover or obstruction and the accumulation front will move upstream to leave behind an accumulation one layer thick.

However, if the velocity exceeds a critical value the ice floe will turn under when it contacts the obstruction, and will be entrained by the flow. Again depending on the flow velocity, it may then be deposited under the downstream ice cover or carried on downstream.

The deposition velocity has yet to be investigated in any detail for freeze-up or breakup conditions. If the latter occurs the ice front cannot move upstream until some event occurs downstream to lower the velocity near the front. If the former occurs, floes will accumulate under the downstream ice cover until the obstruction is such that the surface velocity at the front is reduced and the impinging ice floes are not entrained. The front will then begin to move upstream and the process of entrainment, deposition and surface accumulation repeated. This will result in a steady progression of the front if another condition is satisfied.

It is argued that there is a tendency for the front of such an accumulation to be entrained by the flow as it moves under the accumulation. This requires a local acceleration of the flow which in turn requires a lower piezometric head downstream. This causes a lowering of the water level just downstream of the front, much like the lowering of the water level in subcritical flow over a hump in the bed.

A simple analysis of the hydraulics of the situation along these lines suggests that the front will be engulfed when

$$\frac{V}{\sqrt{gt\,(1 - s_i)}} = \sqrt{2}\,(1 - \frac{t}{h})$$

t_1 = floe thickness
t = accumulation thickness

where V is the average approach velocity, h the approach depth, t the accumulation thickness, and s_i the relative density of the ice (Pariset, Hausser and Gagnon, 1966). A rearranged version of this relation is compared with experimental and field results in Figure 11. The agreement is noteable. Figure 11 indicates that an ice accumulation cannot progress upstream if $F = V/\sqrt{gh} > 0.16$ and that the dimensionless thickness, t/h, of the front portion of the accumulation must be less than 0.33. Field measurements (Kivisild, 1959) suggest that the critical value of F is actually about 0.08-0.10.

If the approach velocity is such that $F > 0.1$ (e.g. about 1.1 m/s for 10 m depth) no accumulation is possible (i.e. any accumulation will be continually engulfed) until a backwater due to some obstruction downstream reduces the velocity below the maximum accumulation velocity. If this occurs the accumulation should then progress, leaving behind a thickness that, initially, is close to 1/3 of the flow depth.

Such are the hydraulic restraints placed on a floating ice jam.

Structural Constraints

As an accumulation progresses upstream an increased area of accumulation is exposed to the drag of the flow passing underneath. This accumulated drag must be transferred back to the original obstruction, or to the banks of the stream. To transfer this load, the accumulation must be strong enough to sustain it. As pointed out by Pariset et al. (1966) the compressive strength of the accumulation is a direct function of its thickness. If the thickness given by the hydro-dynamic constraints is insufficient to sustain the load to be transferred, the accumulation will collapse or shove until it is thick enough. The channel is considered narrow if the maximum thickness of the accumulation given by the hydraulic constraints is sufficient to sustain the additional load from an advance of the front by shear on the banks. In this case the accumulation thickness is governed by the hydraulic constraints.

The channel is considered wide if the accumulation shoves as it lengthens. The shoving increases the maximum thickness until the drag added by an advance of the front is sustained by shear on the bank as shown in Figure 12. When this thickness is reached no additional load is transferred to the obstruction. Thereafter the maximum accumulation thickness remains the same despite a lengthening of the accumulation. The thickness left behind as the accumulation advances is then governed by the strength of the accumulation - that is, by the structural restraint. This maximum thickness has come to be called the equilibrium thickness.

The strength of an accumulation of ice and therefore, in a wide river, its thickness depends on parameters μ, which is related to the porosity and internal friction of the accumulation, and C_i, a cohesion parameter. The maximum accumulation thickness is given by (Michel, 1965; Pariset et al., 1966; Uzuner and Kennedy, 1976).

$$\mu\rho_i\ (1 - s_i)gt^2 - [(g\rho_i S - \frac{2C_i}{B})B]\ t - \tau B = 0$$

B - ice surface exposed to bottom shear

where S is the channel slope, B the channel width at the bottom of the accumulation, and τ is the shear of the water on the bottom of the accumulation as shown in Figure 13.

Similar values of μ have been determined from field measurements in at least two independent investigations (Pariset et al., 1966; Beltaos, 1978) and these values are not inconsistent with those found in the laboratory (Uzuner and Kennedy, 1976). From these investigations a value for μ of 1.2 seems reasonable. Little is known about the cohesion parameter, except that its effect seems to be small in breakup jams. Laboratory tests suggest $C_i \approx 100 - 500$ Pa.

For uniform flow under the accumulation

$$\tau = \rho g h_i S$$

in which h_i is the distance from the bottom of the ice accumulation to the maximum velocity point. The ratio h_i/h_j, where h_j is the depth of flow beneath the jam, can be found from given roughnesses by

$$\frac{h_i}{h_j} = \frac{1}{1 + k_r^{-1/4}} \quad \text{where } k_r = \frac{k_i}{k_b}$$

In turn, h_j can be found from

$$\frac{V_j}{V_*} = 2.5 \ln \frac{R}{k} + 6.2$$

where $V_j = \frac{Q}{h_j B}$: $R = \frac{h_j}{2}$: $k = k_b\left(\frac{1 + k_r^{1/4}}{2}\right)^4$: $V_* = \sqrt{gRS}$

The roughness of the ice cover seems to be related to the thickness of the ice cover (Kennedy, 1958; Nezhikhovskiy, 1964; Tatinclaux and Cheng, 1978) and, reason would suggest, the size of the ice floes. That is

$$\frac{k_i}{\ell_i} = f\left(\frac{t}{\ell_i}\right)$$

where ℓ_i is a typical floe length. A crude estimate of the form of this function is shown in Figure 14.

To calculate the equilibrium accumulation thickness all these relations must be satisfied simultaneously. A suggested procedure is

1. Estimate k_i
2. Calculate h_j
3. Determine B
4. Calculate h_i
5. Calculate τ
6. Calculate t
7. Calculate water level = $h_j + 0.9t$

A typical calculation is detailed in Appendix I. Consideration of the above will indicate that the increased water level is caused both by the additional roughness, and the additional thickness of the accumulation, over that of the normal solid ice cover.* On large flat rivers the former is the more important influence. In smaller steep streams the latter would probably be more important.

Because it is based on uniform flow calculations the above calculations give an estimate for the maximum level along a floating ice jam. However the actual water level will follow a gradually varied flow profile as sketched in Figure 7(a). An actual example is shown in Figure 7(c). The calculation of such profiles is not considered herein, but are little more complicated than gradually varied flow calculations for normal open channel situations if the downstream boundary condition can be determined. This however is difficult at present.

It is important to keep this open channel behaviour of ice covered channels in mind when assessing water levels along such channels.

* If the ln expression for velocity is replaced by a power function approximation, steps 4-7 collapse into the evaluation of the single expression given in Appendix 1. If, further, B varies little with h_j, over the values of h_j of interest, this would include steps 2 and 3 too. The siple relation for maximum ice jam stage that then results is given in Appendix 1 and shown in Figure 15.

In all the above investigations the possibility of channel bed changes have not been considered. Yet such changes could have an important influence on the behaviour of the jam and the water levels it causes, and presumably on such engineering structures as buried pipelines, bridge piers or spur dykes that lie on or under the bed. A field observation of such scour is discussed below. A first attempt to calculate scour under a quasi-steady floating ice jam has been reported by Mercer and Cooper (1977).

Stability of Floating Ice Jams

If the situation that prevailed at formation changes, the accumulation configuration may change. For example if the discharge increases the accumulation can be expected to shove and thicken. However, if the discharge is reduced little should change, other than the water levels. Andres (1980) took advantage of this in their analysis of the 1978 ice jam at Fort McMurray. Likewise if the jam is thickened by the deposition of ice entrained upstream it should simply increase the upstream water levels. On the other hand, if the accumulation begins to melt it can become thin enough to be unstable and shove again.

GROUNDED ICE JAMS

These jams can be caused, for example, by the collapse of a floating ice jam, the sudden stoppage of a surge of ice and water, or by blockage of the flow under a hanging dam. Given the limited and irregular depths of most natural channels, the formation of such jams is an obvious possibility. The destructive jams described by Barnes (1928) and Frankenstein and Assur (1972), on the Allegheny and Israel Rivers respectively, were known to be grounded. The description of the Moira River ice jams at Belleville (Lathem, 1974) suggests that they only became threatening when the passage under the ice was blocked - that is, when the jam primed. Mathieu and Michel (1967) found that if the ratio of the flow depth beneath a floating jam was less than the largest dimension of the entrained floes, the jam would 'prime' and become a grounded jam.

As stated by Michel (1971) "in such jams the headlosses are considerable compared to those of a simple [floating] jam. It has been impossible to determine these losses in a general manner because of the seemingly fortuitous length of grounding in each case and the variable solidarity of the accumulation of the floes". This states the problem succinctly. However, given the possibility that such jams may be responsible for the highest breakup water levels, much further work is required on this type of jam, if only to establish a reasonable upper limit on the high water levels possible.

ICE JAM FORMATION AND FAILURE: THE UNSTEADY CASE

Almost all past work has been concerned with almost-steady flow past an ice jam. However an examination of reports recorded in archives and told by eye-witnesses reveals important features of observed ice jams that are difficult to explain from steady flow considerations. A minor but typical example is provided by Johnson and Kistner (1967). During breakup of the Meade River on the north slope of Alaska "a flow of brownish river water about 40 cm in height was progressing over the top of the river ice (June 7) ... at the pace of a fast walk, perhaps 8 km/h. A floe [sic] of jumbled ice blocks choked the channel behind the slush wave. This ice flow [sic] at times overflowed the unbroken ice or simply created ice blocks as it advanced. The advancing ice flow [sic] with its slurry of water and ice blocks jammed quite suddenly when it reached a narrowing of the channel 0.5 km below camp. The river, now completely choked with jumbled ice blocks, rose rapidly, about 2 m in 1.5 hours ....

On the afternoon of the 10th a very high water level allowed the ice jam to slip downstream ... evidently a similar ice jam had broken upstream ... this time considerable ice arrived from upstream and the river was choked with ice blocks for several kilometres upstream [see Figure 16a]. On the night of the 11th the entire ice floe [sic] broke .... After the dam [sic] released, the river level dropped briefly on the 11th and again on the 13th leaving both banks lined with vertical cliffs of ice blocks 3-4 m high (Figure 16b).

A characteristic of the more dramatic reports is the extremely rapid rise in water levels. For example, in the Athabasca River at Fort McMurray in 1875 "in less than an hour the water rose 57 feet, flooding the whole flat and mowing down trees, some 3 ft. diameter, like grass ..." (Moberly and Cameron, 1929); on the Peace River near the Mikkwa River confluence in 1886 "the ice in the Peace River struck during the night and about 2 a.m. the water rose rapidly in the Red [Mikkwa] River. Two feet more of rise would have put it over the banks ..." (Hudson's Bay Co. Journal, Red River, 1886); on the Athabasca River 35 km upstream of the House River confluence in 1936 "During the night they [three men] awakened to find three feet of water in the room. Scrambling into some clothes they waded out and untied their horses and tried to find higher ground. The water rose so rapidly that all they could do was to climb a tree. Lee and Cinnamon got a safe one and climbed higher as the water rose. They could see Donaldson in difficulties and shouted to him, but he appeared unable to climb or the sapling would not support him and he gradually sank out of sight ..." (Athabasca Echo, 27 April 1936, Athabasca, Alberta); on the Red Deer River near Red Deer the water rose 11 m in about 3 hours and removed the superstructure of a CNR bridge (Morris, 1976).

Such rapid increases can only be explained by the action of surges created by the failure, and perhaps the reformation, of ice jams. That such surges occur is supported by the several reports in the literature of very high velocities. For example Killaly (1887) observed "the ice [on the Missouri River] in the neighborhood of St. Joseph ... came down from above with a rush, causing a sudden rise in the river .... The river foamed and hissed. The whole waterway was filled with broken ice grinding along the bottom, and pitching and tossing on the surface. The water itself was not to be seen, as the mass of broken ice, and drift rolled by - forest trees and masses of brush, wreckage of all sorts, whirling around, and forced into the air by the upward action of heaving ice. A gorge [jam] had broken above ...." Doyle (1977) reports on breakup in 1977 on the Athabasca River at Fort McMurray: "Flood wave estimated to be 5 m high rushes downstream past bridge tossing ice blocks into air as it passes at an estimated velocity of 5 - 6 m/s". With such behaviour possibly preceding the formation of an ice jam it is difficult to imagine they would take up the orderly characteristics envisaged when analysing steady, floating jams. In particular, the increased possibility of priming a grounded ice jam when such 'ice surges' are halted to reform a jam is obvious.

Consideration of the result of a sudden halting of such a surge suggests the answer to another anomaly. The quotation given above reports a 17 m increase in water level just after the passage of a surge on the Athabasca River at Fort McMurray in 1875. If this is simply caused by the passage of a surge released by an ice jam failure upstream, this ice jam would have had to be at least double this height - say about 35 m high. Although such an ice jam may be possible in the deep valley of the Athabasca River upstream of Fort McMurray, it is unlikely. However, if the consequence of a surge reflection caused by the sudden reformation of the jam downstream of Fort McMurray is considered, a much lower initial surge, and hence a lower upstream ice jam, is required to explain the increase in water level noted.

This line of reasoning, and the analysis of surges created by ice jam formation and failure has been pursued by Henderson and Gerard (1981). This analysis considered the consequences of sudden complete failure and subsequent reformation of ice jams. It confirmed the change in water level downstream of an ice jam immediately after failure cannot be more than half the initial water level difference across the jam. It also showed that extremely high velocities can be expected downstream of such a failure. A field example of high velocities after a partial jam failure has been reported by Gerard (1975). The 2-3 m standing waves created by this sudden discharge is shown in Figure 17. Figure 18 shows another example on the Yellowstone River in Montana. Doyle (1977) reports velocities as high as 6 m/s caused within an ice jam as it readjusted within an ice jam as it readjusted. Both Henderson and Gerard (1981) and Beltaos and Krishnappan (1981), the latter using numerical techniques, have investigated the behaviour of the jam documented by Doyle (1977) and report good agreement between prediction and observation. Measurements of the propagation of surges, both in the upstream and downstream directions, have been reported by Calkins (1981). Although often of short duration (from minutes to hours) the possibility of unusual scour by such events is obvious; to quote Killaly (1887) again "On the 24th [February] a gorge occurred .... The river hurled itself, with great force, against dyke No. 6, and washed along its face ... in a few hours the whole face of the dyke had been undermined; the channel having scoured out a depth of thirty-four feet [from the account this seems to represent about 4 m of scour]. The dyke 'turned over'!"

BREAKUP WATER LEVELS

As mentioned before, a major incentive for developing an understanding of ice jam behaviour is the need to predict breakup water levels for river engineering design purposes. These are often more important than water levels caused by summer, or open water, floods. They should therefore be subject to at least as much scrutiny in a river engineering investigation.

Analytical Estimates

Some indication of what these levels might be can be determined by analysis.

Lower Bound

If no ice jams are expected to form at the location of interest the breakup water level will be closely related to the freeze-up water level. As discussed previously indications are that, for a reasonably competent floating ice cover, breakup will occur when the water level rises about a metre or so above the maximum winter stage. This relation can be refined for a particular site if some observations on the time of breakup are available.

After the relationship has been established breakup water levels for various past years can be estimated from winter discharge records and estimates of the thickness and roughness of the ice cover at the time of maximum winter stage. A probability analysis can be carried out on these estimates to fix a lower bound on the breakup stage distribution. It should be noted that in many locations these no-ice-jam levels will be above the 2-5 year summer flood levels.

Upper Bound

On the assumption that only floating jams can form and that they form downstream of the site each year, an upper bound for the probability distribution of breakup water levels can be estimated using discharge records and the analysis of floating ice jams described above.

If no grounded jams form the actual probability distribution should be somewhere between these bounds, depending on the probability of an ice jam forming in the reach each year. Unfortunately, this probability is difficult to determine. The other limitation on the above analysis is that jams other than simple floating jams may form in or near the reach of interest. As pointed out above, the present understanding of breakup events other than quazi-steady floating jams is very poor.

Hence because of these limitations on the current ice jam state-of-the-art, the above deterministic estimates must be supplemented by as much information on actual past breakup water levels as possible.

Empirical Estimates

As noted previously breakup water levels are very site-specific. Therefore to be useful the water level records must come from very near the site of interest. Sometimes information is available from residents, whether permanent or itinerant (eg. farmers, trappers). Other times information can be gleened from archives of a nearby community (newspapers, biographies, maintenance records, journals, family photographs, etc.). In some cases a standard hydrometric gauge is installed in or near the reach, although failure of these installations during breakup is common. If such a gauge exists the original chart recordings or field notes must be examined. If an ice jam did form the water level changes may be rapid and will make interpretation of the chart difficult. An example is shown in Figure 19.

However, more often than not, there are neither inhabitants nor gauges near the reach of interest. The only available information is then that which can be deduced from environmental evidence such as trim lines, windrows, and damaged vegetation. Of the latter the most important items are the ice scars left on trees by high ice, an example of which is shown in Figure 20. The elevations of these scars provide a lower bound on the higher breakup water levels that have occurred during the life of the trees. If the scars are sampled as shown in Figure 21, and their age determined by tree-ring dating (Sigafoos, 1964; Parker and Lozsa, 1973), an approximate history of past high breakup water levels can be reconstructed. A typical record completed in this way is shown in Figure 22.

On the basis of this observational data, both historical and environmental, another estimate of the breakup water level probability distribution can be made. A method for carrying out a probability analysis of such unorthodox data is described by Gerard and Karpuk (1979), exerpts of which are included herein as Appendix II.

An engineering assessment of the results of the analytical and empirical investigations will allow a compromise probability distribution for breakup water levels to be chosen. This should then be combined with the estimated probability distribution for summer floods to get the required probability distribution for design.

Joint Probability Analysis

The two types of floods are more or less independent and are not mutually exclusive (ie. both can occur in a given year). Hence the probability of one or both exceeding a given stage in a year, P, is given by

$$P = P_b + P_s - P_b P_s$$

where P_b = probability of a breakup flood exceeding the chosen stage in a year;

P_s = likewise for summer floods.

This joint probability will obviously be higher than either of the other two. A typical situation is shown in Figure 1(a).

Maximum 'Probable' Breakup Water Levels

As for summer floods it is very useful to have some estimate of the maximum breakup water level that could occur. Like all things associated with ice jams, this is difficult to assess. The potential is exemplified by the following description of an ice jam on the Yukon River (Henry, 1965): "The highest jam causing the greatest depth of flooding, according to reliable reports, occurred at Ruby, Alaska. Ruby is built on a hillside, one of the few villages situated well above the river. In the spring of 1930 a big ice jam formed and the water backed up to the porch level of the present Northern Commercial Company store. Boats, tied to the porch, were at least 35 feet above normal river levels. The river valley is 12 to 15 miles wide at Ruby and remains about the same for miles downstream. So the jam extended at least 15 miles across [sic] and rose to a height of 65 feet. No one knew the location of the blocking jam down river."

With a long well-gounded jam in an entrenched valley the water level is presumably limited only by the discharge and the supply of ice from upstream - the latter being a constraint that should not be overlooked. However, in a reach with a well-developed flood plain, water will be able to move around the toe if the water level rises above the flood plain. The maximum water level should then be a metre or so above the lowest passage on the flood plain. This mechanism limited the water level of the 1963 ice jam on the McLeod River in Alberta shown in Figure 23. (Note that levee construction to provide protection against summer floods could remove this safety valve.)

Although a particular reach may be free of grounded jams it may still be within the backwater from a grounded jam in an entrenched reach downstream, or in the path of a surge released by the sudden failure of one upstream.

Hence at present little more than a qualitative assessment of maximum breakup water levels is possible, but nevertheless such an assessment should be made.

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APPENDIX I

Problem

Determine the water level increase over open water caused by a floating ice jam formed on a river with the average cross-section geometry given below that is carrying a breakup discharge of 2500 m^3/s.

River Slope	0.00005
Bed Roughness k_b	0.3 m

Cross-section geometry (defined from several cross-sections taken along the reach of interest).

Surface Width (m)	Average Depth (m)
558	4.00
616	4.80
830	7.90
881	8.10

Assume μ = 1.3 and C_i = 200 Pa.

Solution

First, as a convenience, graphically find the best-fit power law relation between the surface width and average depth:

$$B = 243\, h_j^{0.6}$$

1. Estimate the hydraulic roughness of the bottom of the ice accumulation

$$k_i \simeq 3.6 \text{ m, say}$$

Composite roughness of flow passage under the accumulation

$$\frac{k}{k_b} \simeq \left(\frac{1 + k_r^{1/4}}{2}\right)^4 \quad : \quad k_r = \frac{k_i}{k_b} = \frac{3.6}{0.3} = 12$$

$$\therefore \; k = 1.26 \text{ m}$$

2. Calculate depth of flow beneath the accumulation. From elementary hydraulics, for uniform flow in a wide channel:

$$\frac{V}{V_*} = 2.5 \ln \frac{R}{k} + 6.2$$

where $R = \frac{h_j}{2}$; $V_* = \sqrt{\frac{gh_jS}{2}} = \sqrt{9.81 \times \frac{h_j}{2} \times 0.00005}$

$$Q = VA = Vh_jB = 2500 \text{ m}^3/\text{s}$$

and $B \simeq 243\, h_j^{0.6}$

Solving for h_j by iteration

$$h_j \simeq 7.8 \text{ m.}$$

3. Determine the flow width immediately under the accumulation

$$B \simeq 243\, h_j^{0.6} = 833 \text{ m.}$$

4. Calculate the distance from the underside of the accumulation to the plane of maximum velocity (or zero velocity gradient, hence zero shear stress).

$$h_i = \frac{h_j}{(1 + k_r^{-1/4})} = 5.07 \text{ m}$$

5. A simple force balance for uniform flow in the upper portion of the flow gives

$$\tau = \rho g h_i S = 9.81 \times 1000 \times 5.07 \times 0.00005 = 2.49 \text{ Pa}$$

6. Calculate the equilibrium thickness of the accumulation

$$\mu\rho_i (1 - s_i) g t^2 - [(g\rho_i S - \frac{2C_i}{B})B]\, t - \tau B = 0$$

therefore

$$[1.3 \times 920 \times (1 - 0.92) \times 9.81]\, t^2$$

where from (assumed)

$$- [(920 \times 9.81 \times 0.00005 - \frac{2 \times 200}{833}) \times 833]\, t - 2.49 \times 833 = 0$$

$$939\, t^2 + 24.1\, t - 2074 = 0$$

$$t = 1.47 \text{ m}$$

by what equation Fig. 14

This gives $k_i \simeq 5.4$ m, which is somewhat different from that first assumed. Hence carrying out a second iteration gives

$$k = 1.64 \text{ m}$$
$$h_j = 7.9 \text{ m} ; V = 0.37 \text{ m/s}$$
$$h_i = 5.32 \text{ m}$$

$\tau = 2.61$ Pa
$t = 1.52$ m

Therefore accept the thickness of the accumulation is 1.52 m. (Note how small this is. It is not known whether ice accumulations of such large rivers are indeed so thin.)

This gives a total depth of

$$h = 7.9 + 0.9 \times 1.52 = 9.3 \text{ m}$$

It is worth noting that this corresponds to the depth for a 20 year flood in this reach.

For open water conditions

$$\frac{V}{V_*} = 2.5 \ln \frac{R}{k} + 6.2$$

solution of which gives h = 5.5 m.

Hence the water level increase caused by the ice accumulation is

$$9.3 - 5.5 = 3.8 \text{ m}$$

Approximate method

If the power function approximation for velocity is used viz.

$$\frac{V}{V_*} \simeq 8.4 \left(\frac{R}{k}\right)^{1/6}$$

steps 4-7 reduce to the evaluation of the expression

$$h' = h_j' + \frac{5.75}{\mu}\left(1 + \sqrt{1 + \frac{0.35\,\mu\, h_j'}{(1 + k_r^{-1/4})}}\right)$$

where $h' = \frac{h}{SB}$: $h_j' = \frac{h_j}{SB} = \frac{\left(\frac{0.19qk^{1/6}}{\sqrt{gS}}\right)^{3/5}}{SB}$

Furthermore, if B varies little over the range of h_j of interest, this would include steps 2 and 3.

For example, in the present case, choosing B = 840 m, the above gives h = 8.7 m, a difference of only 6%.

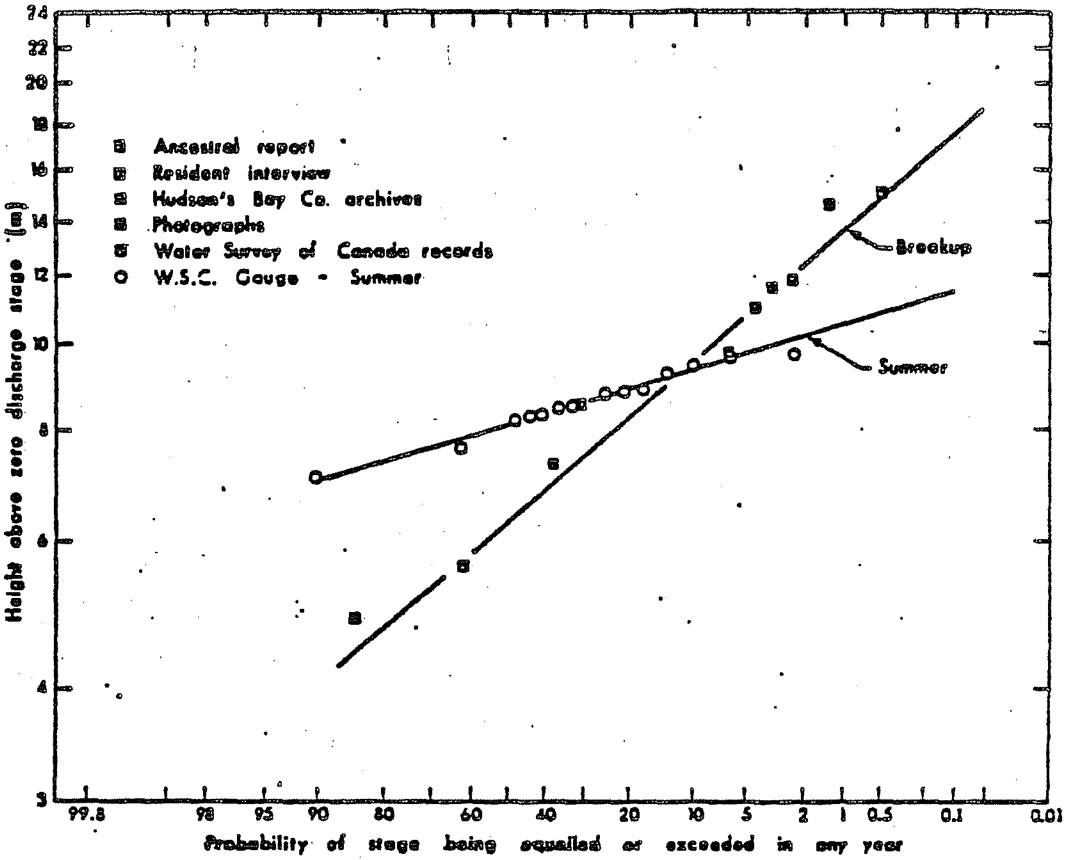


Figure 1(a) Comparison of breakup and summer flood stages, Peace River at Fort Vermilion, Alberta.

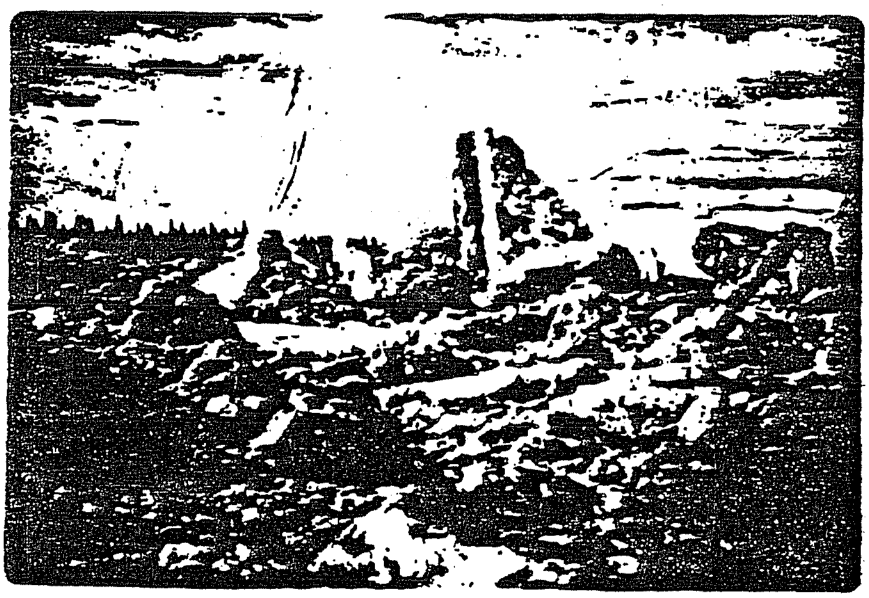


Figure 1(b) Surface of the 1963 ice jam on the Peace River at Fort Vermilion, Alberta.

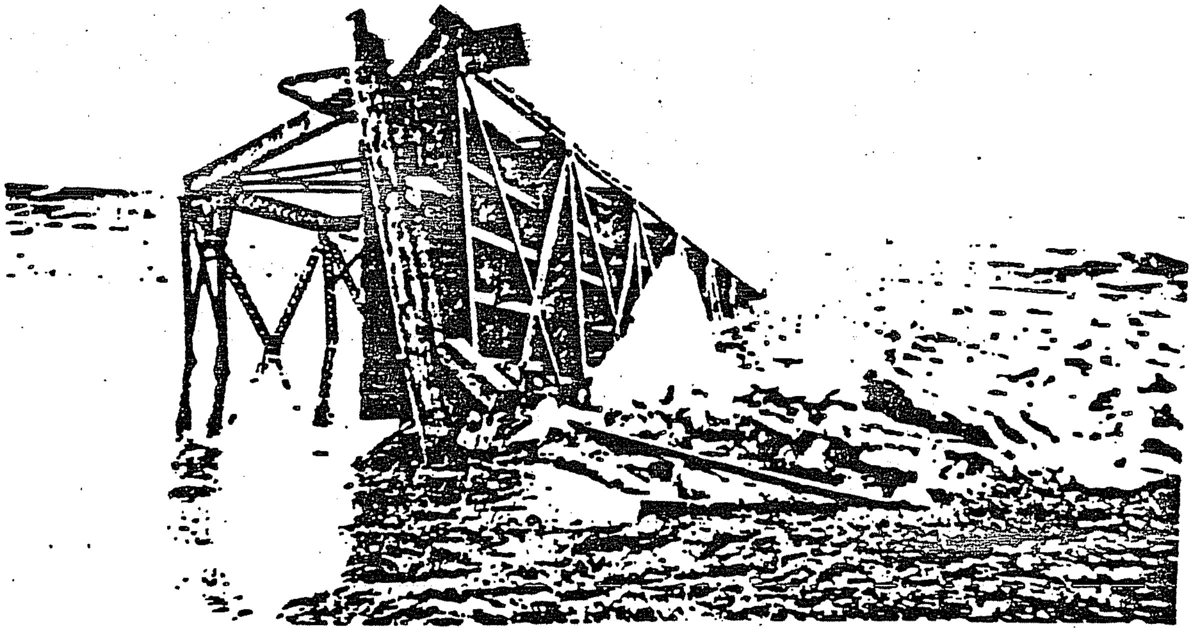


Figure 2 Dead bridge, Milk River near Foremost, Alberta, 1952.

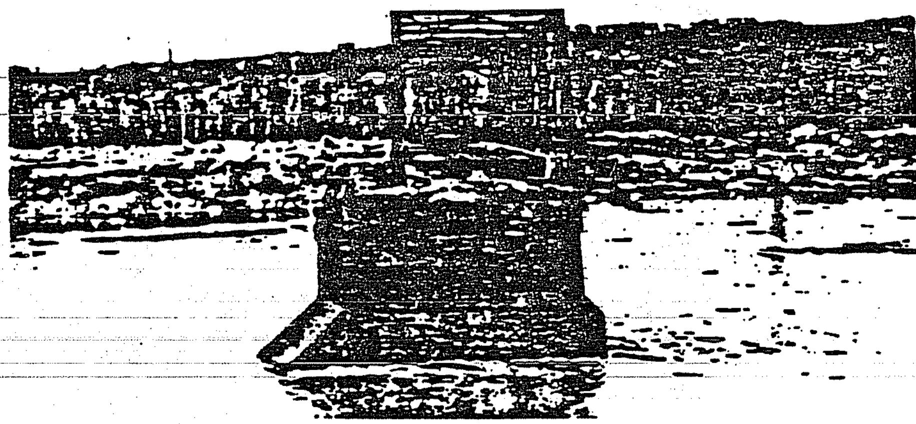
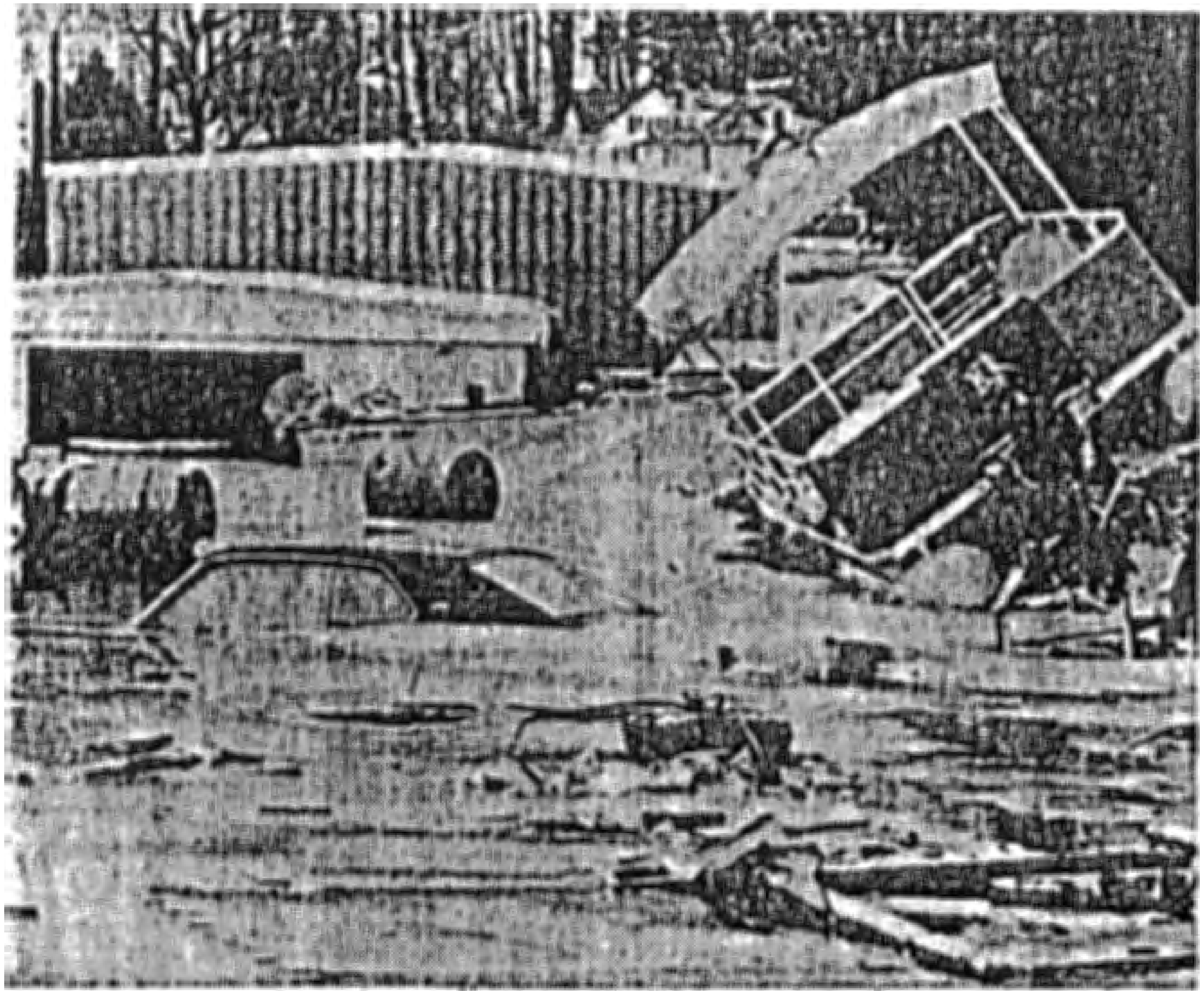


Figure 3 Missing spans, Red Deer River near Content, Alberta, 1928.

(Edmonton Jnl. 31 Jan 78)

Susquehanna ice jam watched



River on rampage

Flooding from the Susquehanna River tossed around boats and inundated cars behind the Pequea Post Office and the Arrowhead Marina in Pennsylvania's Lancaster County. An ice jam caused the flooding.

PEQUEA, Pa. (AP) — Sitting on a bluff at eye level with soaring turkey buzzards, four Pennsylvania Power & Light Co. employees keep watch day and night over this tiny clapboard town.

For six weeks they have staked out a mammoth ice jam on the Susquehanna River a breathtaking 537 feet below. It is the biggest jam since the spring of 1904, when chunks of ice as big as box cars destroyed the upriver town of Safe Harbor, which never was rebuilt.

The men check the ice with binoculars and with stationary transit instruments whose crosshairs are lined up with two amber lights planted by helicopter on the ice, which resembles a sea of moon craters after a dirty snowfall.

Another Pennsylvania Power employee drops a tape into the river every two hours, noting in a log book whether the river is rising or falling.

He and another man have been doing that since Jan. 27, the day the ice arrived from Turkey Hill, a river bottleneck that almost every year fills with debris-packed ice.

"The temperature climbed into the 50s that day and we had three inches of rain," recalled Gordon Stark, 30, whose house sits on the river's bank here.

"That Friday night it was like watching cars on a freeway, those chunks were doing 35 to 40 miles per hour. Then all of a sudden they stopped.

"The river is pretty shallow along here. The big chunks started digging into the mud, and the little ones stacked up behind."

The ice jam spans the milewide river and is about six miles long, starting a few miles upriver from Pennsylvania Power's Holtwood Dam, below town, and extending to the Safe Harbor Dam to the north. The Safe Harbor dam is owned jointly by Pennsylvania Power and Baltimore Gas & Electric.

The ice has already knocked the hydroelectric generating station at Safe Harbor Dam out of operation for six months to a year by backing water into generators, said Arch Knisely, a Pennsylvania Power official in Lancaster. It also toppled a transmission tower, carrying two 230,000-volt circuits.

(Holyoke Transcript 7 Mar. 78)

Figure 4 Report on Susquehanna River Jam, 1978.

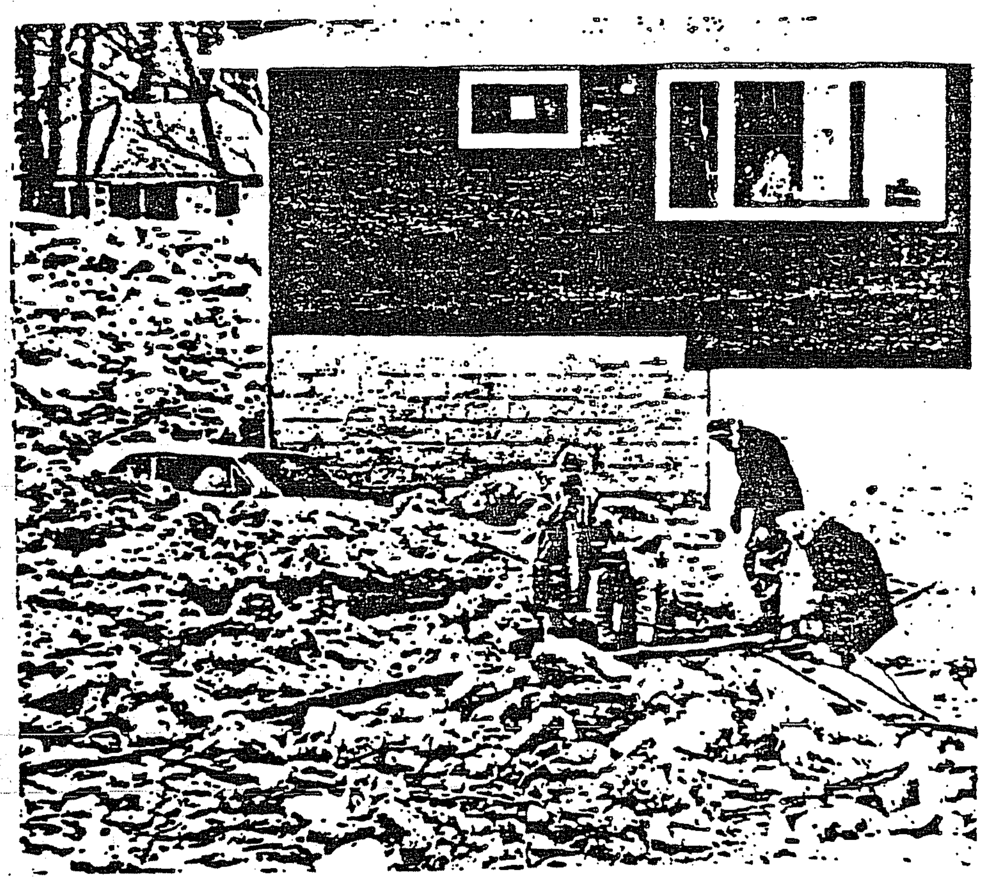


Figure 5 Near Silver Creek, New York, flood waters left these chunks of ice and stranded many residents. (Wide World Photo) (from Troebst, 1963).

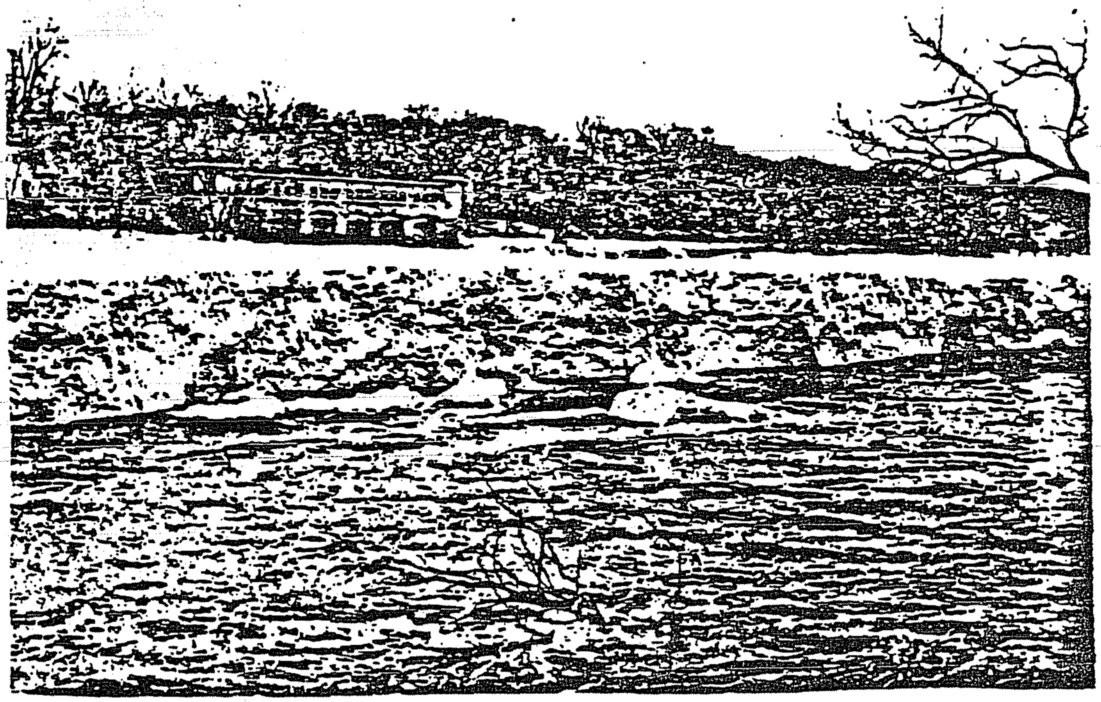


Figure 6 Frazil ice jam on the Fox River after warm weather and rain opened channel, February 1961. (Photo by R.W. Gerdel). (from Gerdel. 1969).

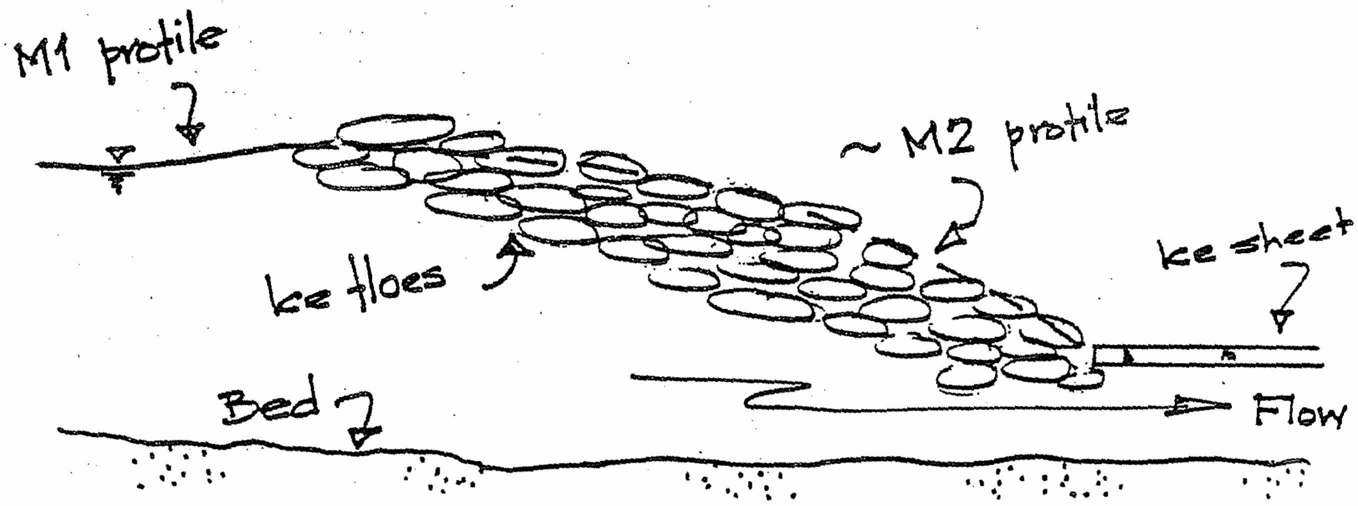


Figure 7(a) Floating ice jam.

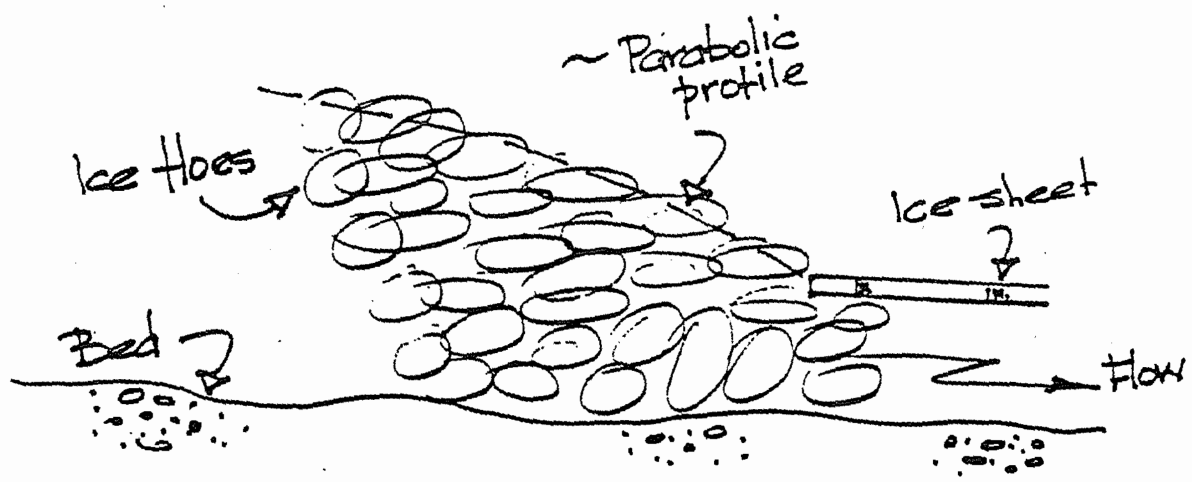


Figure 7(b) Grounded ice jam.

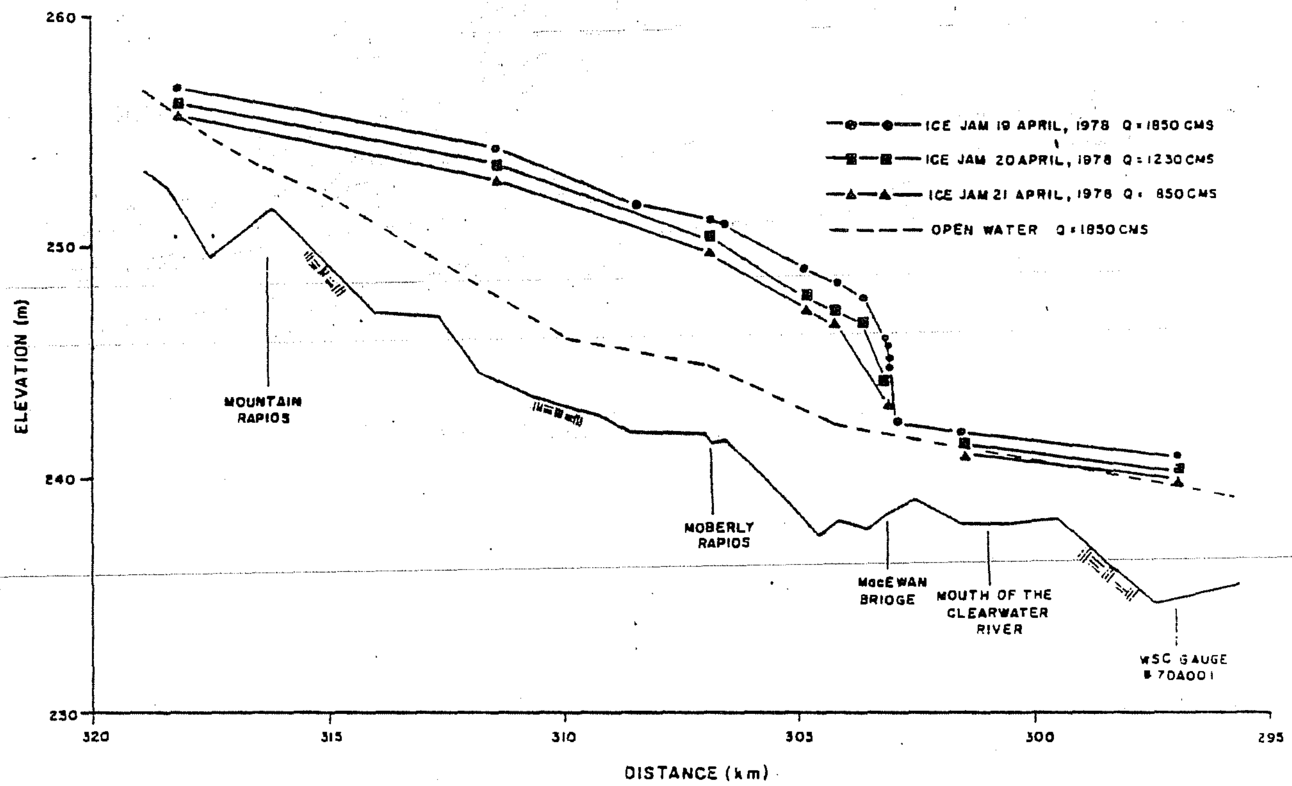
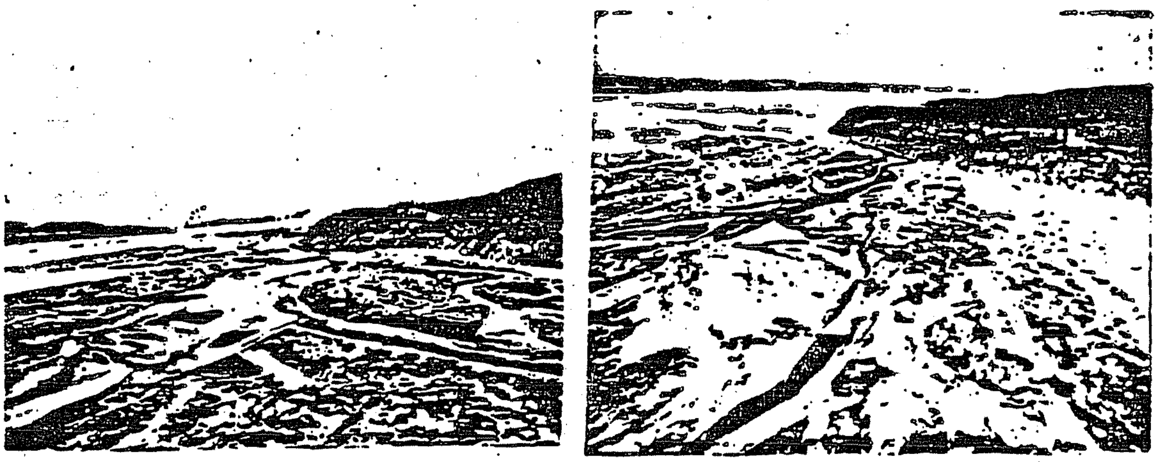


Figure 7(c) Profiles of water levels through jammed reach of the Athabasca River at Fort McMurray, Alberta (Andres, 1980)



a. *Near Donnelly Inn, downstream view.*

b. *Four miles south of Donnelly Dome, downstream view.*

Figure 8 Delta River, Alaska (from Slaughter & Samide, 1971).

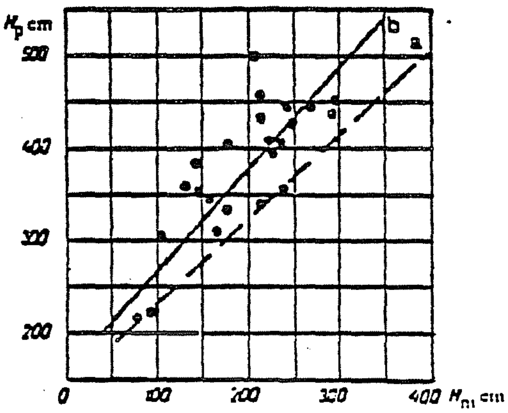


FIGURE 53. Water stage H_p during ice push on the Lena River at Solyanka as a function of the maximum winter stage H_m.

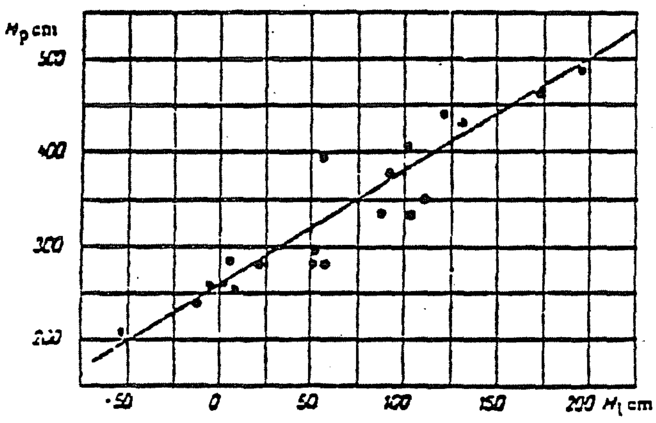


FIGURE 54. Water stage during the first ice push on the Lena River at Krestovskaya, H_p, as a function of the mean water stage during the first 5 days of the stable ice period, H_m.

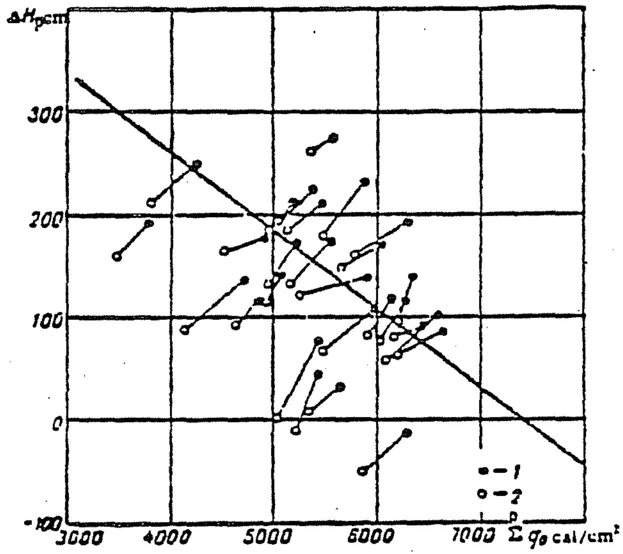


FIGURE 55. Relationship between the rise ΔH_p of the water stage on the Amur River at Komsomolsk-on-Amur over the maximum winter stage and the total heat input Σq_0 on the day of the first ice push.

1 - ΔH and Σq_0 on the day of ice push; 2 - ΔH and Σq_0 on the preceding day.

Figure 9 Relations between freeze-up, break-up and degree-days of thaw.

(from Shuliakovskii, 1963).

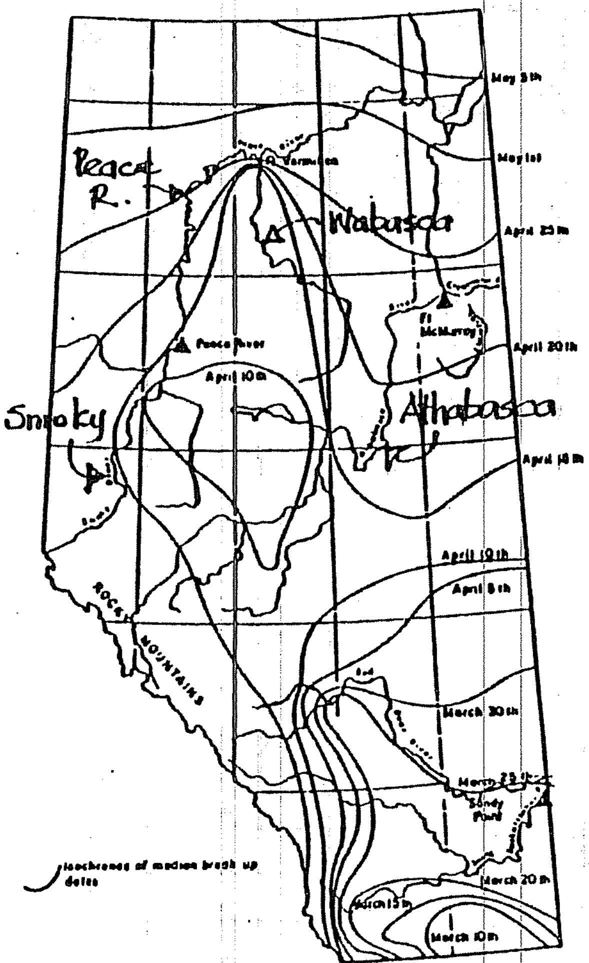


Figure 10 Break-up dates in Alberta

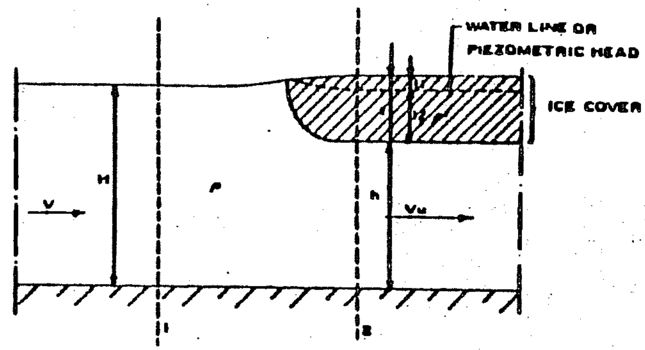


FIG. 2.—ANALYSIS OF EQUILIBRIUM CONDITIONS AT UPSTREAM EDGE OF COVER

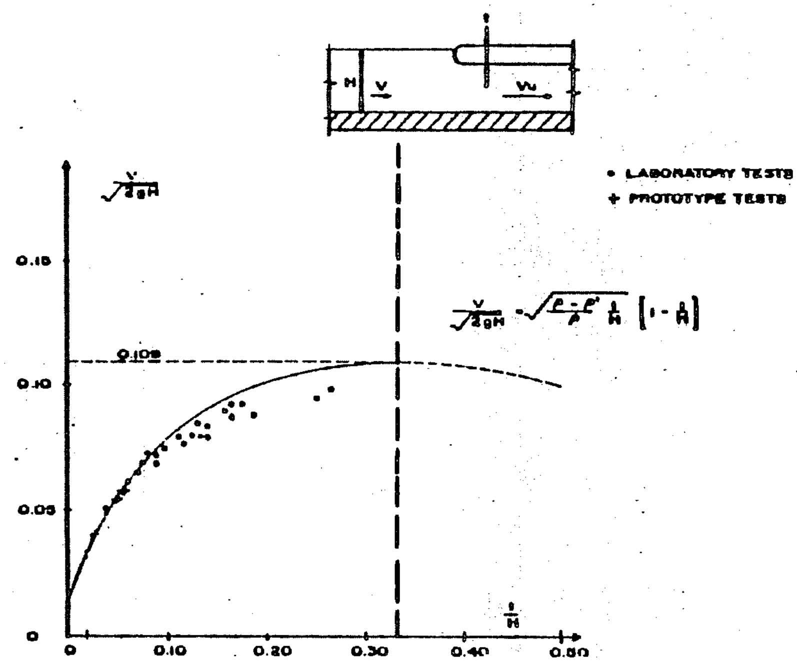


FIG. 3.—THICKNESS AT UPSTREAM EDGE OF COVER

Figure 11 Effects of hydraulic constraints (from Pariset, Hausser & Gagnon, 1966).

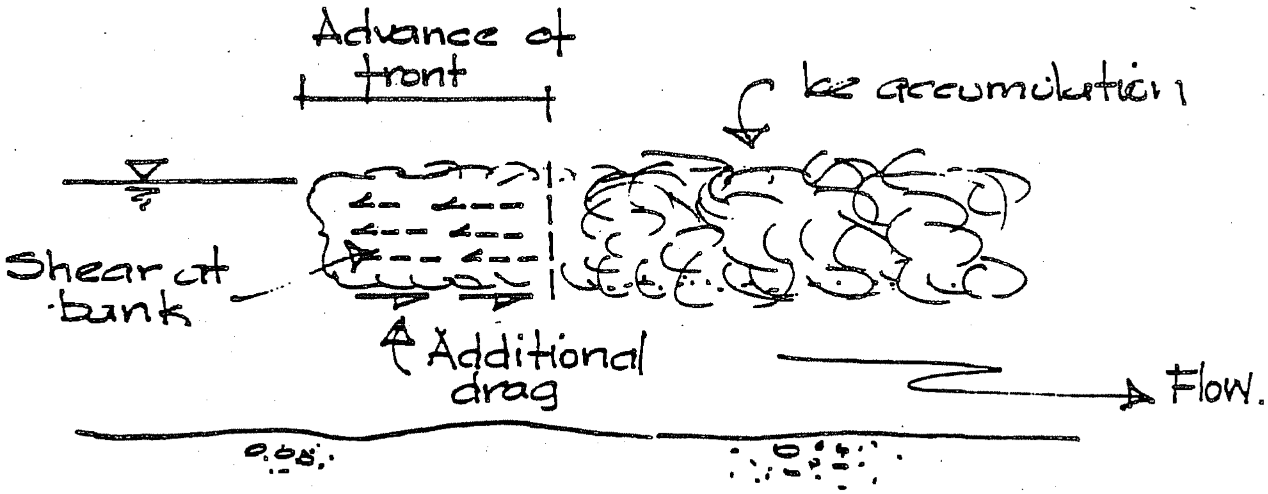


Figure 12 Drag and shear added by advance of upstream end of accumulation.

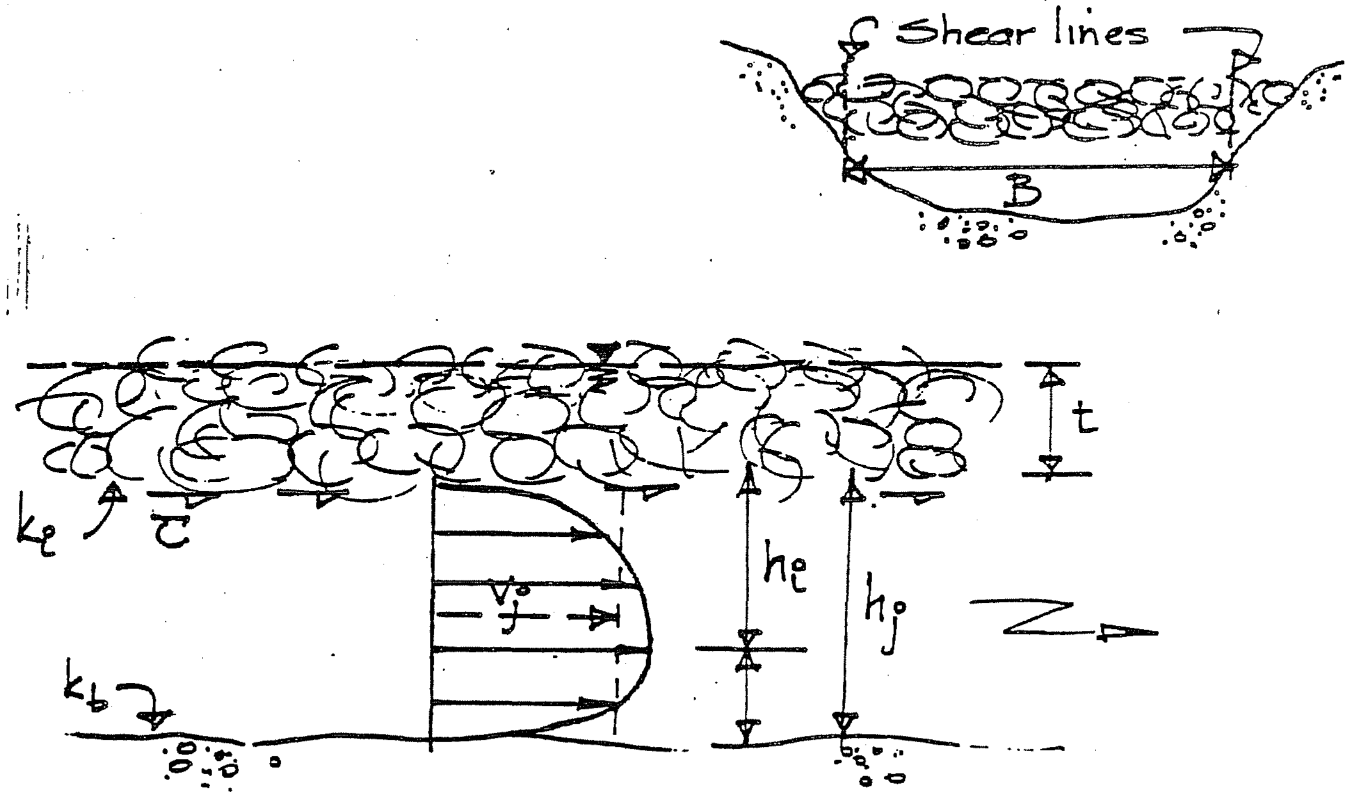


Figure 13 Illustration of terms and velocity distribution under an ice accumulation.

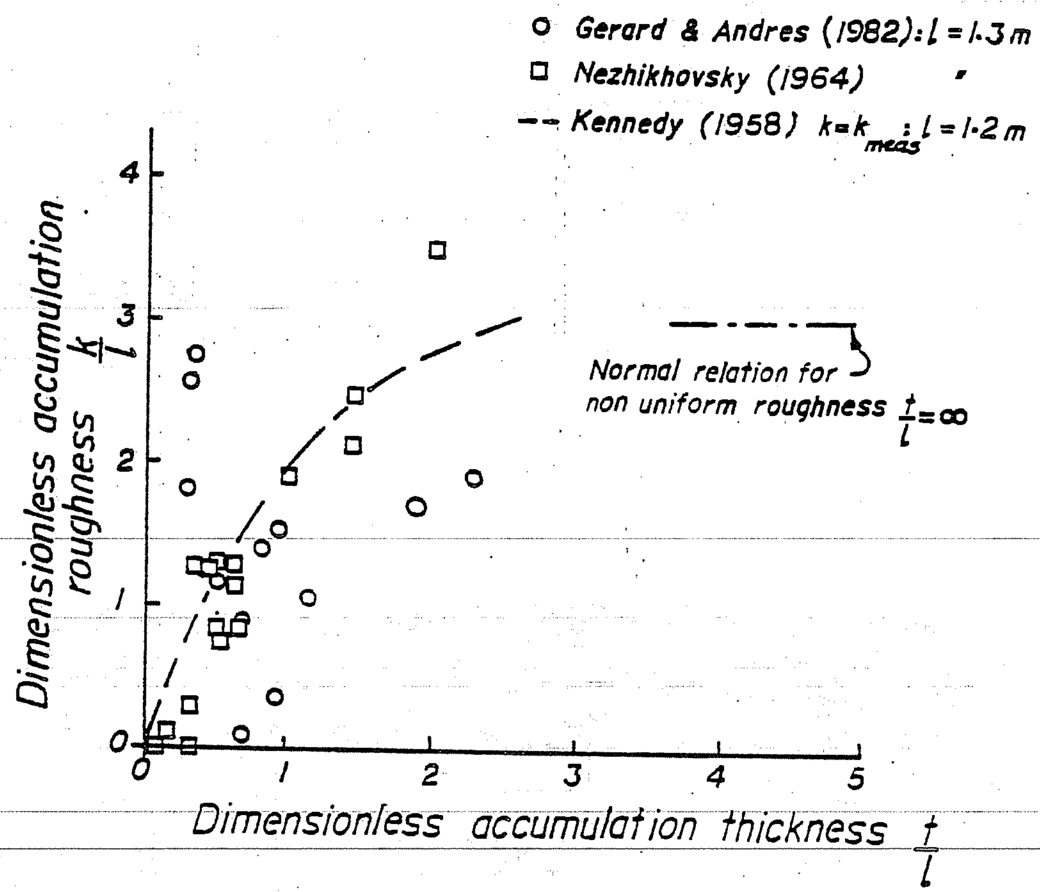


Figure 14. Variation of hydraulic roughness of ice accumulations with accumulation thickness and floe size.

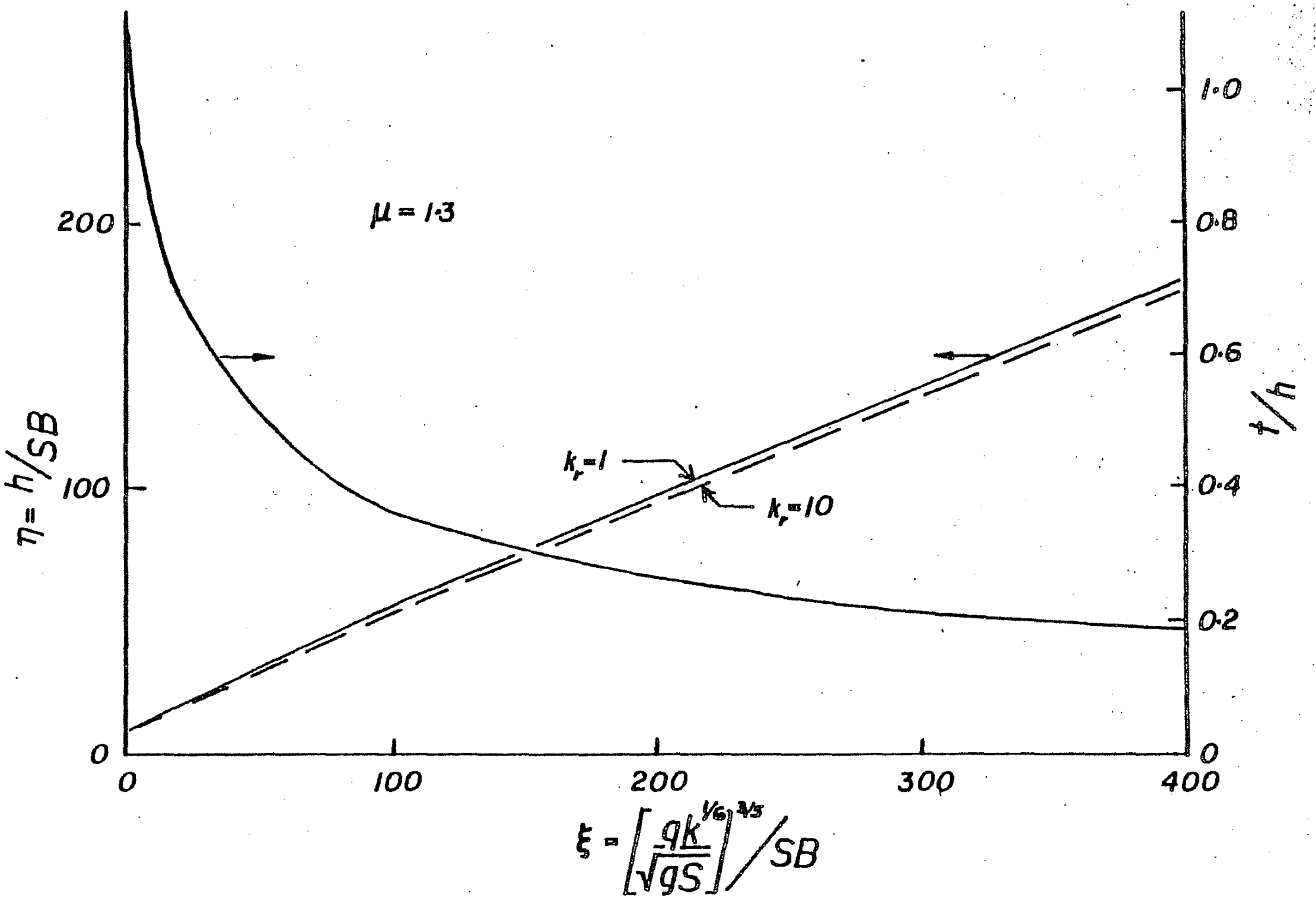


Figure 15 Stability diagram for floating ice jams

1745, 10 June, 1966 — 1800, 13 June

Figure 16 Meade River, Alaska during and after an ice jam (3-4 m high) (from Johnson & Kistner, 1967).

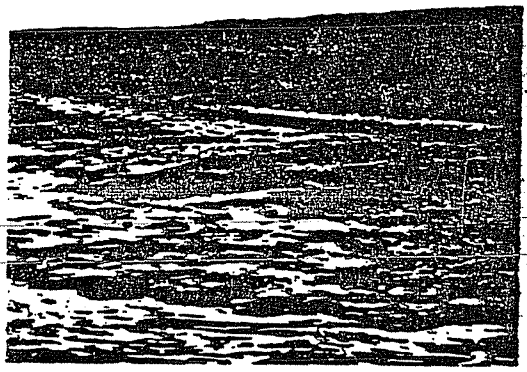


Figure 17 Standing waves on Athabasca River near Ft. McMurray, Alberta following an ice jam failure, 1974 (from Gerard, 1975).

Figure 18 Floodwaters move swiftly down the Yellowstone River following release of an ice jam downstream from the Lower Yellowstone Diversion Da February 16, 1971. (from Burgi, et al., 1971).

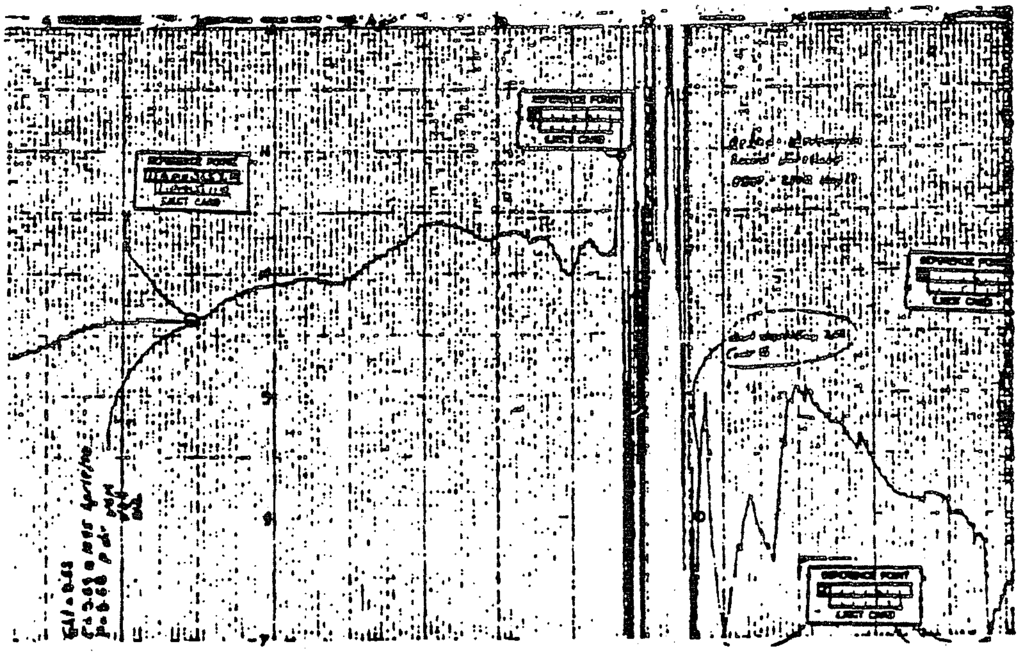


Figure 19   Gauge record of Athabasca River water levels 1 km downstream if ice jam failure.

Figure 20   Ice scarred tree, Smoky River, Alberta, 1979.

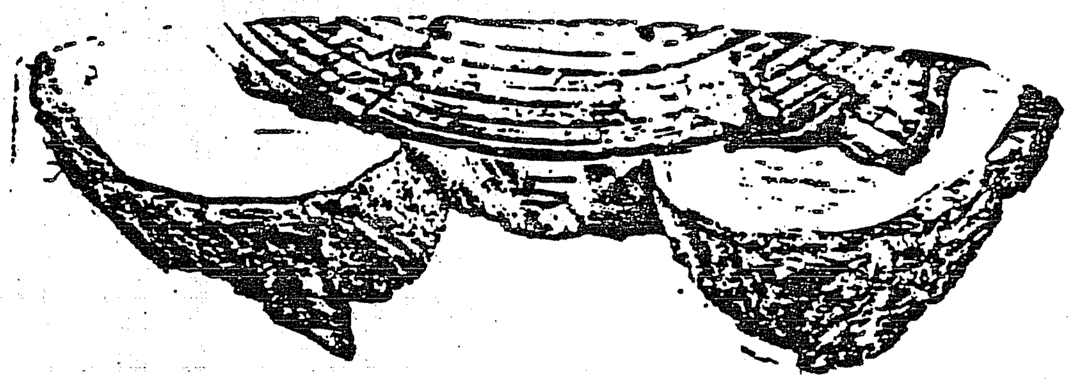


Figure 21 Ice scar sample for tree-ring dating.

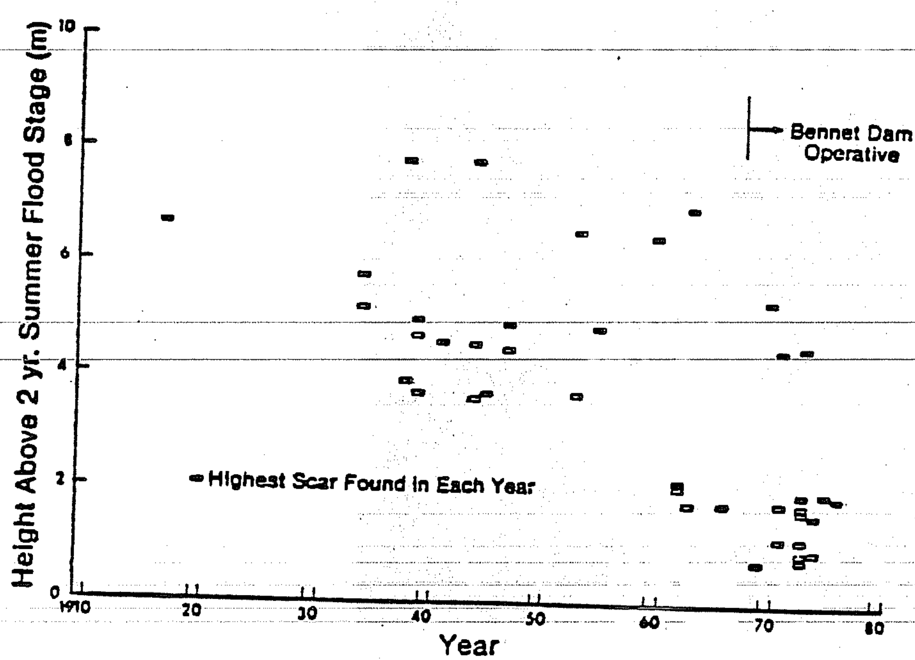


Figure 22 Ice scar record, Peace River at Fort Vermilion, Alberta.

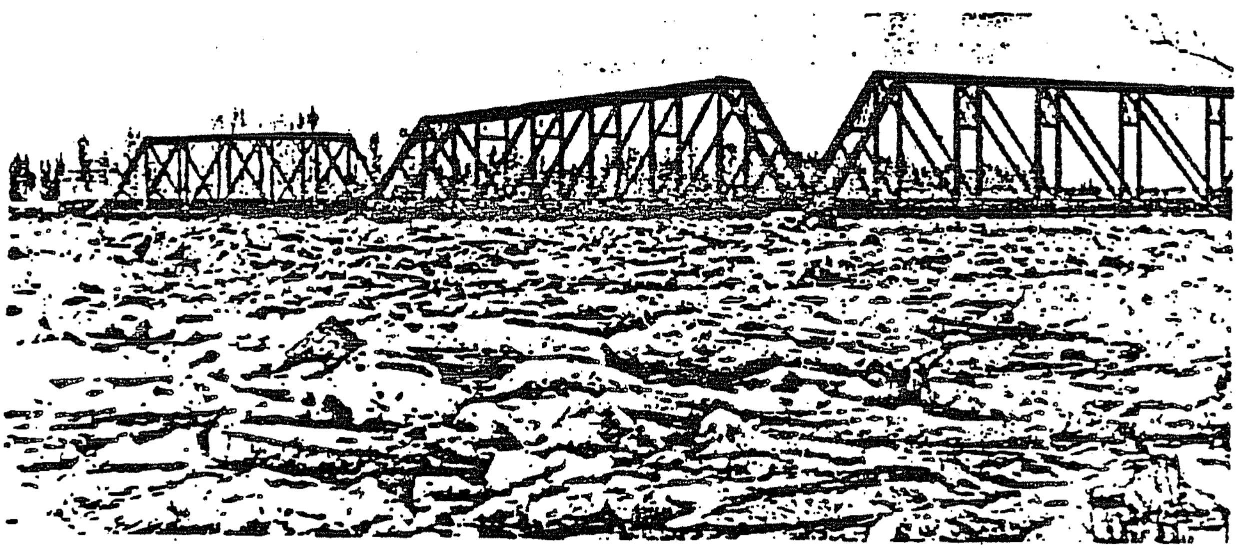


Figure 23 McLeod River - ice jam at railway bridge. Water level is 6 - 8 m above normal.

APPENDIX II

EXCERPT FROM GERARD AND KARPUK (1979)

Analysis of Historical Data: Perception Stage

The crux of the problem of analyzing such historical data is to assign a rank and record length to each reported flood peak. It is suggested here that this can best be done by introducing the concept of a "perception stage" for each source of information. This is defined as the stage above which it is estimated the source would have provided information on the flood peak in any given year.

For instance, the perception stage for a resident is that water level below which it is estimated the maximum stage in a given year would have gone unnoticed, or not be recalled, by the resident. This stage may vary from year to year for a particular resident. A resident living close to the river would be aware of relatively minor water level changes. If, in later years, the resident moved to a location further from the river, only higher water levels would be noted and the perception level should be raised accordingly. Furthermore, as the years pass, recollection of individual lower water level peaks will fade, so that the perception stage should increase with distance back in time. Such changes in perception stage with time would depend on the resident, how the interview was conducted, and whether the interviewer could prompt recollections. During the interview, such features would have to be assessed, and the perception stage and its variation estimated.

The perception stage for archival sources such as journals, newspapers, and maintenance records is the minimum water level that would have called for comment. This level is estimated from the "feeling" gained from all entries. Because the information is recorded soon after the event, the perception stage for such sources will not require modification to allow for failing recollection. For hydrometric records the perception stage would be the minimum gage reading that could be recorded for any given year.

Similar assessments can be made for other sources, and a perception stage allocated to each source for each year of record. The perception stages so determined provide the means whereby the data from the various sources can be merged to estimate the probability distribution. The worth of the perception stage follows from the fact that if the source was in a position to notice and recall if this perception stage was exceeded, *but didn't report it*, it can be presumed the maximum water level was below the perception stage for that year. This simple property of the perception stage allows for the systematic analysis of historical data, as illustrated by examples in the following. Although the determination of these perception stages will generally be quite subjective, it is felt that this subjectivity is more than compensated for by the objective analysis of the historical data it affords.

Reconstructing Record: Preparation of Summary Diagram

To illustr... ie utility of the perception stage concept data collected on maximum spring breakup water levels in the reach of the Peace River through Fort Vermilion, Alberta will be used. Details of this site are shown in Figs. 1-3. The information collected is summarized in Fig. 4, the construction of which is described in the following, in addition to the sources of the data and interpretation of the information obtained. A cross section of the river at Fort Vermilion is shown on Fig. 5.

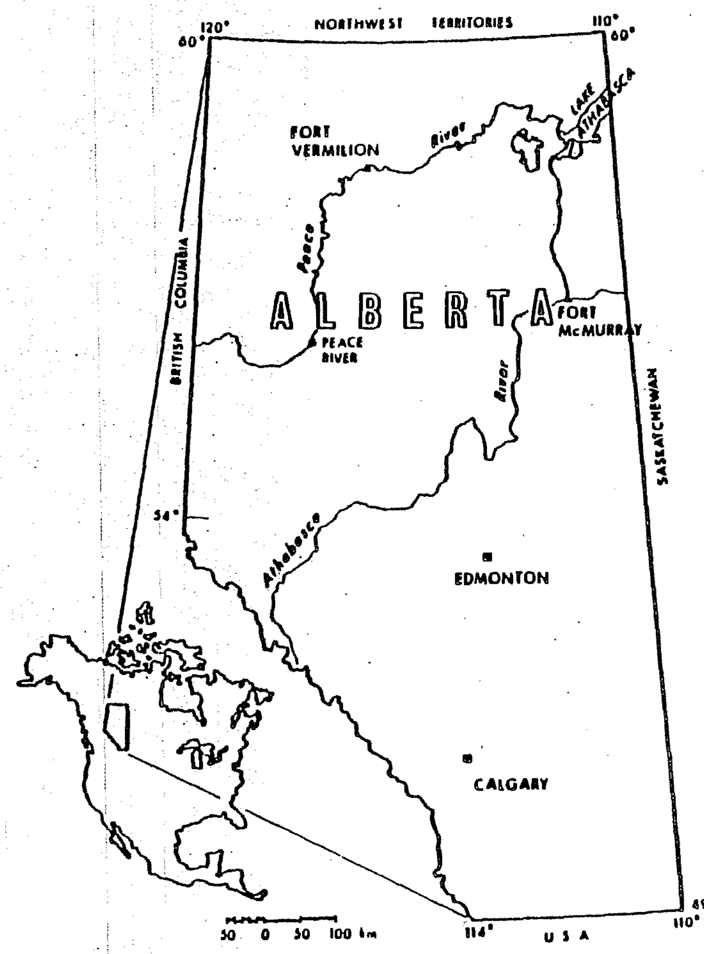


FIG. 1.—Location Map (1 km = 0.62 miles)

Resident Interviews.—Reliable first-hand information from residents living near the river covered the period back to about 1912. It was estimated that the residents interviewed would have mentioned breakup water levels above at least the 10.5-m stage. This was therefore chosen as the "perception and recall" ...ge for the resident interviews. The significance of this stage is that ...s high would have just begun to overtop the low-lying portions of the ...

and be about to flood the road to the airfield. The latter provided the only access to this isolated community at this time of the year. Although the water would still be about 2 m below the bank at the settlement itself, such a water level is obviously high and threatening, and would probably have been recalled.

The early limit for "second-hand" or "ancestral communication," is based on a statement quoted in a biography of Sheridan Lawrence, 1886–1952 (5):

> Never before in living memory, their native neighbours assured them, had the Peace hurled such havoc upon them [as in 1888]; never before had a flood of such proportion occurred.

It is felt that a conservative limit on "living memory" would be about 30 yr, so 1858 was chosen as the early limit for this source. In addition to the account in this biography, the 1888 flood was mentioned in resident interviews as a

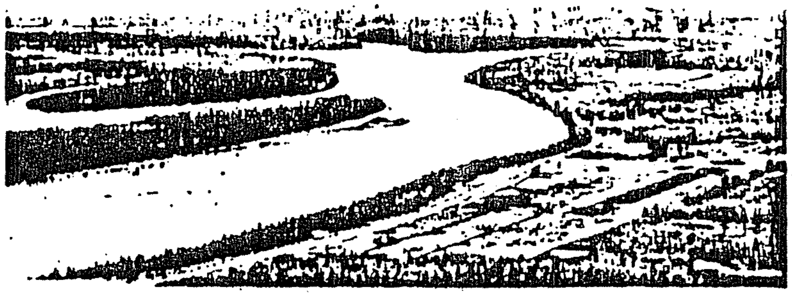


FIG. 2.—Peace River Looking Downstream across Fort Vermilion on Right Bank

result of conversations between present residents and "old timers" early in the century. Such a source would also have an early limit of about 1860. The perception stage was chosen as 12.5 m because, at this level, general flooding of the settlement would have begun and it is unlikely that a flood of this magnitude or higher would not have been mentioned in future conversations.

Hudson's Bay Company Archives.—Daily journals containing information on breakup water levels, written by employees of the Hudson's Bay Company stationed at Fort Vermilion, were available from the Manitoba Archives in Winnipeg for as far back as 1813. The perception stage for this source was chosen as 9.0 m. As indicated in Fig. 5 the island opposite Fort Vermilion begins to flood at this water level and, as there was generally a camp of free traders on this island, this flooding would presumably have been cause for comment. A perception stage considerably lower than that of present day residents

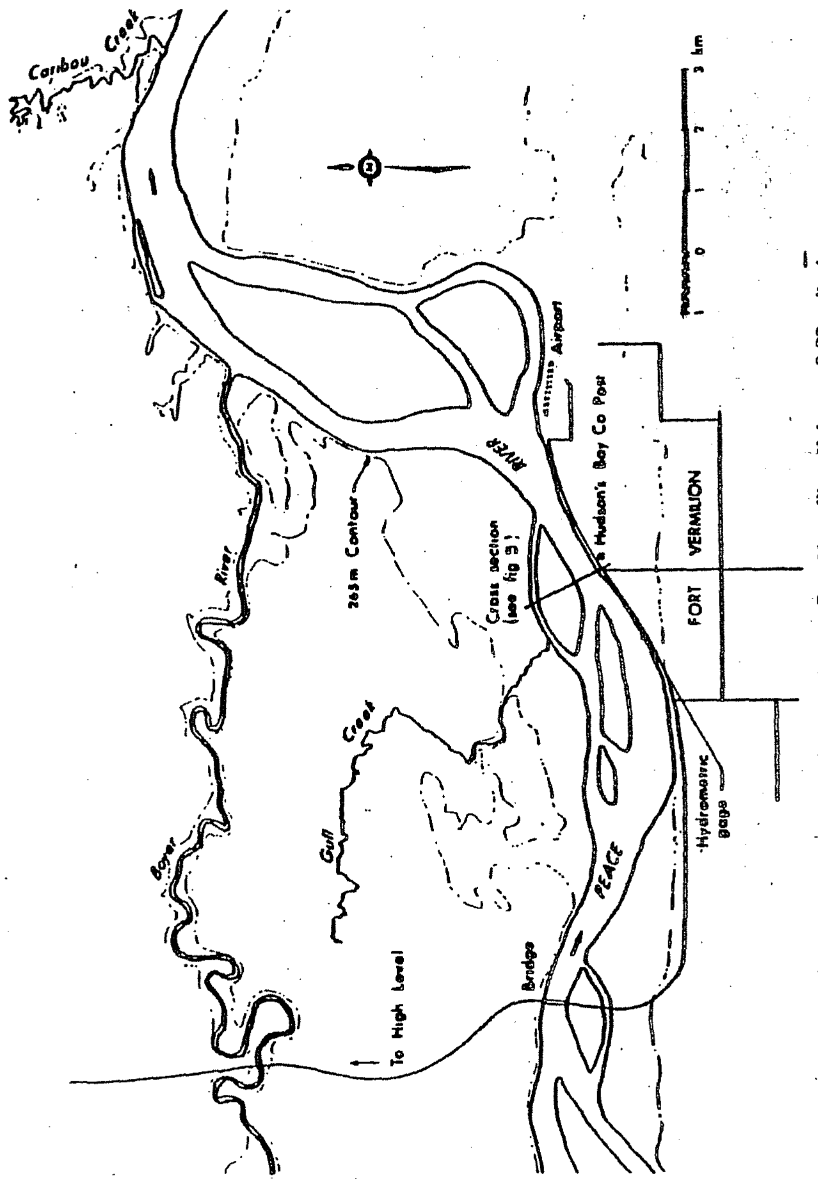


FIG. 3.—Plan of Peace River at Fort Vermilion (1 km = 0.62 miles)

of Fort Vermilion is also justified because events were recorded as they happened, and no recall is involved. As these people were almost totally dependent on the river for transport, communications, and, at times, sustenance, they were also very sensitive to its behavior.

Photographs.—Photographs taken by an employee of the Experimental Farm

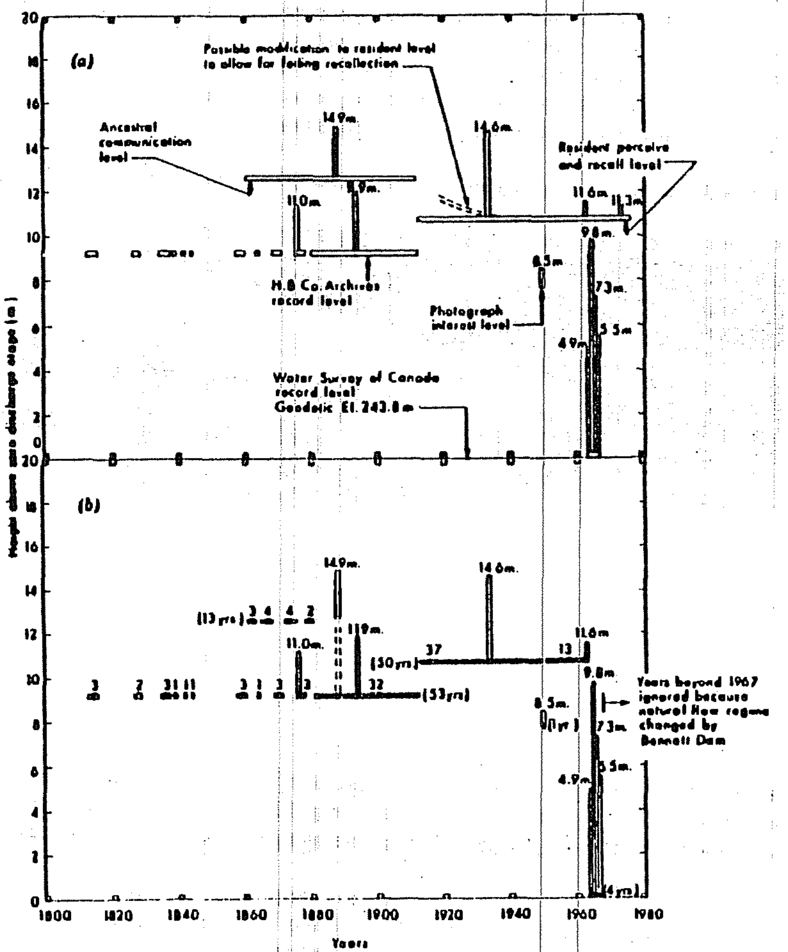


FIG. 4.—Data on Annual Maximum Ice Breakup Stages on Peace River at Fort Vermilion: (a) Initial Summary Diagram; (b) Final Summary Diagram (1 m = 3.28 ft)

at Fort Vermilion were available for the breakup of 1950. The perception stage associated with this source was placed at the level it was felt would prompt a casual o' ver to take a photograph or, perhaps more importantly, would have made photograph significant enough to be preserved. The chosen stage is shown in Fig. 5. It can be seen that at this level the river would have looked "full," being only a meter or so below the 2-yr summer flood stage. As there is no information available on the photographer's background, it is difficult to decide on a period that can reasonably be allocated to this observation. It is possible that the photographer was a casual visitor and in a position to photograph breakup in only that one year, although the fact that the photographs were preserved would suggest it was probably the highest in several years. Nevertheless it was thought prudent to associate only one year with this source.

Hydrometric Records.—The 4-yr period of record during breakup available from the Water Survey of Canada hydrometric gage at Fort Vermilion has a minimum recording level of zero. This is therefore the perception stage for this source.

The information available from these four sources is summarized in Fig. 4(*a*). In this figure an open horizontal bar has been drawn at the estimated perception stage for each source. Each bar was drawn to extend over all years the source

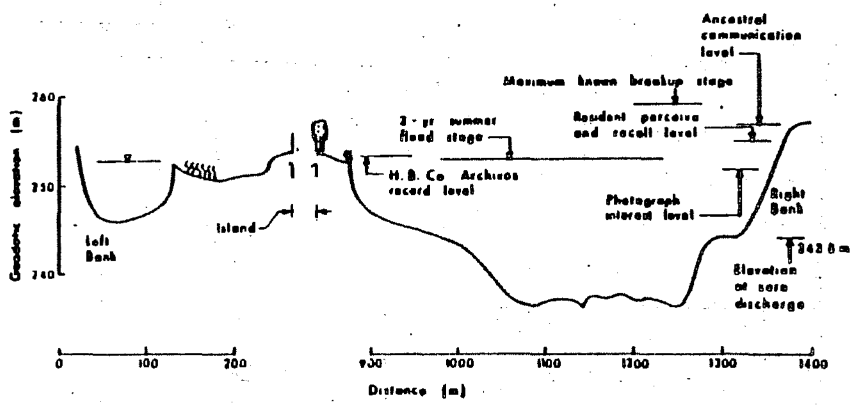


FIG. 5.—Cross Section of Peace River at Fort Vermilion [See Fig. 3 for Location (1 m = 3.28 ft)]

was in a position to notice events during breakup, *regardless of whether that source could provide quantitative information on breakup in that year or not*. Thus, for the resident interviews the horizontal bar is drawn from the present back to 1912; the bar for "ancenstral communication" was drawn from 1860–1912, the latter year being when the direct resident interviews begin to apply; for the Hudson's Bay Company journals the bars were drawn across the years for which entries in the journals covered the breakup period, whether breakup was mentioned or not. Vertical bars for each year for which there was information on breakup stage were then drawn, extending from the perception stage for the source to the maximum breakup stage estimate.

These operations resulted in the initial summary diagram shown in Fig. 4(*a*). The final summary diagram required for the analysis [Fig. 4(*b*)] was prepared by blocking in the lowest perception bar crossing each year.

Records beyond 1967 are ignored for the analysis described in the following. In this year a large dam across the Peace River in British Colur (Bennett

Dam) came into operation and caused major changes in the natural flow regime at Fort Vermilion.

Rank and Record Length

The summary diagram [Fig. 4(*b*)] with the indicated perception stages, allows a rank and record length, which utilizes information from all sources, to be associated with each "peak."

With this method of presentation, the number of years of record associated with each peak shown in given by the sum of all years marked with a solid bar at or below that peak. The rank of the peak is determined by ranking all peaks in the group having a perception stage equal to or lower than the peak.

The breakup water level for 1965 (9.8 m) can be used to illustrate the reasoning behind the aforementioned criteria, and the advantages, if not the necessity, of defining perception stages. If a breakup stage of this magnitude (9.8 m) had occurred during the years covered by the Hudson's Bay Company journals it would have been reported, given that the perception stage allocated to this source is correct. Therefore it can be assumed this breakup stage was not exceeded in the years covered by these journals, except in those years for which higher stages were actually mentioned in the journals. Also, the photograph taken in 1950 suggests that this breakup stage was not reached in that year either. Therefore there are records for 58 yr that would have been reported if this stage had been exceeded. This is the effective record length that can be associated with this peak.

The years governed by the perception stages of residents and hearsay cannot be included in this record length because the chosen perception stages for these sources are above the peak. It is therefore presumed that they would not have been aware of, or would not have recalled, such low peaks. Even the years in which these two perception stages were exceeded cannot be included. These sources provided information for these years only because their perception stage was exceeded. The observations would therefore cause significant bias if included on their own. (The argument is probably not quite as definite as this. In certain situations the increased information provided by referring some stages to perception levels lower than their source may more than compensate for a small amount of bias. For example, the Hudson's Bay Company journal for the year 1888 is missing. From other sources it is known that there was a very large flood in this year, and it is presumed the journal was lost in the flood. It is therefore felt that the little bias introduced if the perception stage for this year is placed at the Hudson Bay Company level, as indicated by the broken lines in Fig. 4(*b*), rather than at the higher level associated with the source of the information, is more than compensated for by the improvement in the probability estimate of this peak. However, at present this can only be a subjective judgement. Further work, and perhaps, more information, is required to define criteria for such decisions.)

It now remains to determine the rank of the 9.8-m stage. In the 58-yr population defined by the perception stages lower than 9.8 m, a 9.8-m stage had been exceeded on three occasions—in 1876, 1888, and 1894 (note that the 1934 peak is not included). Therefore, the 1965 stage has rank 4. Similar arguments can be applied to the other "peaks" shown in Fig. 4(*b*) to arrive at the ranks and record lengths given in Table 1.

Reference Stage and Probability Distribution.—It is intended that the data listed in Table 1 be used to estimate the parameters of a selected probability distribution of annual maximum breakup stages. At present there is little indication of what probability distribution is most appropriate for this parameter. Nevertheless it is possible to deduce some properties that the distribution should have. First the lower limit of the distribution should be such that all possible stages lie above it. An obvious first choice for this limit is zero-flow stage. The upper limit of the distribution is that for which all possible stages lie below it; this is more difficult to define. There is no doubt that there is a physical upper limit to the maximum water level increase an ice jam can cause. For example, in a stream with a broad flood plain it is difficult to imagine an ice jam could cause the water level to rise too much beyond flood-plain level, as then the water is free to flow around the ice accumulation. On the other hand, a stream entrenched in a narrow valley may not have this relief facility and an ice jam could conceivably have no practical upper limit. Thus, for the sake of selecting a distribution to fit to the data, it is practically expedient and a sufficient approximation in many cases to choose infinity as the upper limit. However, the physical characteristics of the location should be kept very much in mind when trying to interpret or extrapolate the data. Another feature of the distribution that can be expected is that it will be skewed towards the smaller stages.

TABLE 1.—Calculation of Cumulative Probabilities for Recorded Maximum Breakup Stages on Peace River at Fort Vermilion

Year (1)	Stage, in meters above zero flow elevation (2)	Rank (3)	Years of record (4)	Probability of being greater than or equal to, as a percentage (5)
1888	14.9	1	121	0.5
1934	14.6	2	121	1.3
1894	11.9	3	108	2.4
1963	11.6	4	108	3.4
1876	11.0	5	108	4.3
1965	9.8	4	58	6.2
1950	8.5	2	5	31
1966	7.3	2	4	38
1967	5.5	3	4	62
1964	4.9	4	4	85

The simplest and most convenient distribution that satisfies these constraints is a log-normal distribution; this distribution has been assumed in this paper. The probability estimates for each peak were therefore calculated using the formula $(m - 3/8)/(N + 1/4)$ (2).

Each probability estimate will have a different certainty and thus when fitting a line to the data each point should be given a different weight. This weight is usually taken as being inversely proportional to the variance, which in turn is simply proportional to the square of the confidence interval. To determine the confidence interval for a given observation the variances of the estimates of the population mean and variance are required. These estimates should be determined from the sample used to get the rank of the given observation, i.e., observations having a perception stage equal to or lower than the peak. However for the purpose of assigning weights for a visual fit of the data the approximate method suggested by Chow (3) was used, with the required standard deviation assumed equal to that given by the line initially fitted to the data. The number of years of record assigned to each peak was as previously described.

The assumed log-normal distribution can be seen to provide a reasonable description of the breakup data, although the similarity of the stage reached

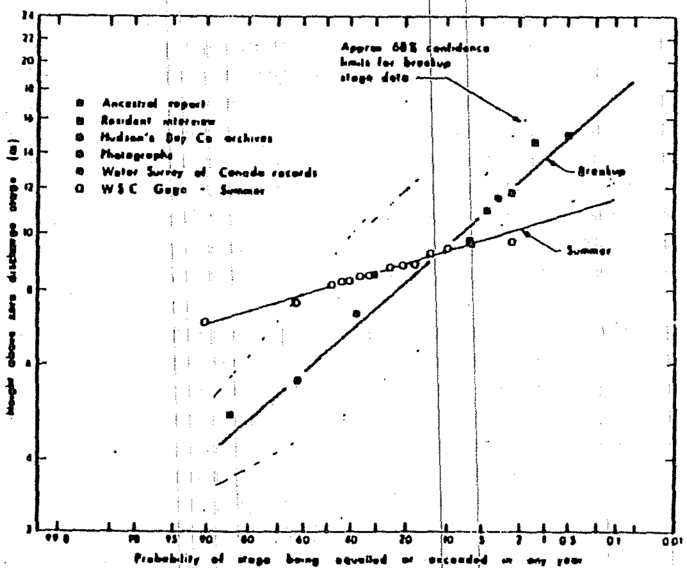


FIG. 6.—Cumulative Probability Distributions of Annual Maximum Stages due to Ice Breakup and Summer Floods, Peace River at Fort Vermilion (1 m = 3.28 ft)

by the two highest ice jams suggests that there may be a physical limit on ice jam height at about this elevation. Yet, as indicated by the El. 265-m contour (i.e., 21-m stage) shown in Fig. 3, the topography of the reach is such that it is difficult to rule out even higher ice jams. It would therefore seem prudent to assume that this similarity of stage is a chance happening and does not indicate an upper limit.

Significance of Ice Breakup Water Levels

To indicate the significance of ice jam stages in the hierarchy of flood stages at Fort Vermilion, as an example of what might be expected in other northern areas, the estimated distribution of summer flood stages prior to 1967 has been added to Fig. 6. (It is not uncommon to assume that annual maximum summer flood discharges follow a log-normal distribution. It is also common for the logarithm of stage, when referred to a datum such that zero stage corresponds to zero discharge, to be linearly related to the logarithm of discharge, particularly at high stage. The cumulative probability distributions of both log-stage and log-discharge should therefore be of the same type. Thus, it is not inappropriate to present maximum summer stages as a log-normal distribution.) It is apparent that ice breakup water levels dominate the distribution of annual maximum water levels for probabilities less than about 10% (i.e., return periods greater than 10 yr), and that to derive this distribution without taking cognizance of ice breakup stages would be folly.

Conclusions

The usual compilation of historical data on high water includes information from sources of varying reliability. As a result it is difficult to allocate a rank and record length to each reported peak for the purpose of estimating the probability of the peak. Because of this only the one or two highest stages in the historical record are commonly utilized in estimating a high water probability distribution, the major emphasis being placed on hydrometric records for which both a rank and record length can usually be simply allocated. Much potentially useful information in the historical record is therefore rejected. This luxury can often be afforded for summer floods because of the availability of hydrometric data and the ease with which it can be transposed to other locations. However, for ice breakup floods, which can be very important in northern areas, often the only source of information is historical; data for other sites, even nearby sites on the same stream, cannot be transposed. Thus, if a probability distribution is to be defined, historical data must be utilized to the fullest.

A simple method has been described that allows the systematic analysis of historical data. The method was illustrated by applying it to data on maximum ice breakup stages collected for the Peace River at Fort Vermilion in northern Alberta, Canada. The resulting probability distribution was compared to that for summer flood stages at this site to emphasize that ice breakup stages can play a dominant role in defining the series of annual maximum stages.

Appendix.—References

1. Benson, M. A., "Use of Historical Data in Flood Frequency Analysis," *Transactions*, American Geophysical Union, Vol. 31, No. 3, June, 1950, pp. 419–424.
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3. Chow, V. T., *Handbook of Applied Hydrology*, McGraw-Hill Book Co., Inc., Toronto, Canada, 1964.
4. Dalrymple, T., "Flood Frequency Analyses," *Manual of Hydrology, Part 3—Flood Flow Techniques*, U.S. Geological Survey Water Supply Paper 1543-A, 1960.
5. Myles, E. L., *The Emperor of Peace River 1886–1952*, Cooperative Press Limited, Edmonton, Alberta, Canada, 1965.

EXAMPLE PROBLEMS

I. A channel 5000 m long, 50 m wide, $Q = 50\ m^3/s$, $S = .001$, $n_b = .035$ has a lateral ice cover closure rate of 0.15 m/°C day and the heat transfer coefficient is 20 W/m²-°C. The average air temp is -20°C.

1. How many days will it take to fully close the river from lateral ice growth?

$$t = \frac{50m}{.15\ m/°C\text{-}Day \times -20°C} = 16.67 \text{ days}$$

2. How much frazil ice would be produced while the river was freezing over?

a) $\forall = \frac{h_a A_o T_a}{\rho \lambda}$ volume of frazil ice per second (m^3/s)

b) open water area f(t) $A_o(t) = L[B - .15 \times 20t]$

$$\forall = \int_0^t \frac{h_a L[B - 3.0t]}{\rho \lambda} T_a\, dt \qquad t = 16.67$$

$$= \frac{h_a L T_a}{\rho \lambda} \int_0^{16.67} (B - 3.0t)\, dt = \frac{h L T_a}{\rho \lambda}\left[Bt - \frac{3}{2}t^2\right]_0^{16.67} \times 86400 \frac{s}{day}$$

$$= \frac{20 \times 5000 \times 20}{1000 \times 334000}\left[50 \times 16.67 - 1.5(16.67)^2\right] \times 86400 = 2.156 \times 10^5\ m^3$$

$2.156 \times 10^5\ m^3$

the equivalent thickness is $\frac{2.156 \times 10^5}{5000 \times 50} = .86m$

3. If the river froze over instantaneously what would be the ice thickness and how does this compare with the equivalent ice thickness from the frazil generation in question 2.

a) from Ashton's notes
η = ice thickness

$$\rho\lambda \frac{d\eta}{dt} = \frac{T_m - T_a}{\frac{\eta}{k} + \frac{1}{h_a}}$$

integrating with T_a = constant & h_a constant

$$\eta^2 = \left[\frac{T_m - T_a}{\rho\lambda} t \times 86400 - \frac{\eta}{h_a}\right] 2k$$

$$\eta^2 = \left[\frac{+20 \times 16.67 \times 86400}{1000 \times 33400} - \frac{\eta}{20}\right] 2 \times 2.24$$

$\eta = .52m$ solid ice thickness

b) the open water ice generation is approximately

$\frac{.86}{.52} = 1.65$ times greater

4. If the bed roughness coefficient is the same as the ice cover roughness, what is the total stage in the channel at uniform flow conditions? Assume rectangular channel.

$$H = 1.32 \left[\frac{Q\, n_c}{B\sqrt{S}}\right]^{.6} + .92t$$

assume $t = 0.52m$

$n_c = n_L = n_b = .035$

$$H = 1.32 \left[\frac{50 \times .035}{50 \times \sqrt{.001}}\right]^{.6} + .92(.52) = 1.88m$$

5. What would be the freeze-up thickness if the cover was to thicken according to eqn [13]; by crushing and shoves.

$$\left(\tau_{\omega} + \rho_i g t_j S\right) B = 2\mu \rho_i \left(1 - \frac{\rho_i}{\rho}\right) g t_j^2 - 2 c t_j$$

a) $\tau_{\omega} = \rho g R_i S$
shear to ice cover

since $n_i = n_b$ $R_i = R_b$

$$Y_i = 1.32 \left[\frac{50 \times .035}{50 \times \sqrt{.001}}\right]^{.6} = 1.40\ m$$

$$R_i = Y_i/2 = 0.7m$$

$$\tau_{\omega} = (1000)(9.8)(.7)\,.001 = 6.86\ N/m^2$$

$\mu = 1.3$
use $c = 200\ N/m$

b) $\left(6.86 + 920 \times 9.8 \times t_j\ .001\right) 50 = 2 \times 1.3 \times 920 \left(1 - .92\right) 9.8\ t_j^2 - 2 \times 200 \times t_j$

$$343 + 450.8 t_j = 1875.3 t_j^2 - 400 t_j$$

$$t_j = 0.75\ m$$

$$t_j/H = 0.75/1.40 + .9(.75) = .36$$

EXHIBIT E

3. Fish, Wildlife, and Botanical Resources - Terrestrial Botanical Resources

Comment 7 (p. E-3-225, para. 2; p. E-3-240, para. 2; p. E-3-244, para. 3; p. E-3-245, para.3; p. E-3-246, para. 5; p. E-3-247, para. 2-4; p. E-3-252, para. 5; p. E-3-253, para. 1; p. E-3-270, para. 1; p. E-3-280, para.5)

Check and correct, as necessary, all calculations of land areas to be impacted or mitigated. Discrepancies have been found within tables (e.g., Table E.3.83 totals for impoundment and for shrubland over the entire Watana facility) and between the text and calculations made from the tables. For example, on p. E-3-225 total direct vegetation removal due to Watana construction is given as 16,582 ha, but this figure should take into account the 2128 ha of unvegetated area; on p. E-3-245, the percentage of total wetlands occupied by palustrine forested areas is not consistent with calculations made from Table E.3.82. Indicate whether unvegetated or disturbed areas were included in the calculations for vegetation removals and whether unvegetated rocky areas were treated differently than river, lake, or ice areas.

Response

All figures of areas to be impacted or mitigated have been checked and recalculated, and some have been re-measured. Tables E.3.79, E.3.80, E.3.83, E.3.84, E.3.85, and E.3.86 required corrections. The revised tables are attached, as are relevant portions of the text that subsequently required modification. Unvegetated areas were not included in the calculations for vegetation removals, but disturbed areas were included. Unvegetated rocky areas were not treated differently from river, lake, or ice areas.

TABLE E.3.79: AREAS OF DIFFERENT VEGETATION TYPES TO BE CROSSED
(REVISED) BY WILLOW-TO-HEALY TRANSMISSION CORRIDOR*

Cover Type	Hectares	Acres	Percent of Total
Moist tundra	58.5	144.5	3.8
Wet tundra	116.4	287.6	7.5
Alpine tundra	25.9	64.1	1.7
Bottomland spruce-poplar forest	83.9	207.3	5.4
Upland spruce-hardwood forest	455.8	1126.2	29.3
Lowland spruce-hardwood forest	236.7	585.0	15.2
Shrublands	443.9	1097.0	28.5
Low brush, muskeg bog	134.7	322.8	8.6
Total	1,555.8	3,844.5	100.0

*Calculated from data in Table 22 from Commonwealth Associates (1982). The values here represent the widening of the corridor to 91 m (300 ft) from the 33 m (110 ft) given by Commonwealth Associates (1982). Thus, the areas presented here represent a corridor width of 58 m (190 ft).

TABLE E.3.80: AREAS OF EACH VEGETATION TYPE TO BE CROSSED BY WATANA-TO-GOLD CREEK TRANSMISSION CORRIDORS AND PERCENT TOTAL* FOR WATANA AND GOLD CREEK WATERSHEDS (REVISED)

	Watana to Devil Canyon**			Devil Canyon to Gold Creek***		
Vegetation Type	ha	acres	%*	ha	acres	%*
Forest	18.6	45.9	0.0	187.1	462.4	0.1
Woodland white spruce	8.7	21.5	0.0	24.6	60.8	0.0
Woodland black spruce	1.2	2.9	0.0	-	-	-
Open black spruce	-	-	-	3.9	9.7	0.0
Open birch	-	-	-	3.0	7.3	0.3
Closed birch	-	-	-	4.9	12.2	1.5
Closed mixed	8.7	21.5	0.1	150.7	372.4	0.9
Shrubland	291.4	720.2	0.0	-	-	-
Open tall	41.7	103.1	0.1	-	-	-
Closed Tall	65.5	161.8	0.1	-	-	-
Birch	105.4	260.6	0.3	-	-	-
Willow	13.3	32.9	0.1	-	-	-
Low (mixed)	65.5	161.8	0.0	-	-	-
Tundra	109.5	270.6	0.0	15.8	38.9	0.0
Wet sedge-grass	-	-	-	15.8	38.9	0.3
Sedge-grass (mesic)	2.9	7.2	0.0	-	-	-
Sedge shrub	53.9	133.1	****	-	-	-
Mat and cushion	52.7	130.3	0.1	-	-	-
Total	419.5	1036.7	0.0	202.9	501.3	0.0

* Percent of total area of each vegetation type in entire Watana and Gold Creek watersheds, based on 1:250,000-scale mapping (McKendrick et al. 1982).

** Based on corridor width of 300 ft.

*** Based on corridor width of 510 ft.

**** Data not available for entire Watana and Gold Creek watersheds.

TABLE E.3.83: HECTARES OF DIFFERENT VEGETATION TYPES TO BE IMPACTED BY THE WATANA FACILITY COMPARED WITH TOTAL HECTARES OF THAT TYPE UPSTREAM OF GOLD CREEK IN THE SUSITNA WATERSHED AND IN THE AREA WITHIN 16 km OF THE SUSITNA RIVER* (MODIFIED FROM MCKENDRICK ET AL. 1982)

Vegetation Type	Dam and Spillways	Impoundment	Camp	Village	Airstrip	Borrow Areas[1] A	D	E	F	H	I	Total	Percent of Watershed Total For That Type	Percent of 16 km* Area For That Type
Forest	34****	10784				181	53	180	81	451	34	11798	3.4	8.3
Woodland black spruce	8	3870				179	16			224		4297	2.6	6.8
Woodland white spruce		397						71	69			537	2.6	4.0
Open black spruce		2864								121	15	3000	3.2	10.6
Open white spruce		769				2		62	11			844	3.2	8.1
Open birch	1	325										326	33.7	21.8
Closed birch	13	460					5					478	148.0**	20.6
Closed balsam poplar		3										3	***	0.5
Open mixed	5	1337					32			106		1480	6.3	15.4
Closed mixed	7	759						47	1		19	833	5.2	6.3
Tundra		84				70	8					162	0.1	0.1**
Wet sedge-grass		84					8					92	1.9	2.6
Mat-and-cushion						70						70	0.1	0.1**
Shrubland	46	1674	63	62	17	81	224		199	38		2404	0.4	1.4
Open tall shrub	6	227				1						234	0.4	1.5
Closed tall shrub	17	287				1	12					317	0.4	2.0
Birch shrub	1	443	34	35	13	4	88		195			813	2.4	1.9
Willow shrub		66							4	17		87	0.9	1.0
Mixed low shrub	22	651	29	27	4	75	124			21		953	0.2	1.0
Herbaceous		45										45	***	250.0**
Unvegetated	13	2104		8		1	2					2128	0.9	7.9
Rock	1	59					2					62	0.1	0.4
River	12	2007										2019	13.8	47.7
Lake		38		8		1						47	0.2	0.8
Total	93	14691	63	70	17	333	287	180	280	489	34	16537	1.0	3.6

[1] Area given is above maximum impoundment fill level.

* An area 16 km (10 mi) on either side of the Susitna River from Gold Creek to the mouth of the Maclaren River.

** Hectares are apparently greater in the impact areas than for the entire basin, because the basin was mapped at a much smaller scale, and many of the stands did not appear at that scale.

*** Areas of this type were too small to be mapped at the scale at which the watershed was mapped.

**** 1 hectare = 2.471 acres.

3B-7-4

ABLE E.3.84: HECTARES OF DIFFERENT VEGETATION TYPES TO BE AFFECTED BY THE DEVIL CANYON FACILITY COMPARED WITH TOTAL HECTARES OF THAT TYPE IN THE WATANA AND GOLD CREEK WATERSHEDS AND IN THE AREA WITHIN 16 km OF THE SUSITNA RIVER* (MODIFIED FROM MCKENDRICK ET AL. 1982).

egetation Type	Dam and Spillways	Impoundment	Camp	Village	Borrow**** Area K	Total	Percent of Watershed Total For That Type	Percent of 16 km* Area For That Type
orest	16****	2289	36	39	119	2499	0.7	1.8
Woodland black spruce		133				133	0.1	0.2
Woodland white spruce		20				20	0.1	0.2
Open black spruce	4	300			11	315	0.5	1.1
Open white spruce		329				329	0.5	3.1
Open birch		57				57	5.9	3.8
Closed birch	3	430				433	134.1**	18.6
Open balsam poplar		6				6	***	***
Closed balsam poplar		8				8	***	1.4
Open mixed	7	279				286	1.2	3.0
Closed mixed	2	727	36	39	108	912	5.7	6.9
undra		11				11	0.0	0.0
Wet sedge-grass		11				11	0.2	0.3
hrubland		70			18	88	0.0	0.1
Open tall shrub		2				2	0.0	0.0
Closed tall shrub		1				1	0.0	0.0
Birch shrub		49			18	67	0.2	0.2
Willow shrub		14				14	0.1	0.2
Mixed low shrub		4				4	0.0	0.0
nvegetated	2	826			11	839	0.3	3.1
Rock		15				15	0.0	0.1
River	1	810				811	5.5	19.1
Lake	1	1			11	13	0.1	0.2
Total	18	3196	36	39	148	3437	0.2	0.7

An area 16 km (10 mi) on either side of the Susitna River from Gold Creek to the mouth of the Maclaren River.

** Hectares of closed birch are apparently greater in the impact areas than for the entire basin, because the basin was mapped at a much smaller scale, and many of the closed birch stands did not appear at that scale.

*** Balsam poplar stands were too small to be mapped at the scale at which the watershed was mapped.

**** 1 hectare = 2.471 acres.

***** Borrow area G (not included) will consist of approximately 22 ha with stands of woodland and open black spruce, closed mixed forest, and open tall shrub.

38-7-5

TABLE E.3.85: AREAS OF EACH VEGETATION TYPE TO BE CLEARED FOR ACCESS, (REVISED) AND PERCENT TOTAL* FOR WATANA AND GOLD CREEK WATERSHEDS

Vegetation Type	Denali Highway to Watana (Road) **			Watana to Devil Canyon (Road) ***			Devil Canyon to Gold Creek (Railroad)****		
	ha	acres	%	ha	acres	%*	ha	acres	%*
Forest	11.2	27.7	0.0	37.5	92.8	0.0	28.3	70.0	0.0
Woodland white spruce	-	-	-	5.7	14.2	0.0	-	-	-
Open white spruce	0.6	1.5	0.0	15.9	39.3	0.0	-	-	-
Woodland black spruce	1.8	4.4	0.0	-	-	-	-	-	-
Open black spruce	-	-	-	0.4	1.1	0.0	1.5	3.7	0.0
Open birch	-	-	-	-	-	-	0.6	1.5	0.1
Closed birch	-	-	-	0.9	2.2	0.3	-	-	-
Closed balsam poplar	-	-	-	-	-	-	0.3	0.7	*****
Open mixed	8.8	21.8	0.0	4.0	9.8	0.0	5.7	14.1	0.0
Closed mixed	-	-	-	10.6	26.2	0.1	20.2	50.0	0.1
Shrubland	181.3	448.0	0.0	103.7	256.3	0.0	0.0	0.0	-
Open tall	-	-	-	7.9	19.6	0.0	-	-	-
Closed tall	-	-	-	22.1	54.5	0.0	-	-	-
Birch (low)	78.9	194.9	0.2	44.6	110.2	0.1	-	-	-
Willow (low)	81.8	202.2	0.8	5.3	13.1	0.0	-	-	-
Mixed (low)	20.6	50.9	0.0	23.8	58.9	0.0	-	-	-
Tundra	61.7	152.6	0.0	21.6	53.4	0.0	0.8	2.0	0.0
Wet sedge-grass	12.3	30.5	0.3	4.4	10.9	0.1	0.8	2.0	0.0
Sedge-grass (mesic)	17.6	43.6	0.0	-	-	-	-	-	-
Sedge-shrub	-	-	-	7.5	18.5	*****	-	-	-
Mat and cushion	31.8	78.5	0.1	9.7	24.0	0.0	-	-	-
Rock	0.6	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	254.8	629.8	0.0	162.8	402.5	0.0	29.1	72.0	0.0

* Percent of total area of each vegetation type in entire Watana and Gold Creek watersheds, based on 1:250,000-scale mapping (McKendrick et al. 1982).
** Based on clearing width of 120 ft.
*** Based on clearing width of 90 ft.
**** Based on clearing width of 50 ft.
***** Data not available for entire Watana and Gold Creek watersheds.

TABLE E.3.86: AREAS OF DIFFERENT VEGETATION TYPES TO BE CROSSED BY TRANSMISSION CORRIDORS*

Vegetation Type	Healy to Fairbanks		Willow to Cook Inlet	
	ha	acres	ha	acres
Forest	1034.9	2557.0	387.6	957.7
Woodland spruce	47.5	117.4	57.4	141.7
Open spruce	554.5	1370.1	29.5	73.0
Closed spruce	16.2	40.1	56.8	140.3
Open deciduous	93.9	231.9	-	-
Closed deciduous	37.7	93.1	-	-
Closed birch	-	-	44.6	110.2
Woodland conifer-deciduous	9.3	22.9	-	-
Open conifer-deciduous	159.3	393.7	30.7	75.9
Closed conifer-deciduous	7.0	17.2	168.6	416.6
Open spruce/open deciduous**	5.2	12.9	-	-
Open spruce/wet sedge-grass/ open deciduous**	5.2	12.9	-	-
Open spruce/low shrub/wet sedge-grass/open deciduous**	99.1	244.8	-	-
Tundra	117.6	290.5	165.7	409.4
Wet sedge-grass	103.1	254.8	165.7	409.4
Sedge-grass (mesic)	6.4	15.7	-	-
Sedge-shrub	8.1	20.0	-	-
Shrubland	247.3	611.3	67.2	166.1
Low mixed shrub	214.9	531.1	67.2	166.1
Low shrub/wet sedge-grass**	32.4	80.2	-	-
Disturbed	7.0	17.2	5.2	12.9
River	20.9	51.5	-	-
Total	1427.7	3527.5	625.7	1546.1

* Calculated from figures E.3.48-50 and E.3.51-52. Right-of-way width was adjusted to 91 m (300 ft) along the entire corridor.

** The Tanana Flats portion of the transmission corridor is an area of extremely complex mosaics of vegetation types. As a result, various complexes were recognized.

CHANGES IN THE TEXT OF THE BOTANICAL SECTION OF CHAPTER 3 RESULTING FROM CORRECTIONS OF BOTANICAL TABLES (the following sentences replace the corresponding sentences in the indicated paragraphs).

p.E-3-220, para. 1	Spruce hardwood forests cover half (49.9 percent) of the total area within the Willow-to-Healy transmission corridor. Upland spruce hardwood stands cover 1126 acres (456 ha), lowland spruce hardwood stands cover 585 acres (237 ha), and bottom land spruce hardwood stands cover 207 acres (84 ha). Shrublands are the next most predominant cover type (28.5 percent), occupying 1097 acres (444 ha).
p.E-3-220, para. 2	Almost 70 percent of the total area (1037 acres, 420 ha) within the Watana-to-Devil Canyon section of the transmission corridor is shrubland. Predominant vegetation types crossed include open tall shrubland (103 acres, 42 ha), closed tall shrubland (162 acres, 66 ha), low birch shrubland (261 acres, 105 ha), low mixed shrubland (162 acres, 66 ha), sedge-shrub tundra (133 acres, 54 ha), and mat and cushion tundra (130 acres, 53 ha). The Devil Canyon-to-Intertie (Gold Creek) section of the transmission corridor covers a total of 501 acres (203 ha), 372 acres (151 ha) of which is closed mixed forest. Smaller areas of woodland white spruce (61 acres, 25 ha) and wet sedge-grass tundra (39 acres, 16 ha) are also crossed.
p.E-3-225, para. 2	Construction of the Watana development will result in the direct removal of vegetation within an area of approximately 35,605 acres (14,409 ha) covering a range of elevations from 1400 to 2400 feet (430 to 730 m). In addition about 5,258 acres (2128 ha) of unvegetated areas will be inundated or developed. Within the dam, spillway, and impoundment areas about 36,531 acres (14,784 ha) will be disturbed by construction and clearing operations.

p.E-3-240, para. 2 — Approximately 5700 acres (2305 ha) of forest and 170 acres (70 ha) of shrubland will be inundated or cleared for the dam, spillways, and impoundment area (Table E.3.84).

p.E-3-243, para. 2 — Approximately 628 acres (254 ha) of primarily shrub and tundra vegetation will be cleared along a 44 mile (71 km) corridor for the Denali Highway-to-Watana access route (Table E.3.85).

p.E-3-243, para. 3 — Construction of this road will entail clearing an additional 402 acres (163 ha) of roadway. A 12-mile (19 km) railroad extension between Devil Canyon and Gold Creek will be constructed on the south side of the Susitna River, removing an additional 72 acres (29 ha) of vegetation.

p.E-3-244, para. 3 — Transmission corridors comprise a total of 10,460 acres (4233 ha) and will constitute another source of vegetation loss and/or disturbance (Tables E.3.79, E.3.80, and E.3.86). The transmission lines from Healy to Fairbanks cover a total of 3528 acres (1428 ha). Open spruce (1370 acres, 554 ha) constitutes the main vegetation type in the right-of-way. The Willow-to-Cook Inlet transmission corridor (total cover 1546 acres, 626 ha) will cross primarily closed conifer-deciduous forest (417 acres, 169 ha) and sedge-grass tundra (409 acres, 166 ha). The Willow-to-Healy transmission corridor (3844 acres, 1556 ha) is composed primarily of upland spruce-hardwood forest (1126 acres, 456 ha) and shrublands (1097 acres, 444 ha). Shrublands (720 acres, 291 ha), forest (511 acres, 206 ha), and tundra (310 acres, 125 ha) are included in the proposed right-of-way for the Watana-to-Gold Creek transmission corridor (total area 1538 acres, 622 ha).

p.E-3-245, para. 3	Far more potential wetland areas are included within the Watana development (30,717 acres, 12,431 ha) than within the Devil Canyon project area (4,216 acres, 1,706 ha) (Table E.3.82). The proportion of the area occupied by wetland types also differs within the two areas. Although potential palustrine forested areas occupy the greatest areal extent of wetland types in the Watana facility (66 percent of total potential wetland), this type occupies 48 percent of the potential wetlands to be affected by the Devil Canyon facility.
p.E-3-246, para. 5	Direct losses for the Watana project include 31,300 acres (12,667 ha) of vegetation for the dam, impoundment and spillway (5,231 acres, 2,117 ha of unvegetated area will also be disturbed). An additional 4,300 acres (1,742 ha) have been designated for use as camp, village, airstrip, and borrow areas. These potential losses account for only 1 percent of all vegetation in the Watana and Gold Creek basins, but 3.3 percent of the vegetation present in a 20 mile (32 km) wide area spanning the Susitna River from the mouth of the Maclaren River to Gold Creek.
p.E-3-247,	Direct losses of vegetation for the Devil Canyon dam, spillway and impoundment areas will include 5,869 acres (2,386 ha) of forests, tundra, and shrubland. 2046 acres (828 ha) of unvegetated land will also be disturbed (Table E.3.84).
p.E-3-247, para. 3	The Watana access road will result in a loss of approximately 628 acres (254 ha) of mostly tundra and shrubland vegetation types. Additional losses of about 402 acres (163 ha) for access roads and 72 acres (29 ha) for rail will be required for access to the Devil Canyon facility.

p.E-3-247, para. 4

Of the total 10,460 acres (4,233 ha) of vegetation on right-of-way for transmission lines, only a small fraction will need be subject to initial clearing, since there will be no clearing of low shrub or tundra types.

p.E-3-252, para. 5 to p.E-3-253, para. 2

Without mitigation, construction of all project facilities would remove vegetation from a total of about 53,624 acres (21,701 ha) apportioned as follows:

	acres	hectares
- Dams and spillways	237	96
- Impoundments	36,959	14,957
- Camps	245	99
- Villages	250	101
- Airstrip	42	17
- Damsite borrow areas	4,292	1,737
- Access borrow areas	35	14
- Access routes	1,104	447
- Transmission corridors*	10,460	4,233

*Ground layer and soil will not be removed.

In addition 7,333 acres (2,968 ha) of unvegetated area will be disturbed. About 95 percent of this area is river channel within the impoundment areas.

Of this cumulative impact, vegetation removal resulting from dams and spillways, impoundments, access routes, and the Watana operational village will be permanent, accounting for about 70 percent (38,454 acres, 15,562 ha). The remaining 30 percent (15,170 acres, 6,139 ha) will allow application of the following range of mitigation options.

p.E-3-256, para. 4	The Denali Highway-to-Watana route will remove about 448 acres (181 ha) of shrubland and about 153 acres (62 ha) of tundra types, accounting for less than one percent of total shrubland or tundra in the Watana and Gold Creek watersheds (Table E.3.85). Only 1.5 acres (0.6 ha) of open white spruce forest will be affected, and the number of individual trees actually cut in this low density vegetation type will be statistically insignificant on a local or regional basis.
p.E-3-257, para. 2	About two-thirds (67 percent) of the route is shrubland (256 acres, 104 ha), about 20 percent is forest (93 acres, 38 ha) and 15 percent is tundra (53 acres, 22 ha) (Table E.3.85).
p.E-3-257, para. 3	The Devil Canyon-to-Gold Creek railroad route will traverse almost entirely closed mixed forest (about 50 acres, 20 ha) and open mixed forest (about 14 acres, 6 ha) (Table E.3.85).
p.E-3-258, para. 3 to p.E-3-259, para. 4	Low abundance vegetation types which will receive the greatest cumulative impact from construction of the impoundments and dams, access and transmission corridors, and all ancillary facilities, will be open and closed birch forest, and wet sedge-grass tundra (Tables E.3.80 and E.3.83-E.3.85). A cumulative total of 3221 acres (1303 ha) of open and closed birch forest could be affected by construction-related clearing between 1985 and 2002. Based on the 1:63,360-scale mapping of the 20-mile (32 km) strip along the Susitna River (the map showing the vegetation of the area in the greatest detail) (Table E.3.52), 34 percent of the total 9,444 acres (3,822 ha) of this vegetation type could be removed by construction. About 3,143 acres (1,272 ha) or 33 percent of the total coverage will be entirely removed by clearing of the impoundments (Tables E.3.83 and E.3.84). The remaining 78 acres (32 ha) will be selectively cleared as discussed further below.

The other low-abundance vegetation type within the Watana and Gold Creek watersheds to be affected by construction, wet sedge-grass tundra, will be crossed by access and transmission corridors (82 acres, 33 ha) (Tables E.3.80, E.3.85) and inundated by the impoundment areas (235 acres, 95 ha) (Tables E.3.83, E.3.84). Borrow Area D (Figure E.3.37) will potentially remove an additional 20 acres (8 ha) (Table E.3.83). The siting of all pads, buildings, and other structural facilities has entirely avoided this vegetation type. Therefore, a total of 337 acres (136 ha) of wet sedge-grass tundra will be potentially affected by construction between 1985 and 2002. This cumulative impact represents about 4 percent of the total 8,691 acres (3,517 ha) present within the 20-mile (32 km) strip mapped at 1:63,360 (Table E.3.52). Mitigative measures which will minimize drainage alterations in this wet vegetation type are discussed in Section 3.4.2(c).

In summary, siting of pads, buildings, the Watana airstrip, and other ancillary facilities has minimized clearing requirements for low-abundance vegetation types. As residual impact, the impoundments and access and transmission corridors will remove about 34 percent of the birch forest, and 4 percent of the wet sedge-grass tundra within the 20-mile (32 km) strip mapped at 1:63,360.

p.E-3-270, para. 1 In fact, as stated in Sections 3.3.4(a) and 3.3.6(a)(iv), the 10,460 acres (4,233 ha) required for transmission corridor rights-of-way will be cleared only to a limited extent, as explained in the following discussion.

p.E-3-274, para. 4 to p.E-3-275 para. 1	Of the approximately 53,624 acres (21,701 ha) potentially subject to vegetation removal on a cumulative basis, about 30 percent, or 15,170 acres (6,139 ha), will allow application of mitigation measures discussed above. Approximately 46 the percent of the total area covered by transmission corridors (4,812 acres, 1947 has, of the total 10,460 acres, 4,233 ha) will be left uncleared or partly cleared. In addition, use of side-borrow and balanced cut-and-fill techniques for construction of the access roads and railroad extension will protect up to 280 acres (112 ha) of vegetated area.
	Using the two examples cited above, measures to minimize vegetation removal will conserve about 5,092 acres (2059 ha), or up to about 35 percent of the land area in question.
p.E-3-280, para. 5	In summary, rectification will restore vegetation to approximately 3,209 acres (1,299 ha) temporarily lost to ancillary facilities. This represents about 6 percent of the cumulative total land area affected by direct loss of vegetation during project construction and operation (53,624 acres, 21,701 ha).
p.E-3-282, para. 3 to p.E-3-282 para. 4	For the Susitna project, the cumulative area lost in this way will total about 38,454 acres (15,562 ha), with 36,959 acres (14,957 ha) covered by the impoundments. Actual acreages of vegetation types which will be removed were discussed previously and quantified in Tables E.3.83 and E.3.84.
	From the preceeding options analysis, it is evident that measures for minimization, rectification and reduction of vegetation loss will apply, at most, to about 30 percent (15,178 acres, 6,139 ha) of the total area of vegetation which will be removed by the project.

CHANGES IN THE TEXT AND TABLES OF THE WILDLIFE SECTION OF CHAPTER 3 RESULTING FROM CORRECTIONS OF BOTANICAL TABLES (the following sentences replace the corresponding sentences in the indicated paragraphs).

p.E-3-461, para. 4	Sentence 2. Should read: "About 26,647 acres (10,784 ha) of forest will be cleared."
p.E-3-463, para. 4	Sentence 1. Should read: "An estimated 6175 acres (2499 ha) will be cleared within the Devil Canyon impoundment area and an additional 519 acres of forest (210 ha) will be used for operational areas, campsites and borrow sites."
p.E-3-476, para. 1	Sentence 2. Should read: "The total area affected (8492 acres, 3437 ha) and the total percent of forested land affected (0.7 percent) are much smaller than in the Watana reservoir area."
p.E-3-498, para. 4	Sentence 1. Should read: "Table E.3.166 indicates an order-of-magnitude estimate of 1,200 small to medium-sized breeding birds lost to the transmission line, less than 0.1 percent of the population within 16 km of the Susitna River between the Maclaren River and Gold Creek." (This correction supercedes the Acres errata of 29 March 1983.)
p.E-3-432, para. 4	Sentence 1. Should read: "Based on the estimate of about one wolverine per 40,320 acres (163 km^2) derived in Section 4.2.1(g), the direct loss of over 40,846 acres (16,530 ha) caused by the Watana impoundment and facilities would lower the carrying capacity by about two wolverines."

p. E-3-441, para. 2	Sentence 2. Should read: "Using a figure of 11,798 ha of forest habitat lost to the Watana impoundment area, borrow sites, construction sites and camps, habitat supporting 100 marten (3.4 percent of the forested habitat in the Susitna watershed upstream from Gold Creek) would be lost."
Table E.3.144	Under Permanent Habitat Loss, Watana alone: the area affected by the access corridor should be changed from 192 to 255 ha. The area affected by the Access Corridor from Denali Highway to Watana should be changed from 192 to 255 ha. The area affected by the permanent village should be changed from 27 to 70 ha. The area affected by the permanent airstrip should be changed from 47 to 17 ha.
	Under Permanent Habitat Loss, Devil Canyon: the area affected by the access corridor should be changed from 218 to 192 ha. The area affected by the access corridor from Watana to Devil Canyon should be changed from 189 to 163 ha.
	Under Habitat Alteration and Temporary Habitat Loss, Watana alone: the area affected by the transmission corridor from Watana to Devil Canyon should be changed from 379.8 to 419 ha. The area affected by the transmission corridor from Devil Canyon to Gold Creek should be changed from 77.5 to 119 ha.
	Under Habitat Alteration and Temporary Habitat Loss, Devil Canyon: the area affected by the transmission corridor from Watana to Devil Canyon should be changed from 209 additional to 0. The area affected by the transmission corridor from Devil Canyon to Gold Creek should be changed from 0 to 84 additional ha.

Table E.3.145	Under (2) Habitat Alteration and Temporary Habitat Loss--transmission corridor. Sentence should read: "Nearly all 152,000 ha of the corridor is likely to become winter habitat of reasonable quality to moose. No existing winter habitat will be made unusable. Corridor will be maintained in early succession throughout the life of the project." Next sentence should read: "Drifting snow is unlikely to be a significant factor in the 300-foot corridor and will not reduce forage availability."
Table E.3.151	Under (5) Increased Human Access-hunting and poaching. Sentence should read: "Much of the current harvest is illegal and the illegal harvest will increase in the absence of better control. Current legal harvest is unlimited (no bag limit) and harvest is likely to increase. The current annual take is 40-45% of the population.

All figures of areas to be impacted or mitigated have been checked and recalculated, and some have been re-measured. Tables E.3.79, E.3.86 and E.3.144 required corrections. These tables, as well as Tables E.3.80, E.3.83, E.3.84, and E.3.85 (previously revised in Suppplemental Information Request Response 3-B-7) are attached, as are relevant portions of the text that subsequently required modification. Unvegetated areas were not included in the calculations for vegetation removals, but disturbed areas were included. Unvegetated rocky areas were not treated differently from river, lake, or ice areas.

TABLE E.3.79: AREAS OF DIFFERENT VEGETATION TYPES TO BE CROSSED
(REVISED) BY WILLOW-TO-HEALY TRANSMISSION CORRIDOR*

Cover Type	Healy to** Gold Creek Acres (Ha)	Gold Creek*** to Willow Acres (Ha)	Healy to Willow Acres (Ha)	Percent of Total
o Moist tundra	--	174(70)	174(70)	5.0
o Wet tundra	187(75)	--	187(75)	5.4
o Alpine tundra	30(12)	17(7)	47(19)	1.4
o Bottomland spruce-poplar forest	10(4)	261(104)	271(108)	7.9
o Upland spruce-hardwood forest	473(189)	296(118)	769(307)	22.4
o Lowland spruce-hardwood forest	--	662(265)	662(265)	19.3
o Shrublands	699(280)	209(83)	908(363)	26.4
o Low brush, muskeg bog	--	419(168)	419(168)	12.2
Total	1,399(560)	2,038(815)	3,437(1,375)	100.0

* Calculated from vegetation maps in Commonwealth Associates Environmental Assessment Report (EAR), March, 1982.

** Healy to Gold Creek right-of-way width used was 130 feet (300 feet minus Intertie ROW of 170 feet).

*** Willow to Gold Creek right-of-way width used was 230 feet (400 feet minus Intertie ROW of 170 feet).

TABLE E.3.80: AREAS OF EACH VEGETATION TYPE TO BE CROSSED BY WATANA-TO-GOLD CREEK TRANSMISSION CORRIDORS AND PERCENT TOTAL* FOR WATANA AND GOLD CREEK WATERSHEDS (REVISED)

	Watana to Devil Canyon**			Devil Canyon to Gold Creek***		
Vegetation Type	ha	acres	%*	ha	acres	%*
Forest	18.6	45.9	0.0	187.1	462.4	0.1
Woodland white spruce	8.7	21.5	0.0	24.6	60.8	0.0
Woodland black spruce	1.2	2.9	0.0	-	-	-
Open black spruce	-	-	-	3.9	9.7	0.0
Open birch	-	-	-	3.0	7.3	0.3
Closed birch	-	-	-	4.9	12.2	1.5
Closed mixed	8.7	21.5	0.1	150.7	372.4	0.9
Shrubland	291.4	720.2	0.0	-	-	-
Open tall	41.7	103.1	0.1	-	-	-
Closed Tall	65.5	161.8	0.1	-	-	-
Birch	105.4	260.6	0.3	-	-	-
Willow	13.3	32.9	0.1	-	-	-
Low (mixed)	65.5	161.8	0.0	-	-	-
Tundra	109.5	270.6	0.0	15.8	38.9	0.0
Wet sedge-grass	-	-	-	15.8	38.9	0.3
Sedge-grass (mesic)	2.9	7.2	0.0	-	-	-
Sedge shrub	53.9	133.1	****	-	-	-
Mat and cushion	52.7	130.3	0.1	-	-	-
Total	419.5	1036.7	0.0	202.9	501.3	0.0

* Percent of total area of each vegetation type in entire Watana and Gold Creek watersheds, based on 1:250,000-scale mapping (McKendrick et al. 1982).

** Based on corridor width of 300 ft.

*** Based on corridor width of 510 ft.

**** Data not available for entire Watana and Gold Creek watersheds.

TABLE E.3.83: HECTARES OF DIFFERENT VEGETATION TYPES TO BE IMPACTED BY THE WATANA FACILITY COMPARED WITH TOTAL HECTARES OF THAT TYPE UPSTREAM OF GOLD CREEK IN THE SUSITNA WATERSHED AND IN THE AREA WITHIN 16 km OF THE SUSITNA RIVER* (MODIFIED FROM MCKENDRICK ET AL. 1982)

Vegetation Type	Dam and Spillways	Impoundment	Camp	Village	Airstrip	Borrow Areas[1] A	D	E	F	H	I	Total	Percent of Watershed Total For That Type	Percent of 16 km* Area For That Type
Forest	34****	10784				181	53	180	81	451	34	11798	3.4	8.3
Woodland black spruce	8	3870				179	16			224		4297	2.6	6.8
Woodland white spruce		397						71	69			537	2.6	4.0
Open black spruce		2864								121	15	3000	3.2	10.6
Open white spruce		769				2		62	11			844	3.2	8.1
Open birch	1	325										326	33.7	21.8
Closed birch	13	460					5					478	148.0**	20.6
Closed balsam poplar		3										3	***	0.5
Open mixed	5	1337					32			106		1480	6.3	15.4
Closed mixed	7	759						47	1		19	833	5.2	6.3
Tundra		84				70	8					162	0.1	0.1**
Wet sedge-grass		84					8					92	1.9	2.6
Mat-and-cushion						70						70	0.1	0.1**
Shrubland	46	1674	63	62	17	81	224		199	38		2404	0.4	1.4
Open tall shrub	6	227				1						234	0.4	1.5
Closed tall shrub	17	287				1	12					317	0.4	2.0
Birch shrub	1	443	34	35	13	4	88		195			813	2.4	1.9
Willow shrub		66							4	17		87	0.9	1.0
Mixed low shrub	22	651	29	27	4	75	124			21		953	0.2	1.0
Herbaceous		45										45	***	250.0**
Unvegetated	13	2104		8		1	2					2128	0.9	7.9
Rock	1	59					2					62	0.1	0.4
River	12	2007										2019	13.8	47.7
Lake		38		8		1						47	0.2	0.8
Total	93	14691	63	70	17	333	287	180	280	489	34	16537	1.0	3.6

[1] Area given is above maximum impoundment fill level.

* An area 16 km (10 mi) on either side of the Susitna River from Gold Creek to the mouth of the Maclaren River.

** Hectares are apparently greater in the impact areas than for the entire basin, because the basin was mapped at a much smaller scale, and many of the stands did not appear at that scale.

*** Areas of this type were too small to be mapped at the scale at which the watershed was mapped.

**** 1 hectare = 2.471 acres.

3B-7-4

ABLE E.3.84: HECTARES OF DIFFERENT VEGETATION TYPES TO BE AFFECTED BY THE DEVIL CANYON FACILITY COMPARED WITH TOTAL HECTARES OF THAT TYPE IN THE WATANA AND GOLD CREEK WATERSHEDS AND IN THE AREA WITHIN 16 km OF THE SUSITNA RIVER* (MODIFIED FROM MCKENDRICK ET AL. 1982).

egetation Type	Dam and Spillways	Impoundment	Camp	Village	Borrow**** Area K	Total	Percent of Watershed Total For That Type	Percent of 16 km* Area For That Type
orest	16****	2289	36	39	119	2499	0.7	1.8
Woodland black spruce		133				133	0.1	0.2
Woodland white spruce		20				20	0.1	0.2
Open black spruce	4	300			11	315	0.5	1.1
Open white spruce		329				329	0.5	3.1
Open birch		57				57	5.9	3.8
Closed birch	3	430				433	134.1**	18.6
Open balsam poplar		6				6	***	***
Closed balsam poplar		8				8	***	1.4
Open mixed	7	279				286	1.2	3.0
Closed mixed	2	727	36	39	108	912	5.7	6.9
undra		11				11	0.0	0.0
Wet sedge-grass		11				11	0.2	0.3
hrubland		70			18	88	0.0	0.1
Open tall shrub		2				2	0.0	0.0
Closed tall shrub		1				1	0.0	0.0
Birch shrub		49			18	67	0.2	0.2
Willow shrub		14				14	0.1	0.2
Mixed low shrub		4				4	0.0	0.0
Jnvegetated	2	826			11	839	0.3	3.1
Rock		15				15	0.0	0.1
River	1	810				811	5.5	19.1
Lake	1	1			11	13	0.1	0.2
Total	18	3196	36	39	148	3437	0.2	0.7

* An area 16 km (10 mi) on either side of the Susitna River from Gold Creek to the mouth of the Maclaren River.

** Hectares of closed birch are apparently greater in the impact areas than for the entire basin, because the basin was mapped at a much smaller scale, and many of the closed birch stands did not appear at that scale.

*** Balsam poplar stands were too small to be mapped at the scale at which the watershed was mapped.

**** 1 hectare = 2.471 acres.

***** Borrow area G (not included) will consist of approximately 22 ha with stands of woodland and open black spruce, closed mixed forest, and open tall shrub.

38-7-5

TABLE E.3.85: AREAS OF EACH VEGETATION TYPE TO BE CLEARED FOR ACCESS,
(REVISED) AND PERCENT TOTAL* FOR WATANA AND GOLD CREEK WATERSHEDS

	Denali Highway to Watana (Road) **			Watana to Devil Canyon (Road) ***			Devil Canyon to Gold Creek (Railroad)****		
Vegetation Type	ha	acres	%	ha	acres	%*	ha	acres	%*
Forest	11.2	27.7	0.0	37.5	92.8	0.0	28.3	70.0	0.0
Woodland white spruce	-	-	-	5.7	14.2	0.0	-	-	-
Open white spruce	0.6	1.5	0.0	15.9	39.3	0.0	-	-	-
Woodland black spruce	1.8	4.4	0.0	-	-	-	-	-	-
Open black spruce	-	-	-	0.4	1.1	0.0	1.5	3.7	0.0
Open birch	-	-	-	-	-	-	0.6	1.5	0.1
Closed birch	-	-	-	0.9	2.2	0.3	-	-	-
Closed balsam poplar	-	-	-	-	-	-	0.3	0.7	*****
Open mixed	8.8	21.8	0.0	4.0	9.8	0.0	5.7	14.1	0.0
Closed mixed	-	-	-	10.6	26.2	0.1	20.2	50.0	0.1
Shrubland	181.3	448.0	0.0	103.7	256.3	0.0	0.0	0.0	-
Open tall	-	-	-	7.9	19.6	0.0	-	-	-
Closed tall	-	-	-	22.1	54.5	0.0	-	-	-
Birch (low)	78.9	194.9	0.2	44.6	110.2	0.1	-	-	-
Willow (low)	81.8	202.2	0.8	5.3	13.1	0.0	-	-	-
Mixed (low)	20.6	50.9	0.0	23.8	58.9	0.0	-	-	-
Tundra	61.7	152.6	0.0	21.6	53.4	0.0	0.8	2.0	0.0
Wet sedge-grass	12.3	30.5	0.3	4.4	10.9	0.1	0.8	2.0	0.0
Sedge-grass (mesic)	17.6	43.6	0.0	-	-	-	-	-	-
Sedge-shrub	-	-	-	7.5	18.5	*****	-	-	-
Mat and cushion	31.8	78.5	0.1	9.7	24.0	0.0	-	-	-
Rock	0.6	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	254.8	629.8	0.0	162.8	402.5	0.0	29.1	72.0	0.0

* Percent of total area of each vegetation type in entire Watana and Gold Creek watersheds, based on 1:250,000-scale mapping (McKendrick et al. 1982).

** Based on clearing width of 120 ft.

*** Based on clearing width of 90 ft.

**** Based on clearing width of 50 ft.

***** Data not available for entire Watana and Gold Creek watersheds.

TABLE E.3.86: AREAS OF DIFFERENT VEGETATION TYPES TO BE BY TRANSMISSION CORRIDORS*

	Healy to Fairbanks		Willow to Cook Inlet	
Vegetation Type	ha	acres	ha	acres
Forest	1034.9	2557.0	515.5	1273.74
Woodland spruce	47.5	117.4	76.3	188.5
Open spruce	554.4	1370.1	39.2	97.1
Closed spruce	16.2	40.1	75.5	186.6
Open deciduous	93.9	231.9	--	--
Closed deciduous	37.7	93.1	--	--
Closed birch	--	--	59.3	146.6
Woodland conifer-deciduous	9.3	22.9	--	--
Open conifer-deciduous	159.3	393.7	40.8	100.9
Closed conifer-deciduous	7.0	17.2	224.2	554.1
Open spruce/open deciduous***	5.2	12.9	--	--
Open spruce/wet sedge-grass/ open deciduous***	5.2	12.9	--	--
Open spruce/low shrub/wet sedge-greass/open dediduous***	99.1	244.8	--	--
Tundra	117.6	290.5	220.4	544.5
Wet sedge-grass	103.1	254.8	220.4	544.5
Sedge-grass (mesic)	6.4	15.7	--	--
Sedge-shrub	8.1	20.0	--	--
Shrubland	247.3	611.3	89.4	220.9
Low mixed shrub	214.9	531.1	89.4	220.9
Low shrub/wet sedge-grass***	32.4	80.2	--	--
Disturbed	7.0	17.2	6.9	17.2
River	20.9	51.5	--	--
Total	1427.7	3527.5	832.9	2056.3

* Calculated from Figures E.3.48-50 and E.3.51-52. Based on development of both Watana and Devil Canyon, a Right-of-Way width of 91 m (300 ft) was used for the Healy to Fairbanks corridor, and 121 m (400 ft) was used for the Willow to Cook Inlet corridor.

** For the purpose of calculation of total acreages it was assumed that vegetation types along the unmapped portion of the route were representative of the vegetative portions of the mapped corridor.

*** The Tanana Flats portion of the Transmission Corridor is an area of extremely complex mosaics of vegetation types. As a result, various complexes were recognized.

TABLE E.3.144. TIME SCHEDULE OF ANTICIPATED IMPACTS TO TERRESTRIAL VERTEBRATES RESULTING FROM SUSITNA HYDRO PROJECT

1. PERMANENT HABITAT LOSS

	Watana (Alone)		Devil Canyon (Additional)	
	Area Affected (ha)	Time Period Over Which Area Increases	Area (ha)	Time Period
Dam and Spillways	93	1985-1991	18	1996-1999
Impoundment	14,691	1985-1993	3,196	1996-2001
- Flooding	14,691	1991-1993	3,196	1999-2001
- Spoil Sites	(all below fill level)	1985-1991	(also below fill level)	1996-1999
- Erosion of Shore After Filling	Approx. 558	1993- ?	?	2001- ?
Access Corridor (Includes Borrow Sites for Access)	255	1985	192	1988-1994
- Denali Highway to Watana	255	1985	---	---
- Watana to Devil Canyon	---	--	163	1988
- Rail, DC to Gold Creek	---	--	29	1991-1994
Permanent Village	35	1987-1988	---	---
Permanent Airstrip	17	1985		1994

2. HABITAT ALTERATION & TEMPORARY HABITAT LOSS

	Area Affected (ha)	Time Period	Area (ha)	Time Period
- Impoundment Clearing	12,587	1989-1992	2,370	1999-2001
- Temporary Village	35	1987-1988	39	1995-2002
- Temporary Camp	63	1985-1994	36	1994-2002
- Borrow Areas (Above Impoundment Level)	1,603	1987-1991	148	1996-1999

TABLE E.3.144. TIME SCHEDULE OF ANTICIPATED IMPACTS TO TERRESTRIAL VERTEBRATES RESULTING FROM SUSITNA HYDRO PROJECT

2. HABITAT ALTERATION & TEMPORARY HABITAT LOSS

	Watana (Alone)		Devil Canyon (Additional)	
	Area Affected (ha)	Time Period Over Which Area Increases	Area (ha)	Time Period
- A	333		---	---
- D	287		---	---
- E	180		---	---
- F	280	Dates Not	---	---
- H	489	Available	------	
- I	34		---	---
- K	---		148	Dates Not Available
- Contractor Work Areas	300	1985-1995	195	1994-2002
Staging Areas				
- Mid Access Road	Data Not Available		---	---
- Cantwell	61	1985-2002	---	---
- Gold Creek	---	---	61	1994-2002
Accessory Roads	Data Not Available	1985- ?	?	1994-2002
Temporary Airstrip (Adjacent to Dam)	Data Not Available	?		
Transmission Corridor				
- Watana to Devil Canyon	419	Dates Not		
- Devil Canyon to Gold Creek	119	Available	84 Additional	

CHANGES IN THE TEXT OF THE BOTANICAL SECTION OF CHAPTER 3 RESULTING FROM CORRECTIONS OF BOTANICAL TABLES (the following sentences replace the corresponding sentences in the indicated paragraphs).

p.E-3-220, para. 1 — Spruce hardwood forests cover half (49.6 percent) of the total area within the Willow-to-Healy transmission corridor. Upland spruce hardwood stands cover 769 acres (307 ha), lowland spruce hardwood stands cover 662 acres (265 ha), and bottom land spruce hardwood stands cover 271 acres (108 ha). Shrublands are the next most predominant cover type (26.4 percent), occupying 908 acres (363 ha).

p.E-3-220, para. 2 — Almost 70 percent of the total area (1037 acres, 420 ha) within the Watana-to-Devil Canyon section of the transmission corridor is shrubland. Predominant vegetation types crossed include open tall shrubland (103 acres, 42 ha), closed tall shrubland (162 acres, 66 ha), low birch shrubland (261 acres, 105 ha), low mixed shrubland (162 acres, 66 ha), sedge-shrub tundra (133 acres, 54 ha), and mat and cushion tundra (130 acres, 53 ha). The Devil Canyon-to-Intertie (Gold Creek) section of the transmission corridor covers a total of 501 acres (203 ha), 372 acres (151 ha) of which is closed mixed forest. Smaller areas of woodland white spruce (61 acres, 25 ha) and wet sedge-grass tundra (39 acres, 16 ha) are also crossed.

p.E-3-225, para. 2 — Construction of the Watana development will result in the direct removal of vegetation within an area of approximately 35,605 acres (14,409 ha) covering a range of elevations from 1400 to 2400 feet (430 to 730 m). In addition about 5,258 acres (2128 ha) of unvegetated areas will be inundated or developed. Within the dam, spillway, and impoundment areas about 36,531 acres (14,784 ha) will be disturbed by construction and clearing operations.

p.E-3-240, para. 2 Approximately 5700 acres (2305 ha) of forest and 170 acres (70 ha) of shrubland will be inundated or cleared for the dam, spillways, and impoundment area (Table E.3.84).

p.E-3-243, para. 2 Approximately 628 acres (254 ha) of primarily shrub and tundra vegetation will be cleared along a 44 mile (71 km) corridor for the Denali Highway-to-Watana access route (Table E.3.85).

p.E-3-243, para. 3 Construction of this road will entail clearing an additional 402 acres (163 ha) of roadway. A 12-mile (19 km) railroad extension between Devil Canyon and Gold Creek will be constructed on the south side of the Susitna River, removing an additional 72 acres (29 ha) of vegetation.

p.E-3-244, para. 3 Transmission corridors comprise a total of 10,559 acres (4258 ha) and will constitute another source of vegetation loss and/or disturbance (Tables E.3.79, E.3.80, and E.3.86). The transmission lines from Healy to Fairbanks cover a total of 3528 acres (1428 ha). Open spruce (1370 acres, 554 ha) constitutes the main vegetation type in the right-of-way. The Willow-to-Cook Inlet transmission corridor (total cover 2056 acres, 833 ha) will cross primarily closed conifer-deciduous forest (554 acres, 224 ha) and sedge-grass tundra (545 acres, 220 ha). The Willow-to-Healy transmission corridor (3437 acres, 1375 ha) is composed primarily of upland spruce-hardwood forest (769 acres, 307 ha) and shrublands (908 acres, 363 ha). Shrublands (720 acres, 291 ha), forest (511 acres, 206 ha), and tundra (310 acres, 125 ha) are included in the proposed right-of-way for the Watana-to-Gold Creek transmission corridor (total area 1538 acres, 622 ha).

p.E-3-245, para. 3

Far more potential wetland areas are included within the Watana development (30,717 acres, 12,431 ha) than within the Devil Canyon project area (4,216 acres, 1,706 ha) (Table E.3.82). The proportion of the area occupied by wetland types also differs within the two areas. Although potential palustrine forested areas occupy the greatest areal extent of wetland types in the Watana facility (66 percent of total potential wetland), this type occupies 48 percent of the potential wetlands to be affected by the Devil Canyon facility.

p.E-3-246, para. 5

Direct losses for the Watana project include 31,300 acres (12,667 ha) of vegetation for the dam, impoundment and spillway (5,231 acres, 2,117 ha of unvegetated area will also be disturbed). An additional 4,300 acres (1,742 ha) have been designated for use as camp, village, airstrip, and borrow areas. These potential losses account for only 1 percent of all vegetation in the Watana and Gold Creek basins, but 3.3 percent of the vegetation present in a 20 mile (32 km) wide area spanning the Susitna River from the mouth of the Maclaren River to Gold Creek.

p.E-3-247,

Direct losses of vegetation for the Devil Canyon dam, spillway and impoundment areas will include 5,869 acres (2,386 ha) of forests, tundra, and shrubland. 2046 acres (828 ha) of unvegetated land will also be disturbed (Table E.3.84).

~~p.E-3-247, para. 3~~

~~The Watana access road will result in a loss of approximately 628 acres (254 ha)~~ of mostly tundra and shrubland vegetation types. Additional losses of about 402 acres (163 ha) for access roads and 72 acres (29 ha) for rail will be required for access to the Devil Canyon facility.

p.E-3-247, para. 4

Of the total 10,559 acres (4,258 ha) of vegetation on right-of-way for transmission lines, only a small fraction will need be subject to initial clearing, since there will be no clearing of low shrub or tundra types.

p.E-3-252, para. 5 to p.E-3-253, para. 2

Without mitigation, construction of all project facilities would remove vegetation from a total of about 53,736 acres (21,734 ha) apportioned as follows:

	acres	hectares
- Dams and spillways	237	96
- Impoundments	36,959	14,957
- Camps	245	99
- Villages	263	109
- Airstrip	42	17
- Damsite borrow areas	4,292	1,737
- Access borrow areas	35	14
- Access routes	1,104	447
- Transmission corridors*	10,559	4,258

*Ground layer and soil will not be removed.

In addition 7,333 acres (2,968 ha) of unvegetated area will be disturbed. About 95 percent of this area is river channel within the impoundment areas.

Of this cumulative impact, vegetation removal resulting from dams and spillways, impoundments, access routes, and the Watana operational village will be permanent, accounting for about 70 percent (38,386 acres, ~~15,525~~ 15,535 ha). The remaining 30 percent (15,350 acres, 6,199 ha) will allow application of the following range of mitigation options.

p.E-3-256, para. 4 — The Denali Highway-to-Watana route will remove about 448 acres (181 ha) of shrubland and about 153 acres (62 ha) of tundra types, accounting for less than one percent of total shrubland or tundra in the Watana and Gold Creek watersheds (Table E.3.85). Only 1.5 acres (0.6 ha) of open white spruce forest will be affected, and the number of individual trees actually cut in this low density vegetation type will be statistically insignificant on a local or regional basis.

p.E-3-257, para. 2 — About two-thirds (67 percent) of the route is shrubland (256 acres, 104 ha), about 20 percent is forest (93 acres, 38 ha) and 15 percent is tundra (53 acres, 22 ha) (Table E.3.85).

p.E-3-257, para. 3 — The Devil Canyon-to-Gold Creek railroad route will traverse almost entirely closed mixed forest (about 50 acres, 20 ha) and open mixed forest (about 14 acres, 6 ha) (Table E.3.85).

p.E-3-258, para. 3 to p.E-3-259, para. 4 — Low abundance vegetation types which will receive the greatest cumulative impact from construction of the impoundments and dams, access and transmission corridors, and all ancillary facilities, will be open and closed birch forest, and wet sedge-grass tundra (Tables E.3.80 and E.3.83-E.3.85). A cumulative total of 3221 acres (1303 ha) of open and closed birch forest could be affected by construction-related clearing between 1985 and 2002. Based on the 1:63,360-scale mapping of the 20-mile (32 km) strip along the Susitna River (the map showing the vegetation of the area in the greatest detail) (Table E.3.52), 34 percent of the total 9,444 acres (3,822 ha) of this vegetation type could be removed by construction. About 3,143 acres (1,272 ha) or 33 percent of the total coverage will be entirely removed by clearing of the impoundments (Tables E.3.83 and E.3.84). The remaining 68 acres (28 ha) will be selectively cleared as discussed further below.

The other low-abundance vegetation type within the Watana and Gold Creek watersheds to be affected by construction, wet sedge-grass tundra, will be crossed by access and transmission corridors (82 acres, 33 ha) (Tables E.3.80, E.3.85) and inundated by the impoundment areas (235 acres, 95 ha) (Tables E.3.83, E.3.84). Borrow Area D (Figure E.3.37) will potentially remove an additional 20 acres (8 ha) (Table E.3.83). The siting of all pads, buildings, and other structural facilities has entirely avoided this vegetation type. Therefore, a total of 337 acres (136 ha) of wet sedge-grass tundra will be potentially affected by construction between 1985 and 2002. This cumulative impact represents about 4 percent of the total 8,691 acres (3,517 ha) present within the 20-mile (32 km) strip mapped at 1:63,360 (Table E.3.52). Mitigative measures which will minimize drainage alterations in this wet vegetation type are discussed in Section 3.4.2(c).

In summary, siting of pads, buildings, the Watana airstrip, and other ancillary facilities has minimized clearing requirements for low-abundance vegetation types. As residual impact, the impoundments and access and transmission corridors will remove about 34 percent of the birch forest, and 4 percent of the wet sedge-grass tundra within the 20-mile (32 km) strip mapped at 1:63,360.

p.E-3-270, para. 1 In fact, as stated in Sections 3.3.4(a) and 3.3.6(a)(iv), the 10,559 acres (4,258 ha) required for transmission corridor rights-of-way will be cleared only to a limited extent, as explained in the following discussion.

p.E-3-274, para. 4 to p.E-3-275 para. 1

Of the approximately 53,736 acres (21,734 ha) potentially subject to vegetation removal on a cumulative basis, about 30 percent, or 15,350 acres (6,199 ha), will allow application of mitigation measures discussed above. Approximately 46 the percent of the total area covered by transmission corridors (4,857 acres, 1959 has, of the total 10,559 acres, 4,258 ha) will be left uncleared or partly cleared. In addition, use of side-borrow and balanced cut-and-fill techniques for construction of the access roads and railroad extension will protect up to 280 acres (112 ha) of vegetated area.

Using the two examples cited above, measures to minimize vegetation removal will conserve about 5,092 acres (2071 ha), or up to about 35 percent of the land area in question.

p.E-3-280, para. 5

In summary, rectification will restore vegetation to approximately 3,209 acres (1,299 ha) temporarily lost to ancillary facilities. This represents about 6 percent of the cumulative total land area affected by direct loss of vegetation during project construction and operation (53,736 acres, 21,734 ha).

p.E-3-282, para. 3 to p.E-3-282 para. 4

For the Susitna project, the cumulative area lost in this way will total about 38,386 acres (15,535 ha), with 36,959 acres (14,957 ha) covered by the impoundments. Actual acreages of vegetation types which will be removed were discussed previously and quantified in Tables E.3.83 and E.3.84.

From the preceeding options analysis, it is evident that measures for minimization, rectification and reduction of vegetation loss will apply, at most, to about 30 percent (15,350 acres, 6,199 ha) of the total area of vegetation which will be removed by the project.

CHANGES IN THE TEXT AND TABLES OF THE WILDLIFE SECTION OF CHAPTER 3 RESULTING FROM CORRECTIONS OF BOTANICAL TABLES (the following sentences replace the corresponding sentences in the indicated paragraphs).

p.E-3-461, para. 4	Sentence 2. Should read: "About 26,647 acres (10,784 ha) of forest will be cleared."
p.E-3-463, para. 4	Sentence 1. Should read: "An estimated 6175 acres (2289 ha) will be cleared within the Devil Canyon impoundment area and an additional 519 acres of forest (210 ha) will be used for operational areas, campsites and borrow sites."
p.E-3-476, para. 1	Sentence 2. Should read: "The total area affected (8492 acres, 3437 ha) and the total percent of forested land affected (0.7 percent) are much smaller than in the Watana reservoir area."
p.E-3-498, para. 4	Sentence 1. Should read: "Table E.3.166 indicates an order-of-magnitude estimate of 1,200 small to medium-sized breeding birds lost to the transmission line, less than 0.1 percent of the population within 16 km of the Susitna River between the Maclaren River and Gold Creek." (This correction supercedes the Acres errata of 29 March 1983.)
p.E-3-432, para. 4	Sentence 1. Should read: "Based on the estimate of about one wolverine per 40,320 acres (163 km^2) derived in Section 4.2.1(g), the direct loss of over 40,846 acres (16,530 ha) caused by the Watana impoundment and facilities would lower the carrying capacity by about two wolverines."

p.E-3-441, para. 2	Sentence 2. Should read: "Using a figure of 11,798 ha of forest habitat lost to the Watana impoundment area, borrow sites, construction sites and camps, habitat supporting 100 marten (3.4 percent of the forested habitat in the Susitna watershed upstream from Gold Creek) would be lost."
Table E.3.144	Under Permanent Habitat Loss, Watana alone: the area affected by the access corridor should be changed from 192 to 255 ha. The area affected by the Access Corridor from Denali Highway to Watana should be changed from 192 to 255 ha. The area affected by the permanent village should be changed from 27 to 35 ha. The area affected by the permanent airstrip should be changed from 47 to 17 ha.
	Under Permanent Habitat Loss, Devil Canyon: the area affected by the access corridor should be changed from 218 to 192 ha. The area affected by the access corridor from Watana to Devil Canyon should be changed from 189 to 163 ha.
	Under Habitat Alteration and Temporary Habitat Loss, Watana alone: the area affected by the transmission corridor from Watana to Devil Canyon should be changed from 379.8 to 419 ha. The area affected by the transmission corridor from Devil Canyon to Gold Creek should be changed from 77.5 to 119 ha.
	Under Habitat Alteration and Temporary Habitat Loss, Devil Canyon: the area affected by the transmission corridor from Watana to Devil Canyon should be changed from 209 additional to 0. The area affected by the transmission corridor from Devil Canyon to Gold Creek should be changed from 0 to 84 additional ha.

Table E.3.145 Under (2) Habitat Alteration and Temporary Habitat Loss— transmission corridor. Sentence should read: "Nearly all 152,000 ha of the corridor is likely to become winter habitat of reasonable quality to moose. No existing winter habitat will be made unusable. Corridor will be maintained in early succession throughout the life of the project." Next sentence should read: "Drifting snow is unlikely to be a significant factor in the 300-foot corridor and will not reduce forage availability."

Table E.3.151 Under (5) Increased Human Access-hunting and poaching. Sentence should read: "Much of the current harvest is illegal and the illegal harvest will increase in the absence of better control. Current legal harvest is unlimited (no bag limit) and harvest is likely to increase. The current annual take is 40-45% of the population.

11046/8-74

RECORD OF TELEPHONE CONVERSATION

ALASKA POWER AUTHORITY RESPONSE TO AGENCY COMMENTS ON LICENSE APPLICATION; REFERENCE TO COMMENT(S): I. 507, I. 508

DATE 12-12-83

FROM Ellen Hall

CLIENT/PROJECT Susitna FERC License Application

SUBJECT Responses - RVD Values

CHARGE: DEPT. NO. 942 CLIENT SYMBOL APA OFS NO. 2592.104

DISCUSSION WITH

Joe Mehrkens, Regional Economist
USDA Forest Service

COMMENTS

I called to ask Joe what values the Forest Service is using for recreation visitor days (RVDs) in Alaska (FS Region 10). He quoted the following figures from the 1984 RPA Draft Program:

sport Fishing (Fresh)	$18.00/user day
(anadromous)	52.00
small game (waterfowl, etc)	30.00
big game	48.00
nongame	40.00
primitive	28.00
semiprimitive nonmotorized	22.00
semiprimitive motorized	20.00
roaded natural	15.00

BY Ellen J Hall (NAME) Sr. Resource Planner (TITLE) 942 (DEPT. NO.)

CC: