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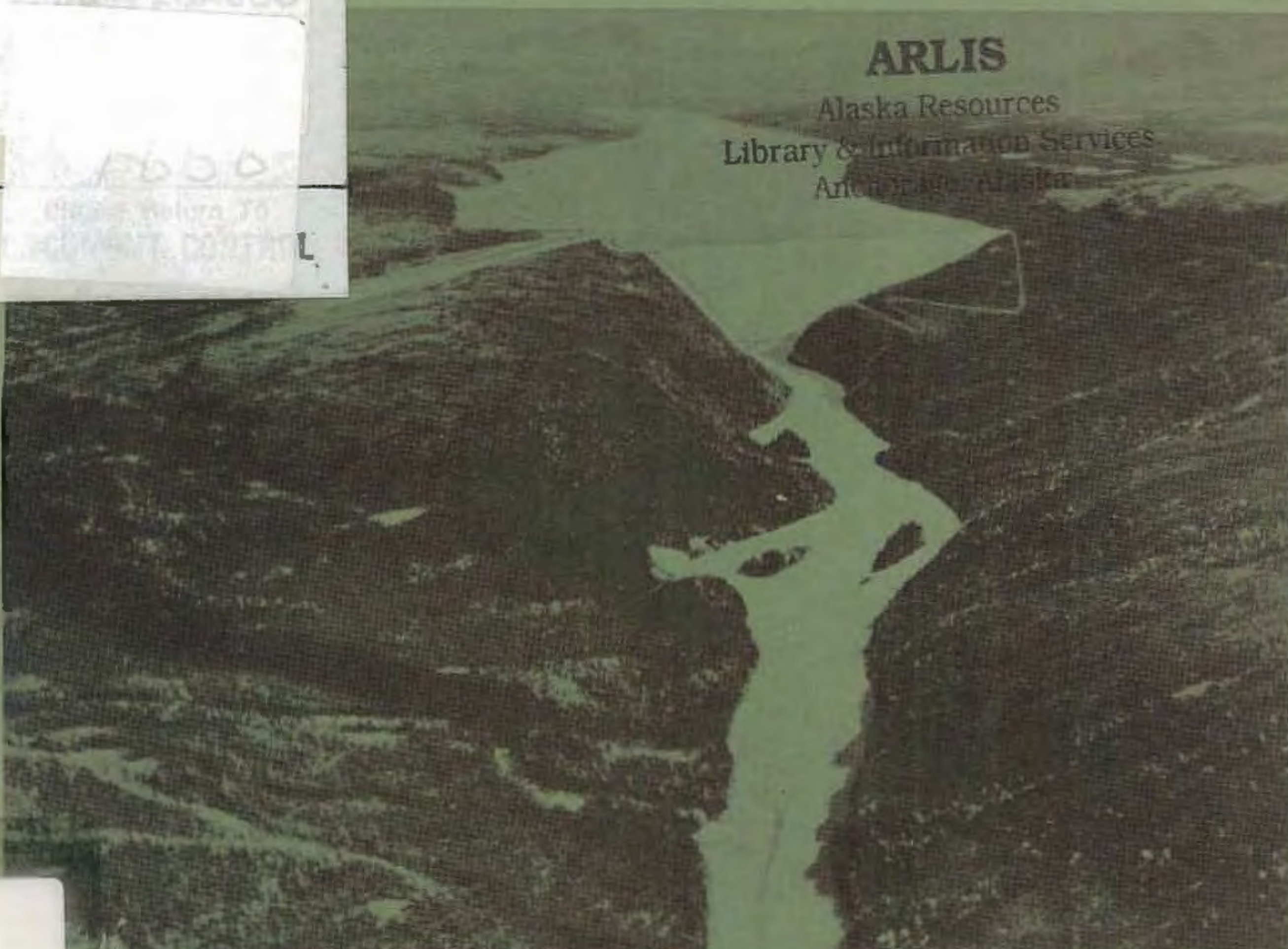
SUSITNA HYDROELECTRIC PROJECT

FERC No. 7114

ALASKA

Draft Environmental Impact Statement

Volume 4: Appendices H and I



OFFICE OF ELECTRIC POWER REGULATION
FEDERAL ENERGY REGULATORY COMMISSION

MAY 1984

FEDERAL ENERGY REGULATORY COMMISSION
OFFICE OF ELECTRIC POWER REGULATION

DRAFT ENVIRONMENTAL IMPACT STATEMENT

SUSITNA HYDROELECTRIC PROJECT
FERC NO. 7114 - ALASKA

Volume 4.

Appendix H. Water Resources

Appendix I. Fisheries and Aquatic Resources

Applicant: Alaska Power Authority
333 West 4th Avenue
Suite 31
Anchorage, Alaska 99501

Additional copies of the Draft-EIS may be ordered from:

Division of Public Information
Federal Energy Regulatory Commission
825 North Capitol St., NE.
Washington, D.C. 20426

May 1984

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DRAFT ENVIRONMENTAL IMPACT STATEMENT

SUSITNA HYDROELECTRIC PROJECT, FERC NO. 7114

APPENDIX H

WATER RESOURCES

Prepared by

Jerry W. Elwood, Donald W. Lee, Michael J. Sale,
and Alan J. Witten

Oak Ridge National Laboratory

H.1 BASIN CHARACTERISTICS

H.1.1 River Morphology

The headwaters of the Susitna River and its major, upper basin tributaries are dominated by broad, braided, gravel floodplains below glaciers in the Alaska Range (Gatto et al. 1980). The West Fork of the Susitna River joins the main river about 18 mi (29 km) below Susitna Glacier. Below the West Fork confluence, the Susitna River develops a split-channel configuration with numerous islands. The river is generally constrained by low bluffs for about 55 mi (89 km). The two major tributaries in the upper basin are the Maclaren River, a glacial tributary, and the nonglacial Tyone River, which drains Lake Louise and the swampy lowlands of the southeastern upper basin; both tributaries enter the Susitna River from the east (Figure H.1-1).

Below the confluence with the Tyone River, the Susitna River flows west for 96 mi (154 km) through steep-walled canyons. This reach contains the Watana and Devil Canyon dam sites at River Miles (RMs) 184.4 and 151.6, respectively. River gradients are high, averaging nearly 14 ft/mi (4 m/km) in the reach upstream of the Watana dam site. Downstream from Watana to Devil Creek, the river gradient is approximately 10.4 ft/mi (3.2 m/km) (Figure H.1-2). In the 12-mi (19-km) reach between Devil Creek and Devil Canyon, the river gradient averages 31 ft/mi (9.5 m/km). The channel type between the Tyone River and Devil Canyon is primarily a single channel with intermittent islands. Cross sections in studies by R & M Consultants, Inc. (1982a), illustrate the single-channel configuration. Bed material consists mainly of large gravel cobbles.

Devil Canyon to Talkeetna

Between Devil Canyon and Talkeetna, the Susitna has been subdivided into five separate reaches (R & M 1982b). Cross-sectional data are contained in the report on hydraulic and ice studies by R & M Consultants (1982a). Aerial photographs of the river are presented in Exhibit E, Chapter 2.

From RM 149 to RM 144, the Susitna flows predominantly in a single channel confined by valley walls. At locations where the valley bottom widens, deposition of gravel and cobble has formed mid-channel or side-channel bars. Occasionally, a vegetated island or fragmentary floodplain has formed, with elevations above normal flood levels. The presence of cobbles and boulders in the bed material aids in stabilization of the channel geometry.

From RM 144 to RM 139, a broadening of the valley bottom has allowed the river to develop a split channel with intermittent, well-vegetated islands. The bankfull stage is approximately equal to the water surface elevation at the mean annual flood. Where the main channel impinges on valley walls or terraces, a cobble armor layer has developed, with a top elevation at roughly bankfull flood stage. At RM 144, a periglacial alluvial fan of coarse sediments confines the river to a single channel.

From RM 139 to RM 129.5, the river is characterized by a well-defined split-channel configuration. Vegetated islands separate the main channel from side channels. Side channels and sloughs occur frequently in the alluvial floodplain and are inundated only at flows above 15,000 to 20,000 ft^3/s (425 to 566 m^3/s). Where the main channel impinges valleys walls or terraces, a cobble armor layer has developed, with a top elevation at roughly bankfull flood stage. The main channel bed has been frequently observed to be well armored. Primary tributaries in this reach include Indian River (RM 138.5), Gold Creek (RM 136.8), and Fourth of July Creek (RM 131.1). Each has formed an alluvial fan extending into the valley bottom, constricting the Susitna to a single channel. Each constriction has established a hydraulic control point that regulates water surface profiles and associated hydraulic parameters at varying discharges.

From RM 129.5 to RM 119, river patterns are similar to those in the previous reach. Prominent characteristics between Sherman and Curry include the main channel flowing against the west valley wall and numerous side channels and sloughs along the east floodplain. The alluvial fan at Curry constricts the Susitna to a single channel and terminates the above patterns.

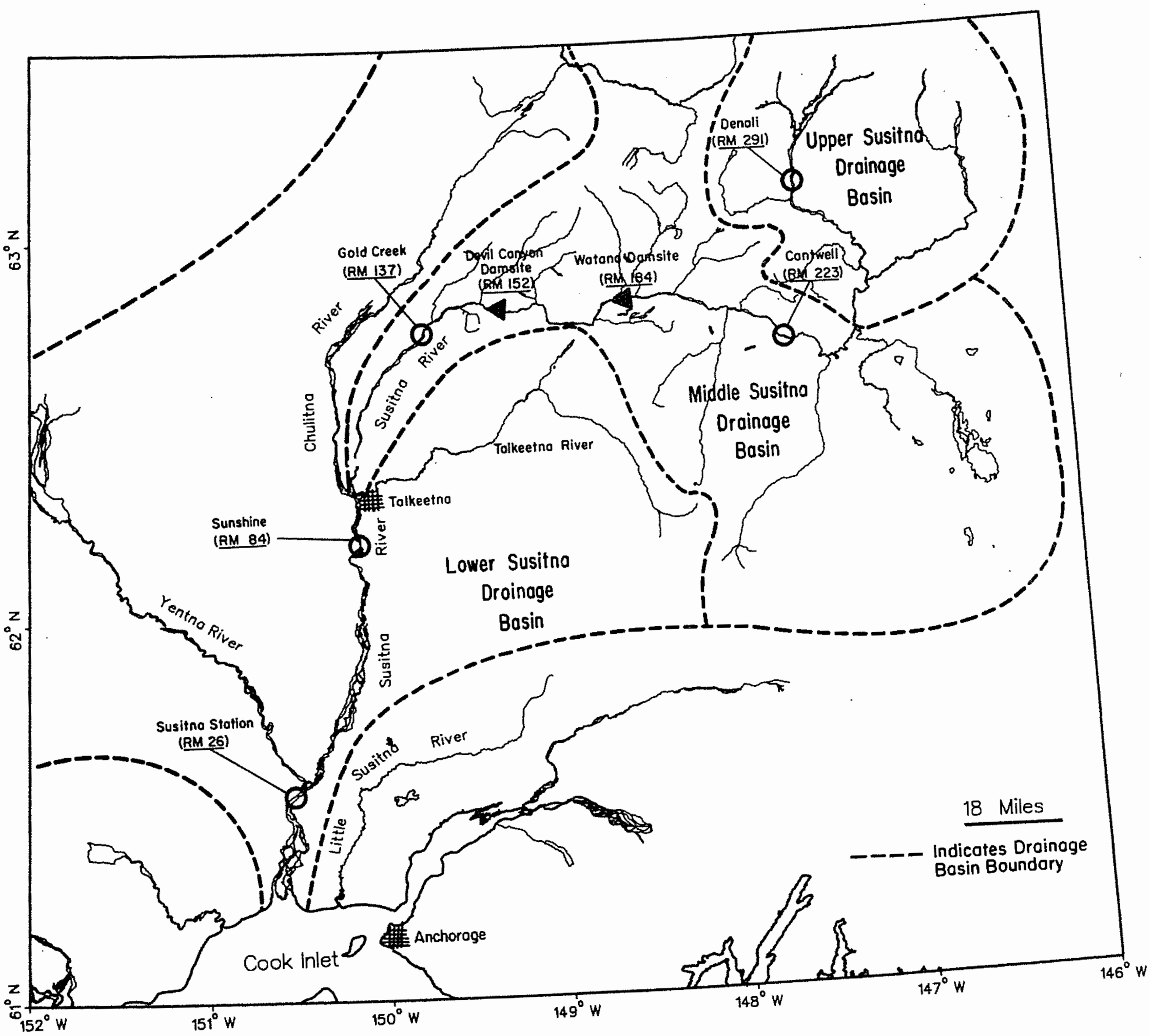


Figure H.1-1. Susitna River Basin.

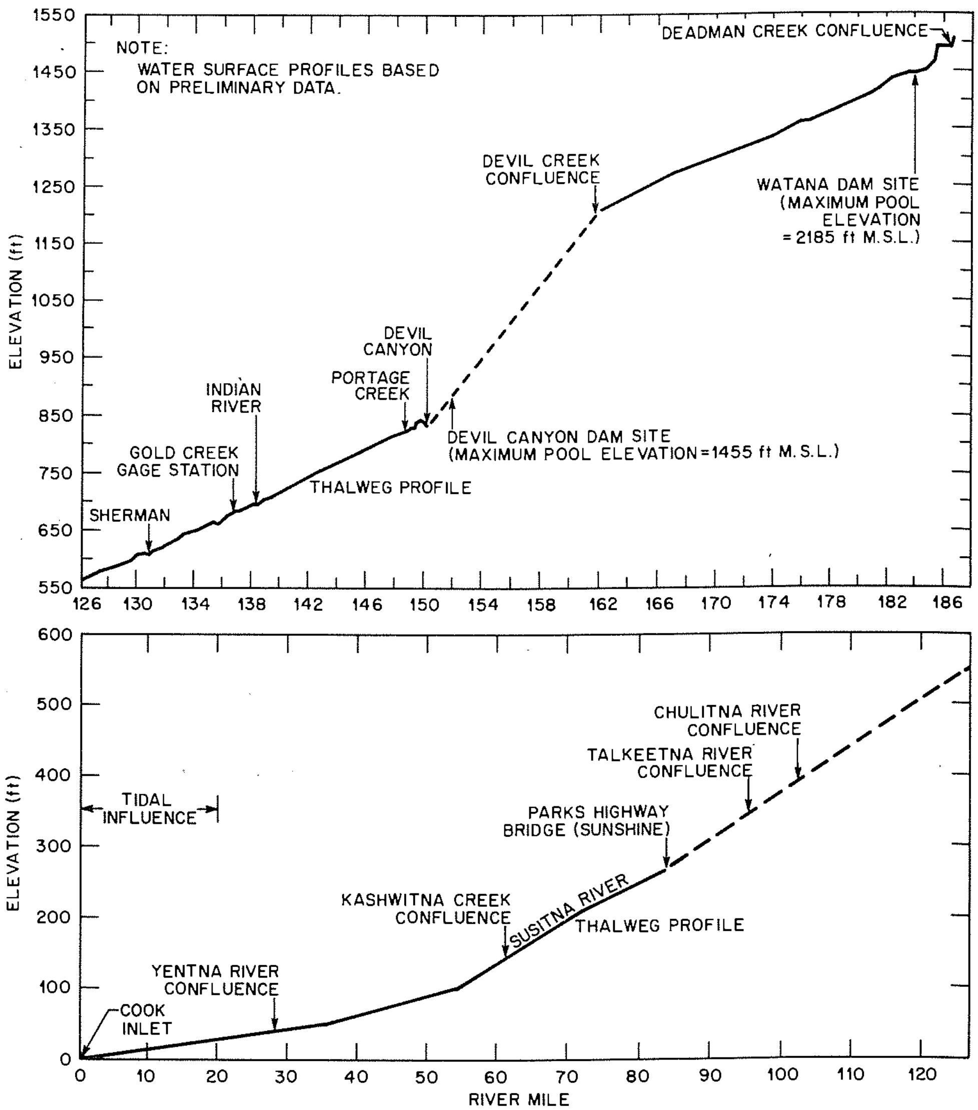


Figure H.1-2. Longitudinal profile of the mainstem of the Susitna River. Source: Redrawn from Exhibit E, Figures E.2.6, E.2.7, and E.2.9.

A fair correlation exists between bankfull stage and mean annual flood through this reach. Comparison of 1950 and 1980 aerial photographs reveals localized changes in bank lines and island morphology.

The west valley wall is generally nonerodible and has occasional bedrock outcrops. The resistant boundary on one side of the main channel has generally forced a uniform channel configuration with a well-armored perimeter. The west valley wall is relatively straight and uniform except at RMs 128 and 125.5. At these locations, bedrock outcrops deflect the main channel to the east side of the floodplain.

From RM 119 to RM 104, the river is predominantly a very stable, single, incised channel with a few islands. The channel banks are well armored with cobbles and boulders, as is the bed. Several large boulders occur intermittently along the main channel and are believed to have been transported down the valley during glacial ice movement. They provide local obstruction to flow and navigation, but do not have significant impact on channel morphology.

Below Talkeetna

At the confluence of the Susitna, Chulitna, and Talkeetna rivers, there is a dramatic change in the Susitna from a split-channel to a braided-channel pattern. The river emerges from the confined middle basin into the unconfined lowlands of the lower basin, enabling the river system to develop laterally. High bedload and a gradient decrease also contribute to establishing the braided pattern.

The glacial tributaries of the Chulitna River are much closer to the confluence than are the Susitna glacial tributaries. As the Chulitna River emerges from an incised canyon 20 mi (32 km) upstream of the Susitna-Chulitna confluence, it is transformed into a braided pattern, with moderate vegetation growth on the intermediate gravel bars. At about the midpoint between the canyon and the confluence, the Chulitna exhibits a highly braided pattern with no vegetation on intermediate gravel bars - evidence of recent lateral instability. This pattern continues beyond the confluence, giving the impression that the Susitna is tributary to the dominant Chulitna River. The split-channel Talkeetna River is a tributary to the dominant braided pattern.

Terraces bound the broad floodplain, but provide little control over channel morphology. General floodplain instability results from the three-river system striving to balance out the combined flow and sediment regime.

From RM 95 to RM 42, downstream from the three-river confluence, the Susitna continues its braided pattern, with multiple channels interlaced through a sparsely vegetated floodplain. The channel network consists of the main channel, usually one or two subchannels, and a number of minor channels. The main channel meanders irregularly through the wide gravel floodplain and intermittently flows against the vegetated floodplain. It has the capability of migrating laterally within the active gravel floodplain, reworking the gravel that the system previously deposited. When the main channel flows against vegetated banks, erosion is retarded owing to the vegetation and/or bank materials that are more resistant to erosion. Flow in the main channel usually persists throughout the entire year.

Subchannels are usually positioned near or against the vegetated floodplain and are generally on the opposite side of the floodplain from the main channel. The subchannels normally bifurcate from the main channel when it crosses over to the opposite side of the floodplain and terminate where the main channel meanders back across the floodplain and intercepts them. The subchannels have smaller geometric dimensions than the main channel, and their thalwegs are generally about 5 ft (1.5 m) higher. Their flow regimes are dependent on the main channel stage and hydraulic flow controls at the point of bifurication. Flow may or may not persist throughout the year. Minor channels are relatively shallow, wide channels that traverse the gravel floodplains and complete the interlaced braided pattern. These channels are very unstable and generally short lived.

The main channel and subchannels are intermittently controlled laterally where they flow against terraces. Since the active floodplain is very wide, the presence of terraces has little significance except for determining the general orientation of the river system. An exception occurs where the terraces constrict the river to a single channel at the Parks Highway bridge. Minor channels react to the behavior of both of the larger channels.

From RM 61 to RM 42, downstream from the Kashwitna River confluence, the Susitna River branches into multiple channels separated by islands with established vegetation. This reach of the river is known as the Delta Islands because it resembles the distributary channel network common to large river deltas. The multiple channels are forced together by terraces just upstream of Kroto Creek (Deshka River).

Through this reach, the very broad floodplain and channel network can be divided into three categories: (1) western braided channels, (2) eastern split channels, and (3) intermediate meandering channels. The western braided-channel network is considered to be the main portion of this very complex river system. Although not substantiated by river surveys, it appears to constitute the largest flow area and lowest thalweg elevation. The reason for this is that the western braided channels constitute the shortest distance between the point of bifurcation and the confluence of the Delta Island channels. Therefore, it has the steepest gradient and highest potential energy for conveyance of water and sediment.

From RM 42 to RM 0, downstream from the Delta Islands, the Susitna River gradient decreases as it approaches Cook Inlet (Figure H.1-2). The river tends toward a split-channel configuration as it adjusts to the lower-energy slope. There are short reaches where a braided pattern emerges. Downstream of RM 20, the river branches out into delta distributary channels before entering Cook Inlet. Terraces constrict the floodplain near the Kroto Creek confluence and at Susitna Station. Further downstream, the terraces have little or no influence on the river. The Yentna River joins the Susitna at RM 28 and is a major contributor of flow and sediment.

Tides in Cook Inlet rise above 30 ft (9 m), controlling the water surface profile and, to some degree, the sediment regime of the lower river. A river elevation of 30 ft (9 m) exists near RM 20, which corresponds to the location where the Susitna begins to branch out into its delta channels.

H.1.2 Habitat Types

The fluvial morphology of the Susitna River creates several unique physical habitat types, which are important to the aquatic biota of the basin. Seven distinct habitats have been identified (Figure H.1-3): (1) mainstem habitat, (2) side-channel habitat, (3) side-slough habitat, (4) upland-slough habitat, (5) tributary habitat, (6) tributary-mouth habitat, and (7) lake habitat. Differences among these habitat types are biological and physical; there is species-specific, temporal, and spatial variability in utilization patterns of the habitat types (see Appendix I.1.3), and there are also important differences in how the quality and quantity of various habitat types change with changes in mainstem discharge (ADFG 1983; Trihey 1982).

Mainstem Habitat

The mainstem habitat consists of that portion of the river channel which conveys streamflow throughout the year, including both single- and multiple-channel patterns. Water velocities are generally high and substrate is well armored, consisting of boulder and cobble-sized material in a groutlike matrix of small gravels and glacial sand. Suspended sediment concentrations are high during the summer due to the predominance of glacial melt water (Appendix H.5.2), but turbidity decreases significantly by October as stream-flow decreases. Groundwater and tributary inflows are relatively small contributors to mainstem discharge and the physical characteristics of mainstem habitat. The mainstem is ice covered from late November to May.

Water surface elevations for various Watana discharges in the reach between Deadman Creek (RM 186.8) and Devil Creek (RM 162.1) are listed in Table H.1-1. The elevations were determined with the use of the HEC-2 computer program entitled Water Surface Profiles, developed by the U.S. Army Corps of Engineers. The water surface elevations at the discharge of 42,200 ft^3/s (1,195 m^3/s) would be similar to those of the mean annual flood of 40,800 ft^3/s (1,155 m^3/s). The HEC-2 program was also used to predict water levels for the reach between Devil Canyon and Talkeetna (Table H.1-2). The water levels presented for the Gold Creek flow of 52,000 ft^3/s (1,473 m^3/s) would be slightly higher than those associated with the mean annual flood of 49,500 ft^3/s (1,402 m^3/s).

Side-Channel Habitat

The side-channel habitat conveys appreciable mainstem flow during the open-water season (June-October), becoming dewatered only during low flows. Side channels are either well-defined overflow channels or less-well-defined channels through partially submerged gravel bars or islands. Compared to mainstem habitat, side channels have lower velocities, shallower depths, and finer substrate. Bed elevations are generally lower than the mainstem stage at the mean monthly flows in June through August, leaving the side channels wetted during this period. Ice cover forms over the side channels at the same time as it does on the mainstem; however, open-water leads are often observed in the winter in selected side channels. Therefore, groundwater upwelling may be an important contribution to side-channel flows during low-flow periods.

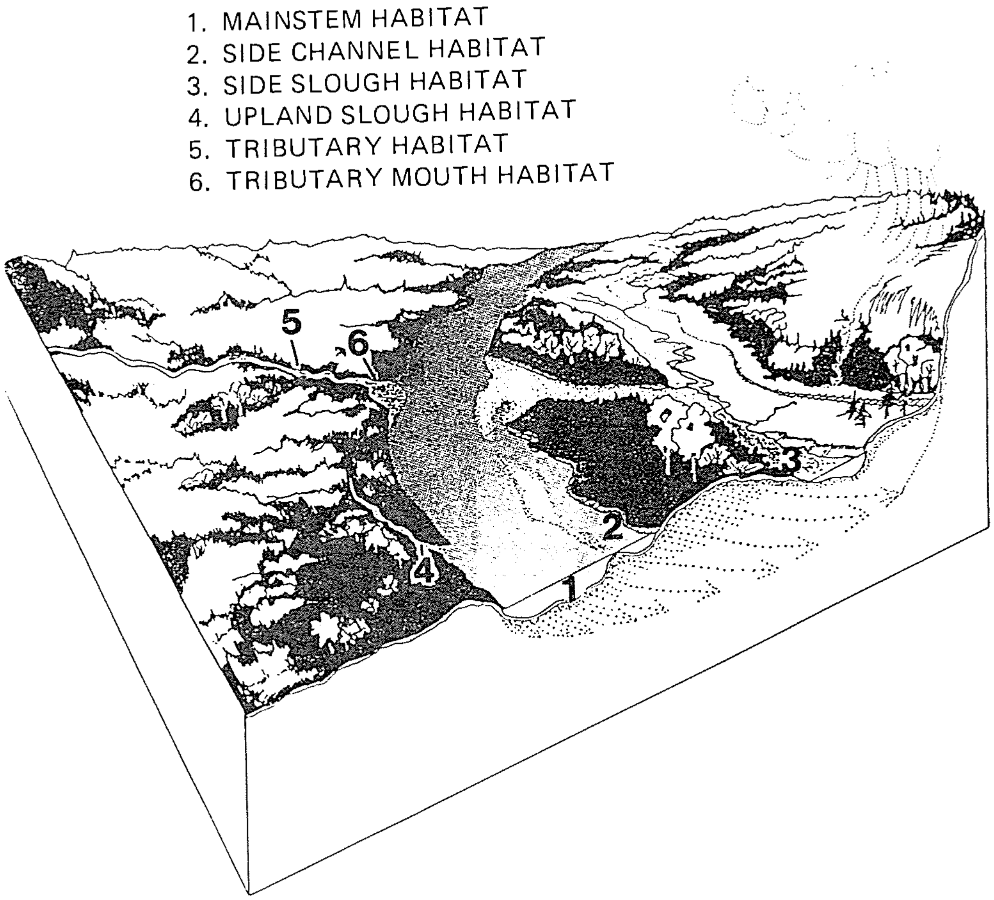


Figure H.1-3. General habitat types in the Middle Susitna River Basin.
Source: ADFG 1983, Trihey 1982.

Table H.1-1. Main Channel Water Surface Elevations from Deadman Creek to Devil Creek Predicted by HEC-2 Modeling

	Deadman Creek to Devil Creek for Selected Watana Flows (ft^3/s)					
River Mile	8100	17200	26700	30700	42200	46400
162.1	1211.2	1213.5	1215.7	1216.5	1218.4	1219.3
167.0	1276.3	1278.7	1279.9	1280.6	1281.4	1281.3
173.1	1330.8	1333.0	1334.9	1335.7	1337.3	1337.9
174.0	1340.0	1342.8	1344.2	1345.0	1346.0	1346.2
176.0	1363.9	1366.5	1367.9	1368.5	1369.5	1369.8
176.7	1370.8	1373.5	1375.1	1375.9	1377.3	1377.6
178.8	1391.6	1394.3	1396.3	1397.2	1398.8	1399.2
180.1	1410.6	1412.1	1412.9	1413.4	1414.2	1414.6
181.0	1414.4	1416.5	1417.8	1418.3	1419.2	1419.4
181.8	1428.8	1432.0	1434.2	1435.1	1436.6	1436.8
182.1	1435.3	1437.9	1439.8	1440.7	1442.4	1442.8
182.5	1440.7	1442.4	1443.8	1444.5	1445.7	1446.0
182.8	1443.7	1445.6	1446.8	1447.4	1448.3	1448.5
183.5	1449.8	1452.2	1453.8	1454.5	1455.7	1456.0
183.8	1451.6	1454.1	1455.8	1456.5	1457.8	1458.0
184.0	1453.5	1456.3	1458.1	1458.9	1460.3	1460.6
184.2	1454.6	1457.5	1459.4	1460.2	1461.6	1461.8
184.4	1456.2	1459.3	1461.3	1462.3	1464.0	1464.4
184.8	1462.9	1465.9	1467.4	1468.1	1469.1	1469.2
185.4	1473.0	1475.8	1477.4	1478.1	1479.4	1479.7
185.9	1497.3	1497.9	1498.3	1498.5	1498.3	1499.0
186.5	1505.3	1509.0	1510.9	1511.6	1513.5	1513.1
186.8	1510.1	1513.0	1515.0	1515.9	1517.8	1518.2

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: R & M Consultants, Inc. (1982b).

Table H.1-2. Main Channel Water Surface Elevations from Devil Canyon to Talkeetna Predicted by HEC-2 Modeling

	Devil Canyon to Talkeetna for Selected Gold Creek Flows (ft^3/s)					
River Mile	9700	13400	17000	23400	34500	52000
98.6	344.0	344.5	345.5	346.5	348.0	348.5
99.6	348.6	350.1	350.8	352.3	353.1	355.1
100.4	359.2	359.4	359.7	359.9	360.7	362.0
101.0	362.7	363.4	363.8	364.5	365.3	366.8
101.5	366.6	367.2	367.6	368.4	369.2	370.8
102.4	373.0	373.9	374.5	375.6	376.7	378.4
103.2	378.1	379.4	380.3	381.8	383.4	386.2
104.8	391.5	392.5	393.2	394.2	395.5	397.8
106.7	409.9	410.6	411.2	412.0	413.1	415.1
108.4	421.6	422.8	423.6	424.8	426.4	429.2
110.4	437.6	438.8	439.6	440.8	442.6	445.9
110.9	443.8	444.7	445.4	446.3	447.8	450.6
111.8	452.5	453.2	453.8	454.8	455.7	458.0
112.3	455.7	456.6	457.2	458.3	459.4	461.6
112.7	459.4	460.1	460.5	461.4	462.3	464.0
113.0	461.3	462.1	462.7	463.8	464.9	466.6
116.4	485.6	486.6	487.4	489.0	490.7	493.5
117.2	495.5	496.2	496.7	497.8	499.0	501.1
119.2	510.0	511.2	512.0	513.4	514.9	516.5
119.3	511.6	512.5	513.3	514.5	515.9	517.5
120.3	520.0	520.4	520.8	521.8	522.6	524.5
120.7	512.7	522.6	523.3	524.3	525.4	527.2
121.6	530.6	530.9	531.1	532.7	533.4	534.8
122.6	538.5	539.4	539.9	541.5	542.8	544.6
123.3	542.9	534.7	544.4	545.7	547.1	549.4
124.4	555.2	555.8	556.3	557.1	558.2	560.1
126.1	571.0	571.7	572.3	573.3	574.2	575.8
127.5	585.3	585.9	586.5	587.3	588.1	589.4
128.7	595.0	595.9	596.5	597.6	598.4	599.7
129.7	605.2	606.0	606.7	607.8	608.9	610.8
130.1	612.9	613.7	614.1	614.2	615.0	616.1
130.5	616.0	616.9	617.4	618.0	619.0	620.4
130.9	617.7	618.7	619.4	620.3	621.6	623.3
131.2	619.5	620.5	621.3	622.7	624.2	626.6
131.8	627.1	627.6	628.0	628.9	629.4	630.4
132.9	639.0	639.9	640.6	641.8	643.4	645.6
133.3	645.8	646.3	646.6	647.5	648.2	649.7
134.3	655.1	655.9	656.5	657.5	658.6	660.4
134.7	659.9	660.6	661.2	662.3	663.6	665.7

Table H.1-2. (Continued)

River Mile	Devil Canyon to Talkeetna for Selected Gold Creek Flows (ft^3/s) 9700	13400	17000	23400	34500	52000
135.4	668.9	669.4	669.8	670.4	671.1	672.4
135.7	671.2	672.1	672.7	674.1	675.4	677.1
136.4	681.2	682.2	683.0	684.1	685.3	687.3
136.7	684.0	685.1	685.8	687.0	688.1	689.9
137.0	687.1	688.2	688.9	690.5	692.0	694.9
137.2	690.6	691.6	692.3	693.2	694.6	697.0
137.4	693.1	694.1	694.9	695.7	697.2	699.5
138.2	702.0	702.9	703.6	704.5	705.4	706.9
138.5	703.7	704.7	705.5	706.7	707.8	709.7
138.9	707.2	708.1	708.9	710.3	711.7	714.3
139.4	716.8	717.4	717.8	718.3	719.1	720.7
140.2	723.6	724.5	725.2	726.3	727.3	728.9
140.8	733.2	734.1	734.8	736.0	737.4	739.9
141.5	744.0	744.8	745.4	746.2	747.2	749.0
142.1	752.2	753.2	753.9	755.4	756.7	758.7
142.3	754.4	755.3	756.1	757.6	759.0	761.3
143.2	763.9	764.7	765.2	766.2	767.5	769.9
144.8	786.0	787.1	788.0	789.4	790.9	793.3
147.6	818.8	819.9	820.7	822.1	823.8	827.0
148.7	832.9	834.3	735.3	836.6	838.6	841.7
148.9	835.1	836.4	837.5	838.8	840.9	844.2
149.2	837.5	838.8	839.8	841.1	843.1	846.5
149.3	839.6	840.9	841.9	843.3	845.3	848.9
149.4	841.5	842.6	843.5	844.7	846.9	850.5
149.5	844.3	845.1	845.8	846.8	848.4	851.3
149.8	848.4	849.4	850.1	851.1	852.4	854.6
150.2	850.6	851.9	852.8	854.0	855.8	858.7

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: R & M Consultants, Inc. (1982b).

Side-Slough Habitat

The side-slough habitat is the most biologically significant habitat type and the most responsive to changes in mainstem discharge. These sloughs are overflow channels that exist along the edge of the floodplain, separated from the river by well-vegetated bars. An exposed alluvial berm often separates the head of the sloughs from the mainstem or side-channel flow. The controlling stream bank elevations at the upstream end of the sloughs are less than the mainstem water surface elevations during median and high flow periods. At intermediate and low flows, the sloughs convey clear water from small tributaries and upwelling groundwater (ADFG 1982). Side-channel sloughs studied by ADFG (1983) are identified in Figure H.1-4.

Differences between mainstem water surface elevations and the streambed elevation of the sloughs are notably greater at the upstream entrance to the sloughs than at the mouth of the sloughs. The gradients within the sloughs are typically greater than the adjacent mainstem because of their shorter thalweg length compared to the mainstem. The upstream end of the sloughs generally has a higher gradient than the lower end (e.g., Figure H.1-5). The sloughs vary in length from 2,000 to 6,000 ft (610 to 1,829 m). Cross sections of the sloughs are typically rectangular with flat bottoms. At the head of the sloughs, substrates are dominated by boulders and cobbles [8 to 14 in (20 to 36 cm) in diameter]. Downstream toward the slough mouth, the substrate particles decrease in size, with gravels and sands predominating (Figure H.1-5). Beavers frequently inhabit the sloughs. Active and abandoned beaver dams are visible. Vegetation commonly covers the banks to the water's edge, with bank cutting and slumping occurring during spring breakup flows, high summer flows, and winter overtopping.

The water surface elevation of the mainstem generally causes a backwater effect at the mouth of the sloughs. Upstream of the backwater effects, the sloughs function like small stream systems conveying water from local runoff and groundwater upwelling during low-flow periods and mainstem water during high-flow periods when the upstream end of the slough is overtopped by the mainstem flow (ADFG 1983).

H.2 FLOW REGIMES

H.2.1 Preproject Flows

Continuous historical streamflow records of various length [7 to 32 years through water year (WY) 1981] exist at gaging stations on the Susitna River and its tributaries (Table H.2-1, Figure H.1-1). Continuous U.S. Geological Survey (USGS) historical streamflow records exist at Gold Creek from 1952 to the present. Because the Gold Creek gage has the longest record in the Susitna Basin and because it is centrally located in the portion of the river that will receive the largest flow regulation, this site will serve as the reference point for evaluating postproject flows. Complete 30-year streamflow data sets (summarized in Table H.2-2) for the other gaging stations were generated, using a correlation analysis to estimate missing mean monthly flows (Exhibit E, Chapter 2). This analysis was based on the program FILLIN developed by the Texas Water Development Board (1970). The procedure is a multisite regression technique, which analyzes monthly time series data and fills in missing portions in the incomplete records. The program evaluates the statistical parameters that characterize the data set (i.e., seasonal means, seasonal standard deviations, lag-one autocorrelation coefficients, and multisite spatial correlation coefficients) and creates a filled-in data set in which these statistical parameters are preserved. For the analysis, all streamflow data up to 1981 were used (32 years of data at Gold Creek).

Mean monthly flows at the Watana and Devil Canyon dam sites were estimated, using a linear drainage area-flow relationship between the Gold Creek and Cantwell (Vee Canyon) gage sites (Exhibit E, Chapter 2). The monthly flows for each month of the 32-year-modified-record for Gold Creek and Sunshine are presented in Tables H.2-3 and H.2-4. The variation between summer and winter mean monthly flows is greater than a 10-to-1 ratio at all stations. This large seasonal difference is due to the characteristics of a glacial river system. Glacial melt, snow melt, and rainfall provide the most of the annual river flow during the summer. A comparison of the maximum and minimum monthly flows for May through September indicated a high flow variability at all stations from year to year. At Gold Creek, 88% of the annual streamflow volume occurs during the months of May through September.

The most common floods in the Susitna River Basin occur in May to July and are composed of snow melt or a combination of snow melt and rainfall over a large area (Figure H.2-1). Floods occur between May and July, with the majority occurring in June. Floods attributable to heavy rains have occurred in August and September. These floods are augmented by snow melt from higher elevations and glacial runoff. Examples of flood hydrographs for 1964, 1967, and 1970 at Gold Creek and Watana are illustrated in Figure H.2-1. The daily flow at Cantwell and Gold Creek and the linear drainage area-flow relationship between them was used to determine the average monthly flows at Watana. Figure H.2-1a shows the largest snow-melt flood on record at Gold Creek. The 1967 spring flood hydrograph shown in Figure H.2-1b has a daily

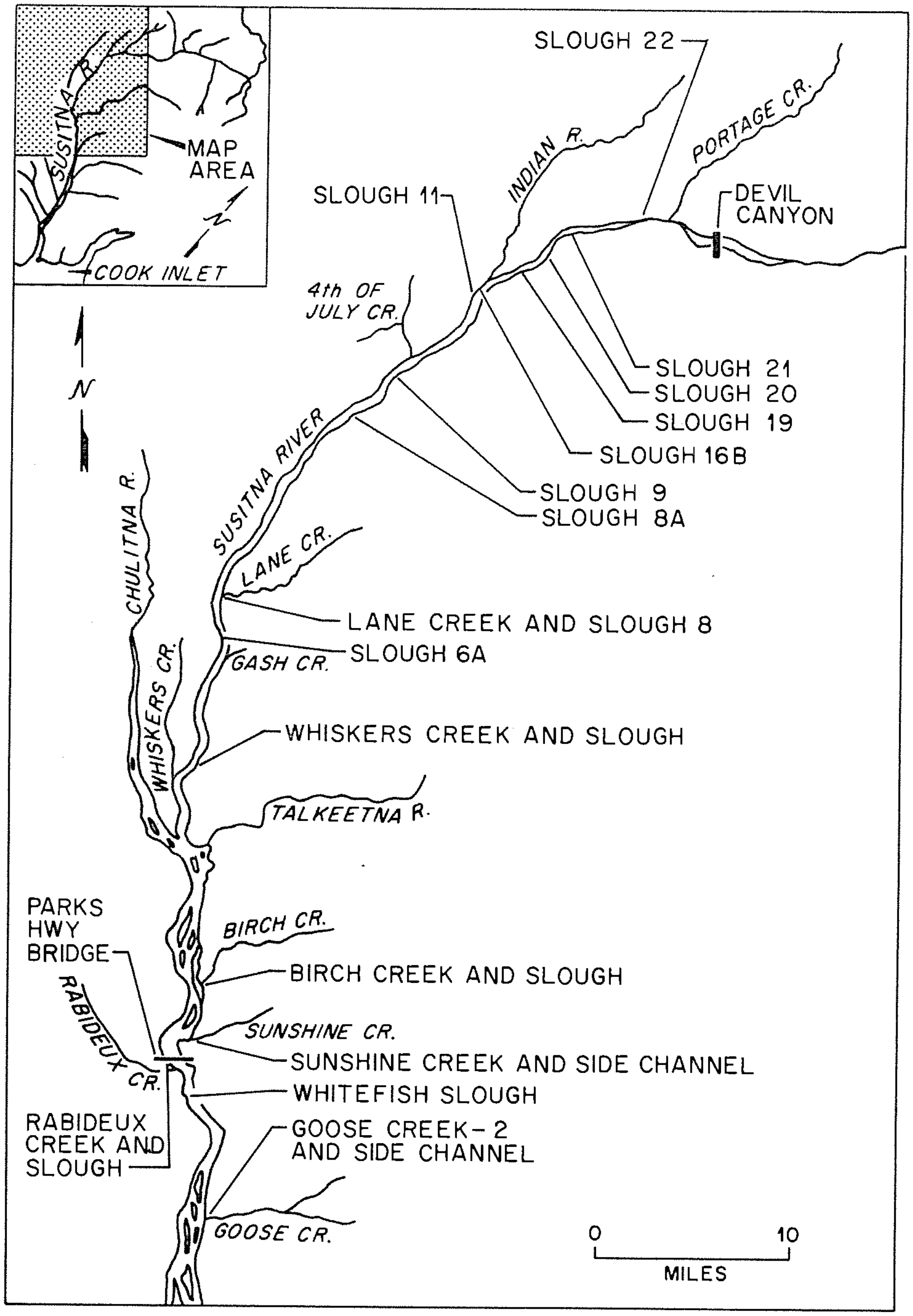


Figure H.1-4. Side-channel sloughs studied in the ADFG SuHydro Aquatic Studies Program. Source: ADFG 1983.

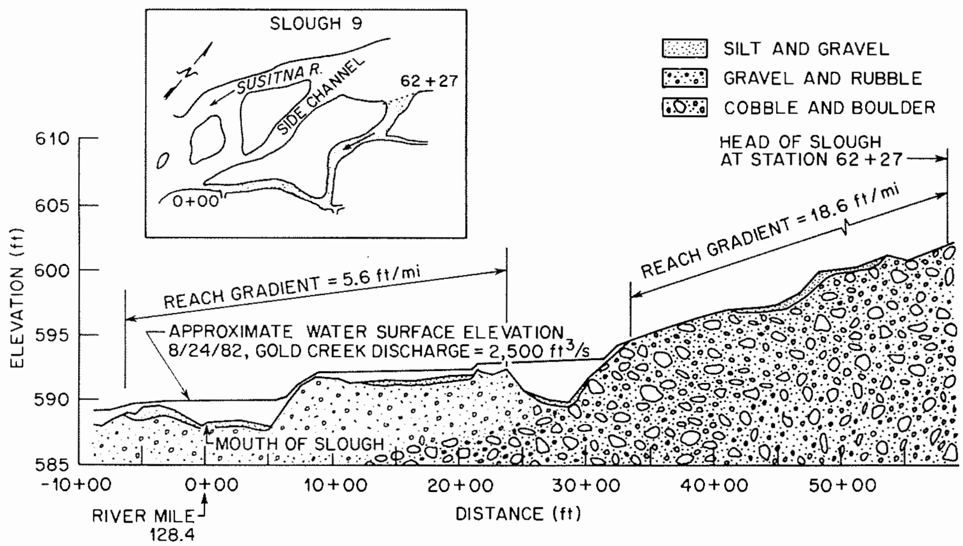


Figure H.1-5. Morphology of a typical side-channel slough.
Source: Exhibit E, Figure E.2.21.

Table H.2-1. USGS Gaging Stations for the Susitna River Basin

Station Name	USGS Gage Number	Susitna River Mile	Drainage Area (mi^2)	Periods of Record Streamflow (Continuous)
Susitna River near Denali	15291000	290.8	950	5/57-9/66, 11/68-Present
Susitna River near Cantwell (Vee Canyon)	15291500	223.1	4,140	5/61-9/72, 5/80-Present
Susitan River at Gold Creek	15292000	136.6	6,160	8/49-Present
Susitna River at Sunshine	15292780	83.9	11,100	5/81-Present
Susitna River at Susitna Station	15294350	25.8	19,400	10/74-Present
Maclaren River near Paxson	15291200	259.8	280	6/58-Present
Chulitna River near Talkeetna	15292400	98.0	2,570	2/58-9/72, 5/80-Present
Talkeetna River near Talkeetna	15291500	97.0	2,006	6/64-Present
Skwentna River near Skwentna	15294300	28.0	2,250	10/59-Present
Yentna River near Susitna Station	15294345	28.0	6,180	10/80-Present

Conversion: To convert from square miles to square kilometers, multiply by 2.590.

Source: Exhibit E, Table E.2.2.

Table H.2-2. Maximum, Mean, and Minimum Monthly Flows (ft^3/s) in the Simulated, 32-year Data Set for the Susitna River Basin†[1]-†[3]

Month		Gaging Station										
		Denali	Cantwell	Watana	Devil Canyon	Gold Creek	Sunshine	Susitna	Maclaren	Chulitna	Talkeetna	Skwentna
Oct	Max	2,165	5,472	6,458	7,518	8,212	18,555	58,640	734	9,314	4,438	7,254
	Mean	1,165	3,149	4,513	5,312	5,757	13,906	31,102	418	5,040	2,720	4,329
	Min	528	1,638	2,403	2,867	3,124	18,593	15,940	249	2,898	1,450	1,929
Nov	Max	878	2,487	3,525	3,955	4,192	9,400	31,590	370	3,277	1,786	4,195
	Mean	500	1,460	2,052	2,383	2,568	6,104	13,361	182	2,083	1,209	1,867
	Min	192	780	1,021	1,146	1,215	3,978	6,606	95	1,236	765	678
Dec	Max	575	1,658	2,259	2,905	3,264	6,137	15,081	246	2,143	1,239	2,871
	Mean	315	951	1,405	1,652	1,793	4,249	8,426	117	1,487	846	1,295
	Min	146	543	709	810	866	2,650	4,279	49	891	515	624
Jan	Max	651	1,694	1,780	2,212	2,452	4,739	12,669	162	1,673	1,001	2,829
	Mean	248	850	1,157	1,352	1,463	3,550	7,971	99	1,288	682	1,068
	Min	85	437	619	687	724	2,218	5.032	44	974	459	600
Feb	Max	422	1,200	1,560	1,836	2,028	4,057	11,532	140	1,414	805	1,821
	Mean	206	706	979	1,147	1,243	3,009	7,117	81	1,092	568	911
	Min	64	426	602	682	723	2,082	4,993	42	820	401	490
Mar	Max	290	1,273	1,560	1,779	1,900	3,898	9,193	121	1,300	743	1,352
	Mean	192	659	898	1,042	1,123	2,683	6,397	74	979	491	826
	Min	42	408	569	664	713	2,013	4,910	36	738	379	522
Apr	Max	415	1,702	1,965	2,405	2,650	5,109	12,030	145	1,600	1,038	2,138
	Mean	231	835	1,113	1,282	1,377	3,257	7,242	86	1,194	573	1,088
	Min	43	465	609	697	745	2,205	5,531	50	700	371	607

Table H.2-2. (Continued)

Month		Denali	Cantwell	Watana	Devil Canyon	Gold Creek†[1]	Sunshine†[2]	Susitna	Maclaren	Chulitna	Talkeetna	Skwentna
		Gaging Station										
May	Max	4,259	13,751	15,973	19,777	21,890	50,302	94,143	2,131	20,025	8,840	22,370
	Mean	2,306	7,473	10,398	12,230	13,277	27,955	61,376	832	9,519	4,150	8,555
	Min	629	1,915	2,857	3,428	3,745	8,645	29,809	208	2,355	1,694	1,635
June	Max	12,210	34,630	42,842	47,816	50,580	110,073	176,219	4,297	40,330	19,045	40,356
	Mean	7,532	17,567	22,913	25,938	27,658	63,810	123,830	2,888	22,892	11,416	18,462
	Min	4,647	9,909	13,233	14,710	15,500	39,311	67,838	1,751	15,587	5,207	10,650
July	Max	12,110	22,790	28,767	32,388	34,450	85,600	181,400	4,649	35,570	15,410	28,620
	Mean	9,688	16,873	20,778	23,101	24,383	64,538	134,130	3,241	27,044	11,118	16,997
	Min	6,756	12,220	14,844	15,651	16,100	45,267	102,121	2,441	20,820	7,080	11,670
Aug	Max	12,010	22,760	31,435	35,270	38,538	84,940	159,600	4,122	33,670	18,033	20,590
	Mean	8,431	14,614	18,431	20,709	21,996	56,642	112,851	2,644	22,732	10,459	13,335
	Min	3,919	6,597	7,772	8,484	8,879	24,656	62,368	974	11,300	3,787	7,471
Sep	Max	6,955	12,910	17,206	19,799	21,240	53,703	104,218	2,439	23,260	10,610	13,371
	Mean	3,334	7,969	10,670	12,276	13,175	32,169	66,790	1,167	11,956	6,084	8,371
	Min	1,194	3,376	4,260	4,796	5,093	14,268	34,085	470	6,424	2,070	3,783
Ann	Max	3,651	7,962	9,833	10,947	11,565	28,226	63,159	1,276	12,114	5,276	10,024
	Mean	2,885	6,184	7,986	9,084	9,703	23,611	48,873	998	9,045	4,226	6,622
	Min	2,127	4,159	4,712	5,352	5,596	14,355	31,428	693	6,078	2,233	4,939

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

†[1]Gold Creek data are not filled, since 32 years of record are available.

†[2]Sunshine discharge for WY 1980 and October-April WY 1981 were computed from Gold Creek, Talkeetna, and Chulitna discharges for the same period.

Table H.2-3. Historical Monthly Flows (ft^3/s) at Gold Creek Including Adjusted Data for WY 1969

Year	Month												Annual
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
1	6335	2583	1439	1027	788	726	870	11510	19600	22600	19880	8301	8032.1
2	3848	1300	1100	960	820	740	1617	14090	20790	22570	19670	21240	9106.0
3	5571	2744	1900	1600	1000	880	920	5419	32370	26390	20920	14480	9552.1
4	8202	3497	1700	1100	820	820	1615	19270	27320	20200	20610	15270	10090.4
5	5604	2100	1500	1300	1000	780	1235	17280	25250	20360	26100	12920	9681.6
6	5370	2760	2045	1794	1400	1100	1200	9319	29860	27560	25750	14290	10256.4
7	4951	1900	1300	980	970	940	950	17660	33340	31090	24530	18330	11473.3
8	5806	3050	2142	1700	1500	1200	1200	13750	30160	23310	20540	19800	10384.1
9	8212	3954	3264	1965	1307	1148	1533	12900	25700	22880	22540	7550	9476.4
10	4811	2150	1513	1448	1307	980	1250	15990	23320	25000	31180	16920	10559.9
11	6558	2850	2200	1845	1452	1197	1300	15780	15530	22980	23590	20510	9712.3
12	7794	3000	2694	2452	1754	1810	2650	17360	29450	24570	22100	13370	10809.3
13	5916	2700	2100	1900	1500	1400	1700	12590	43270	25850	23550	15890	11565.2
14	6723	2800	2000	1600	1500	1000	830	19030	26000	34400	23670	12320	11072.9
15	6449	2250	1494	1048	966	713	745	4307	50580	22950	16440	9571	9799.6
16	6291	2799	1211	960	860	900	1360	12990	25720	27840	21120	19350	10168.8
17	7205	2098	1631	1400	1300	1300	1775	9645	32950	19860	21830	11750	9431.8
18	4163	1600	1500	1500	1400	1200	1167	15480	29510	26800	32620	16870	11218.5
19	4900	2353	2055	1981	1900	1900	1910	16180	31550	26420	17170	8816	9810.6
20†[1]	4272	1906	1330	1086	922	833	1022	9852	20523	18093	16322	9776	7200.1
21	3124	1215	866	824	768	776	1080	11380	18630	22660	19980	9121	7591.2
22	5288	3407	2290	1442	1036	950	1082	3745	32930	23950	31910	14440	10251.0
23	5847	3093	2510	2239	2028	1823	1710	21890	34430	22770	19290	12400	10885.5
24	4826	2253	1465	1200	1200	1000	1027	8235	27800	18250	20290	9074	8086.2
25	3733	1523	1034	874	777	724	992	16180	17870	18800	16220	12250	7631.0
26	3739	1700	1603	1516	1471	1400	1593	15350	32310	27720	18090	16310	10275.4
27	7739	1993	1081	974	950	900	1373	12620	24380	18940	19800	6881	8189.3
28	3874	2650	2403	1829	1618	1500	1680	12680	37970	22870	19240	12640	10109.0
29	7571	3525	2589	2029	1668	1605	1702	11950	19050	21020	16390	8607	8194.5
30	4907	2535	1681	1397	1286	1200	1450	13870	24690	28880	20460	10770	9489.3
31	7311	4192	2416	1748	1466	1400	1670	12060	29080	32660	20960	13280	10747.7
32	7725	3986	1773	1454	1236	1114	1368	13317	18143	32000	38538	13171	11255.3
Max	8212	4192	3264	2452	2028	1900	2650	21890	50580	34400	38538	21240	11565.2
Min	3124	1215	866	824	768	713	745	3745	15530	18093	16220	6881	7200.1
Mean	5771	2577	1807	1474	1249	1124	1362	13240	27815	24445	22228	13321	9753.3

†[1]Original data for WY 1969 (year 20), October 1969 through September 1970, were 3822, 1630, 882, 724, 723, 816, 1510, 11050, 15500, 16100, 8879, 5093 ft^3/s, respectively, with an annual average flow of 5600 ft^3/s.

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Exhibit E, Table E.2.8.

Table H.2-4. Historical Monthly Flows (ft^3/s) Estimated at the Sunshine USGS Gaging Station

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
	Month												
1	14003	5639	3611	2748	2276	2033	2311	22418	45613	59179	54849	27734	20347.1
2	12226	4712	3804	2930	2435	2144	3563	42196	58872	69474	58356	51069	26136.1
3	13713	5702	3782	3470	2511	2282	2357	11258	68738	64937	53363	32057	22117.5
4	17394	7199	4080	2818	2343	2317	4292	50302	64075	54231	49954	33737	24544.3
5	13227	5092	3977	3667	2889	2423	3204	32595	54805	53386	57701	28376	21921.8
6	12188	6340	4313	3927	3189	2577	2658	21758	69686	70894	77692	35385	26041.6
7	11011	4367	3161	2612	2286	2209	2244	33157	73941	80569	69034	44495	27588.4
8	15252	7029	4907	4006	3471	2844	2907	34140	79153	62302	53243	48121	26550.7
9	18399	9032	6139	4067	2996	2643	3399	27759	60752	59850	56902	20098	22824.2
10	11578	5331	3592	3387	3059	2280	2895	29460	64286	67521	71948	36915	25345.8
11	15131	6415	4823	4059	3201	2675	2928	34802	39311	58224	55315	43086	22651.3
12	16996	6109	5504	4739	3478	3480	5109	32438	60886	63640	60616	36071	25075.2
13	14579	6657	4820	4222	3342	2975	3581	24520	87537	67756	61181	38711	26766.6
14	13956	6052	4690	4074	3621	2399	2025	35245	56629	78219	52938	29182	24260.8
15	18555	5907	3533	2797	2447	2013	2381	8645	111073	58836	46374	23267	23864.9
16	15473	7472	4536	3373	2962	2818	3435	24597	58488	65042	56375	53703	24971.3
17	18208	5321	3965	3404	3009	2875	3598	16479	69569	55243	62007	30156	22934.7
18	11551	4295	3856	3698	3294	2793	2639	32912	66162	77125	82747	37379	27566.1
19	10706	5413	4563	4181	3986	3898	4359	36961	76770	69735	46730	20885	24149.1
20	10524	4481	3228	2689	1731	2022	2442	21306	49349	48565	42970	24832	17950.7
21	9416	3978	2848	2600	2448	2382	3150	25687	47602	60771	54926	27191	20393.7
22	12264	7467	4930	3325	2514	2351	2640	10652	76208	64787	74519	32402	24629.0
23	14313	6745	4922	4257	3801	3335	3210	36180	66856	62292	51254	34156	24407.1
24	13588	6018	4030	3312	2984	2646	2821	18215	59933	51711	51085	25238	20235.8
25	11284	4699	3524	2882	2519	2220	2916	31486	43713	51267	43222	29114	19195.1
26	12302	4938	3777	3546	2990	2810	3160	29380	72836	75692	51678	35567	25023.2
27	15565	4238	2734	2507	2355	2281	3294	22875	56366	55506	52155	18502	20000.7
28	10620	5888	5285	4231	3640	3171	3537	27292	87773	62194	55157	32719	25221.6
29	17399	7130	5313	4213	3227	3002	3542	22707	48044	57930	42118	22742	19910.2
30	11223	5648	4308	3674	3206	2963	3704	33876	59849	71774	48897	26790	23144.3
31	17688	9400	5189	4218	3699	3519	4627	26907	65084	84273	50624	27835	25416.2
32	16580	8195	4805	4433	4057	3412	4292	36160	50890	85600	84940	32460	28226.1
Max	18555	9400	6139	4739	4057	3898	5109	50302	111073	85600	84940	53703	28226.1
Min	9416	3978	2734	2507	1731	2013	2025	8645	39311	48565	42118	18502	17950.7
Mean	13966	6028	4267	3565	2999	2681	3226	27949	64089	64641	57215	32499	23731.6

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Table E.2.9.

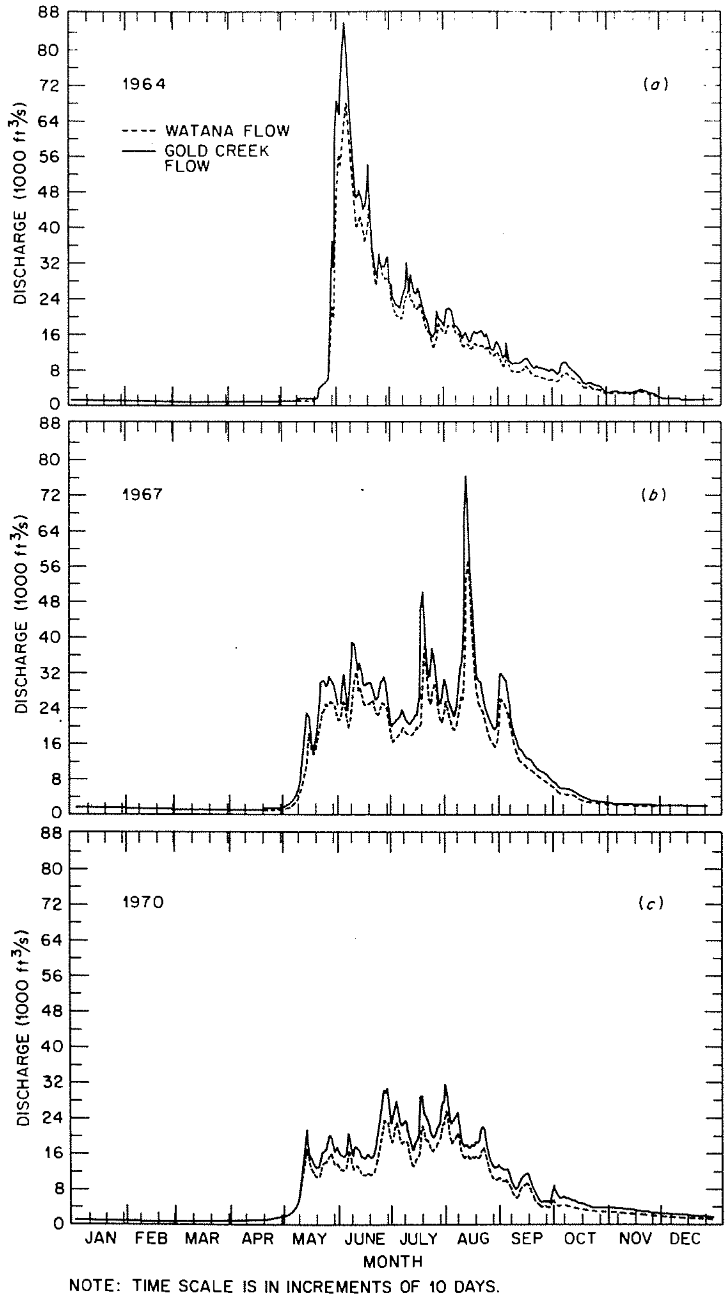


Figure H.2-1. Representatiave annual hydrographs at the Watana dam site and the Gold Creek gaging station for two wet years with spring (1964) and fall (1967) floods and for one dry year (1970). Source: Exhibit E, Figures E.2.24, E.2.25, and E.2.26.

peak equal to the mean annual daily flood peak. In addition, the summer daily flood peak of 76,000 ft^3/s (2,152 m^3/s) is the second largest flood peak at Gold Creek on record. Recurrence intervals for high flows persisting for 7 consecutive days are shown in Figure H.2-2. The maximum recorded instantaneous flood peaks for Denali, Cantwell, and Maclaren, recorded by the USGS, are presented in Table H.2-5. Probable-maximum-flood (PMF) studies were conducted for both the Watana and Devil Canyon dam sites for use in the design of project spillways and related facilities (Exhibit E, Chapter 2). The PMFs were determined by using the SSARR watershed model developed by the Portland District, U.S. Army Corps of Engineers and are based on Susitna Basin climatic data and hydrology. The probable maximum precipitation was derived from a maximization study of historical storms. The studies indicate that the PMF peak at the Watana dam site is 326,000 ft^3/s (9,232 m^3/s).

The flow-duration curves based on preproject mean daily flows are shown in Figure H.2-3. In the majority of cases, the three-parameter lognormal distribution provides the best fit to the data (R & M and Harrison 1981). The shape of the monthly and annual flow duration curves is similar for each of the stations within the basin and is indicative of flow from northern glacial rivers (Exhibit E, Chapter 2). Streamflow is low in the winter months, with little variation in flow and no unusual peaks. Groundwater contributions are the primary source of the small but relatively constant winter flows. Flow begins to increase slightly in April as breakup approaches. Peak flows in May are an order of magnitude greater than in April. Flow in May also shows the greatest variation for any month, as low flows may continue into May before the high snow-melt/breakup flows occur. June has the highest peaks and the highest median flow for the middle and upper basin stations. The months of July and August have relatively flat flow-duration curves. This situation is indicative of rivers with strong base flow characteristics, as is the case on the Susitna with its contributions from snow and glacial melt during the summer. More variability of flow is evident in September and October as cooler weather becomes more prevalent accompanied by a decrease in glacial melt and hence discharge.

From the flow-duration curve for Gold Creek (Figure H.2-3), it can be seen that flows at Gold Creek are less than 20,000 ft^3/s (566 m^3/s) from October through April. As a result of the spring breakup in May, flows of 20,000 ft^3/s are exceeded 30% of the time. During June and July, the percent of time Gold Creek flows exceed 20,000 ft^3/s increases to 80%. This percentage decreases to 65% in August and further decreases to only about 15% in September. On an annual basis, a flow of 20,000 ft^3/s is exceeded 20% of the time.

The 7-day low-flow values determined for selected months at Gold Creek are shown in Figure H.2-4 may exhibits substantial variability. Both low winter flows and high breakup flows usually occur during May, and thus significant changes occur from year to year. June exhibits more variability than July. Flow variability increases again in the August through October period. Heavy rainstorms often occur in August, with 28% of the annual floods occurring in this month. Flow variability in the winter months is reduced considerably, reflecting the low base flow.

Glacial Effects

The glaciated portions of the Susitna River Basin above Gold Creek play a significant role in the hydrology of the area. Located on the southern slopes of the Alaska Range, the glaciated regions receive the greatest amount of snow and rainfall in the basin. During the summer months, these regions contribute significant amounts of snow and glacial melt. The glaciers cover about 290 mi^2 (750 km^2) and act as reservoirs that produce most of the water in the basin above Gold Creek during drought periods. The drainage area upstream of the Denali and Maclaren gages comprises 20% of the basin above Gold Creek, but contributes 40% of the average annual flow at Gold Creek (47% of the flow at Watana). In terms of yield, the area upstream of the Denali and Maclaren gages contributes 3.1 $ft^3/s/mi^2$ (0.23 $m^3/s/km^2$), and the area downstream to Gold Creek contributes 1.2 $ft^3/s/mi^2$ (0.09 $m^3/s/km$). In the record drought year of 1969, the proportion of flow at Gold Creek contributed from upstream of the Denali and Maclaren gages increased to 53.4%. The applicant chose to dismiss this low-flow year as an extremely rare occurrence by adjusting the mean monthly flows for WY 1969 upward (see Table H.2-3 and Exhibit E, p. E-2-57).

There is some evidence from the East Fork Glacier that glacier wasting has been a major contributor to the runoff at Gold Creek since 1949 (R & M and Harrison 1981, 1982). However, the magnitude of the runoff from glacier wasting has not been well documented and is subject to error [an error of 37% may exist in the estimate of 163 ft (50 m) of surface altitude loss at the East Fork Glacier]. Extrapolation of the results from East Fork Glacier to the other 275 mi^2 (712 km^2) (or 95%) of the glaciers in the basin is speculative. Rates of wasting vary naturally among sites, and all glaciers undergo natural cycles of wasting (Sugden and John 1976). Even though there is evidence that the glaciers have been wasting since 1949, there is little data available to determine what the impact of wasting has been on the recorded flow at Gold Creek or what will occur in the future. Large glaciers, such as those in the Susitna Basin, take decades to attain equilibrium after a change in climate. They also

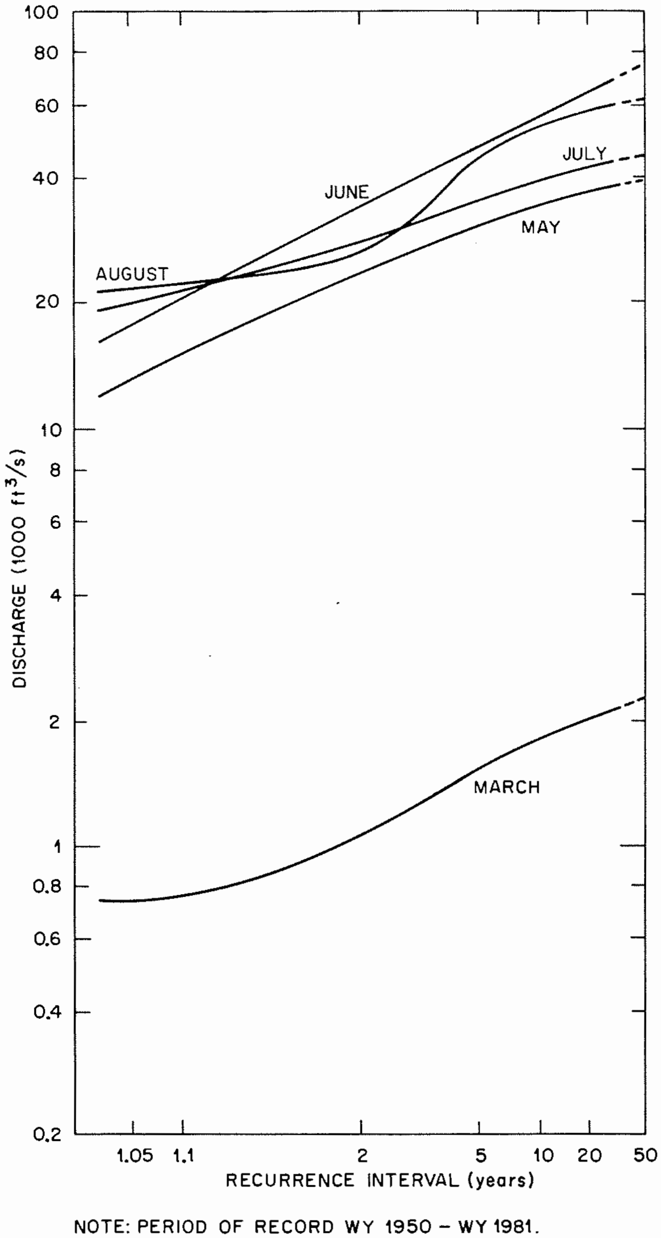


Figure H.2-2. Recurrence intervals for 7-day high flows at Gold Creek during open-water months (May-August) and a ice-covered, low-flow month (March).

Table H.2-5. Maximum Flows of Record at Selected USGS Gaging Stations in the Susitna River Basin

Denali		Cantwell		Gold Creek		Maclaren	
Date	Flow (ft^3/s)	Date	Flow (ft^3/s)	Date	Flow (ft^3/s)	Date	Flow (ft^3/s)
8/10/71	38,200	8/10/71	55,000†[1]	6/7/64	90,700	8/11/71	9,260
8/14-15/67	28,200	6/8/64	51,200	8/10/71	87,400	9/13/60	8,920
7/28/80	24,300	6/15/62[3]	46,800	6/17/72	82,600	8/14/67	7,460
8/4/76	22,100	6/17/72	44,700	6/15/62	80,600	7/18/63	7,300
8/9-10/81	22,000†[3]	8/14/67	38,800	8/15/67	80,200	6/16/72	7,070
7/12/75	21,700	7/18/63	32,000†[4]	6/6/66	63,600	6/14/62	6,540
7/27/68	19,000	8/14/81	30,500†[3]	8/25/59	62,300	8/5/61	6,540

†[1]Estimated maximum daily flow based on discharge records at Denali and Gold Creek.

†[2]Approximate date.

†[3]Maximum daily flow from preliminary USGS data.

†[4]Maximum daily flow.

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Exhibit E, Table E.2.11.

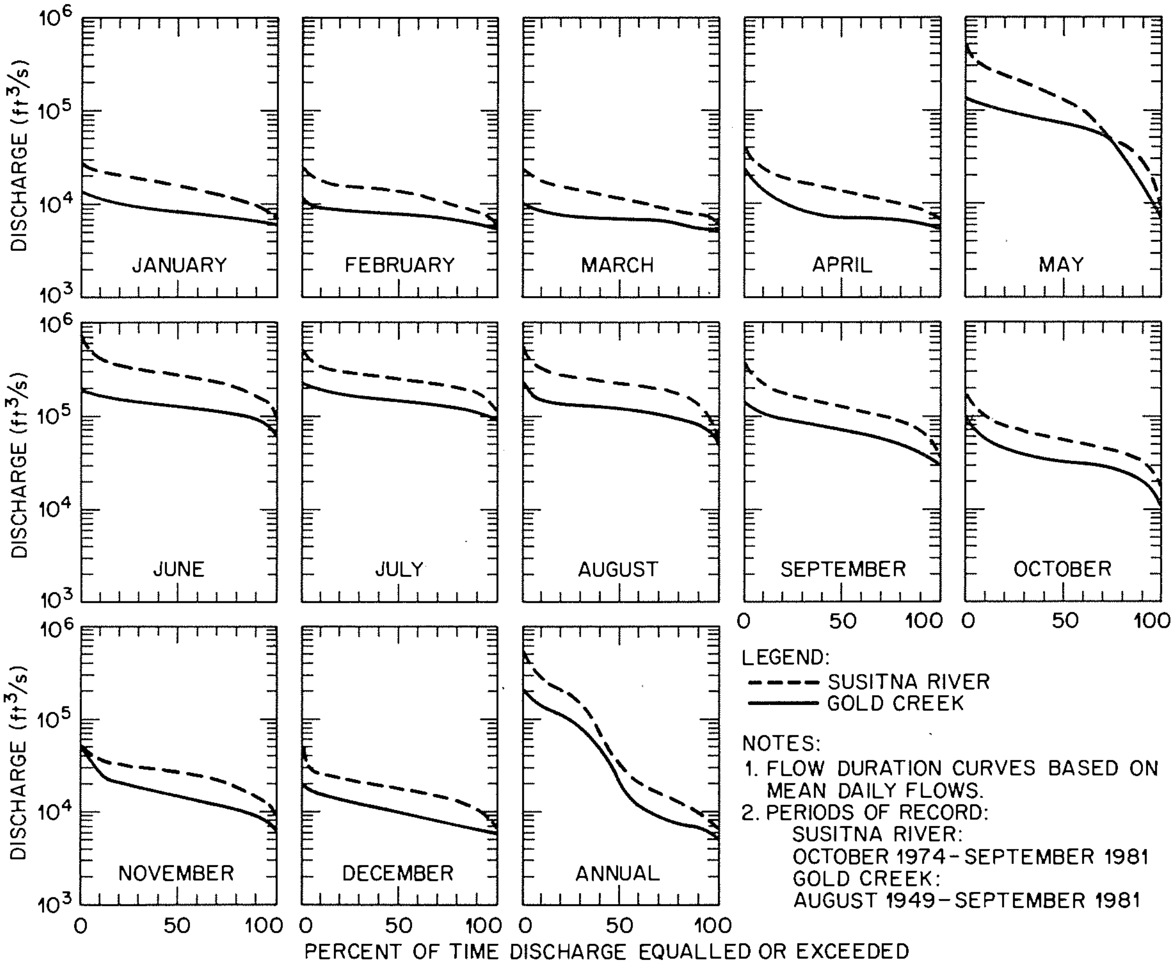


Figure H.2-3. Pre-project flow duration curves for the Gold Creek and Sunshine gaging stations based on mean daily flows. Source: Exhibit E, Figure E.2.39.

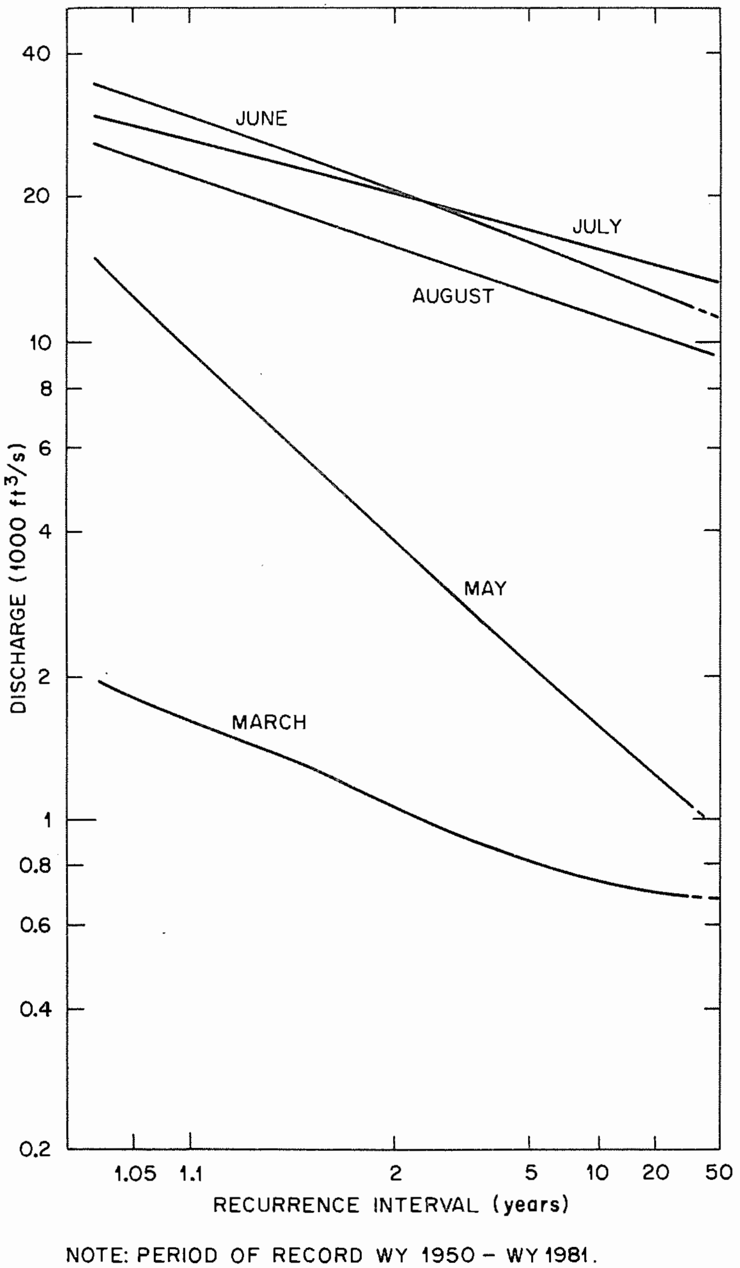


Figure H.2-4. Recurrence intervals for 7-day low flows at Gold Creek during open-water months (May-August) and a ice-covered, low-flow month (March). Source: Exhibit E, Figures E.2.55, E.2.57, and E.2.59.

undergo shorter-term fluctuations on the order of 30 to 50 years. The Susitna Basin glaciers may have reached their most recent maximum extent during the Little Ice Age, which persisted until the early 1800s and may still be responding to the change in climate since that time. If the estimated rate of glacier wasting of East Fork Glacier were also applied to Susitna and West Fork glaciers, almost 36% of the recorded streamflow [990 ft^3/s (28 m^3/s)] at Denali and 22% [220 ft^3/s (6.2 m^3/s)] at Maclaren would have been from glacier melt. Therefore, 12.5% of the annual flow at Gold Creek and 15% of the annual flow at Watana might be attributable to glacier wasting. If the glaciers were to stop wasting due to, perhaps, a climate change, there could be implications for hydrological changes throughout the basin. On the other hand, the wasting of the glaciers could easily continue over the life of the project.

H.2.2 Postproject Flows

The postproject flow regimes were estimated by the applicant, using a multireservoir energy simulation model described in Exhibit E, Chapter 2.3, and Exhibit B. The proposed operational flow regimes are based on the applicant's trade-off analysis between net benefits from hydroelectric power production and fishery impacts. These proposed flows incorporate minimum release requirements at Gold Creek of 5,000 ft^3/s (142 m^3/s) from October through April, 6,000 ft^3/s (170 m^3s) from May 1 through July 31, 12,000 ft^3/s (340 m^3/s) from August 1 through September 15, and 6,000 ft^3/s for the remainder of September. The average monthly flows at the Gold Creek and Sunshine gaging stations that would be produced by the 32-year historical flow record are presented in Tables H.2-6, H.2-7, H.2-8 and H.2-9. Comparisons of the flow-duration curves at Gold Creek and Sunshine under preproject, Watana, and combined Watana-Devil Canyon operational flows are presented in Figure H.2-5 and H.2-6. Pre- and postproject recurrence intervals for the mean annual flood at Gold Creek are presented in Figure H.2-7.

H.3 HABITAT ALTERATION

The mainstem flow regime resulting from the proposed project will cause changes in physical habitat along the river below the dams. These changes were analyzed, using the preproject monthly flow regimes at the Gold Creek and Sunshine gaging stations (Tables H.2-3 and H.2-4) and the postproject monthly flow regimes described by the applicant under the proposed operating schedule [Case C, minimum August flow = 12,000 ft^3/s (340 m^3/s)]. The predicted postproject flows at Gold Creek and Sunshine stations for Watana alone and Watana-Devil Canyon operations are presented in Tables H.2-6 through H.2-9.

Changes in the availability of side-slough habitat were evaluated three ways. First, the frequency of occurrence of various hydraulic regimes was examined under preproject and postproject flow regimes. The three hydraulic regimes in side sloughs were defined as (1) overtopping, (2) backwater, and (3) isolation (see Exhibit E, Appendix E.2.A). Second, the frequency of occurrence of accessibility limitations for spawning salmonids was examined, based on access criteria established by the ADFG (1983). Third, the frequency of occurrence of changes in the wetted surface area was evaluated under postproject flow regimes relative to preproject flows.

<u>Slough Hydraulic Regimes</u>

Three hydraulic regimes in side sloughs along the Susitna River have been defined (Exhibit E, Appendix E.2.A). The first condition is overtopping, where the mainstem stage is above the gravel berm at the upper end of the side slough and the slough is acting as a true overflow channel. Under this overtopping regime, hydraulic characteristics are completely dependent on mainstem discharge. Slough discharge is typically on the order of several hundred cubic feet per second. The second condition is one where backwater effects predominate: the mainstem stage is below the elevation of the upstream berm and a backwater extends upstream from the lower month of the slough. Under this backwater regime, the mainstem stage at the lower end of the slougn acts as a hydraulic control. Hydraulic slough characteristics are largely independent of mainstem discharge, and slough discharge drops by an order of magnitude or more. The third regime is isolation of the side slough, where the mainstem stage drops below the bed elevation of the lower mouth of the side slough and the backwater zone disappears. Under the isolation regime, slough discharge is completely dependent on groundwater seepage and local runoff, acting essentially as a minor tributary to the mainstem.

The applicant established thresholds of mainstem flow at Gold Creek at which these hydraulic regimes occurred in three selected side sloughs above Talkeetna and one side slough below Talkeetna (Table H.3-1). These thresholds were compared to the flow-duration curves (Figures H.2-5 and H.2-6) for pre- and postproject flows to estimate the frequency of occurrence of mainstem flows which would produce each hydraulic regime. For the three sloughs above Talkeetna, an average threshold was used (Table H.3-1). Using the average slough response, this analysis indicates that overtopping (Regime I) would occur very rarely above Talkeetna after Watana Dam began operating (Table H.3-2). The backwater condition (Regime II) would persist only in June, July, and August (12, 2, and 16% of the

Table H.2-6. Predicted Postproject Monthly Flows (ft^3/s) at Gold Creek under Watana Operation

	Month												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1	7280	10216	11555	9918	9105	8238	7574	8487	8022	8024	12000	9282	9145.8
2	6390	6833	7910	7342	6437	6589	5989	10314	7108	7562	12000	9300	7831.3
3	8061	10738	12016	10491	9317	8392	7624	6529	11599	9076	12000	9300	9595.1
4	10186	11491	11816	9991	9137	8332	8319	15608	10810	7406	12000	9300	10380.5
5	7076	7092	11616	10191	9317	8292	7939	13953	10736	7967	12000	9300	9635.0
6	7195	7955	12161	10685	9717	8612	7904	7860	10153	10622	16276	9300	9882.5
7	8469	9894	11416	9871	9287	8452	7654	14207	15257	14078	15432	13411	11468.8
8	9377	11044	12258	10591	9817	8712	7904	10575	12008	8110	12000	12213	10384.1
9	11783	11948	13380	10856	9624	8660	8237	9746	8566	7883	12000	9121	10162.0
10	6875	6933	8170	10339	9624	8492	7954	12818	9829	9288	16209	11843	9874.3
11	10129	10844	12316	10736	9769	8709	8004	12318	7167	8287	12000	9300	9978.8
12	8227	10994	12810	11343	10071	9322	9354	13838	11869	9478	12000	9300	10726.1
13	7329	10694	12216	10791	9817	8912	8404	9299	24152	9986	14667	10430	11381.9
14	10294	10794	12116	10491	9817	8512	7534	15342	10296	15149	15147	9300	11263.3
15	7778	10244	11610	9939	9283	8225	7449	6061	26092	7887	12000	9300	10468.3
16	7291	6967	7679	9658	9177	8412	8064	9736	9470	9772	12000	13506	9309.7
17	10776	10092	11747	10291	9617	8812	8479	7810	13487	8262	12000	9300	10056.4
18	6616	6903	7985	10391	9717	8712	7871	12067	11636	10363	22704	11951	10593.9
19	8471	10347	12171	10872	10217	9412	8614	12740	13602	10043	12000	9300	10654.4
20	6582	6882	7830	7839	9239	8345	7726	7169	7866	6852	12000	9300	8128.7
21	6629	7004	8013	7518	6586	6771	5920	7272	9214	8997	12000	9300	7947.1
22	7491	7701	8482	7681	6678	6848	6091	6390	10484	7762	13149	9300	8181.2
23	8728	11087	12626	11130	10345	9335	8414	18135	16602	7692	12000	9300	11289.7
24	6222	6865	11581	10091	9517	8512	7731	6207	8914	6484	12000	9300	8615.7
25	6457	6742	7725	7179	6725	8236	7696	12773	7949	7483	12000	9300	8370.1
26	6551	7008	8138	7574	6719	6896	6121	9025	13491	11081	12000	9300	8671.0
27	9816	9987	11197	9865	9267	8412	8077	9568	9350	6513	12000	8051	9347.6
28	6728	7351	8393	7616	6647	7982	8384	9665	19061	7908	12000	9300	9255.0
29	7469	10068	12705	10920	9985	9117	8406	8669	6617	7243	12000	9300	9378.3
30	7015	7274	8119	7476	6537	6577	5811	9811	6908	11719	12000	9300	8235.0
31	6842	11972	12532	10639	9783	8912	8374	8888	11113	15152	12030	9300	10469.9
32	10320	11980	11890	10344	9552	8626	8071	10118	6000	9792	26494	10461	11172.4
Max	11783	11980	13380	11343	10345	9412	9354	18135	26092	15152	26494	13506	11468.8
Min	6222	6742	7679	7179	6437	6577	5811	6061	6000	6484	12000	8051	7831.3
Mean	8014	9186	10693	9708	8951	8324	7740	10405	11420	9185	13378	9840	9745.4

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Exhibit E, Table E.2.44.

Table H.2-7. Predicted Postproject Monthly Flows (ft^3/s) at Sunshine Under Watana Operation

Year	Month												Annual
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
1	14948	13272	13727	11639	10593	9545	9015	19395	34035	44603	46969	28715	21460.9
2	14768	10245	10614	9312	8052	7993	7935	38420	45190	54466	50686	39129	24861.4
3	16203	13696	13898	12361	10828	9794	9061	12368	47967	47623	44443	26877	22160.5
4	19378	15193	14196	11709	10660	9829	10996	46640	47565	41437	41344	27767	24834.4
5	14699	10084	14093	12558	11206	9935	9908	29268	40291	40993	43601	24756	21875.2
6	14013	11535	14429	12818	11506	10089	9362	20299	49979	53956	68218	30395	25667.8
7	14529	12361	13277	11503	10603	9721	8948	29704	55858	63556	59936	39576	27583.9
8	18823	15023	15023	12897	11788	10356	9611	30965	61001	47102	44703	40534	26550.7
9	21970	17026	16255	12958	11313	10155	10103	24605	43618	44853	46362	21669	23509.9
10	13642	10114	10249	12278	11376	9792	9599	26288	50795	51809	56977	31838	24660.1
11	18702	14409	14939	12950	11518	10187	9632	31340	30948	43531	43725	31876	22917.7
12	17429	14103	15620	13630	11795	10992	11813	28916	43305	48548	50516	32001	24992.0
13	15992	14651	14936	13113	11659	10487	10285	21229	68419	51892	52298	33251	26583.3
14	17527	14046	14806	12965	11938	9911	8729	31557	40925	58968	44415	26162	24451.1
15	19884	13901	13649	11688	10764	9525	9085	10399	86585	43773	41934	22996	24533.6
16	16473	11640	11004	12071	11279	10330	10139	21343	42238	46974	47255	47859	24112.2
17	21779	13315	14081	12295	11326	10387	10302	14644	50106	43645	52177	27706	23559.4
18	14004	9598	10341	12589	11611	10305	9343	29499	48288	60688	72831	32460	26941.5
19	14277	13407	14679	13072	12303	11410	11063	33521	58822	53358	41560	21369	24992.9
20	12834	9457	9728	9442	10048	9534	9146	18623	36692	37324	38648	24356	18879.2
21	12921	9767	9995	9294	8266	8377	7990	21579	38186	47108	46946	27370	20749.6
22	14467	11761	11122	9564	8156	8249	7649	13297	53762	48599	55758	27262	22559.2
23	17194	14739	15038	13148	12118	10847	9914	32425	49028	47214	43964	31056	24811.2
24	14984	10630	14146	12203	11301	10158	9525	16187	41047	39945	42795	25464	20765.2
25	14008	9918	10215	9187	8467	9732	9620	28039	33792	39950	39002	26164	19934.2
26	15114	10246	10312	9604	8238	8306	7688	23055	54017	59053	45588	28557	23418.8
27	17642	12232	12850	11398	10672	9793	9998	19823	41336	43079	44355	19672	21159.0
28	13474	10589	11275	10018	8669	9653	10241	24277	68864	47232	47917	29379	24367.6
29	17297	13673	15429	13104	11544	10514	10246	19426	35611	44153	37728	23435	21094.0
30	13331	10387	10746	9753	8457	8340	8065	29817	42067	54604	40437	25320	21889.9
31	17219	17180	15305	13109	12016	11031	11331	23735	47117	66765	41694	23855	25138.4
32	19175	16189	14921	13324	12374	10924	10996	32962	38747	63392	72896	29750	28143.3
Max	21970	17180	16255	13630	12374	11410	11813	46640	86585	66765	72896	47859	28143.3
Min	12834	9457	9728	9187	8052	7993	7649	10399	30948	37324	37728	19672	18879.2
Mean	16209	12637	13153	11798	10701	9881	9604	25114	47694	49381	48365	29018	23723.7

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Exhibit E.2.46.

Table H.2-8. Predicted Postproject Monthly Flows (ft^3/s) at Gold Creek Under Combined Watana-Devil Canyon Operation

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
	Month												
1	7179	10934	12578	11650	10939	8865	7473	7324	7179	7206	12000	9300	9380.2
2	6749	7141	8135	7498	6524	6632	7139	8785	6555	6708	12000	9300	7776.4
3	6839	10431	12669	11727	11181	9860	7523	6195	9795	7902	12000	9300	9609.5
4	7307	11650	12668	11690	11212	9983	8218	11255	12070	6776	12000	9300	10337.3
5	7252	7248	11896	11316	10980	8919	7838	11870	9085	7156	12000	9300	9573.3
6	7287	7392	12739	11782	11311	10536	7803	7151	10161	8894	12000	10444	9788.5
7	7933	11124	12572	11625	10950	9079	7553	11582	12282	11089	13620	18330	11473.3
8	8788	11674	12683	11722	11278	10459	8834	8556	11415	7132	12000	10173	10384.1
9	10983	11849	13134	11797	11208	10383	9465	9008	9227	6982	12000	9300	10443.8
10	7116	7230	8182	9993	11287	9119	7853	10728	8423	7949	12783	14603	9592.6
11	9540	11577	12750	11805	11280	10439	8856	10231	6577	7265	12000	9300	10137.1
12	7204	10747	12887	12046	11453	10604	9759	10900	12635	8837	12000	9300	10692.4
13	7074	10063	12681	11701	11234	10433	9195	7354	12998	9032	17532	15890	11257.3
14	9705	11333	12581	11697	11282	10356	8333	10911	11714	11390	12000	11551	11072.9
15	9431	11474	12599	11639	11191	8852	7348	6000	13305	9366	12000	9300	10199.1
16	7306	9196	12487	11601	10840	9039	7963	7766	9244	9185	12000	10645	9769.4
17	10187	11322	12689	11739	11293	9948	8378	7117	12900	7381	12000	9300	10345.3
18	6931	7213	8172	9698	11380	9339	7770	10069	11354	9841	15192	16870	10305.0
19	7882	11423	12737	11752	11301	10510	9519	10652	12076	10472	12000	9300	10800.3
20	6890	7179	8091	8778	10902	8972	7625	6687	7094	6484	12000	9300	8318.1
21	6921	7212	8196	7607	6614	6743	6578	6746	7960	7842	12000	9300	7820.4
22	7515	7725	8500	7697	6656	6770	5950	6562	8695	6750	12000	10053	7914.2
23	8829	11485	12762	11868	11406	10581	9559	12380	12820	9462	12000	9300	11037.3
24	6453	11030	12542	11620	11214	9529	7630	6021	8279	6484	12000	9300	9329.5
25	6820	7104	8041	7424	6457	8102	7595	10612	7121	6807	12000	9300	8132.5
26	6850	7200	8269	7635	6698	6818	5990	9487	11922	10438	12000	9300	8565.2
27	8528	11217	12532	11440	10930	9039	7976	7890	8011	6484	12000	9300	9606.7
28	7001	7516	8491	7708	6687	9215	8283	8184	12592	9629	12000	9300	8895.9
29	7357	11299	12808	11811	11340	10516	9494	6986	6213	6662	12000	9300	9641.2
30	7191	7439	8272	7582	6587	6618	7366	8522	8244	10003	12000	9300	8275.9
31	7096	9129	12650	11690	11226	10431	9358	6922	12307	11846	12000	9300	10325.4
32	8334	11633	12677	11760	11268	10448	8994	8150	6000	8941	21146	13171	11053.7
Max	10983	11849	13134	12046	11453	10604	9759	12380	13305	11846	21146	18330	11473.3
Min	6453	7104	8041	7424	6457	6618	5950	6000	6000	6484	12000	9300	7776.4
Mean	7765	9631	11271	10597	10191	9286	8100	8706	9883	8387	12634	10510	9745.5

Conversion: To convert from cubic feet to cubic feet to cubic meters, multiply by 0.0283.

Source: Exhibit E.2.54.

Table H.2-9. Predicted Postproject Monthly Flows (ft^3/s) at Sunshine Under Combined Watana-Devil Canyon Operation

Year	Month												Annual
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
1	14847	13990	14750	13371	12427	10172	8914	18232	33192	43785	46969	28733	21695.3
2	15127	10553	10839	9468	8139	8036	9085	36891	44637	53612	50686	39129	24806.6
3	14981	13389	14551	23597	12692	11262	8960	12034	46163	46449	44443	26877	22174.9
4	16499	15352	15048	13408	12735	11480	10895	42287	48825	40807	41344	27767	24791.3
5	14875	10240	14373	13683	12869	10562	9807	27185	38640	40182	43601	24756	21813.5
6	14105	10972	15007	13915	13100	12013	9261	19590	49987	52228	63942	31539	25573.7
7	13993	13591	14433	13257	12266	10348	8847	27079	52883	60568	58124	44495	27588.4
8	18234	15653	15448	14028	13249	12103	10541	28946	60408	46124	44703	38494	26550.7
9	21170	16927	16009	13899	12897	11878	11331	23867	44279	43952	46362	21848	23791.6
10	13883	10411	10261	11932	13039	10419	9498	24198	49389	50470	53551	34598	24378.4
11	18113	15142	15373	14019	13029	11917	10484	29253	30358	42509	43725	31876	23076.1
12	16406	13856	15697	14333	13177	12274	12218	25978	44071	47907	50516	32001	24958.3
13	15737	14020	15401	14023	13076	12008	11076	19284	57265	50938	55163	38711	26458.7
14	16938	14585	15271	14171	13403	11755	9528	27126	42343	55209	41268	28413	24260.8
15	21537	15131	14638	13388	12672	10152	8984	10338	73798	45252	41934	22996	24264.4
16	16488	13869	15812	14014	12942	10957	10038	19373	42012	46387	47255	44998	24571.8
17	21190	14545	15023	13743	13002	11523	10201	13951	49519	42764	52177	27706	23848.3
18	14319	9908	10528	11896	13274	10932	9242	27501	48006	60166	65319	37379	26652.5
19	13688	14483	15245	13952	13387	12508	11968	31433	57296	53787	41560	21369	25138.8
20	13142	9754	9989	10381	11711	10161	9045	18141	35920	36956	38648	24356	19068.6
21	13213	9975	10178	9383	8294	8349	8648	21053	36932	45953	46946	27370	20622.9
22	14491	11785	11140	9580	8134	8171	7508	13469	51973	47587	54609	28015	22292.2
23	17295	15137	15174	13886	13179	12093	11059	26670	45246	48984	43964	31056	24558.8
24	15215	14795	15107	13732	12998	11175	9424	16001	40412	39945	42795	25464	21479.0
25	14371	10280	10531	9432	8199	9598	9519	25918	32964	39274	39002	26164	19696.6
26	15413	10438	10443	9665	8217	8228	7557	23517	52448	58410	45588	28557	23313.0
27	16354	13462	14185	12973	12335	10420	9897	18145	39997	43050	44355	20921	21418.1
28	13747	10754	11373	10110	8709	10886	10140	22796	62395	48953	47917	29379	24008.5
29	17185	14904	15532	13995	12899	11913	11334	17743	35207	43572	37728	23435	21356.9
30	13507	10552	10899	9859	8507	8381	9620	28528	43403	52897	40437	25320	21930.9
31	17473	14337	15423	14160	13459	12550	12315	21769	48311	63459	41664	23855	24993.9
32	17189	15842	15709	14739	14090	12746	11919	30994	38747	62541	67548	32460	28024.6
Max	21537	16927	16009	14739	14090	12746	12315	42287	73798	63459	67548	44998	28024.6
Min	13142	9754	9989	9383	8134	8036	7508	10338	30358	36956	37728	20921	19068.6
Mean	15960	13082	13731	12687	11941	10843	9964	23415	46157	48584	47620	29689	23723.7

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Exhibit E, Table E.2.56.

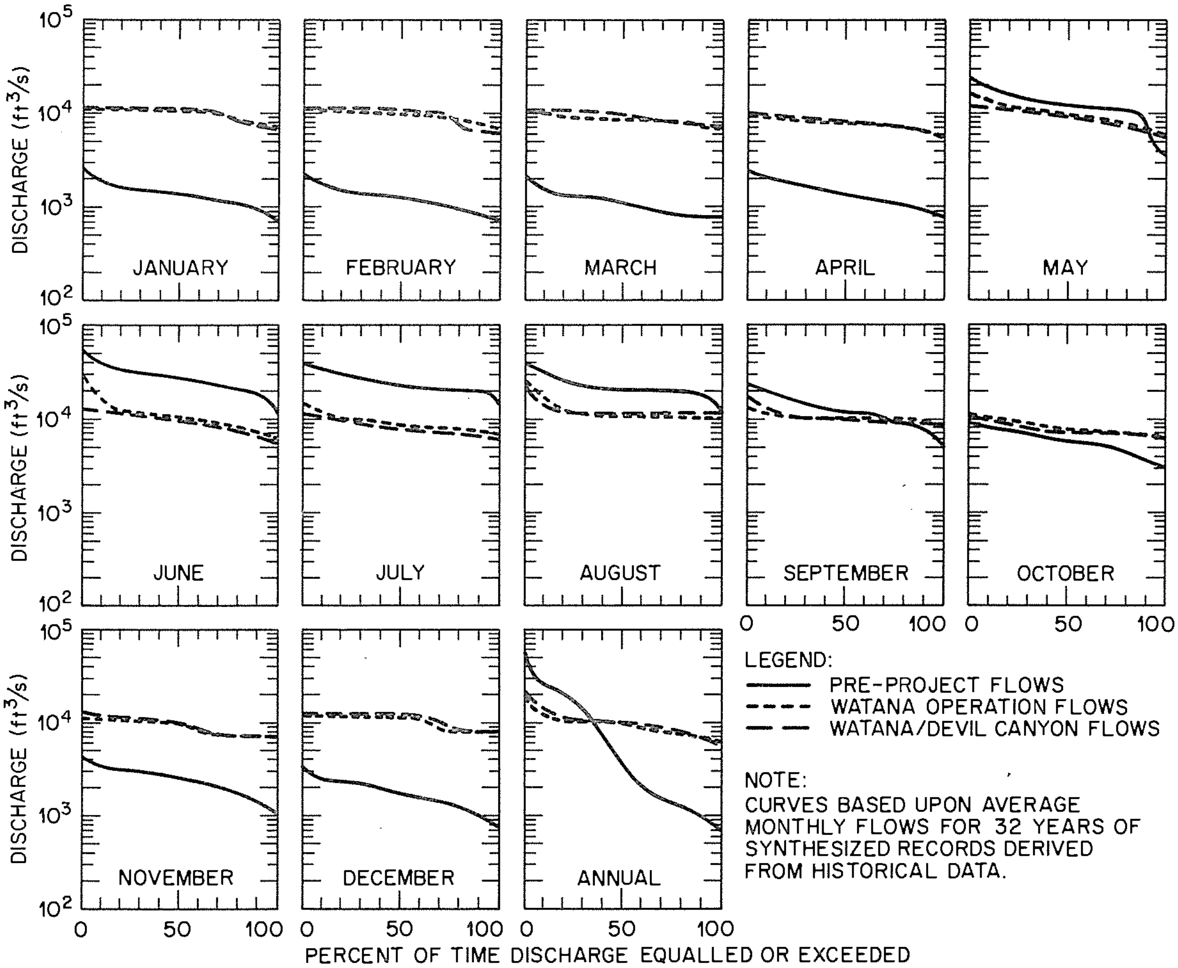


Figure H.2-5. Flow duration curves at Gold Creek for pre-project, Watana, and Watana-Devil Canyon operational flows. Source: Exhibit E, Figures E.2.160 and E.2.208.

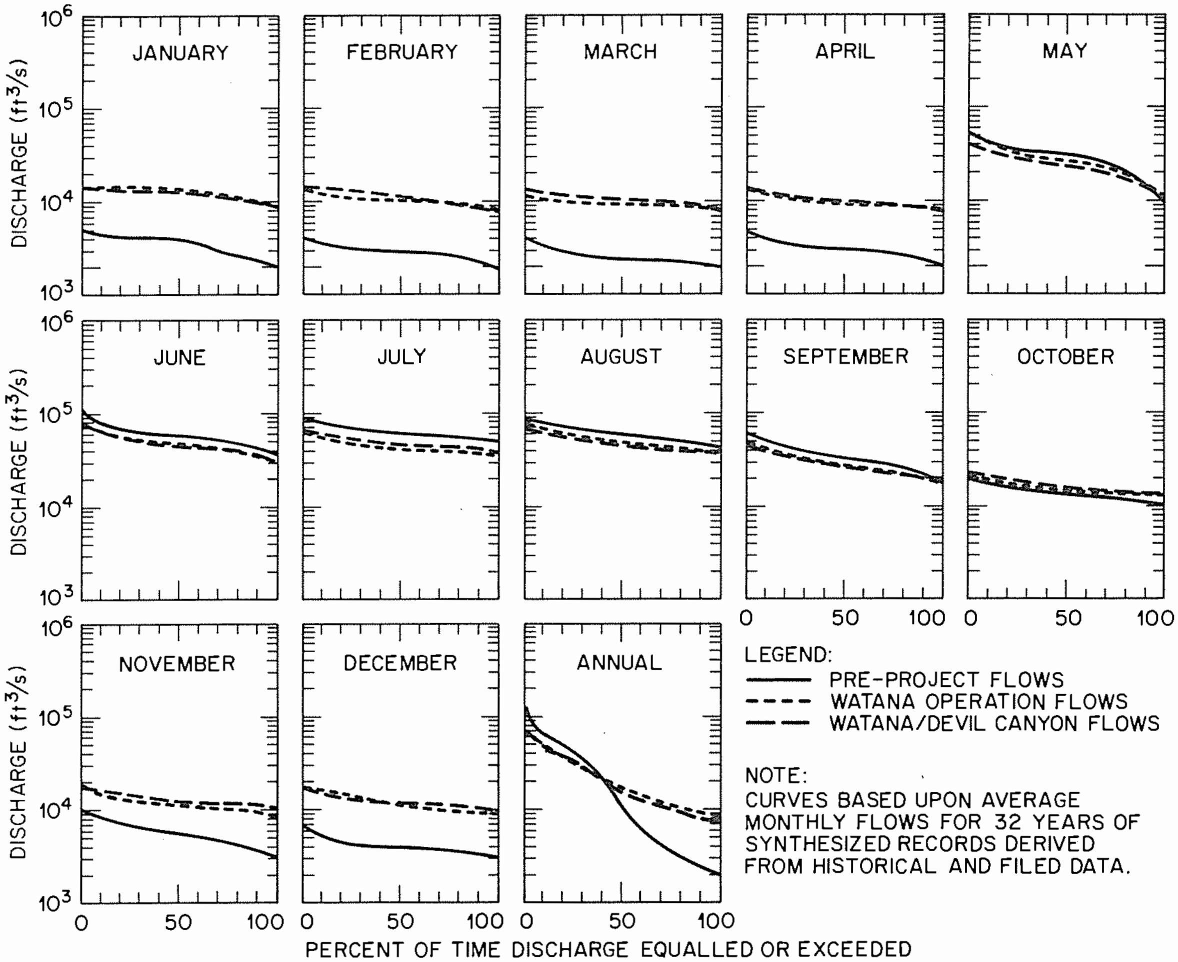


Figure H.2-6. Flow duration curves at Sunshine for pre-project, Watana, and Watana-Devil Canyon operational flows. Source: Exhibit E, Figures E.2.161 and E.2.209.

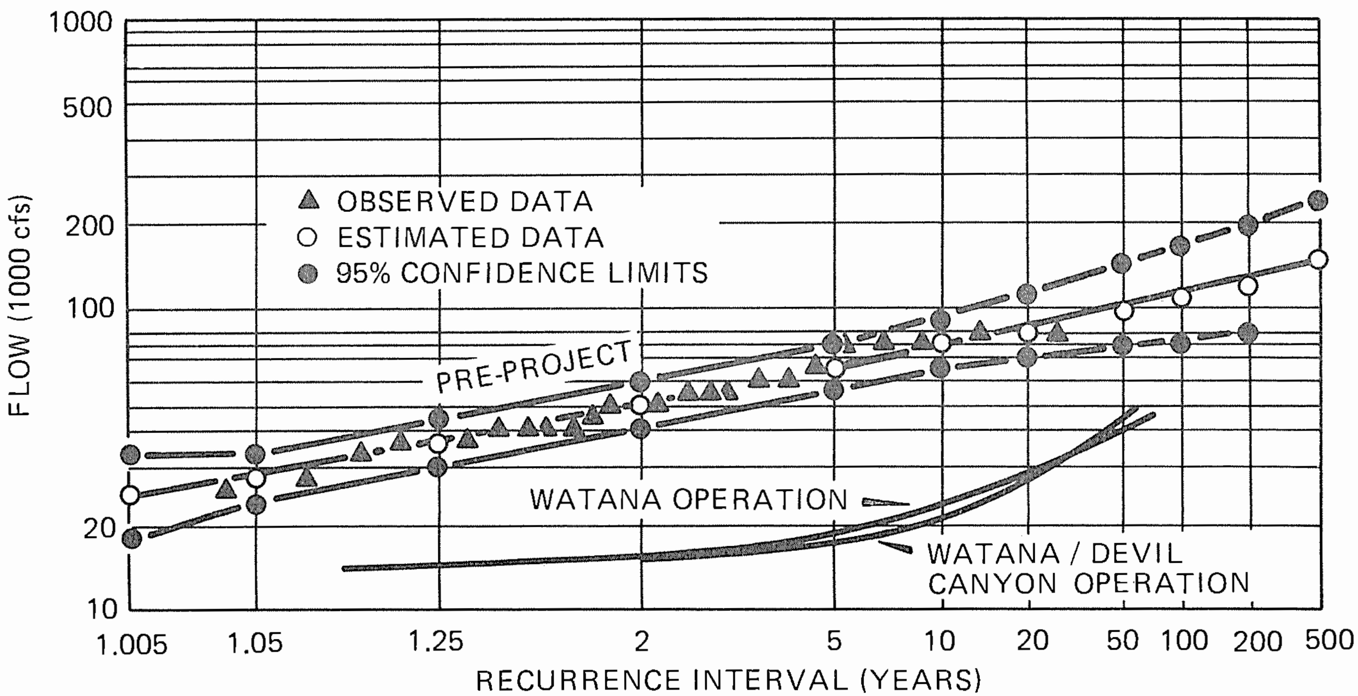


Figure H.2-7. Comparison of recurrence intervals for mean annual floods at Gold Creek under preproject, Watana, and Watana-Devil Canyon operational flow regimes. Source: Exhibit E, Figures E.2.29, E.2.155, and E.2.186.

Table H.3-1. Thresholds in Mainstem Flow (ft^3/s) at Which Hydraulic Regimes Occur at Selected Side-Channel Sloughs

Location	Hydraulic Regime: I Overtopping	II Backwater	III Isolation
Above Talkeetna†[1]			
Slough 8A (RM)	30,000	26,000-10,000	10,000
Slough 9 (RM)	23,000	20,500-11,000	11,000
Slough 21 (RM)	26,000	24,800-21,400	21,400
Average	26,000	26,000-14,000	14,000
Below Talkeetna†[2]			
Rabideau Slough	65,000	65,000-10,000	10,000

†[1]Flows in cubic feet per second at the Gold Creek gaging station.

†[2]Flows in cubic feet per second at the Sunshine gaging station.

Conversion: To convert from cubic feet to cubic meters, mulitply by 0.0283.

Source: Exnibit E, Appendix E.2.A, Table A-1.

Table H.3-2. Frequency of Occurrence of Various Hydraulic Regimes of Side Sloughs in Openwater Season Before and After Project Begins Operations (Assumes Average Thresholds of 26,000, 14,000 to 26,000 and 14,000 ft^3/s for Sloughs Above Talkeetna and 65,000, 65,000 to 10,000, and 10,000 ft^3/s Below Talkeetna for Regimes I, II, and III, Respectively)

Month	Preproject Regimes†[1]			Postproject Regimes†[2] (Watana Alone)		
	I	II	III	I	II	III
Sloughs Above Talkeetna						
May	15	38	53	0	0	100
June	53	43	4	1	12	87
July	39	58	3	0	2	98
August	26	63	11	1	16	83
September	6	32	62	0	0	100
October	0	4	96	0	0	100
Rabideaux Slough Below Talkeetna						
May	0	86	14	0	75	25
June	49	51	0	10	90	0
July	61	39	0	0	100	0
August	23	77	0	14	86	0
September	2	98	0	0	100	0
October	0	88	12	0	100	0

†[1]Preproject analysis based on average daily flows.

†[2]Postproject analysis based on average monthly flows.

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: FERC staff

time, respectively) above Talkeetna. While overtopping had been the most frequently occurring condition in June (53% preproject occurrence), it would be effectively eliminated under the backwater regime. Isolation conditions (Regime III) would persist throughout the open-water season. Since the flow regime with combined Watana-Devil Canyon operation would be very similar to that of Watana alone, the slough hydraulic regimes would also be similar. However, during filling of the reservoirs, downstream flows would be equal to the proposed minimum flows of 12,000 ft^3/s (340 m^3/s) (Aug. 1 - Sept. 15) and 5,000 ft^3/s (142 m^3/s) at other times. It is obvious from the Applicant-defined flow thresholds (Table H.3-1) that these filling flows would result in extreme isolation of the side-channel sloughs above Talkeetna.

The only slough studied for hydraulic regimes below Talkeetna was Rabideau Slough (Table H.3-1). Although it would not be impacted as much as the sloughs above Talkeetna, Rabideau Slough would be subjected to a significant reduction in the frequency of overtopping throughout the open-water months (Table H.3-2). It would not be isolated from the main channel to any significant degree, but this may be due only to the unique characteristics of this site. Hydraulic-regime thresholds for more sloughs below Talkeetna need to be studied before the trends in Table H.3-2 can be verified.

The preceding discussion in this section applies only to the open-water months on the Susitna River. During the ice-cover season, the flow thresholds for the overtopping and backwater regimes would be lower due to the effects of ice-induced staging in the main channel. The degree of staging would vary along the river due to localized ice-jamming and the proximity of hydraulic controls. Flow thresholds for hydraulic conditions such as overtopping have not been established, but it is possible to estimate the amount of staging that might be required to cause overtopping. The maximum winter flow has been estimated at about 15,000 ft^3/s (425 m^3/s) at Gold Creek. This would occur when the powerhouse at Watana was at full generating capacity, which can be assumed to occur quite frequently, since winter would be the peak demand period. The amount of mainstem staging required to cause overtopping at sloughs 8A, 9, and 21 is approximately 2 ft (0.6 m) (Table H.3-3). This amount of staging could easily occur; therefore, winter overtopping is likely to be a frequent phenomenon.

Table H.3-3. Calculation of Ice-Related Staging Required for Winter Overtopping of Selected Sloughs

	Slough 8A	Slough 9	Slough 21
River Mile at upstream berm†1	126.1	129.2	142.2
Overtopping flow (ft^3/s)†1	30,000	23,000	26,000
Water surface elevations (ft)†2			
@ Overtopping	573.8	602.7	756.8
@ 15,000 ft^3/s	572.0	601.2	754.6
Ice staging needed for winter overtopping (ft)	1.8	1.5	2.2

†1 From Exhibit E, Appendix E.2.A.

†2 From Exhibit E, Table E.2.15.

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283. To convert from feet to meters, multiply by 0.3048.

Source: FERC staff

Slough Accessibility

Mainstem flows at which selected sloughs are accessible to salmon were identified by the Alaska Department of Fish and Game (ADFG) (Table H.3-4). Of the nine sloughs studied for accessibility by ADFG (1983), sloughs 6A and 19 are upland sloughs and all the others are side-channel sloughs. The frequency at which these thresholds are equaled or exceeded was examined by using the preproject, Watana, and combined Watana-Devil Canyon operational flows (Figures H.2-5 and H.2-6). Results of this initial analysis, which ignored utilization, are shown in Table H.3-5.

A cumulative accessibility analysis was also carried out to examine overall availability of quality spawning habitat in the sloughs. A relative value was assigned to each slough, based on the observed utilization in the 1981 and 1982 seasons (Table H.3-4). Sloughs with high, medium, low, and no utilization received values of 1, 2/3, 1/3, and 0, respectively. The cumulative percent of these weighted spawning values was then plotted against mainstem flows (Figure H.3-1). This analysis indicates that 50% of the weighted spawning habitat in the sloughs studied has unrestricted access at Gold Creek flows above 12,500 ft^3/s (354 m^3/s). However, the second 50% of weighted slough spawning habitat has acute access limitations until main channel flows exceed 18,000 ft^3/s (510 m^3/s).

Wetted Surface Area in Sloughs

The ADFG (1983) published data on wetted surface area vs. mainstem flow for nine sloughs above Talkeetna (Table H.3-6) and five sloughs below Talkeetna (Table H.3-7). These response data included total wetted surface area independent of microhabitat type and a habitat type called "backwater H-II zones." These H-II zones are backwater areas, not directly connected to the main channel, which have a mean velocity less than 0.5 ft/s (0.15 m^3/s) (ADFG 1983). Changes in generalized slough habitat were examined by converting the preproject, Watana, and combined Watana operational flows into wetted surface area values for each slough and month in the flow record.

Change in surface area for each slough and month combination was calculated as

$$DAREA_i = 100\ (SA_{pre,i} - SA_{post,i})/SA_{pre,i}\ ,$$

where $DAREA_i$ is the percent change in wetted surface area for the i^{th} month in the flow record, $SA_{pre,i}$ is the surface area calculated from mean monthly preproject flow during the i^{th} month in the flow record, and $SA_{post,i}$ is the surface area calculated from the simulated postproject flow for the i^{th} month of the record. The resulting record of DAREA values was then subjected to a frequency analysis as well as other simple statistical analyses. Figure H.3-2 shows the mean percent change in total wetted surface area with error bars of plus/minus one standard deviation for filling, Watana, and Watana-Devil Canyon operations. The response of cumulate area in the H-II zones to mainstem flows is shown in Figure H.3-3.

Table H.3-4. Access Thresholds of Mainstem Discharge at Gold Creek for Selected Side-Channel Sloughs Between Devil Canyon and Talkeetna, Including Relative Utilization by Adult Salmon in 1981 and 1982

Slough (River Mile)	Access Thresholds (ft^3/s) Acute Limitations	Unrestricted	Relative Utilization†[1]
Wiskers Creek (RM 101.2)	8,000	10,000	Low
Slough 6A (RM 112.3)	unavailable	8,000	Medium
Slough 8A (RM 125.3)	7,860	12,500	High
Slough 9 (RM 129.2)	18,000	20,000	High
Slough 11 (RM 135.3)	unavailable	6,700	High
Slough 16B (RM 138.0)	18,000	26,400	None
Slough 20 (RM 140.1)	20,000	21,500	Medium
Slough 21 (RM 142.0)	20,000	23,000	High
Slough 22 (RM 144.3)	20,000	22,500	Low

†[1]High = chum salmon exceed 100 per slough, frequently more than 1000 per slough.
Medium = zero to 100 fish per slough for chum, sockeye, and pinks.
Low = at least one species observed.
None = no salmon observed.

Conversion: To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Alaska Department of Fish and Game (1983).

Table H.3-5. Frequency of Access Limitations in Selected Sloughs

Month	Percent Occurrence†[1] Preproject Acute	Minor	None	Watana Acute	Minor	None	Watana-Devil Canyon Acute	Minor	None
May	54	9	37	60	14	26	65	16	19
June	8	9	83	56	14	30	61	14	25
July	6	19	75	63	16	21	67	16	17
August	16	21	63	52	9	39	54	11	35
September	51	12	37	56	19	25	55	18	27
October	76	20	4	69	16	15	71	14	15

†[1]Percent of the months in historical record or in applicant's simulated postproject flow record in which each condition occurs; "minor" indicates flows are between the thresholds for acute limitations and unrestricted access.

Source: FERC staff.

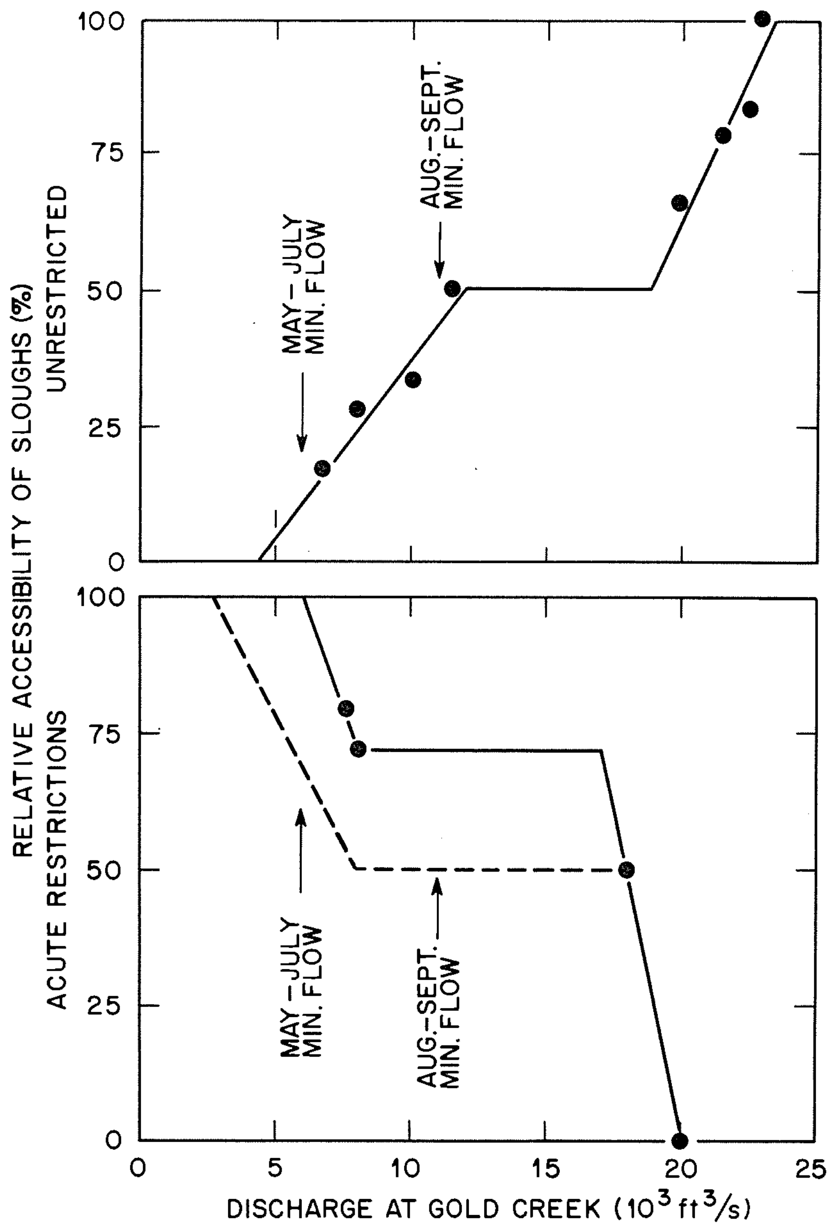


Figure H.3-1. Cumulative response of slough accessibility to mainstem discharge (dashed line in bottom graph assumes a acute accessibility threshold at Sloughs 6A and 11 at 5,000 cfs).

Table H.3-6. Wetted Surface Areas (103 ft2) in Sloughs Above Talkeetna

Location	Discharge at Gold Creek (10^3 ft^3/s) 12.5	15	17.5	20	22.5	25	27.5
Slough 21							
Total	88	129	160	161	163	173	194
H-II zone	52	64	69	42	16	4	12
Slough 20							
Total	57	69	82	94	106	118	130
H-II zone	2	0.4	0	0	0	0	2
Slough 19							
Total	16	20	26	32	38	44	44
H-II zone	4	0	9	11	14	26	26
Slough 11							
Total	58	77	97	116	136	143	145
H-II zone	22	32	46	73	105	109	110
Slough 9							
Total	150	171	193	215	237	259	280
H-II zone	10	84	128	109	77	44	11
Slough 8A							
Total	186	194	201	208	215	223	230
H-II zone	156	164	173	182	190	199	208
Lane Creek/Slough 8							
Total	35	39	43	47	51	55	59
H-II zone	6	9	14	14	16	45	47
Slough 6A							
Total	128	129	131	132	134	135	137
H-II zone	128	129	131	132	134	135	137
Wiskers Creek							
Total	170	179	189	198	208	217	218
H-II zone	29	38	52	66	80	84	84

Conversion: To convert from square feet to square meters, multiply by 0.0929. To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Alaska Department of Fish and Game (1983).

Table H.3-7. Wetted Surface Areas (10^3 ft^2) in Sloughs Below Talkeetna

	Discharge at Gold Creek (10^3 ft^3/s)							
Location	35	40	45	50	55	60	65	70
Birch Creek								
Total	362	368	374	380	386	394	400	406
H-II zone	84	147	150	153	225	365	378	385
Sunshine Creek								
Total	168	185	202	219	236	253	270	287
H-II zone	25	55	86	118	148	178	128	121
Rabideau Creek								
Total	1020	1050	1070	1110	1120	1150	1180	1200
H-II zone	496	826	880	933	987	1040	1090	1150
Whitefish Slough								
Total	21	37	51	61	67	72	77	80
H-II zone	21	37	51	61	67	72	77	80
Goose Creek								
Total	139	143	148	152	157	161	166	170
H-II zone	0	58	117	109	103	94	86	78

Conversion: To convert from square feet to square meters, multiply by 0.0929. To convert from cubic feet to cubic meters, multiply by 0.0283.

Source: Alaska Department of Fish and Game (1983).

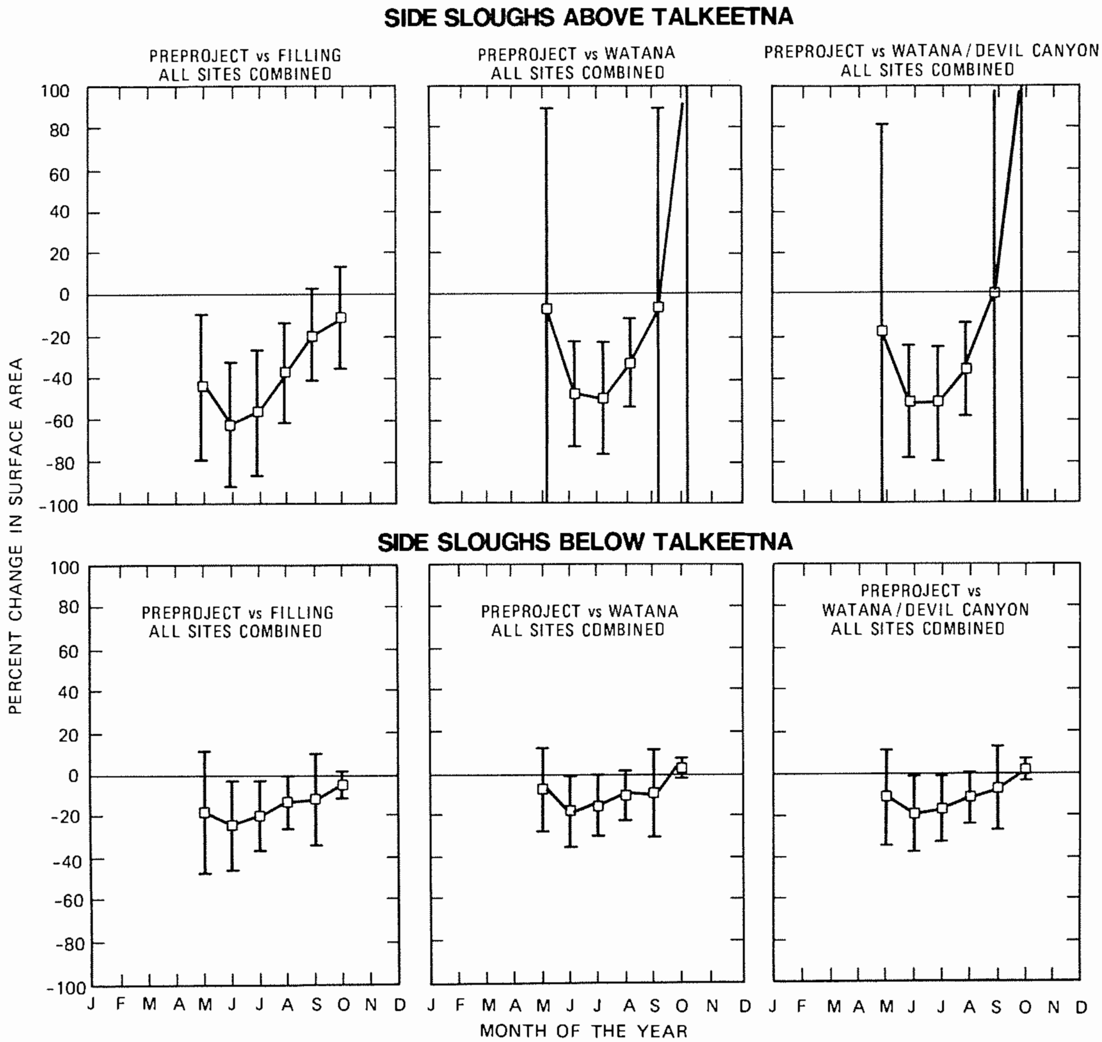


Figure H.3-2. Response of Zone H-II wetted surface area to mainstem flows.
Source: ADFG 1983.

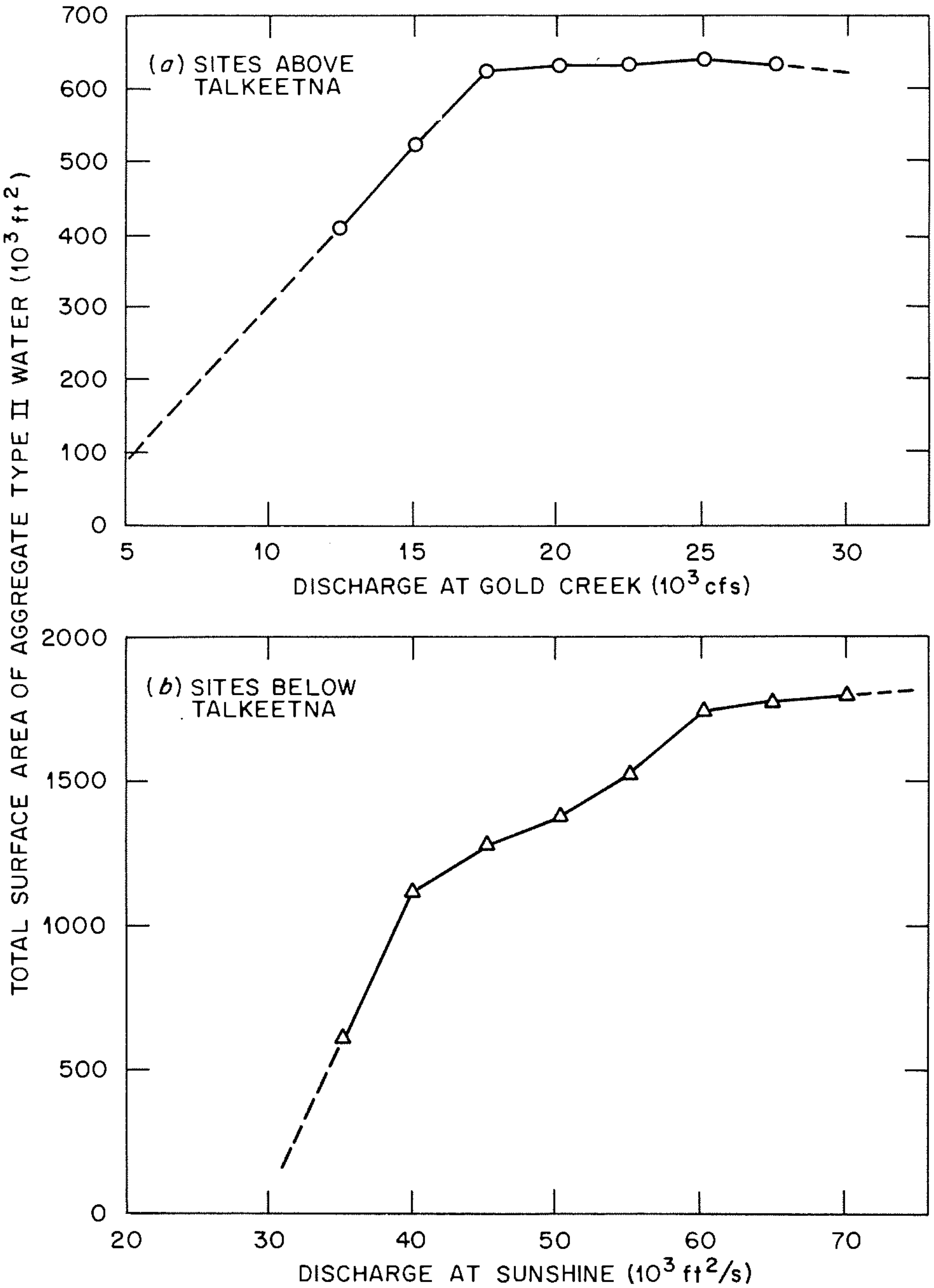


Figure H.3-3. Changes in total wetted surface area in sloughs during filling, Watana, and Watana-Devil Canyon operational flows.

H.4 TEMPERATURE

Thermal Model

Prediction of temperatures downstream of the dams is made using an analytic model which relates the time-rate-of-change of water temperature to the sum of the heat flux components across the water surface. The components considered in this model include (1) incoming solar irradiation, (2) infrared back radiation, (3) evaporation, and (4) convection. The formulation of these flux terms is given by Eraslan (1983) and described below:

(1) Solar Irradiation -

$$q_{SR} = Q_{SR} = \text{constant}$$

Q_{SR} is normally modified by a sine function to account for variations in insolation during the daylight hours and the absence of insolation at night. For the late fall/early summer simulation Q_{SR} was taken as zero due to the small number of daylight hours. For the summer simulation Q_{SR} can be assumed constant due to the large number of daylight hours. No value of Q_{SR} is available for the site vicinity so an estimated value of 341 W/m^2 - ^oK was used. It is not believed that the uncertainty in this number influences the temperature predictions. To verify this hypothesis, the value of Q_{SR} was doubled to yield a value which would be realistic for northern California, and the model subsequently reapplied. This large change in Q_{SR} only produced a 1°C increased in predicted water temperature over 50 river miles.

(2) Back Radiation -

$$q_{BR} = -\,0.8\,\sigma[T + 273]^4$$

Back radiation is represented by black body radiation where σ is the Stefan-Boltzmann constant and T is the water temperature. The 0.8 factor reflects the fact that water radiates less efficiently than a black body.

(3) Evaporation -

$$q_{ev} = -\,h_{ev}\,(1 - R_h)\,(1 + V_w/V_{ref})\,(T - T_a)\,H\,(T - T_a)$$

$$H\,(T - T_a) = \begin{cases} 1 \text{ for } T > T_a \\ 0 \text{ for } T \leq T_a \end{cases}$$

In this formulation h_{ev} is a surface film coefficient, 11.4 W/m^2 - ^oK, R_h is the relative humidity, V_w is the wind speed, V_{ref} is a reference wind speed and T_a is the air temperature. For the simulations performed R_h and V_w were assumed to be zero and a value of T_a = 12.2°C was taken for the late fall/early winter case, and a value of T_a = 15.5°C was used in the summer case.

(4) Convection -

$$q_{CN} = -h_{CN}\,(1 + V_w/V_{ref})\,(T - T_a)$$

The parameters V_w, V_{ref}, and T_a are described and defined under evaporation. The coefficient $h_{CN} = h_{ev}$. The resulting model equation is given by

$$\frac{\partial T}{\partial t} = (q_{SR} + q_{BR} + q_{ev} + q_{CN})/\rho CD$$

where t is time, ρ is the density of water, 1000 kg/m^3, and C is the specific heat of water, 4186 J/kg-^oK, and D is the local water depth. The above equation can be integrated to yield

$$T = T_{out}\,e^{-At/D} + B(1 - e^{-At/D})$$

where T_{out} is the outlet temperature at the dam and

$$A = [h_{CN}\,(1 + V_w/V_{ref}) + 6.5 \times 10^7\,\rho + h_{ev}\,(1 - R_h)\,(1 + V_w/V_{ref})]/\rho c$$

and

$$B = [Q_{SR} + h_{CN}\,(1 + V_w/V_{ref})\,T_a + h_{ev}\,(1 - R_h)\,(1 + V_w/V_{ref}) - 4.4 \times 10^9\,\sigma]/\rho C.$$

Time, t, can be replaced by downstream distance, x, through the relationship t = x/u, where u the local flow velocity which, in turn, is related to the discharge Q, the river width w, and D by u = Q/WD. Thus the temperature at cross-section i+1 can be determined based upon the temperature at cross-section i by

$$T_{i+1} = T_i e^{-At_{i+1}/D_{i+1}} + B\,(1 - e^{-At_{i+1}/D_{i+1}})$$

where $t_{i+1} = t_i + W_i D_i\,(x_{i+1} - x_i)/Q$, $t_o = x_o = 0$, and $T_o = T_{out}$. Value of W_i and D_i are based on channel cross-sections provided in R&M (1982).

H.5 SURFACE WATER QUALITY

H.5.1 Salinity

The Susitna River is a major contributor of freshwater to Cook Inlet, with the measured flow at Gold Creek accounting for approximately 19% of the measured flow at Susitna Station near Cook Inlet (Exhibit E, Chapter 2). As such, the Susitna River has a major influence on the salinity of the upper Cook Inlet. At node 27 near the mouth of the Susitna River (Figure H.5.1-1), salinity ranges annually from approximately 6 to 21 parts per thousand (ppt) (g/L) (Figure H.5.1-2). As one proceeds down Cook Inlet toward the Gulf of Alaska, the salinity increases, approaching that of seawater (Figure H.5.1-2), and the annual variation in salinity decreases, owing to the declining influence of freshwater inputs to Cook Inlet.

H.5.2 Suspended Solids

To assess the effect of dredging for Watana Dam on suspended sediments in the Susitna River, the incremental increase in suspended solids was calculated by assuming that a certain fraction of dredged material would be lost to entrainment in river water. Results of geotechnical surveys conducted at the Watana Dam site indicate that alluvial deposits in the river channel upstream of where dredging will occur consist of clastics, ranging from boulders to coarse sand and silt (Harza/Ebasco Susitna Joint Venture 1983). The fraction of the gravel-sand materials in the silt-clay size category [<0.0025 in (<63 μm)] was approximately 5% of the total by weight. Assuming that (1) the specific gravity of the material to be dredged averages 0.064 lb/in^3 (1.77 g/cm^3), (2) 6.54 x 10^7 yd^3 (50 x 10^6 m^3) of material would be dredged from the river during the summers of the 6-year construction period (Exhibit E), (3) 5% of the total weight of material to be dredged is lost to entrainment in river water, and (4) this material remains in suspension, the calculated increase in suspended solids at Gold Creek during summer is approximately 140 ppm (mg/L). This calculated increase in suspended solids is most likely an overestimate because it is unlikely that all of the material in the silt-clay size range would be entrained, and not all of the material that is entrained would remain in suspension as it is transported downstream. In addition, the fraction of material that is actually entrained during dredging would most likely be less than 5% of the total weight. For these reasons, the predicted increase in suspended solids at Gold Creek due to dredging for the construction of Watana Dam is considered to be a conservative overestimate. Inasmuch as dredging within the Susitna River for the Susitna project would occur primarily during the construction of Watana Dam, the major changes in suspended solids resulting from excavation of borrow materials would occur during the construction of Watana Dam.

The clearing of vegetation and disposal of spoil materials within the area to be impounded by Watana Dam would result in disturbances of soil cover and the subsequent erosion of some spoil materials into the Susitna River. The magnitude of increases in suspended solids in the river resulting from these disturbances of soil cover cannot be predicted because of the lack of information on soil erosion rates in disturbed areas in the upper Susitna Basin that are underlain by discontinuous permafrost. It is anticipated that impacts on suspended solids resulting from vegetation clearing would be minimal; however, because erosion from such disturbed areas would occur primarily during spring breakup and summer, the period when suspended solids in the Susitna River are at their annual maximum concentration. In addition, the applicant has proposed using mitigative measures to minimize the impact of vegetation clearing on water quality (Sec. 2.1.8).

As the reservoir begins to fill, Watana would act either as a source or a sink for suspended solids in the Susitna River, depending on the time of year. The ability of a reservoir to retain suspended sediments, referred to as the trapping efficiency, is expressed as the percentage of inflowing sediment that is retained in the reservoir basin. Trapping efficiency varies as a function of (1) inflowing sediment particle size, (2) the hydraulic flushing rate, or detention storage time of water in the reservoir, (3) location and operation of the reservoir outlet, (4) reservoir shape, (5) induced mixing of reservoir water, and (6) chemical properties of the water. Detention storage time is probably the single most important factor determining the trapping efficiency of a reservoir.

The trapping efficiency of Watana Reservoir during the first year of filling was predicted using the Brune (1953) curve, an empirical relationship between the trapping efficiency of reservoirs and their detention storage time. The predicted trapping efficiency ranges from approximately 40% at the end of June to approximately 90% at the end of October. These predicted reductions are, however, considered overestimates by FERC staff because the Brune curve is not based on data from reservoirs in which glacial flour, which has a low settling velocity, dominates the load of inflowing suspended solids. In addition, water released from Watana during the first year of filling would pass through the low-level outlet. This would most likely result in a lower trapping efficiency than that predicted by the Brune curve because sluicing operations such as this tend to reduce the trapping efficiency relative to that in comparable reservoirs with surface discharges (Brune 1953).

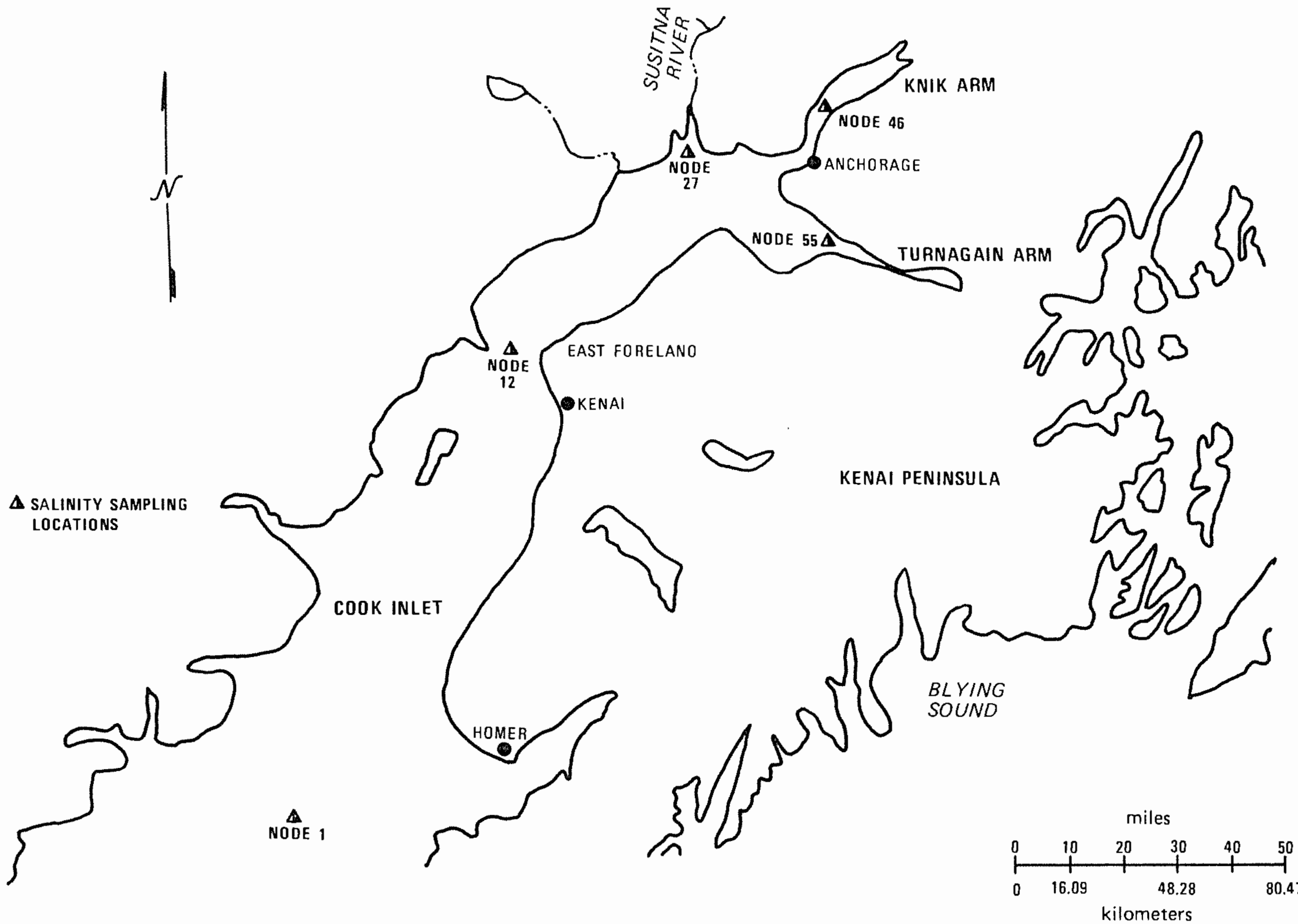


Figure H.5 -1. Locations of sampling stations for salinity in Cook Inlet (Exhibit E, Chapter 2).

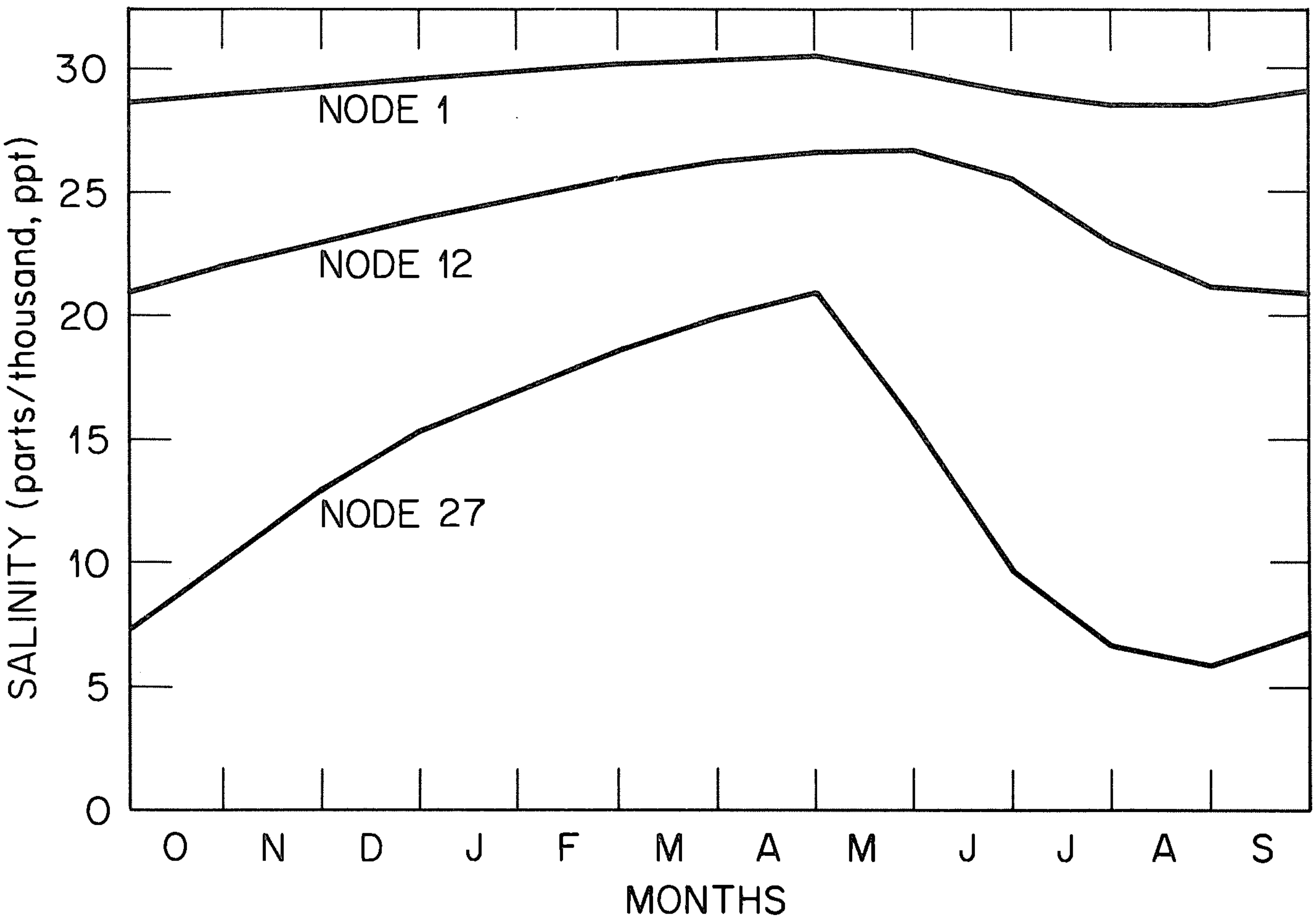


Figure H.5-2. Seasonal pattern in the salinity of water in Cook Inlet at nodes 1, 12, and 27. The location of the sampling stations (nodes) is illustrated in Figure H.5 -1 (Exhibit E, Table E.2.31).

During the first winter of filling, the concentration of suspended solids at the outlet of Watana would exceed that in the Susitna River under preproject conditions. This is a result of the outflow of suspended solids retained in the reservoir during the first filling period, June to October. Because of the sluicing operation during the first year of filling, the concentration of suspended solids at the outlet of Watana during winter is predicted to exceed 50 ppm (mg/L). During the second winter of the filling period, the trapping efficiency should approximate that of the full-pool (operational) efficiency when suspended solids in winter are less than 50 ppm.

During the filling of Watana, additional suspended solids would be introduced into the reservoir due to shore erosion and landslides resulting from slope instability. This instability is a result of the thawing of permafrost as it is submerged within the reservoir. The effect of shoreline slumping and shoreline erosion on suspended solids in reservoirs is influenced by the amount of fine-grained (silt, clay) particles in soils within the impoundment zone, wave action, and the age of the reservoir (Newbury et al. 1978). Fine-grained particles are more easily eroded and, once entrained, would remain in suspension longer because of their lower settling velocity. As these fine-grained materials are eroded from the shoreline and as bank slumping declines, stable shorelines would develop, resulting is less entrainment of soil particles within the impoundment zone. Information on the amount of fine-grained materials in soils in the impoundment zone of Watana was not available. If the silt and clay content is high, shoreline erosion and bank slumping could result in significant increases in suspended solids in, and downstream of, Watana Reservoir. It is anticipated that the contribution of bank erosion and bank slumping to suspended solids in Watana Reservoir and in the Susitna River downstream of the reservoir would be maximal during and immediately after filling and would decline in importance when stable shorelines develop as the reservoir ages. Predicting the magnitude of suspended solids that would be added to Watana as a result of these processes is not possible. It is anticipated, however, that the turbidity and suspended-solids concentration in Watana Reservoir and in the Susitna River downstream of Watana during filling would be controlled primarily by glacial scouring in the headwaters of the Susitna River rather than by bank slumping, slides, and erosion within the impoundment area.

The net increase in suspended solids in the Susitna River downstream of Watana during operation in winter has been estimated by the applicant (Exhibit E, Chapter 2), using the DEPOSITS model (Peratrovich et al. 1982). This model describes the sediment transport and deposition processes in a reservoir as a function of basin geometry, the inflow hydrograph for sediments and water, sediment characteristics, the outlet structure, and the hydraulic behavior of flow within the reservoir basin. Because the model does not take into account dispersive (longitudinal) mixing of inflowing sediments, and because the dead storage volume in the reservoir is difficult to predict, time variation in suspended solids discharged from the dam cannot be estimated with the model. Assuming that the reservoir would behave as a plug flow system by ignoring dispersive mixing implies that the suspended solids leaving the reservoir during winter entered the reservoir approximately 19 months earlier in summer when suspended solids are at their annual maximum. Thus, ignoring dispersive mixing tends to provide a conservative overestimate of the winter discharges of suspended solids because it assumes no dilution of high sediment loads with water containing low sediment loads that would have previously entered the reservoir in winter. Although reentrainment of deposited sediment would tend to increase the concentration in winter, this should be minimal, since the reservoir would be covered with ice and wind-induced mixing and erosion would therefore be minimal. Under these winter conditions, the trapping efficiency of the reservoir is predicted by the applicant to be in the range of 94 to 96%, depending on the assumed dead storage volume of the reservoir.

The trapping efficiency for Watana Reservoir in summer, as estimated using the DEPOSITS model (Peratrovich et al. 1982), ranges from 78 to 90%, depending on the assumed dead storage volume in the reservoir. Using the average concentration of suspended solids at Vee Canyon in summer as the input, the calculated concentration at the outlet of Watana during summer would range from 80 to 176 ppm (mg/L) (Table H.5.2-1). As previously discussed, the effect of ignoring dispersive mixing of suspended solids entering Watana Reservoir would be to conservatively overestimate the concentration at the outlet. However, this calculation also ignores internally generated sources of suspended solids from shore erosion, bank slumping, and resuspension. The magnitude of these sources cannot be predicted, but they could be significant, particularly during and immediately after filling when bank slumping and shore erosion are likely to be at a maximum.

The effect of reentrainment of sediments on the reservoir bottom due to wind mixing, shore erosion, and bank slumping would tend to increase the concentration at the outlet relative to that predicted by the model. Reentrainment is likely to be minimal, however, because most sedimentation would occur in the upstream end of the reservoir. With the long detention storage time of water in Watana, most of the resuspended sediments would settle out of the water column during quiescent periods before reaching the dam.

Table H.5 -1. Maximum, Minimum, and Average Preproject Concentration of Suspended Solids in the Susitna River at Gold Creek in Winter and Summer, and the Calculated Postproject Concentration with Watana in Operation.†

Season	Suspended Solids (ppm)†2			
	Preproject			Postproject
	Maximum†3	Minimum†3	Average†3	(Watana Alone)
Winter	76	1	12	32†4-50†5
Summer	2620	7	740	80†4-176†5

†1 Postproject values were calculated using trapping efficiencies derived from the DEPOSITS model (Peratrovich et al. 1982). Ranges are based on assumed range of dead storage volumes. The maximum value is for a dead storage volume equal to approximately 10% of the total (live plus dead) storage volume. The minimum value is for a dead storage volume equal to the average difference between total and live storage volumes (Peratrovich et al. 1982).

†2 1 ppm - 1 mg/L.

†3 U.S. Geological Survey Water Quality Annual Report for Alaska (USGS 1982). Averages for the period, 1949-1982.

†4 Assumes dead storage volume of 900,000 acre-ft (1.11 x 10^9 m^3) (i.e., storage time of water = (total volume - dead storage volume)/annnual inflow).

†5 Assumes entire volume below 2050 ft (625 m) in Watana is dead storage.

The reliability of a predicted range of suspended solids at the outlet of Watana Reservoir in summer can be evaluated by comparing it with measured concentrations of suspended solids in an existing Alaskan reservoir that should have a trapping efficiency comparable to that predicted for Watana. Lake Eklutna, a reservoir located in south-central Alaska, has a calculated hydraulic flushing rate of 646 days compared to 635 days for Watana. The load of suspended solids entering Lake Eklutna is also dominated by glacial flour and thus should be comparable to Watana in terms of the settling characteristics of suspended-solids. The estimated suspended solids concentration at the outlet of Lake Eklutna in summer, as estimated from measured turbidity, which is then converted to suspended-solids concentration using an empirically derived regression equation for turbidity and suspended solids in the Susitna River (Peratrovich et al. 1982), ranges from 110 to 220 ppm (mg/L). This compares to the predicted range of 80 to 176 ppm at the outlet of Watana in summer, using the minimum and maximum estimated trapping efficiency from the DEPOSITS model (Table H.5.2-1). The similarity in the measured and predicted concentrations of these two reservoirs, which are expected to exhibit similar trapping efficiencies, tends to support the predicted values for suspended solids at the outlet of Watana Reservoir.

H.5.3 Nitrogen Gas Saturation

In order to maintain the required downstream flow of 12,000 ft^3/s (340 m^3/s) in the Susitna River during August and September, flow augmentation of powerhouse (turbine) discharges at Watana would be required. This flow augmentation would involve releasing water through the outlet facility. Because of the height of the dam, releases from the outlet facility will have a large hydrostatic head. The energy in this large hydrostatic head would be dissipated by installing fixed cone valves at the downstream end of the outlet facility. The exact level of supersaturation below the dam cannot be predicted with available information but would be influenced by the level of saturation of water leaving the reservoir and the amount of air entrained in water released from the outlet facility. Levels of nitrogen saturation during spillway discharges that exceed 130% are not uncommon below some large dams on the Columbia and Snake rivers with hydrostatic heads less than that which would exist at Watana (Ebel 1971; Blahm et al. 1976). Thus, without the fixed cone valves, nitrogen saturation levels of 130% and greater would be expected during outlet flows at Watana. If the cone valves are not effective in reducing the hydraulic momentum, diluting the excess flows by mixing them with turbine flows should reduce the level of nitrogen supersaturation to less than the Alaska Department of Environmental Conservation (ADEC) statute of 110%, provided that (1) the level of saturation in augmentation flows does not exceed 140% of saturation, (2) the level of saturation in turbine flows is at or about saturation, and (3) rapid mixing of outlet and turbine flows occurs downstream of the dam. Augmentation flows at Watana would be required in almost every year during August and September, based on the 1995 energy-demand scenario (Exhibit E, Table E.2.50). Since augmentation flows would almost certainly be supersaturated witn nitrogen to a level greater than 110% if the cone valves were ineffective in preventing air entrainment, reducing the saturation level to less than the ADEC statute immediately below the dam would depend primarily on the rate of mixing. This is because diffusion across the air-water interface increases with turbulent mixing and mixing decreases with increasing flow in the Susitna River (Peratrovich et al. 1983). Thus, although the level of nitrogen supersaturation would decrease exponentially with distance from diffusion alone downstream of the dam in the absence of mixing with turbine flows, saturation levels in excess of 110% would exist for tens of miles downstream. The exact distance of the supersaturation would depend on the nitrogen saturation level immediately below the dam and the decay rate (i.e., rate of supersaturation decay) for gaseous nitrogen as a function of distance downstream of Watana. If mixing of augmentation and turbine flows is slow, a plume of water containing gaseous nitrogen in excess of the ADEC statute would exist downstream of Watana during augmentation flows in August and September of almost every year of operation with the 1995 energy-demand. With the energy-demand scenario for the year 2000, turbine discharge would increase, thus reducing the need for augmentation flows and, in turn, reducing nitrogen supersaturation.

During excess flows that are required to maintain the normal maximum operating level of Watana at 2185 ft (666 m), water would be released from the outlet facility. Because of the greater volume of excess flows (Exhibit E, Table E.2.50), dilution with turbine flows alone would be insufficient to reduce the level of nitrogen supersaturation to less than the ADEC statute immediately downstream of the dam if the fixed cone valves were ineffective. As a result, nitrogen supersaturation in excess of 110% would occur for several miles downstream of Watana during excess flows, resulting in significant degradation of water quality for aquatic life, particularly fish and benthic invertebrates. Based on the 1995 energy simulation (Exhibit E, Table E.2.50) and using a 30-year simulation period of flows in the Susitna River, excess flows that would most likely result in nitrogen supersaturation greater than the ADEC statute have a probability of occurrence of 23%, occurring seven times in a 30-year period. The proposed mitigative strategy of simulating peak flows in the Susitna River by releasing water through the outlet facility would also cause nitrogen supersaturation in excess of the ADEC statute if the cone valves did not prevent air entrainment, resulting in significant degradation of water quality for aquatic life.

H.5.4 Nutrients

Reported concentrations of inorganic nitrogen and phosphorus in the Susitna River at Vee Canyon and the computed molar nitrogen:phosphorus ratio in river water of 10:1 in summer and in excess of 20:1 in winter (R & M Consultants 1982) suggest that phosphorus is the element most likely to limit primary production in the river during winter, while both nitrogen and phosphorus may be limiting during summer (Smith 1982). Under preproject conditions, however, primary production in the Susitna River is most likely limited more by suspended sediments, which limit light penetration and scour substrates, than by nutrients. While the trapping of suspended solids by the reservoirs would improve conditions for primary production downriver in the summer, the concentration of suspended solids would still remain at levels that restrict light penetration, thereby limiting primary production.

The trophic status of clear-water reservoirs and lakes has been assessed, using the nutrient loading rates and the hydraulic flushing rates (Peterson et al. 1982). In the case of turbid lakes, such as the proposed Watana and Devil Canyon reservoirs, the response of phytoplankton to nutrient inputs is less certain because of both light limitation, due to the high turbidity, and the effects (adsorption-desorption) of nonalgal solids on available nutrient supplies in water (Smith 1982). An assessment based on the spring concentrations of phosphorus in Watana, as computed from the phosphorus concentrations at Vee Canyon in June, suggests that Watana would be oligotrophic (Peterson et al. 1982). Assuming that suspended sediments would not be a source of nutrients for phytoplankton, this predicted trophic response of Watana to the estimated phosphorus loading is a conservative overestimate because it neglects the effect, on primary production rates of phytoplankton, of low light penetration due to the high concentration of suspended solids in reservoir water.

REFERENCES FOR APPENDIX H

Alaska Department of Fish and Game (ADFG). 1982. Susitna Hydroelectric Project, Final Draft Report, Aquatic Studies Program. Acres American, Inc., Buffalo, NY.

Alaska Department of Fish and Game (ADFG). 1983. Susitna Hydro Aquatic Studies Phase II Report, Synopsis of the 1982 Aquatic Studies and Analysis of Fish and Habitat Relationships. Alaska Department of Fish and Game, Susitna Hydro Aquatic Studies, Anchorage, AK.

Blahm, T.H., B. McConnell, and G.R. Snyder. 1976. Gas Supersaturation Research, National Marine Fisheries Service, Prescott Facility - 1971 to 1974, pp. 11-19. In D. H. Fickeisen and M. J. Schneider (eds.), Gas Bubble Disease. CONF-741033. Tech. Info. Center, U.S. Energy Research and Development Administration, Oak Ridge, TN.

Brune, G.M. 1953. Trap efficiency of reservoirs. Trans. Am. Geophys. Union 34:407-418.

Ebel, W.J. 1971. Dissolved Nitrogen Concentrations in the Columbia and Snake Rivers in 1970 and Their Effect on Chinook Salmon and Steelhead Trout. NOAA Tech. Report NMFS SSRF-646, U.S. Dept. of Commerce, Superintendent of Documents, Washington, DC.

Eraslan, A.H. 1983. ESTONE: A Computer Code for Simulating Fast Transient, One-Dimensional Hydrodynamic, Thermal, and Salinity Conditions in Controlled Rivers and Tidal Estuaries for the Assessment of the Aggregated Impact of Multiple Power Plant, Operation, NUREG/CR-2621.

Gatto, L.W., C.J. Merry, H.L. McKim, and D.E. Lawson. 1980. Environmental Analysis of the Upper Susitna River Basin Using Landsat Imagery. CRREL Report No. 80-4, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Harza/Ebasco Susitna Joint Venture. 1983. Susitna Hydroelectric Project, Watana Development, Winter 1983 Geotechnical Exporation Project, Vols. I and II. Alaska Power Authority, Anchorage, AK.

Newbury, R.W., K.G. Beaty, and G.K. McCullough. 1978. Initial Shoreline Erosion in a Permafrost Affected Reservoir, Southern Indian Lake, Canada, pp. 834-839. In Proceedings, Third International Conference on Permafrost, July 10-13, 1978, Edmonton, Alberta, Vol. I. National Research Council Canada, Ottawa, Canada

Peratrovich, Nottingham, and Drage, Inc., and I.P.G. Hutchison. 1982. Susitna River Sedimentation and Water Clarity Study. Acres American, Inc., Anchorage, AK.

Peratrovich, Nottingham, and Drage, Inc. 1983. Susitna Hydroelectric Project Nitrogen Supersaturation Study. Acres American, Inc., Anchorage, AK.

Peterson, L.A., and Associates and R & M Consultants, Inc. 1982. Water Quality Effects Resulting from Impoundment of the Susitna River. Acres American, Inc., Buffalo, NY.

R & M Consultants, Inc., and L. A. Peterson & Associates. 1982. Task 3: Hydrology, Water Quality Interpretation - 1981. R & M Consultants, Inc., Anchorage, AK.

R & M Consultants, Inc. (R & M) and W. D. Harrison. 1982. Susitna Hydroelectric Project, 1982 Susitna Basin Glacier Studies. Acres American, Inc., Buffalo, NY.

R & M Consultants, Inc. (R & M) and W. D. Harrison. 1981. Susitna Hydroelectric Project, Glacier Studies. Acres American, Inc., Buffalo, NY.

R & M Consultants, Inc. 1982. Susitna Hydroelectric Project - River Morphology.

R & M Consultants, Inc. (R & M). 1982a. Susitna Hydroelectric Project, Hydraulic and Ice Studies. Acres American, Inc., Buffalo, NY.

R & M Consultants, Inc. (R & M). 1982b. Susitna Hydroelectric Project, River Morphology. Acres American, Inc., Buffalo, NY.

Smith, V.H. 1982. The nitrogen and phosphorus dependence of algal biomass in lakes: An empirical and theoretical analysis. Limnol. Oceanogr. 27:1101-1111.

Sugden, D.E. and B.W. John. 1976. Glaciers and Landscape, a Geomorphicological Approach. Edward Arnold (Publishers) Ltd., London, England.

Texas Water Development Board. 1970. A Completion Report on Stochastic Optimization and Simulation Techniques for Management of Regional Water Resource Systems, Volume IIB: FILLIN-1 Program Description.

Trihey, E.W. 1982. Preliminary Assessment of Spawning Salmon Access to Side Slough Habitat Above Talkeetna. Acres American, Inc., Buffalo, NY.

U.S. Geological Survey (USGS). 1982. Water Quality Annual Report for Alaska. USGS Water Data Report. National Technical Information Service, Springfield, VA.

DRAFT ENVIRONMENTAL IMPACT STATEMENT

SUSITNA HYDROELECTRIC PROJECT, FERC NO. 7114

APPENDIX I

FISHERIES AND AQUATIC RESOURCES

Prepared by

Charles C. Coutant and Webster Van Winkle, Jr.

Oak Ridge National Laboratory

I.1 AFFECTED ENVIRONMENT

The Susitna River fisheries constitute one of the major exploited resources of the project environs. The text section (3.1.4) briefly introduces the species in the region; their importance to commercial, sport, and subsistence harvests in upper Cook Inlet and the Susitna drainage; and the habitats they use in four major zones: (1) the potentially inundated zone above Devil Canyon, (2) upland areas to be affected by access facilities or transmission lines, (3) the Susitna River between Devil Canyon and the confluence of the Susitna, Talkeetna, and Chulitna rivers, and (4) the Susitna downstream of Talkeetna. In section (4.1.4), the text briefly summarizes the anticipated impacts of the project on the existing fishery and aquatic resources. This appendix section (I.1) provides additional background and detail so that existing knowledge about the affected species and the environs they inhabit can be placed in the context of project alterations of the environment. Section I.2 provides details of the analytical process used for estimating impacts.

I.1.1 Plant and Invertebrate Communities

The Susitna River and its tributaries contain sparce algal communities. The phytoplankton (drifting) and periphyton (attached) communities are limited by silt scour (mainstem), cold temperatures, low levels of nutrients, and rapid flow rates. There is better development in backwaters of sloughs, but quantitative study has been lacking. Emergent vegetation and the surrounding terrestrial environment (Sec. 3.1.5.1) provide organic matter input to a primarily heterotrophic aquatic system.

Zooplankton consisting of copepods and cladocerans is found in sloughs where abundance is sufficiently large to provide an important food source for plankton-feeding sockeye salmon juveniles in August and September (ADF&G 1983c). Few zooplankters are found in rapidly flowing tributaries or the mainstem.

Streambottom invertebrates are also sparce in the Susitna mainstem, although populations of mayflies (Ephenenptera), true flies (Diptera), stone flies (Plecoptera), caddis flies (Trichoptera), aquatic mites (Hydracarina), aquatic worms (Oligochaetes), and Ostracods have been collected in slough and tributary habitats (Table I.1-1). All of these invertebrates are important food sources for young salmon and have been quantified in fish stomach analyses (Figure I.1-1). Population composition differed among sloughs and between the two tributaries examined (Fourth of July Creek and Indian River).

I.1.2 Biology and Habitat Suitability Requirements of Fish Species

This section provides information on the biology and habitat preferences of major species in the project area (Table I.1-2). Emphasis is placed on life-cycle information relevant to defining impacts in the Susitna drainage (Sec. I.2). Habitat suitability criteria for each species is stressed here, whereas habitat availability and fish abundance in geographic locations of the Susitna drainage are discussed in Sec. I.1.3. Unless specifically referenced, information is from Exhibit E of the application, McClane (1965), or Alaska Department of Fish and Game data reports (ADF&G 1981a-f, 1983a-e).

I.1.2.1 Pacific Salmon (*Oncorhynchus* species)

There are six Pacific salmon species, five of which occur in North America and the Susitna drainage. They are the chinook, locally called king (*Oncorhynchus tshawytscha*), coho or silver (*O. Kisutch*), sockeye or red (*O. nerka*), pink (*O. gorbuscha*), and chum or dog (*O. keta*). The genus as a whole has a range from Formosa to San Diego, California. Stocks on the Pacific coast of North America have diminished, especially in the southern part of their range, due to overfishing, habitat destruction, creation of barriers to migration such as irrigation diversions and hydroelectric dams, and pollution. Although adult fish passage facilities are provided at many dams, many upriver stocks have been lost. Recent introductions greatly extended the species' range, especially to the Laurentian Great Lakes.

Table I.1-1. Invertebrate Taxa Present in Drift Net (D) and Kick Screen (K) Collections from all Sites Sampled in 1982 (X Indicates Presence in Both Collecting Types, D or K Indicates Only One Type, 0 Indicates Absence)

Site	Slough 8A	Slough 11	Slough 20	Slough 21	Fourth of July Creek	Indian River
Diptera						
Chironomidae	X	X	X	X	X	X
Empididae	X	X	D	X	K	X
Psychodidae	X	0	X	D	0	0
Simuliidae	X	D	X	K	X	X
Tipulidae	K	D	K	K	X	X
Ephemeroptera						
Baetidae	D	0	X	K	X	X
Ephemerellidae	K	0	K	K	X	X
Heptageniidae	D	0	X	X	X	X
Siphlonuridae	0	0	K	0	X	D
Plecoptera						
Capniidae	X	D	X	K	X	X
Chloroperlidae	X	D	K	X	K	X
Nemouridae	0	D	X	K	X	D
Perlodidae	K	D	X	K	K	X
Taeneopterygidae	X	0	D	D	X	D
Trichoptera						
Brachycentridae	0	0	0	0	X	0
Glossosomatidae	0	0	0	0	X	D
Hydropsychidae	0	0	0	0	K	0
Limnephilidae	X	0	Z	X	X	X
Rhyachophilidae	0	0	X	0	X	0
Collembola	X	D	X	X	D	D
Copepoda	X	K	D	0	0	0
Hydracarina	X	D	X	X	X	X
Oligochaetae	X	X	X	X	X	X
Ostracoda	K	0	0	0	D	D

Source: ADF&G (1983c).

Pink and sockeye salmon are the most important in commercial catches, both locally and throughout the range of the genus. Sockeye is the most valued. Chinook and coho are most important for sport fisheries although other species are taken. Chum is generally considered the least valued of the North American species, although it is abundant and catches are high. All species are used locally for subsistence.

All the species spawn in freshwater, add most body growth in the marine environments of the northern Pacific and the Gulf of Alaska, and die after spawning in their natal streams. Upstream migrations of adults can occur throughout the year, but occur principally in June-October (Figure I.1-2). Eggs are laid in river or stream gravels in nests (redds) where fine particles are fanned away by the adults, mostly the female. Incubation, hatching, and development through resorption of the large yolk sac occur in the interstices of the gravel, with freshwater and oxygen being supplied by intragravel water flow derived either from the stream or upwelling groundwater. The salmon have stringent requirements for gravel size and water permeability, which limit spawning habitat suitability. Incubation and early development (alevins) in redds are strongly temperature dependent, with hatching and emergence times characterized by "temperature units" [i.e., the cumulative number of degrees (F) times each 24-h day of exposure (Celsius degree-days are 5/9 of the Fahrenheit temperature units). Temperature units data have been developed largely in hatchery conditions, and their general applicability to field situations and to different stocks of the same species is uncertain. Salmon fry emerge from the gravel in spring when the yolk is completely or nearly used up. They may go to the ocean immediately (chum and pink), or remain in freshwater for three to four months (fall chinook) or for a year or more (coho, chinook, sockeye). Freshwater rearing is generally in productive shallows and embayments, particularly where clear water is suitable for sight feeding. Young salmon often emigrate to the sea during spring or summer high flows. Survival of smolts in the sea is primarily a function of growth rate and of the time spent in the coastal regime where predators are plentiful. The main mechanism which removes smolts from coastal areas to offshore seems to be transport by surface currents enhanced by

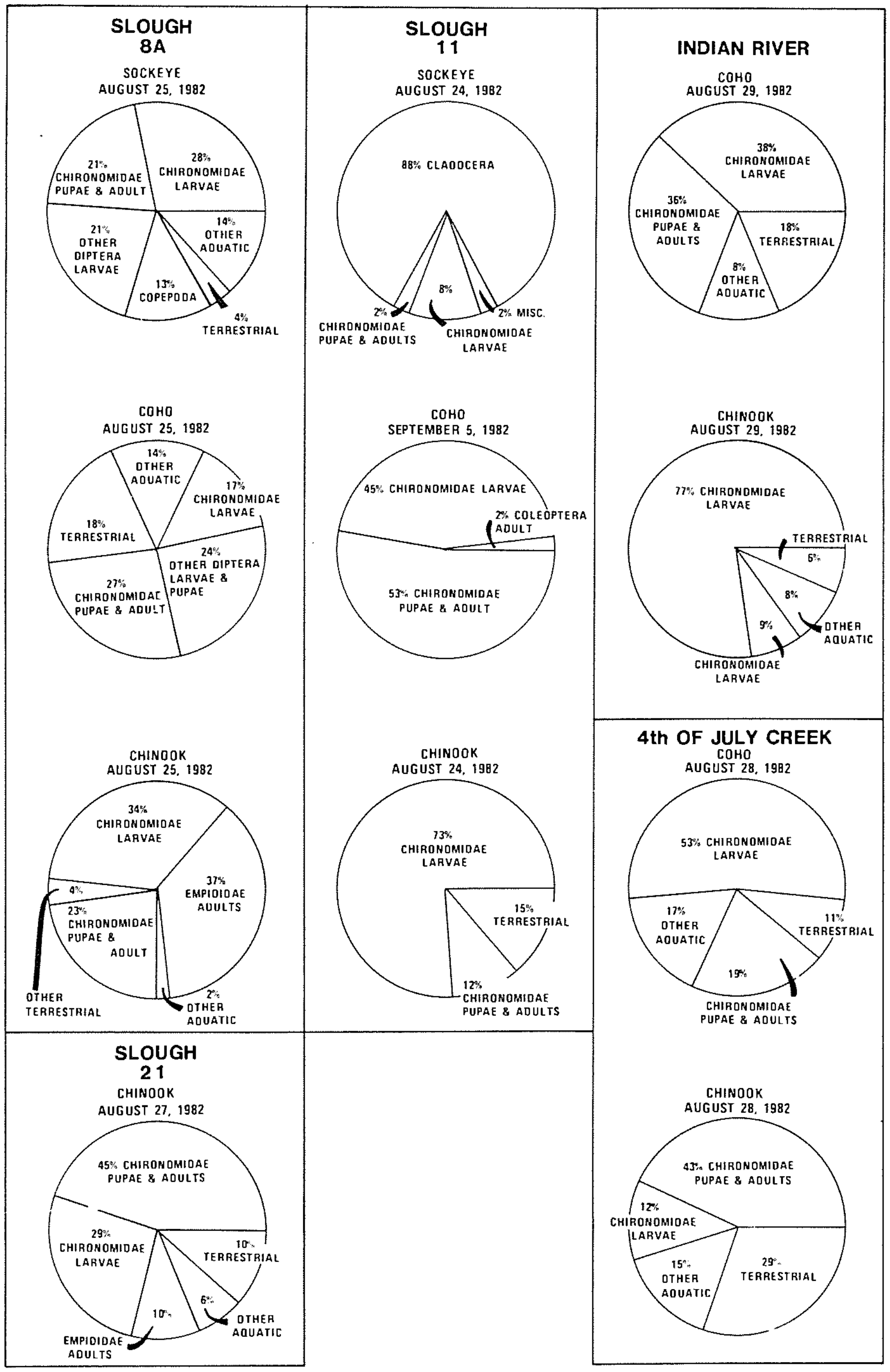


Figure I.1-1. Aquatic Invertebrates used for Food (Stomach Samples, Aug-Sept) by Juvenile Salmon from Representative Rearing Habitats in Susitna River Sloughs and Tributaries (ADF&G 1983). Pie Diagrams Show Percentage Composition.

Table I.1-2. Common and Scientific Names of Fish Species Recorded from the Susitna Basin

Scientific Name	Common Name
Petromyzontidae	
Lampetra japonica	Arctic lamprey
Salmonidae	
Coregonus laurettae	Bering cisco
Coregonus pidschian	Humpback whitefish
Oncorhynchus gorbuscha	Pink salmon
Oncorhynchus keta	Chum salmon
Oncorhynchus kisutch	Coho salmon
Oncorhynchus nerka	Sockeye salmon
Oncorhynchus tshawytscha	Chinook salmon
Prosopium cylindraceum	Round whitefish
Salmo gairdneri	Rainbow trout
Salvelinus malma	Dolly Varden
Salvelinus namaycush	Lake trout
Thymallus arcticus	Arctic grayling
Osmeridae	
Thaleichthys pacificus	Eulachon
Esocidae	
Esox lucius	Northern pike
Catostomidae	
Catostomus catostomus	Longnose sucker
Gadidae	
Lota lota	Burbot
Gasterosteidae	
Gasterosteus aculeatus	Threespine stickleback
Cottidae	
Cottus cognatus	Slimy sculpin

freshwater runoff. Marine mammals are important predators, especially fur seal, sea lion, beluga and other toothed whales, and the Pacific whiteside dolphin. The length of ocean life is varied, from two years for pink and coho to seven to eight with some sockeye. Most species exhibit a span of years for returning adults for a certain spawn year, whereas pink salmon are wholly predictable, yielding distinct odd-year and even-year stocks. Stocks in the ocean mix freely and range widely. The food base of the ocean does not appear to be the limiting factor for sizes of Pacific salmon stocks. A precise homing behavior to natal streams for spawning has fascinated observers and reflects numerous discrete genetic stocks, which must be carefully considered when environmental changes or mitigations are contemplated.

Chinook Salmon (Oncorhynchus tshawytscha)

This is the largest of the Pacific salmon (thus the name "king"), which may reach over 125 lb (57 kg), but it rarely exceeds 60 lb (27 kg) and the average mature fish is near 18 lb (8 kg). There are several races throughout its range that are distinguishable by timing of adult migrations, which varies from January to late fall, area of spawning, and length of freshwater residence of juveniles. In the Susitna, chinook are of the spring-summer race which enters the river in late May to mid-July, spawns in July and August in tributaries, and generally goes to sea after spending one full year in freshwater (Figure I.1-3).

The species matures at ages from one (males only) to eight years. Precocious males (jacks) may be fertile even before entering the sea. The median age of adults in the Susitna varies according to location, possibly due to discrete genetic stocks in various tributaries. For example, in 1982, chinook at Susitna Station were mostly three- or four-year-olds, with some five- or six-year-olds; at Sunshine Station six-year-olds predominated but ages were widely spread from three to seven years; at Talkeetna Station four-year-olds predominated (ADF&G 1983b). Based on 1982 data, approximately 11,000 chinook enter the Susitna above Talkeetna, which is about 20% of those which pass the Sunshine Station (Figure I.1-4). Adults migrate

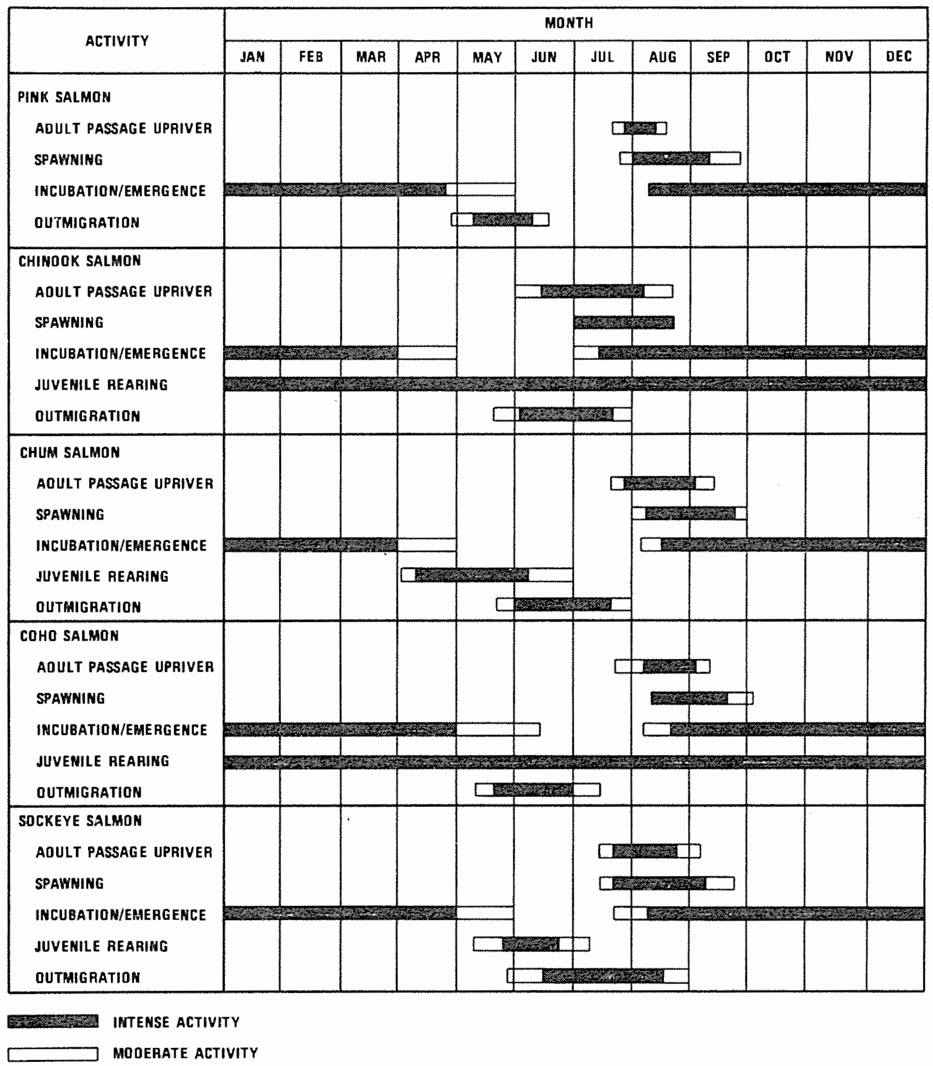


Figure I.1-2. General Timing of Life-Cycle Activities of Pacific Salmon in the Susitna River.

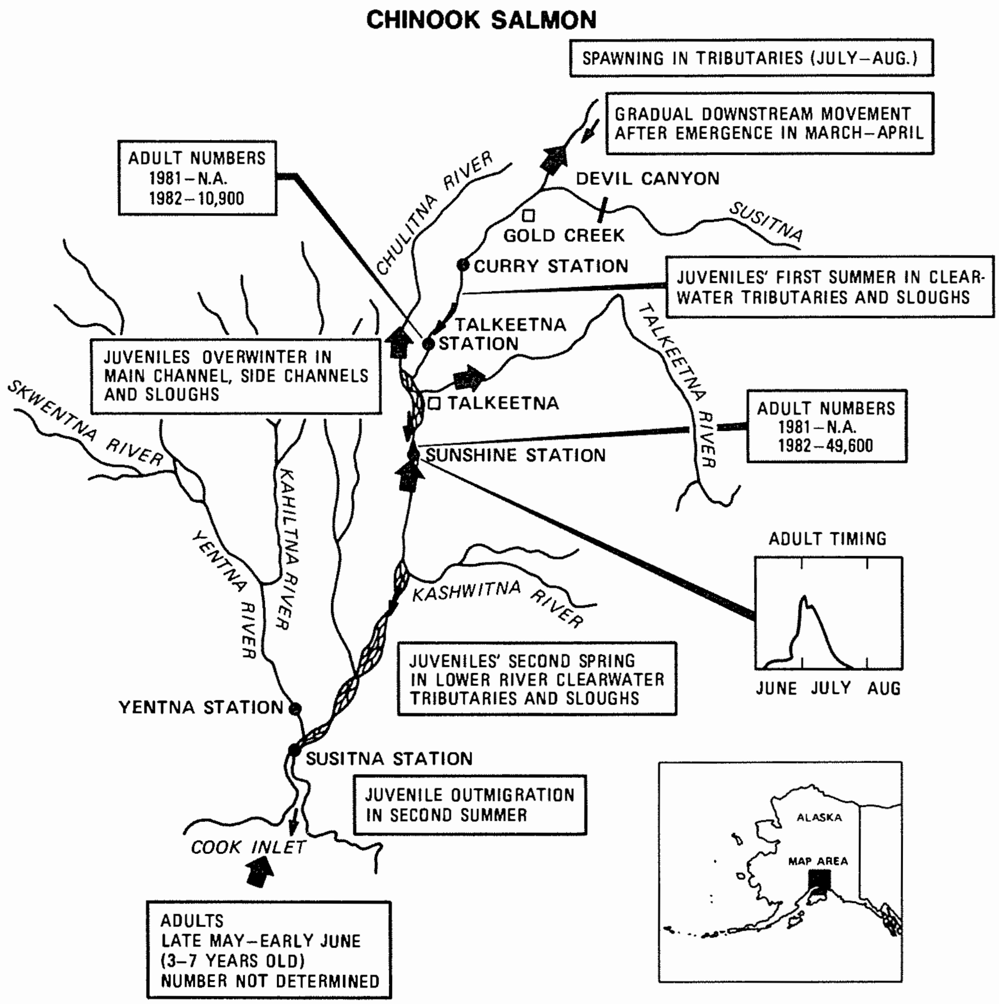


Figure I.1-3. Chinook Salmon (Oncorhynchus tshawytscha) - Generalized Life Cycle and Habitat Suitability in the Susitna River Drainage.

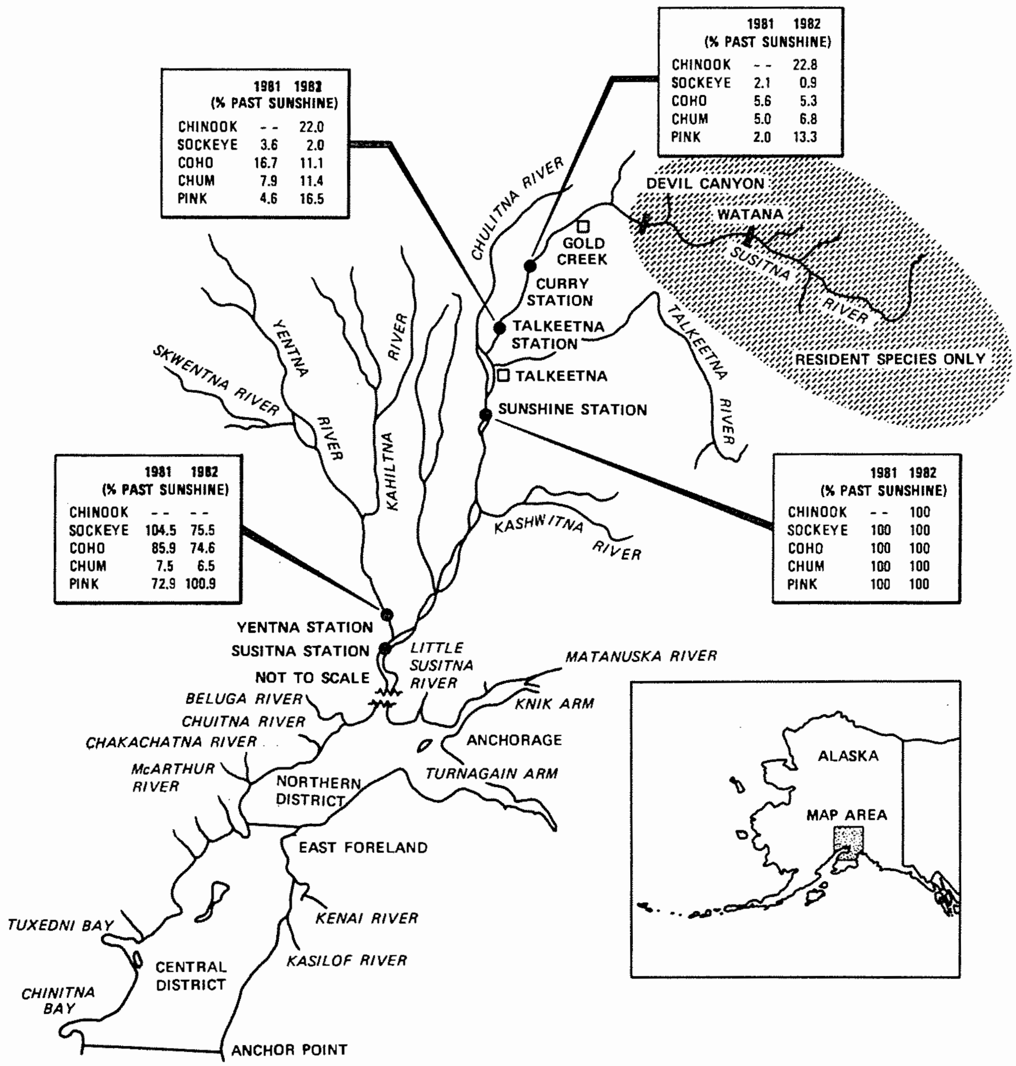


Figure I.1-4. Upper Cook Inlet and the Susitna Drainage Showing Percentage of Salmon Migrating Past Sunshine Station and the Relative Sizes of Runs Past the Yentna and Sunshine Stations.

close to shorelines in depths of less than 4 ft (1.2 m). Travel to natal streams is interspersed with milling near tributary mouths (ADF&G 1981b, 1983b). Each female in Alaska will deposit 4,000 to 13,000 eggs in tributary stream gravels (Morrow 1980). Habitat features preferred for spawning have not been identified for the Susitna stocks, but in the Skagit River, Washington, the 80% intervals (range encompassing 80% of the data, centered on the median) were 1.7 to 4.2 ft (0.5-1.2 m) for depth and 1.8-3.7 ft/s (0.5-1.1 m/s) for velocity (Graybill et al 1979).

Incubation of eggs in the redds occurs through the winter, with hatch occurring in early spring. Alevins generally remain in the redd until the yolk sac has been absorbed and then emerge from the gravel and become free-swimming, feeding fry (Morrow 1980). Standard references for daily temperature units (TU) required for hatching and emergence suggest 750 and 1600, respectively (Piper et al. 1982; Table I.1-3). Detailed studies showed considerable variability, in TUs for chinook salmon, however, even among eggs from the same female, with 900 to 1000 TUs to hatch and near 1900 TUs for emergence for experimental chinook redds on the Skagit River, Washington (Graybill et al. 1979). Olson et al. (1970) found the temperature-unit approach satisfactory for estimating developmental stages of Columbia River fall chinook spawned over a wide range of dates. They estimated about 900 to 1000 TUs for hatching and 1600 for beginning of feeding (emergence). Warmer temperatures during incubation appear to yield smaller fry at time of emergence, although the difference is not great (Olson et al. 1970; Seymour 1956). When Graybill et al. (1979) examined river temperatures that were shifted to either warmer or cooler regimes than normally experienced, a form of TU compensation was observed that somewhat dampered the predicted changes in timing of emergence. Data for temperature dependence of incubation of Susitna River stocks are not available.

Table I.1-3. Daily Temperature Unit Required for Egg Development of Pacific Salmon

Species	Daily Temperature Units: To Eye F	To Eye C	To Hatch F	To Hatch C	To Emerge F	To Emerge C
Chinook salmon	450	250	750	417	1,600	888
Coho salmon	450	250	750	417	1,750	972
Chum salmon	750	417	1,100	611	1,450	806
Pink salmon	750	417	900	333	1,450	806
Sockeye salmon	900	333	1,200	667	1,800	1000

Source: After Piper et al. (1982).

Chinook fry school in the first year after emergence, but become territorial as they grow. They feed on terrestrial and aquatic insects and small crustaceans (ADF&G 1983c, Becker 1973, Dauble et al. 1980). Analysis of scales from adult chinook in the Susitna in 1981 and 1982 showed that most juveniles leave freshwater in their second year. There is a gradual downstream movement after emergence, with major nursery areas occurring in clear-water tributary mouths and sloughs in summer. Mainstem and slough sites receive progressively greater use in winter as tributary flows diminish and ice develops (ADF&G 1981d). Chinook juveniles change from territorial feeding in streams to hiding without feeding in cover at low temperatures near 41°F (5°C) (Chapman and Bjornn 1969). Juvenile growth is temperature dependent with optimum near 15°C.

Sockeye Salmon (*Oncorhynchus nerka*)

This species is the most valuable of the Pacific salmon, for it is highly prized for its high oil content, excellent flavor, color of flesh, and uniform size. It is found from Japan to California, but enters rivers south of the Columbia River only as strays. It enters rivers, usually those fed by lakes, in March to July. Spawning is most common in lakes or immediately adjacent in inlet or outlet streams, although some sockeye spawn in rivers without lakes. Young rear, usually in lakes, for one to three years and migrate to the sea as 0.14 to 0.21 oz (4-6 g) smolts in March to May. Some races are nonmigratory and are known as kokanee, which are popular among sportsmen in the northwest United States. Some sockeye of sea-run stock will also live their whole lives in freshwater. Kokanee have been popular in reservoirs behind high dams where they provide a high-quality, naturally sustained, salmonid fishery that replaces sea-run stocks which are cut off.

There are two distinct sockeye spawning runs into the Susitna River, one occurring in early June and the other in late July and early August (Figure I.1-5). The first run is primarily destined for the Fish Creek subdrainage of Chunila (Clear) Creek, a Talkeetna River tributary that has two lakes, Papa Bear and Sockeye. They spawn there at the end of July and beginning of August. The second run is distributed through the Susitna river system. In both runs, adults are primarily five years old and migrated to saltwater in their second year. The second-run fish, however, has a wider range of ages (3-7), with nearly a quarter of the run being four-year-olds.

Second-run sockeye spawn in sloughs of the main river and some tributary mouths, occupying about one-third of the sloughs along the Talkeetna-Devil Canyon reach. These fish are not distinct stocks from those of the second run which enter the Talkeetna and Chulitna rivers, based on studies by Bernard et al. (1983). There is evidence that sockeye spawned in lakes associated with Chase Creek (RM 106.9) (Barrett 1974) and Indian River (RM 138.6), although none was observed in the SuHydro studies. Peak spawning activity occurs during the last week in August and the first three weeks of September. Habitat features preferred by the species for spawning were summarized in suitability curves by Bovee (1978) (Figure I.1-5). Kokanee requirements differ somewhat from those of anadromous stocks, particularly in requiring slower water velocities. Adult sockeye are believed to spend about 12 d at the spawning site before dying, based on estimates derived for the Chakachamna system on the west side of Cook Inlet (Bechtel Civil and Minerals, Inc. 1983). This information is used to convert aerial fish counts to estimates of spawning. Mature sockeye females typically deposit 2500 to 4300 eggs in a gravel until emerging from April to June. Approximately 1200 TUs (F) are generally required for hatching and 1800 for emergence (Piper et al 1982; Table I.1-3). The relationship between development rate and temperature for the species, including Susitna stocks, was summarized by Wangaard and Burger (1983) as:

$$\ln (R_h) = \ln (3.71) + 0.15 \text{ (temperature)}$$

$$\ln (R_a) = \ln (2.61) + 0.14 \text{ (temperature)}$$

where R_h = development rate per day (x 1000) to hatching
R_a = development rate per day (x 1000) to complete yolk absorption.

The major emergence of sockeye fry occurs in March in the Susitna, with complete yolk sac absorption in April, at lengths of approximately 33 mm. Elsewhere, where sockeye spawn in or near lakes, fry move to the lake for one to three years of rearing before migrating to the ocean. The Susitna above Talkeetna has few lakes, however, and the fate of fry produced in that reach is uncertain. There appears to be a general downstream redistribution of fry during June-July of their first summer, based on scoop-trap samples. Scales of returning adults show few fish entering the ocean in their first year (although samples from Curry Station are highest at 1%), suggesting either poor survival of slough-spawned fry or overwintering and rearing in the lower river. Collection of large numbers of 0+ juveniles and several 1+ fish in sloughs not used for spawning suggests that sloughs may substitute for normal lake rearing. Growth shown by juveniles collected throughout the summer in traps suggests that important rearing habitat may be found in the river above Talkeetna. Sockeye fry in the Susitna feed on all stages of aquatic and terrestrial insects (especially chironomids) and cladoceran and copepod zooplankton. Zooplankton is the normal food of lake-reared fry.

Growth, energetics, and performance of juvenile sockeye salmon have been studied extensively, particularly of British Columbia stocks in relation to water temperature (Brett 1971, 1974). There is a notable thermal zone of optimium metabolism and performance near 59°F (15°C), which is higher than temperatures normally found in the Susitna River, but which may occur in lakes. Both the upper and lower lethal temperatures show a continuous increase over most of the acclimation (prior holding) temperature range. An upper plateau occurs near 77°F (25°C) for the high lethals, and there is a corresponding lower plateau for the low lethals, just below 32°F (0°C). Juvenile sockeye prefer 59°F (15°C) in thermal gradients, with selected temperature falling progressively on either side as acclimation temperatures depart further from the preferred. Standard or resting metabolism displays the almost universal characteristic of continuous increase with temperature, whereas the active rate reaches an optimum at 59°F (15°C) and decreases thereafter in a slow decline to the lethal temperature. These metabolic relationships are reflected in the curves for metabolic scope of activity and performance which both show prominent optima at 59°F (15°C). Young sockeye show a sharp growth optimum at 59°F (15°C); the growth curve flattens with increasing size and age. A progressive shift to a lower temperature occurs in the growth optimum as the quantity of food is restricted. Maximum food intake occurs near 63°F (17°C) and appetite is inhibited at 75°F (24°C). Gross food conversion efficiency (% flesh from food) was calculated from ration and growth rate and shows a broad zone of high levels from about 41°F (5°C) to 63°F (17°C) with an optimum near 53°F (11.5°C) and a rapid decline above 68°F (20°C). In food-limited conditions, juvenile sockeye salmon in lakes showed an extensive diurnal migration in summer between the surface at about 63°F (17°C) and the bottom at about 41°F (5°C), which is presumed to be an energy-conserving, growth-maximizing ecological strategy.

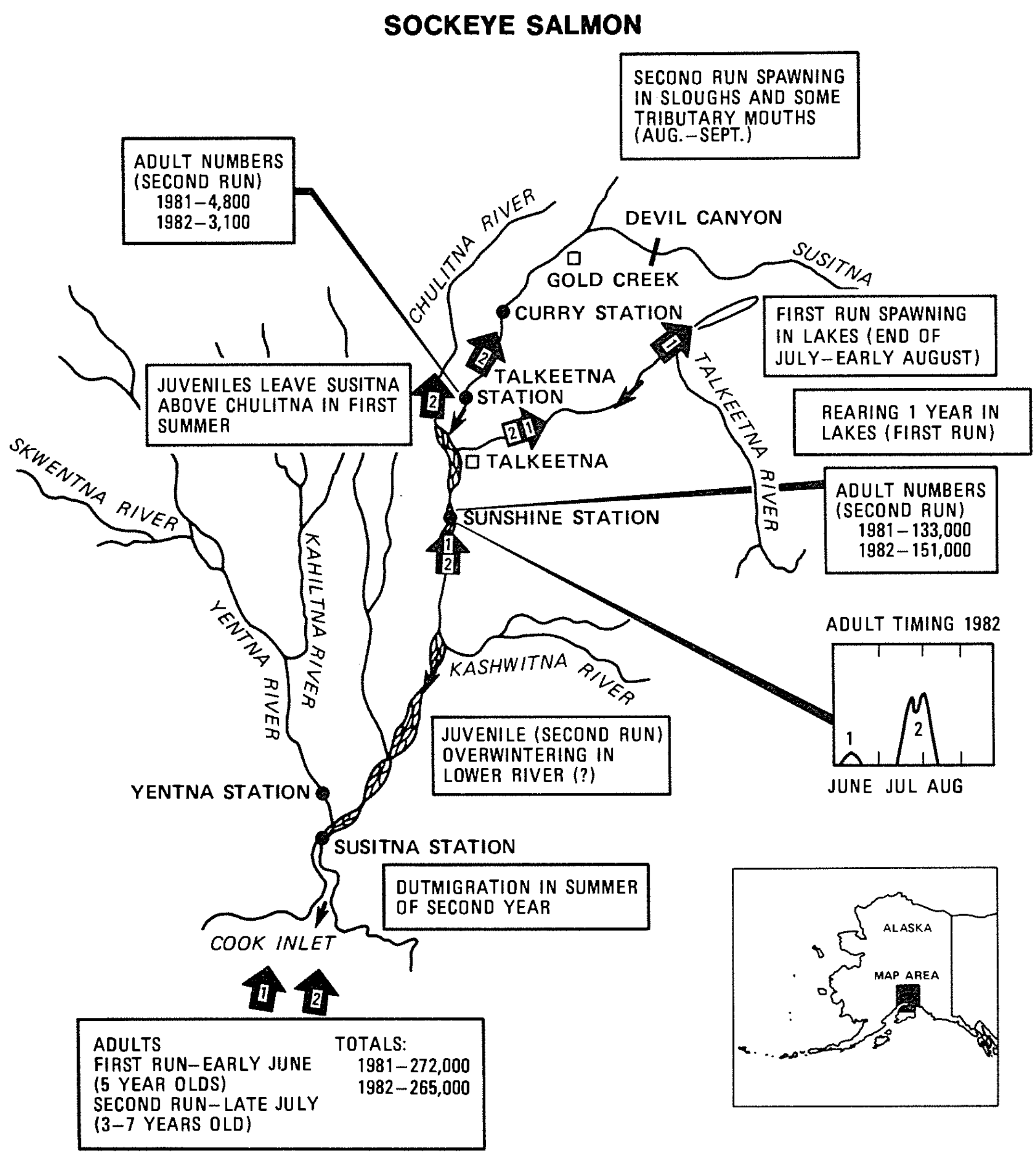


Figure I.1-5. Sockeye Salmon (Oncorhynchus nerka) - Generalized Life Cycle in the Susitna River Drainage.

Out-migration of sockeye smolts may be triggered by temperature. Sudden increases in temperature reversed rheotoxis from positive (upstream) to negative (downstream) in laboratory studies (Keenleyside and Hoar 1955). Positive rheotoxis predominated in fish acclimated to below 50°F (10°C), whereas downstream swimming predominated above that level. Outmigration often peaks at temperatures near 50°F (10°C), although it can begin from lakes when surface temperatures exceed 39 to 41°F (4-5°C). Outmigration dates for juvenile sockeye salmon from lakes coincide with the general climatic conditions over the north-south range of the species, with more southern (warmer) populations migrating earlier than more northern populations (Hartman et al. 1967). Short-term elevations of temperature stimulated pulses of outmigration, whereas cool temperatures decreased migration rates.

Coho Salmon (Oncorhynchus kisutch)

Coho salmon, also called silver salmon or hooknose, is a popular gamefish that may reach over 30 lb (13.6 kg), although 6 to 12 lb (2.7-5.4 kg) at maturity is typical. The species is found from California to Japan, and it has been introduced successfully in freshwater, especially the Laurentian Great Lakes. In coastal waters of the Northwest and Alaska, coho salmon do not travel far from the parent stream. Populations originating in Alaska contribute principally to the Alaskan fishery. Coho spawn at ages of two to four years in rivers and streams which they enter in summer, with spawning complete in the fall. Young generally remain in freshwater for a year, but timing is not tightly regulated and some go earlier while others wait until their third year.

In the Susitna, runs approaching 80,000 adults (1981 and 1982 estimates were 36,000 and 79,800, respectively) enter the river beginning in late June or early July, peaking between mid-July and early August, and ending in September (Figure I.1-2, I.1-6). About one-half of these divert to the Yentna (Figure I.1-4). Almost all fish are either three-year-olds that emigrate their second year or four-year-olds that leave freshwater in their third year (a small percentage are four- or five-year-olds that go to sea in their fourth year). The younger-maturing fish seem destined for the river reaches above Talkeetna. Migration is characterized by periods of milling or holding in semiplacid areas such as near mouths of clear-water tributaries. Susitna coho spawn in either the mainstem, where they mingle with chum salmon, or in tributary creeks; sloughs are utilized rarely. Peak Susitna spawning occurs generally in mid-September, with considerable variation among sites. Habitat features preferred for spawning in the Susitna are not well established, but generalized suitability curves for velocity, depth, temperature, and substrate were developed by Bovee (1978).

The average of 3500 eggs deposited by a female (Hartman 1971) incubate in the gravel through the winter until emergence in March or April. Approximately 1750 TUs (F) are required for emergence, based on hatchery experiences (Piper et al. 1982). Although exact temperature dependence of development rate probably varies among stocks, there are no data specific to the Susitna stocks. Fry are first captured in the Susitna in June. Coho juveniles spend two years in freshwater before emigrating to the ocean. Thus, in any summer season, there may be three year classes present: newly emerged fry (0+), yearlings (1+), and two-year-old fish prior to emigration (2+). They utilize the mainstem and sloughs for rearing and are captured in downstream migrant traps throughout the June-October period.

As temperatures drop in winter, coho juveniles typically change from being solitary and territorial feeders to hiding without feeding in cover or in deep water, often in groups (Hartman 1965; Bustard and Narver 1975a). Natural or artificial side pools used by coho fry in Pacific coast streams as winter refuge were attractive to them near 35 to 41°F (2 to 5°C), but the fish left for the mainstem at higher temperatures (Bustard and Narver 1975b). In the Susitna, they use sloughs for overwintering.

Although coho smolt outmigration seems to be timed by lunar control of thyroxine levels, rapid temperature increases have been shown to cause a change in rheotoxis (current orientation) from positive (upstream) to negative (downstream) (Keenleyside and Hoar 1955). Temperatures in the range 43 to 48°F (6-9°C) are associated with predominantly positive rheotoxis, whereas 57 to 70°F (14-21°C) temperatures are associated with downstream swimming. The changeover occurs near the temperature of maximal downstream migration in the stock studied, about 50°F (10°C).

Environmental requirements of coho salmon juveniles are well known from hatchery experience in the Pacific Northwest. Relevance of this information for Susitna stock is unknown.

Chum Salmon (Oncorhynchus keta)

This Pacific salmon species, also called the dog salmon in Alaska, is third in value for commercial salmon fisheries (behind sockeye and pink), but it is infrequently sought by sport fishermen. It can reach a weight of 33 lb (15 kg), although it is ususally taken in sizes of 8-18 lb (3.6-8 kg). Its range, the widest of any Pacific salmon, is from northern California to Korea and Japan, where it usually spawns in the lower reaches of coastal rivers. In Alaska, however, it ranges far up the major rivers, including the Susitna; in the Yukon the

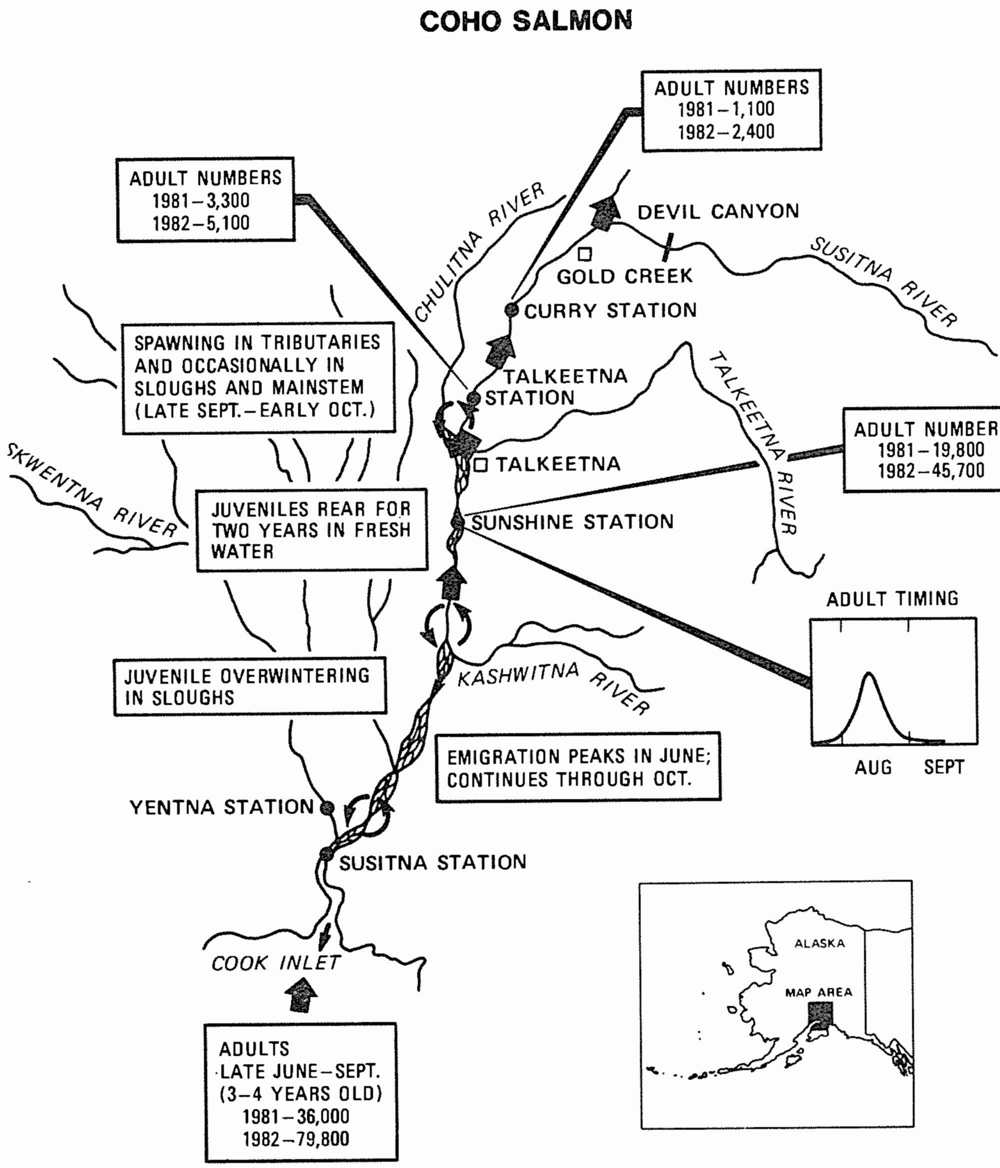


Figure I.1-6. Coho salmon (<u>Oncorhynchus kisutch</u>) - Generalized Life Cycle in the Susitna River Drainage.

species is found 2000 mi (3200 km) from the sea. Runs of chum are marked by wide yearly fluctuations in numbers, and in part of its range it has distinct summer and fall forms. It generally matures at 4 to 5 years of age, when it enters rivers in July to December. Young migrate out of spawning rivers soon after emerging from redds (within 1 month in coastal sites but up to 3 months later in Alaska rivers) and most of the life is spent in the sea (Bakkala 1970, Hale 1981c).

Susitna River chum enter freshwater between early July and mid-September in runs that may number about 400,000 fish (1981 and 1982 estimates were 283,000 and 458,000, respectively) (Figure I.1-7). Peak migration past Sunshine Station is in early August. The Yentna accounted for about 28,000 fish of the total in 1982 (Figure I.1-4). Migrants are primarily four-year-old fish, although three- and five-year-olds represent about 15%. Considerable milling in the river, tributary mouths, and the mouth of Devil Canyon seems characteristic before fish seek spawning sites, mostly in sloughs. A few main channel and side channel spawning sites (10 in 1982) were identified, all above the Chulitna confluence. Chum spawn in the same general slough areas and at the same time (mid-August to mid-September) as sockeye. Tributaries are also utilized, mainly Indian River, Fourth of July Creek, and Portage Creek, in decreasing order of importance. Temperatures suitable for migration range from about 8 to 14°C, with changes in this range having little influence on upstream migration (Hale 1981b). Chum salmon have less ability to surmount rapids and waterfalls than other species of Pacific salmon (Scott and Crossman 1973). Water flows of about 2.5 m/s are near the upper limit of sustained swimming speed (Thompson 1972). Adult chums were observed traveling upstream in shallow riffles with the upper part of their bodies above water, but the distance that could be covered in this fashion is unknown (Hale 1981b). Thompson (1972) suggested that the minimum water depth in streams used by chum for migration was 7 in (18 cm).

Two to three thousand eggs are deposited by females in redds dug at sites that are usually clearly identified with areas of water upwelling. Piper et al. (1982) indicate approximately 1100 TUs (F) are required for hatching and 1450 for emergence, based on studies throughout the species range (Table I.1-3). Wangaard and Berger (1983), using Susitna stocks, indicated relationships between temperature and incubation rate for hatching and complete yolk absorption (usually occurring at emergence) to be:

$$R_h = 3.23 + 1.40\ (\text{temperature}) \quad ,$$

$$R_a = 2.25 + 0.59\ (\text{temperature}) \quad ,$$

where R_h = development rate per day (x 1000) to hatching
R_a = development rate per day (x 1000) to complete yolk adsorption

Juveniles generally emerge from gravels of sloughs along the Susitna in March-May, peaking in April. The time spent in the gravel by eggs and alevins is a time of heavy mortality. Requirements for intragravel flow, dissolved oxygen, and other factors were studied in detail (Hale 1981b). Survival rate from eggs to fry in natural streams typically averages less than 10% (Hale 1981b).

Most chum salmon fry begin their downstream migration to the ocean soon after emergence. They emigrate nocturnally, at temperatures ranging from 2 to 10°C, generally remaining near the surface in main channels, with little feeding activity along shore (McPhail and Lindsey 1970). Movement is a combination of displacement by water currents and active swimming. In the Susitna, fry trap collections show downstream migrating chum fry well into the summer (although in diminishing numbers after late June), with individuals having grown beyond the size of emergence [usually about 1.4 in (35 mm)]. Chum fry apparently feed and grow in Susitna River sloughs, where they are found from April to August. All scales of returning adults examined in the Susitna, however, showed juveniles entering the ocean in their first year. The bulk of the diet of Alaskan chum fry in freshwater consists of benthic organisms, chiefly aquatic insects such as chironomid larvae, mayfly and stonefly nymphs, caddisfly and blackfly larvae (Bakkala 1970; ADF&G 1983c). Chum fry generally avoid temperatures above about 59°F (15°C), preferring 53.6 to 57.2° of (12-14°C) (Brett 1952). Growth will occur in the range 40 to 60.3°F (4.4-15.7°C) but is fastest between 50.2 and 55.2°F (10.1 and 12.9°C) (McNeil and Bailey 1975).

Predation is a major source of mortality to chum fry during the downstream migration period. Common predators of chum fry in other North American streams that occur in the Susitna are rainbow trout, Dolly Varden, coho salmon smolts, sculpins, and predaceous birds such as kingfishers and mergansers.

Pink Salmon (*Oncorhynchus gorbuscha*)

This species is the smallest but most abundant of the Pacific salmon, usually only 3 to 5 lb (1.4-2.3 kg) at maturity, reaching 10 lb (4.5 kg) maximum. It matures in two years (15 months

CHUM SALMON

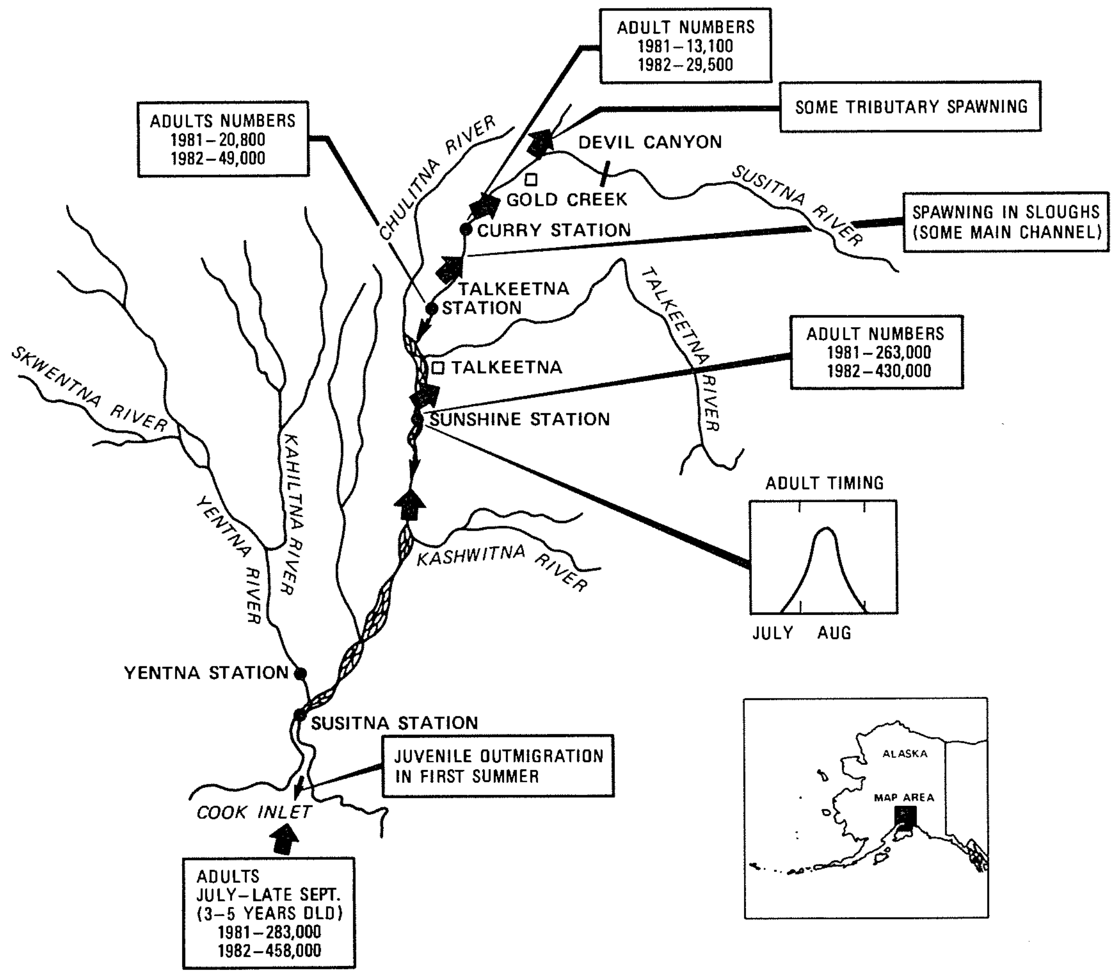


Figure I.1-7. Chum salmon (Oncorhynchus keta) - Generalized Life Cycle in the Susitna River Drainage.

at sea), and has genetically distinct odd-year and even-year runs that can be of greatly disproportionate sizes. Pinks are the second highest in value to the commercial fishery (after sockeye), even though the catch is higher in numbers. Sportsmen catch them in the ocean, often confusing them with young of other species. The native male at maturity develops a large hump on the back in addition to the hooked snout, leading to colloquial names (e.g., humpie). It ranges from California to Korea and Japan. Most abundant in Asian water, it is widely distributed in coastal Alaska. Streams used for spawning range from extremely small, short coastal streams to tributaries of large river systems.

Pink salmon enter the Susitna River system to spawn in early July through early September (Figure I.1-8). The 1981 and 1982 runs amounted to approximately 86,000 and 890,000 fish, respectively, of which approximately one-half went into the Yentna drainage (Figure I.1-4). The migration peaked sharply near August 1. About 73,000 (8%) of the Susitna run passed the Talkeetna station and 59,000 (7%) passed Curry in 1982, indicating that numerous pinks use the Chulitna and Talkeetna rivers as well as the upper Susitna. The majority of pink salmon entering the Talkeetna to Devil Canyon reach spawning tributaries, although several sloughs account for about one-sixth of the escapement. One mainstem spawning site was identified in 1982. Most used tributaries include Indian River (26%), Fourth of July Creek (25%), Lane Creek (22%), and Portage Creek (6%). Temperature appears not to be a critical factor in upstream migration, occurring generally from 45 to 60°F (7.3 to 15.5°C) (Bell 1973). Although depths of 18 cm are considered mininum for extended migration (Thompson 1972), pink salmon have been observed passing over shallow riffles less than 9 cm deep (Wilson et al. 1981). The female pink salmon deposits between 800 and 2000 eggs in a redd (depending on fish size) excavated in gravel. Water temperatures associated with spawning were studied extensively (Kreuger 1981a) and there is a general pattern of acceptable temperatures that range from 45 to 55°F (7.2 - 12.8°C). Temperatures up to about 62.6°F (17°C) were apparently used when necessary. Pink salmon seem to ripen and spawn as summer temperatures are in decline. Water currents of 1 to 26 ft/s (0.3 - 0.8 m/s) or significant upwelling water seem to be required, with depths of 0.7 to 1.6 ft (0.2 - 0.5 m) when not crowded (Krueger 1981a). According to Piper et al. (1982), about 900 TUs (F) are required for eggs to hatch and 1450 for emergence (Table I.1-3).

Sustantial mortality of pink salmon eggs and alevins was documented in selected reaches of streams in Alaska and British Columbia (Krueger 1981a). Most mortality seems to be in the egg stage. Sometimes exceeding 75% (occasionally 90%), this mortality appears to be the major limitation to production. Extreme temperatures [beyond the range 40 to 56°F (4.4-13.3°C)] have been implicated, although later developmental stages tolerate colder water.

Pink salmon fry in the Susitna emerge as sac fry during March, and remain in the river system for only a short period of time. The major outmigration appears to be complete by June; no fry have been found as late as the end of July. The species generally utilizes main channels, does not often enter shallows, emigrates nocturnally, and hides in river gravel by day (McPhail and Lindsey 1970). In turbid waters, movement may be throughout the day (Krueger 1981a). Because freshwater residence is so short, there have been few attempts to define physiological requirements of outmigrants.

I.1.2.2 Other Anadromous Species

Eulachon (Thaleichthys pacificus)

The eulachon, often called "hooligan" in Alaska, is a small, slender, anadromous smelt that seldom exceeds 12 in (30 cm) in length. It constitutes a small but important fishery as it is highly esteemed as a food. Sportsmen and native peoples dip net fish from the densely schooled spawning runs. It spends most of its time in marine waters, but it enters freshwater streams from northern California to the Bering Sea to spawn from March to June.

Eulachon mature at sea after 2 to 3 years in the south or three (about 75%) or four (about 25%) years in Alaska. They enter the Susitna in two distincts runs (based on 1982 sampling only), one in mid-May and the other in early June (Figure I.1-9). The second run is the larger (4.5 times). Initiation of observed spawning runs in 1982 coincided with first ice-free conditions in the Susitna main channels, but there was little correlation with tides or temperature changes. The spawning migration enters the lower 60 mi (96 km) of the river (including the lower Yentna) and fish spawn within a few days at temperatures of 37.4 to 49.1°F (3.0-9.5°C). Although many eulachon die after spawning, a sizable number of spawned-out adults in the Susitna return to the ocean (it is unclear whether there is repeat spawning). Spawning occurs in the water column over riffle areas or off cut banks over loose gravel or sand. The eggs, which may reach 25,000 in a single female, are adhesive, sticking to sand or other material and hatching in two to three weeks. Juvenile eulachon feed on planktonic crustaceans and move out of the spawning rivers and into estuaries during their first spring.

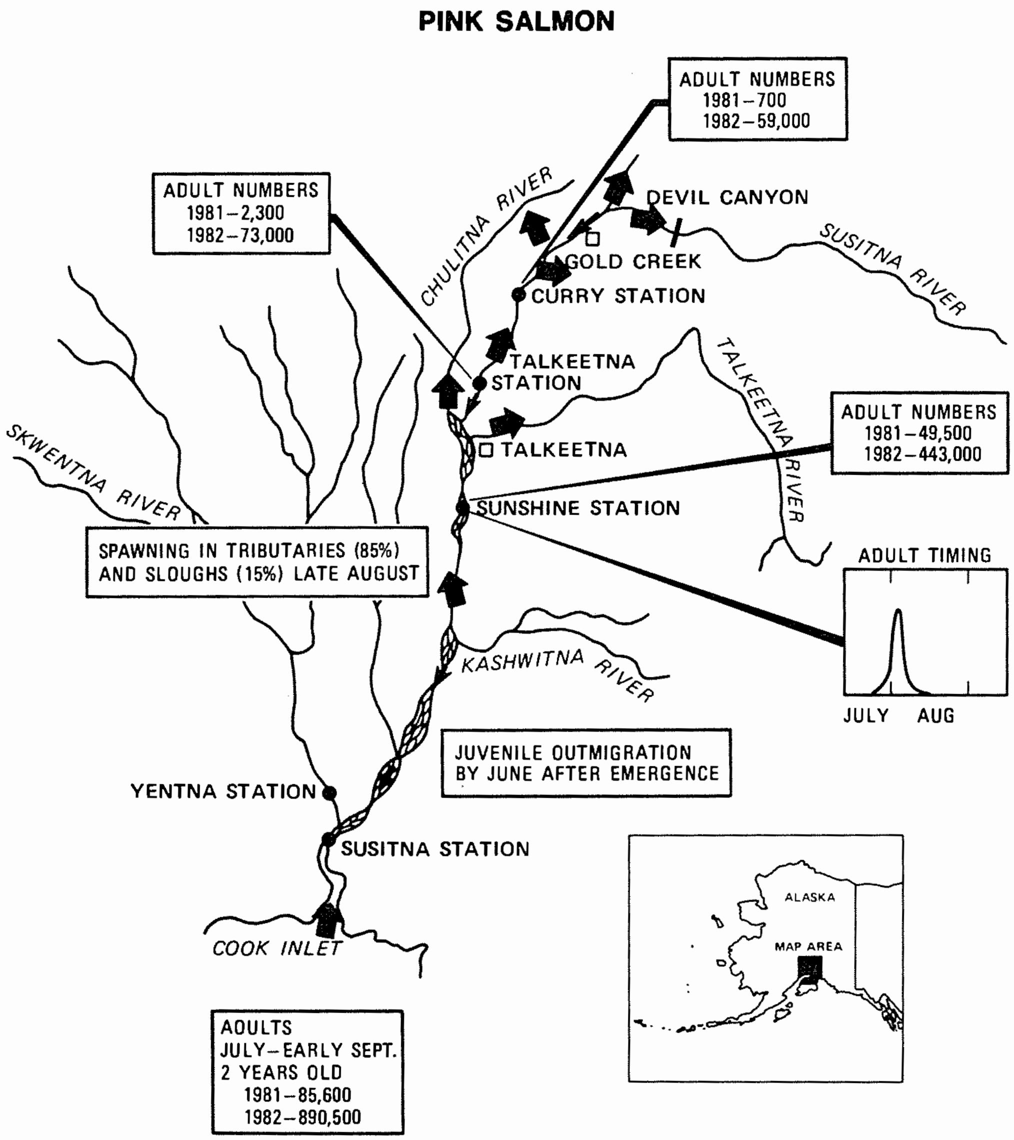


Figure I.1-8. Pink salmon (Oncorhynchus gorbuscha) - Generalized Life Cycle in the Susitna River Drainage.

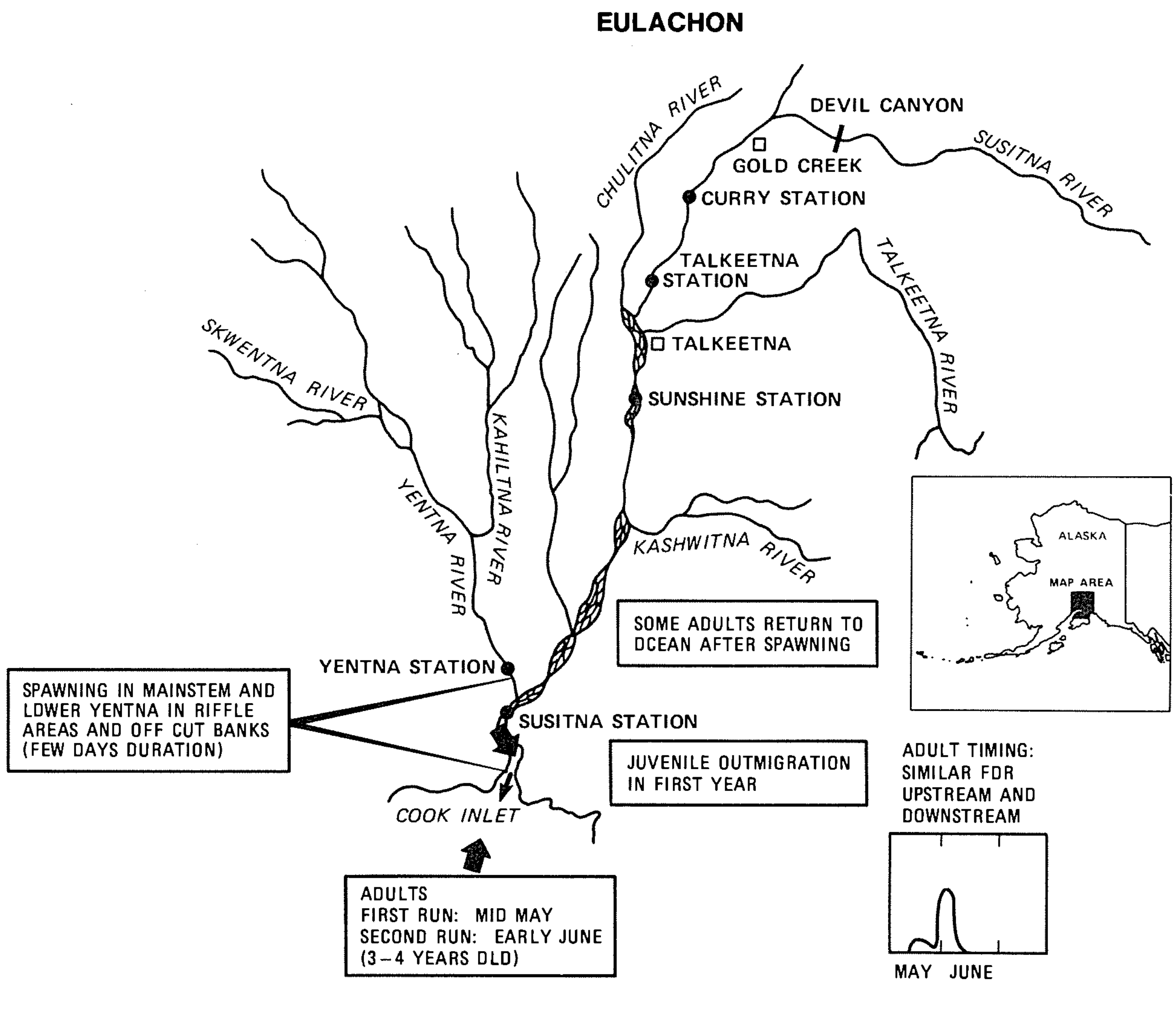


Figure I.1-9. Eulachon (Thaleichthys pacificus) - Generalized Life Cycle and Habitat Suitability in the Susitna River Drainage.

Bering Cisco (Coregonus laurettae)

The Bering cisco is a whitefish species that occurs in the Arctic from the Beaufort Sea to Cook Inlet (Alt 1973). The species was not known to inhabit the Susitna River drainage prior to the Susitna hydroelectric project studies in 1980. Interior and western Alaska populations appear to contain both anadromous and freshwater resident forms; in the Susitna they appear to be anadromous and migrate to areas principally below Talkeetna. It has only a small fishery.

Spawning migrations begin sporatically in early August but do not peak at the Susitna River mouth until early September (Figure I.1-10). The peak reaches Sunshine Station in late September-early October. The adults were captured in fishwheels operated primarily for salmon. There is no estimate of total population size. Migrants ranged in age between four and six years (mostly five-year-olds), and scales indicated seaward emigration of juveniles in their first year. Sizes were generally 12.6 to 14 in (32-36 cm). Spawning has been identified at numerous mainstem sites and is presumed to occur throughout the reach between RM 30 and RM 100. Spawning substrates consisted of coarse gravel. Peak spawning is in the second week of October, with adults occupying the spawning sites for 15 to 20 d. After spawning, the adults return to the sea. Contrary to our understanding of the situation in other river systems, Susitna stocks show repeat spawning.

Other than recognition that it occurs close to the southern limit of its distribution (implying sensitivity to water much warmer than it finds in the Susitna currently), little is known of the habitat requirements of the species.

Dolly Varden (Salvelinus malma)

The Dolly Varden is an important and sought-after sport fish, but where it occurs together with salmon the large adults are significant predators on salmon fry and fingerlings. It is a char that is not universally recognized as distinct from the anadromous Arctic char, Salvelinus alpinus (Morrow 1980). Both anadromous and resident Dolly Varden occur in Alaska south of the Alaska Range (Krueger 1981b). Taken together with the Arctic char, the "species" occurs throughout the northern latitudes. In the Susitna studies, the Dolly Varden has been treated as a resident species. This distinction is unsettled, because downstream of Devil Canyon (both above and below the Chulitna confluence) adults were caught in fishwheels and juveniles in scoop traps, gear designed to sample upstream and downstream migrating stages respectively, of anadromous species. The numbers caught were small, however, and tagging studies yielded few returns. Upstream of Devil Canyon, more clearly resident forms of the species are widely distributed in tributaries in the impoundment reach. Although not well studied, they presumably winter in the Susitna River mainstem.

Spawning generally occurs between September and November in redds constructed by the female in side channels of rivers or main channels of streams. After spawning, one-half or more of the males may die (presumably as a result of aggressive behavior), whereas female mortality is generally less than 10%. They may spawn again in following years. Overall longevity is 9 to 12 years in southeast Alaska.

Dolly Varden eggs, 1000 to 2000 per female, are deposited in the cleared gravel of a redd much as are salmon eggs. Development takes place over the winter and requires somewhat over 200 d at winter temperatures. There is little information available on either temperature-tolerance limits or temperature-dependent development rates. On emergence, Dolly Varden fry occupy relatively quiet stream reaches, stay near the bottom feeding on benthos, and often remain motionless in gravel interstices. Habitat selection by older, presmolt Dolly Varden is not well documented, but they appear to use all types of stream habitat. The larger fish become more oriented toward pools. Resident adults in the Susitna tributaries occupied plunge pool habitats.

Humpback Whitefish (Coregonus pidschian)

Although Alaska has a complex of three closely related species of whitefish, those found in the Susitna River were determined through gill raker counts to be the humpback. The other species, C. clupeaformis (lake whitefish) and C. nelsoni (Alaska Whitefish, not recognized as a distinct species by the American Fisheries Society), may also occur. The humpback whitefish, unlike the other species, is considered anadromous. Migration habits vary widely in different river systems, and its status in the Susitna is unclear. Most individuals found in the Susitna study program were captured in fishwheels in the summer season, although others were collected at slough and tributary mouths. Spawning migrations for the species typically begin in June, with spawning in October and November (Morrow 1980). Occurrence of a few individuals above Devil Canyon suggests that there may be resident as well as migratory stocks (or that upstream individuals are of the resident species). Generally, the humpback whitefish is most abundant in the Talkeetna to Cook-Inlet reach of the Susitna. Fish ranged in ages from two to seven years, with age 4 predominant. The environmental requirements of the species are poorly known.

BERING CISCO

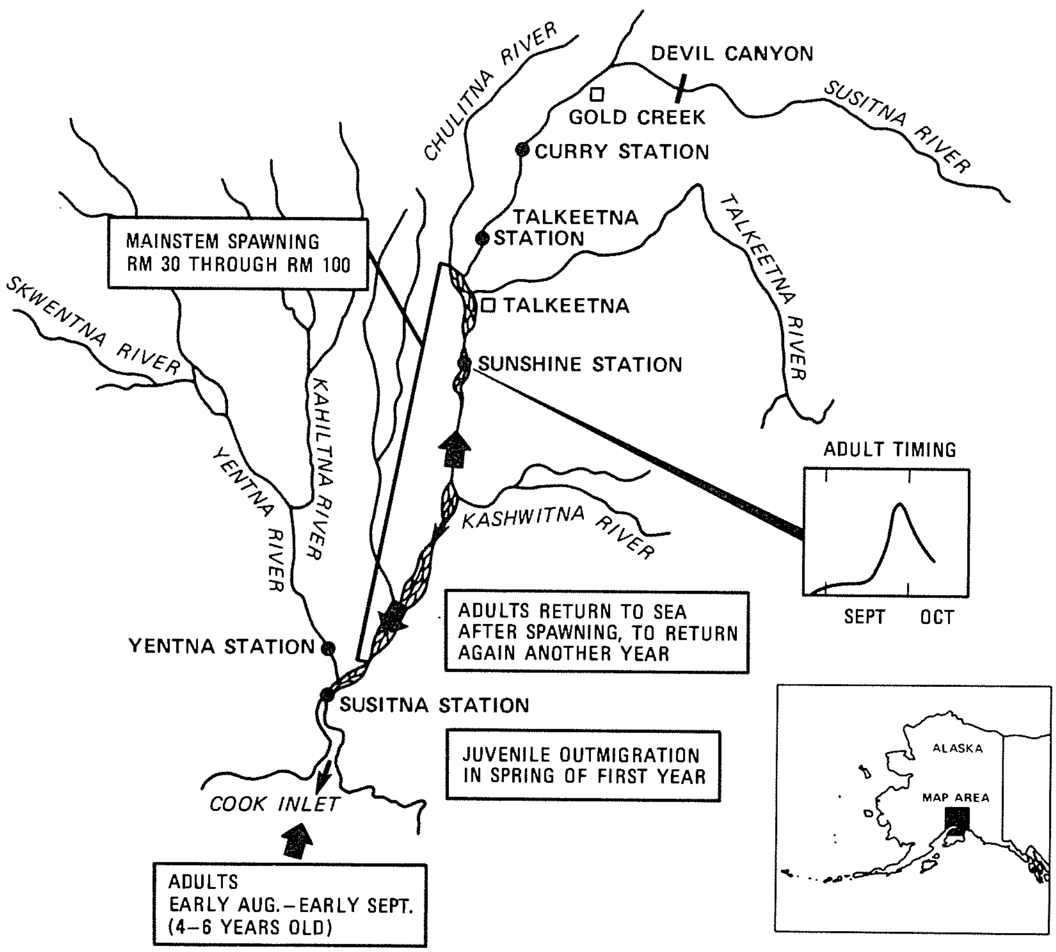


Figure I.1-10. Bering Cisco (<u>Coregonus lauretta</u>e) - Generalized Life Cycle in the Susitna River Drainage.

Arctic Lamprey (Lampetra japonica)

The Arctic lamprey is one of four lamprey species that occur in Alaska. It was observed in the Susitna River during 1981. The Pacific lamprey, Lampetra tridentata, an anadromous species that was reported to range into the lower Susitna River (Morrow 1980), was not observed during Susitna investigations.

Some populations of Arctic lamprey are composed of both anadromous and freshwater forms. It was speculated that a portion (30%) of the Susitna population is anadromous, based on analysis of length frequencies. The anadromous form is parasitic; hosts include adult salmon, trout, whitefish, ciscoes, suckers, burbot, and threespine stickleback (Heard 1966). The freshwater forms have been reported to be both parasitic and nonparasitic. A chinook smolt and a long nose sucker were captured in the Susitna in 1982 while parasitized.

Arctic lamprey spawn during the spring and early summer in streams of low to moderate flow. Eggs develop into a larval ("ammocetes") stage and spend one to four years burrowed into a soft substance before tranforming into small lampreys and migrating downstream. After an indefinite period in large water bodies or the sea, adults migrate upstream to spawn.

Adult Arctic lamprey were found abundantly at Sustina River tributary mouths below RM 50.5; they were much less abundant above Talkeetna, but there are localized concentrations of both adults and ammocetes in Whiskers and Gash creeks. Environmental requirements of the species are virtually unknown.

Inconnu (Stenodus leucichthys)

Also called sheefish, this species is a member of the whitefish group of salmonidae. It migrates into the freshwater portions of estuaries in Alaska and northern Canada in June and July. It is the only fish-eating whitefish in North America, and is a prized gamefish that often reaches over 10 lb (4.5 kg) and over 20 years of age. It was not recorded in the Susitna studies, but it is likely found in some of the streams to be affected by the project.

I.1.3. Resident Species

Arctic Grayling (Thymallus arcticus)

The Arctic grayling is a striking gamefish, highly prized for its beauty. The species occurs in relict or introduced populations in Colorado, Montana, Wyoming, Idaho, and Utah, but the most productive North American populations are in Alaska and the Canadian Northwest. The species is both a lake and a river fish over much of Alaska. Unlike trout, grayling rove in schools, which are often seen cruising in search of food. Arctic grayling are small, with most adults ranging between 2 and 3 lb (0.9 and 1.4 kg). Their distribution shows a definite preference for clear water (Krueger 1981c).

In general, Arctic grayling are found throughout the Susitna River basin during the ice-free months, and the species is the most significant fish of economic importance in the impoundment zone. They seem most abundant in the Susitna above the Chulitna confluence, but they also occur downstream and in downstream tributaries. The Susitna River grayling exhibit annual movements and life cycle patterns typical of other Alaskan populations (Krueger 1981c). They move out of clear-water tributaries as freeze-up approaches in mid-September to October to overwinter in the clear-water mainstem. At the time of spring breakup (end of May), the largest adult Arctic grayling move into the clear-water tributaries to spawn in June and rear in the summer. They appear to return to the same stream year after year, based on tagging and recapture data in the upper Susitna. Many juveniles less than 7.9 in (200 mm) inhabit mainstem confluence areas of tributaries and sloughs in July and August, and significant numbers of juveniles and small adults use the mainstem in June through August. Other than movements in and out of tributaries, Arctic grayling exhibit only local movements. Juveniles also appear to overwinter in the mainstem. Adult population sizes were estimated in eight tributary habitat locations in 1982 (Table I.1-4).

The lifespan of Arctic grayling is variable across its range. Age at maturity in Alaska is four to nine years, with the longest time being spent in the northernmost regions. Maximum ages of fish from various Tanana River drainages were about 11 years (Tack 1973); in the upper Susitna it was 9 years (ADF&G 1983e). The most abundant age class in upper Susitna tributaries is age 5, with a length of 12.4 in (315 mm). Grayling spawn in streams at temperatures above 39.2°F (4°C) [usually below about 50°F (10°C)], with current velocities less than 4.6 ft/s (1.4 m/s), at varying depths, and over relatively small, unimbeded gravels about 1 in (2.5 cm) in diameter. Spawning was observed in shallow backwater areas of lake inlets (Wojcik 1954, 1955) as well as in streams. Males establish territories into which females venture for spawning. There is no redd, and fertilized eggs fall to the bottom and adhere to the substrate in the interstitial spaces. There is no parental care of eggs. Fecundity varies greatly; egg numbers have been reported ranging from 2000 to 14,000 per

Table I.1-4. Arctic Grayling Population Estimates by Tributary Habitat Evaluation Location, Proposed Impoundment Areas, 1982

Location	Population†[1] Estimate	Confidence†[2] Interval	Grayling/ Mile	Grayling/ Acre
Oshetna River	2426	1483-4085	1103	56
Goose Creek	949	509-1943	791	90
Jay Creek	1592	903-3071	455	101
Kosina Creek	5544	3792-8543	1232	69
Watana Creek	3925	1880-6973	324	44
Deadman Creek†[3]	734	394-1502	1835	273
Tsusena Creek†[4]	1000	743-1530		
Fog Creek†[4]	176	115-369	440	
Totals	16,346	9,819-28,016	664	

†[1]Correction factor included.

†[2]95%.

†[3]Includes only that part of Deadman Creek below falls.

†[4]1981 estimates.

Conversion: To convert from miles to kilometers, multiply by 1.6; to convert from acres to hectares, multiply by 0.4047.

Source: ADF&G (1983e).

female. Egg development occurs rapidly (13-32 d), influenced primarily by water temperature [e.g., 8 d at 60°F (15.5°C; 19 days at 39 to 48.5°F (3.9 - 9.2°C). Survival to the fry stage is low [6% was estimated by Kruse (1959)], with better survival for eggs that hatch within the protection of gravels. Newly hatched grayling were observed in mid-June both above and below the proposed impoundment elevation.

Growth rates are extremely variable across its range, due to differences in length of open water (growing) seasons, temperatures, and food supplies. Young are often found in shallow margins of lakes and streams and in other low-velocity zones. Large concentrations have been found in the Susitna in early summer at tributary mouths and throughout the summer in clear-water sloughs off the mainstream. No experimental data are available to quantify growth rates at different temperatures, but tolerance tests show juveniles able to withstand temperatures that exceed 76°F (24.5°C) (La Perrier and Carlson 1973). Old fish are less tolerant, but are more able to move to cooler areas. Individuals in the field have reached 0.8 to 2.0 in (20-50 mm) fork length by July of their first year. Arctic grayling are opportunistic feeders and consume larger prey as they grow. Young feed on zooplankton and chironomid larvae; adults consume aquatic and terrestrial insects. Older fish move progressively into more rapidly flowing water areas. Because they spend summers in small streams that may freeze solid in winter, Arctic grayling require overwintering areas. They typically use deep lakes, deep pools of larger streams or rivers, or deeper spring-fed streams, all of which may be quite distant from rearing areas. Migration routes are therefore essential for population success.

Rainbow Trout (Salmo gairdneri)

This native North American trout is high on the list of game fishes of the world. Its natural range is from the mountains of Mexico to the Aleutian Islands. It may be anadromous (steelhead), feeding in the North Pacific Ocean, or a permanent resident in freshwater.

In the Susitna drainage, rainbow trout are residents that are distributed throughout the system below Devil Canyon but are most common in clear-water tributaries and sloughs. They use the mainstem in the clear-water season from September to spring when they move back into tributaries to spawn. They are relatively nonmigratory elsewhere, using only short reaches of river (McPhail and Lindsey 1970), and appear from telemetry studies to be so in the Susitna, also. Juveniles rear in tributaries, but some are found in clear-water sloughs. Rainbow trout appear to be more abundant above the confluence of the Chulitna than below.

The rainbow trout is one of the most studied of fish species, and its physiological requirements are well known (how well the data represent Susitna stocks is uncertain). In the region that will be affected by the Susitna project, rainbow trout occur mostly as adults during their overwintering period.

Lake Trout (*Salvelinus namaycush*)

The lake trout is a large char, of historically large economic value in North America, that inhabits deep, clear lakes from northern New England and the Great Lakes, westward across northern parts of the Canadian border provinces and interior Alaska except the Yukon drainage. In the upper Susitna drainage it occurs as a resident in Sally and Deadman lakes where there are limited sport fisheries. Sally Lake is within the impoundment contours for Watana Reservoir.

Through much of its range, the lake trout requires thermally stratified lakes with oxygenated hypolimnia; in Alaska it finds sufficiently cool water close to shore in shallows. Lake trout spawn in the fall over gravel or rocky bottoms. No nest is built although the general area is swept clear of silt. Incubation requires about 165 d at winter temperatures of 39.2°F (4°C). Young fish remain in deep water; in high light intensities of shallow water, they develop abnormally. Insects and crustaceans make up the diet of young, while adults feed on fish such as whitefish, burbot, sculpins or young salmon, and trout. Adults captured in Sally Lake were largely five-year-olds. Lake trout are highly susceptible to predation by lampreys, and the distribution of this species and the several species of lamprey are almost mutually exclusive.

Burbot (*Lota lota*)

Also called ling, the burbot is the only member of the cod fish family found in freshwater in North America. It supports a limited sport fishery throughout its range, which extends from New England and the Susquehanna River system in the east, throughout the Hudson Bay drainage and westward including the Columbia River. Burbot are found in the Susitna River and throughout most of Alaska (McLean and Delaney 1978). Usually less than 30 in (76 cm), the Alaskan form is larger and may attain a length of 4.9 ft (1.5 m) and weigh 66 lb (30 kg). They mature between three and six years in Alaska and may live a total of 15 to 20 years (ages 4-8 were most common in the Susitna).

Burbot is a cold water species, usually found in lakes where it seeks deep, cold water in summer. It occurs in both swift and sluggish streams and often becomes abundant there. Spawning takes place under the ice between mid-December and April, over sand or gravel substrate, in shallow 1 to 4 ft (0.3 to 1.3 m) water, and at night. The burbot is a voracious nocturnal predator, consuming fish and larger benthic organisms. It is a strong competitor with salmonids and eats large numbers of salmonids, whitefish, and ciscos.

In the Susitna, burbot have been caught throughout the river from Cook Inlet through the upper end of the impoundment reach. They were common at all tributary and slough mouths. Tagging studies suggested only limited movements by adults. Juveniles occur in the mainstem and in sloughs. During low flows, adults were restricted to deeper sloughs and side channels, but they entered shallower areas at high flows.

Environmental requirements, other than cold water, are poorly known. Its nocturnal behavior and preference for turbid water in summer suggest a negative response to light.

Round Whitefish (*Prosopium cylindraceum*)

The round whitefish is one of the most widespread and common fish species in northern waters of North America. It occurs from New England across the Great Lakes (except Erie) and Canada (except the southern part of the western provinces) and throughout most of Alaska (McPhail and Lindsey 1970, Hale 1981c). In Alaska it is used to a limited extent by subsistence fishermen and a small sports fishery, although it has commercial importance in the Great Lakes and in the USSR. Despite such wide distribution, its life history and environmental requirements are poorly known. It is assumed to have fairly wide habitat tolerances (Hale 1981c). A shallow-water species when found in deep lakes, it appears to prefer clear water with turbidity levels below 15 ppm. Sampling in the Susitna drainage found it mostly in tributaries (near tributary mouths) and sloughs, although significant numbers were also collected in the mainstem in adult salmon fishwheels and downstream migrant traps.

Adults spawn in the fall (late September through October in Alaska) in shallow, graveled areas of lake shores or streams. There is no major migration. Eggs are broadcast over the substrate and they settle into crevices in the gravel to incubate. Fecundity usually ranges from 2,000 to 14,000 eggs per female; there is no parental care. Eggs hatch in April or May at temperatures from 32 to 35.6°F (0 - 2°C), and the fry remain in the shelter of bottom materials. Fry appear to disperse after about one month in the same general areas of stream occupied by the adults. The round whitefish is a bottom feeder, consuming mostly benthic invertebrates in shallow streams and inshore zones of lakes. In Alaskan waters, they generally grow to less than 15.8 in (40 cm) fork length and usually weigh less than 1 lb (0.5 kg), although specimens up to 20 in (52 cm) and 3.3 lb (1.5 kg) have been taken. They reach sexual maturity at about six to eight years in the north.

Threespine Stickleback (Gasterosteus aculeatus)

This small, hardy, extremely widespread (throughout northern latitudes of North America and Eurasia) fish occurs throughout coastal areas of southern Alaska and into large river systems (Hale 1981a). It has distinct forms that occur in freshwater (G. a. leiurus), marine waters (G. a. trachurus) and in intermediate zones (G. a. semiarmatus). In the Susitna, all three forms can be expected; although no distinction has been made in identification by the Susitna team of ADF&G, the freshwater form is the most probable. The farthest upstream they have been captured is at the Talkeetna Station where they appeared in the downstream migrant trap. Most sticklebacks in the Susitna appear to be residents located in tributary mouths and sloughs. The species' principal economic importance is as a predator on salmon eggs and as a competitor with young salmonids for invertebrate food resources. Stickleback in turn are prey for large trout, salmon, and northern pike.

A great deal is known about the environmental requirements and reproductive behavior of this species. Because of its hardiness it has been used extensively in Europe and North America as a laboratory organism. How closely the requirements and behavior of these laboratory animals match Alaskan populations is poorly known. Spawning in the Susitna below the Chulitna confluence apparently occurs from June through July, with young 0.6 to 0.8 in (15-20 mm) in late July to early August. The species is tolerant of a wide range of temperatures, although its being near the northern limit of its range may indicate a sensitivity for temperatures much lower than those it already experienced in the lower Susitna.

Longnose Sucker (Catostomus catostomus)

The longnose sucker, the only representative of the sucker family found in Alaska, is ubiquitous and occurs in most of the mainland drainages. It is widely distributed from Alaska to Maine. A deep, cold-water species, it has little economic value. Spawning usually occurs in spring after iceout. Spawning runs (i.e., movement from lakes into inlet streams or from deep pools into shallower, gravel-bottomed stream areas) are initiated when water temperatures exceed 41°F (5°C). Longnose sucker feed almost exclusively on benthic invertebrates but will occasionally ingest live or dead fish eggs. They were collected throughout the study area from Cook Inlet to the upper reaches of the impoundment area. Their environmental requirements are poorly known.

Slimy Sculpin (Cottus cognatus) and Other Cottids

All sculpin species captured in the Susitna River have been grouped together. The slimy sculpin is the most common species, although there may be others not yet positively identified. Most sculpins (cottids) are small fish characterized by large, flattened heads, expansive pectoral fins, and a habitat among rocks on stream or lake bottoms. They have developed a reputation in salmonid waters of preying on eggs and alevins in redds, although they feed principally on bottom invertebrates. The slimy sculpin is a cold-water species found throughout northern North America, including the Great Lakes. It has been collected throughout the Susitna River study area and appears to prefer clear-water tributaries. Its environmental requirements are poorly understood, and may vary if there are several species represented in the basin.

Northern Pike (Esox lucius)

This popular, circumpolar gamefish of lakes and rivers is most abundant in the zone across New York, the Greak Lakes, and Nebraska. It has been stocked widely, however, and is found in several interior lakes of Alaska. It is a large [up to 20 lb (or 9 kg)] voracious predator noted for its large, toothy mouth and elongated shape. It lies in clear-water, shallow weedbeds where its keen eyesight allows it to spot and attack passing fishes. Although not common in the Susitna project area, it may occur in lakes to be affected by the project, and could become established in the new reservoirs. It uses tributary streams or stream mouths for spawning in early spring as ice goes out. Much is known about the environmental requirements of the species which would be valuable for possible management in the Susitna project area.

I.1.4 Habitat Utilization

Except where indicated the base-line description of utilization of the Susitna River aquatic habitat presented below is based on Exhibit E, Chapter 3, Sec. 2.2.2, and on reports by ADF&G for the 1980-1981 field season (ADF&G 1981a-f, 1982a) and the 1981-82 field season (ADF&G 1983a-e). These reports characterize, on a seasonal basis, the use of habitat by anadromous and resident species within the study area. Habitat utilization is discussed below for three reaches of the river: Oshetna River to Devil Canyon (RM 236 to RM 152), Devil Canyon to Talkeetna (RM 152 to RM 98), and Talkeetna to Cook Inlet (RM 98 to RM 0).

The continuum of habitats available in the Susitna River may be grouped into four types: mainstem, side channel, slough, and tributary mouth. The size and occurrence of these habitat types respond, often dramatically, to changes in mainstem discharge.

- Mainstem habitat consists of that portion of the Susitna River that conveys streamflow at all times. Both single- and multichannel reaches are included in this category. Groundwater and tributary inflow are generally minor contributors to streamflow within a river segment, although major tributaries provide more than one-half of the flow in the river downstream from Talkeetna.

- Side-channel habitat consists of those portions of the Susitna River that normally convey streamflow only during the high-flow, open-water season but which become appreciably dewatered during periods of low flow. In general, shallower depths, lower velocities, and smaller streambed materials occur in side channels than occur in the mainstem. However, the streamflow, sediment, and thermal regimes of side-channel habitats respond directly to mainstem conditions. Tributary and groundwater inflow may prevent side-channel habitats from becoming completely dewatered at low mainstem flows.

- Sloughs are overflow channels that convey glacial meltwater from the mainstem during moderate and high-flow periods and convey clear water from local runoff and ground water during intermediate and low-flow periods. The streambed elevation in a slough is notably higher at the upstream entrance than at the mouth, and sloughs often function like small stream systems. A portion of the channel in each slough, which may vary in length from several hundred to several thousand feet (near one hundred to a thousand meters or more), conveys water without the influence of the mainstem backwater. The physical characteristics of slough habitat appear to depend on the interaction of four principal factors: the discharge of the mainstem Susitna River, surface runoff patterns from the adjacent catchment area, groundwater flow contributions, and ice processes within the mainstem river system. These four principal factors interact to varying degrees during different portions of the year to provide a unique habitat type.

- Tributary habitat is not dependent on mainstem river conditions that exist at the tributary mouth. The streamflow, sediment, and thermal regimes reflect the integration of the hydrology, geology, and climatology of the tributary drainage. At the mouth of most tributaries the stage of the mainstem river causes a backwater that extends into the tributary, and the tributary flow creates a clear-water plume along the bank in the mainstem.

I.1.4.1 Upstream of Devil Canyon

The water resources and habitat availability of the impoundment reach of the Susitna River are characterized in Appendix A, Section 2.1.1. Only mainstem and tributary habitat occur in this reach.

I.1.4.1.1 Mainstem Habitat

Although adult chinook salmon were documented for the first time at RM 156.8 in 1982, no other anadromous species have been reported in the mainstem Susitna in the impoundment reach. Current opinion is that hydraulic characteristics of the Susitna River at Devil Canyon act as a barrier to upstream salmon movement during high flows.

Seven resident species occur in the mainstem: arctic grayling, longnose sucker, humpback whitefish, round whitefish, Dolly Varden, burbot, and slimy sculpin. The longnose sucker, round whitefish, and burbot occur almost exclusively in the mainstem near the mouths of the tributaries, areas which they appear to use as year-round habitat. Based on tagging studies, the arctic grayling occupy mainstem locations mostly in winter. These locations appear to provide primary overwintering habitat and migration routes between tributaries.

I.1.4.1.2 Tributary Habitat

There are eight major tributaries in the impoundment reach: Fog and Tsusena creeks in the Devil Canyon impoundment; and Deadman, Watana, Kosina, Jay, and Goose creeks and the Oshetna River in the Watana impoundment. At least two resident species, arctic grayling and cottids, occur in tributaries. Other species captured near the mouths of tributaries probably also use the tributaries periodically.

Abundance estimates for grayling from 1982 data indicate that in excess of 16,300 grayling inhabit clear-water tributaries in the impoundment zone during the summer. Although spawning has not been observed in the impoundment zone, suitable spawning habitat (sandy gravel) does exist in all of the tributaries sampled, and it is likely that spawning occurs in the lower reaches of these tributaries. Grayling fry were found in the lower reaches of Watana Creek, indicating that spawning had occurred nearby. Grayling that have completed spawning move upstream into areas that have pool-type habitats where they remain throughout the summer.

I.1.4.2 Devil Canyon to Talkeetna

The water resources and habitat availability of the Susitna River from Devil Canyon to Talkeetna are characterized in Appendix A, Sec. 2.1.2.

I.1.4.2.1 Mainstem and Side-Channel Habitat

The mainstem and side channels between Devil Canyon and Talkeetna are used primarily by anadromous and resident species as a migrational corridor and overwintering area. The availability and utilization of mainstem aquatic habitat are discussed below for various species of commercial and recreational importance.

Five species of Pacific salmon were observed in the Susitna River between Devil Canyon and Talkeetna. Studies indicate that adult salmon utilize the mainstem upstream from Talkeetna from late spring into the fall during migration and spawning periods. Use periods for adults of each species are:

Chinook--mid-June through July;
Sockeye--mid-July through mid-September;
Coho--late July through September;
Chum--late July through mid-September; and
Pink--late July through August.

Relative abundance estimates based on 1981 and 1982 escapement data and population estimates are given in Table I.1-5 for each of the salmon species that use this reach of the Susitna River primarily as a passage way to spawning areas. The mainstem reach from Devil Canyon to Talkeetna serves as a migration corridor for a relatively small percentage of the total Susitna River salmon escapement (Figure I.1-4). During migration periods, various behavioral and distribution patterns are associated with certain characteristics of mainstem habitat, including water depth, velocity, channel configuration, and location or absence of obstructions.

Generally, passage of adult salmon during migration corresponds with the summer high-flow season. However, passage of adult salmon on a daily basis (measured by side-scan sonar) indicate that salmon movements decrease during periods of highest flows [40,000 ft^3/s (68,000 m^3/min)] and increase as flows subside following major flow events. It is hypothesized that increased water velocities associated with peak flows discourage passage and encourage milling. Radiotelementry investigation and gillnetting indicate that the confluence of the Talkeetna, Chulitna, and Susitna rivers is a milling area for chum, pink, coho, and chinook and that sockeye, chum, coho, pink, and chinook mill in the mainstem one mile (1.6 km) below Devil Canyon.

Chum were observed spawning at 10 sites and coho at 4 of the 11 mainstem spawning sites identified in the Devil Canyon to Talkeetna reach during 1982. Mainstem spawning appeared to be restricted by lack of suitable spawning substrate and groundwater upwelling.

Juvenile salmon are also present in the mainstem at various times of the year. Periods of use and relative abundance in 1981 and 1982 are outlined below.

Chinook--During the winter following hatching the preceding spring, juveniles were most abundant in the mainstem. Prior to June 1 through the end of July, age 1+ juveniles were abundant as they were observed moving downstream in the mainstem.

Sockeye--In 1982, sockeye juveniles moved out of the Devil Canyon to Talkeetna reach as age 0 fish, primarily during June and July following hatching in spring 1982.

Coho--During winter, coho are most abundant in the mainstem. During summer they are slightly less abundant in the mainstem than at the tributary mouths. In 1982, out-migration peaked in June.

Chum--The majority of the chum juveniles migrated downstream as age 0 fish prior to July 1 in 1982.

Pink--Studies to date have caught few pink juveniles in the mainstem.

Table I.1-5. Side-scan Sonar Counts of Salmon Migrating Past Yentna Station and Peterson Population Estimates and Corresponding 95% Confidence Intervals of Salmon Migrating to Sunshine, Talkeetna and Curry Stations, 1981-1982

Station		Chinook		Sockeye		Coho		Chum		Pink	
		1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
Yentna Station		--	--	139,000	114,000	17,000	34,100	19,800	27,800	36,100	447,000
Sunshine Station	No. of Fish	--	49,600	133,000	151,000	19,800	45,700	263,000	430,000	49,500	443,000
	95% Confidence		45,000	120,000	139,000	18,000	42,000	235,000	408,000	46,400	407,000
	Interval		55,100	150,000	167,000	22,000	50,300	298,000	456,000	53,100	487,000
Talkeetna Station	No. of Fish		10,900	4,800	3,100	3,300	5,100	20,800	49,100	2,300	73,000
	95% Confidence		8,300	4,300	2,800	2,800	4,300	18,400	45,200	1,900	70,500
	Interval		12,500	5,400	3,500	6,200	6,200	22,800	53,800	2,943	75,800
Curry Station	No. of Fish		11,300	2,800	1,300	1,100	2,400	13,100	29,400	1,000	59,000
	95% Confidence		8,300	2,600	1,100	7,090	1,800	11,800	26,700	700	53,600
	Interval		16,000	3,100	1,500	2,500	3,800	14,600	32,700	2,100	65,300

Source: Exhibit E, Table E.3.5.

Resident species in this reach include all of the resident fish reported in the Susitna River drainage (Table I.1-2) except for lake trout. Resident species, other than burbot and longnose sucker, primarily use this mainstem area as a migration channel to spawning, rearing, and summer feeding areas in the tributaries. No mainstem spawning or rearing areas have been located. Rainbow trout and grayling overwinter in mainstem habitats. Burbot and longnose sucker use the mainstem as year-round habitat. Burbot catches during low flows were restricted to the mainstem and deep side channels. During high flows, burbot were captured at a greater number of locations, including shallow side channels.

I.1.4.2.2 Slough Habitat

Adults and/or juveniles of five salmon species have been observed in slough habitat between Devil Canyon and Talkeetna. Estimates of the total number of spawning salmon by species and by slough are given in Table I.1-6. Adult sockeye and chum salmon are the most numerous salmon in these sloughs during peak spawning periods, while coho and chinook are rarely present. Two factors contributing to the salmon spawning in the sloughs in this reach are as follows: (1) clear-water base flows originating from sources such as groundwater upwelling, local surface runoff, or interstitial inflow ensure maintenance flows; and (2) the presence of groundwater upwelling in the sloughs oxygenates spawning substrate, keeps silt from compacting the spawning gravels, and provides a stable temperature regime that maintains incubating embryos through the winter.

Sloughs serve as rearing and overwintering habitat for juvenile chinook and coho salmon. During summer, tributary sites appear to be more important chinook-rearing habitat, although clear-water sloughs also provide rearing habitat. Coho juveniles appear to use sloughs and tributary mouth sites for summer rearing. Chum, pink, and sockeye fry were present in slough habitat during part of the summer. The importance of sloughs as juvenile overwintering and summer rearing habitat may be related to (1) ice-free, clear-water conditions during winter compared to lowered flow and icing in coho and chinook natal tributaries; and (2) the high stage of the mainstem in summer acting as a hydraulic control at the slough outlet, increasing the depth of water in the lower end of the slough, and prompting benthic production in clear-water areas, which improves the quality of the rearing habitat for juvenile salmon.

All resident species reported in this reach of the Susitna drainage have been observed in slough habitat between Devil Canyon and Talkeetna except for lake trout. Available data indicate that most species are present in slough habitats as well as the mainstem through winter. During summer, most adult residents are not abundant in slough habitat. Those that were relatively abundant in slough habitat during summer included burbot, longnose sucker, and rainbow trout. Sloughs provide rearing habitat during late summer months for juvenile whitefish, grayling, and rainbow trout.

I.1.4.2.3 Tributary Habitat

In addition to numerous smaller streams draining the surrounding hillsides, the six principal tributaries to the Susitna River in the Devil Canyon to Talkeetna reach are Portage Creek, Indian River, Gold Creek, Fourth of July Creek, Lane Creek, and Whiskers Creek. Tributaries in this reach serve as primary spawning habitat for chinook, coho, chum, and pink salmon. Important spawning tributaries include Indian River (chinook, pink, chum, and coho), Portage Creek (chinook, coho, pink, and chum), Gash Creek (coho), Lane Creek (chinook and pink salmon), and Fourth of July Creek (chinook, pink, and chum).

Tributaries in this reach also serve as rearing and summer feeding habitat for juvenile chinook and coho. Redistribution of juveniles from areas of emergence in tributaries to more favorable rearing habitat, including the mouths of tributaries, occurs throughout the summer as fish become more mobile.

Between Devil Canyon and Talkeetna, tributaries and mouths of tributaries provide spawning habitat, juvenile-rearing areas, and summer feeding habitat for several resident species including rainbow trout, arctic grayling, round whitefish, and Dolly Varden. In general, these fish migrate from mainstem or slough habitat to the clear-water tributaries to spawn in the spring (or early fall for Dolly Varden). Once spawning is completed, the fish move into favorable tributary habitat for rearing and summer feeding. As freeze-up begins, the fish migrate from the tributaries to the mainstem or deeper pools near the mouths of tributaries. Limited information on winter distribution and abundance indicates that few resident fish overwinter in the tributaries.

I.1.4.3 Talkeetna to Cook Inlet

The water resources and habitat availability of the Susitna River from Talkeetna to Cook Inlet are characterized in Appendix A, Sec. 2.1.3.

Table I.1-6. Estimated number of slough-spawning sockeye, chum, and pink salmon in sloughs between Devil Canyon and Talkeetna, 1981 to 1982[†1]

Slough	River Mile	Sockeye 1981	Sockeye 1982	Chum 1981	Chum 1982	Pink 1981	Pink 1982
1	99.6	0	0	6	0	0	0
2	100.4	0	0	30	0	0	0
3B	101.4	2	0	0	0	0	0
3A	101.9	9	0	0	0	1	0
5	107.2	0	0	0	2[†2]	0	0
6A	112.3	1	0	11	2	0	35[†2]
8	113.2	0	0	480	0	25	0
8D	121.8	0	0	0	23[†2]	0	0
8C	121.9	0	2	0	75	0	0
8B	122.2	0	5	1	80[†2]	0	0
Moose	123.5	0	8	167[†2]	65	0	9
A	124.6	0	0	140[†2]	0	0	0
A	124.7	0	0	60	0	2	0
8A	125.1	191	133	620[†2]	748	0	28
B	126.3	0	9	0	73	0	32[†2]
9	128.3	14	6	260[†2]	420	0	32
9B	129.3	203	1	190	5	0	0
9A	133.3	3	1	207	173	0	0
10	133.8	0	0	0	2	0	0
11	135.3	1762	1131	765	732	0	276
13	135.7	0	0	5	0	0	0
15	137.2	0	0	1	1	0	135
16	137.3	10	0	3	0	0	0
17	138.2	49	0	94	21[†2]	0	0
19	139.7	2[†2]	0	3	1	0	1
20	140.1	64	106	16	30[†2]	0	133
21	141.0	0	0	457	1222	0	64[†2]
21A	145.5	0	0	10	2	0	0
Estimated total		2315	1402	3526	3674	28	735

1981 estimated total: 5869 slough-spawning salmon.
1982 estimated total: 5811 slough-spawning salmon.

[†1] Total numbers estimated by calculating the area under the curve formed from plotting number of live salmon in sloughs versus the date and dividing by the average estimated stream life (as in Bell 1980). The estimated stream life was 12 d for sockeye, 10 d for chum, and 7 d for pinks.

[†2] In some cases the peak live count exceeded the calculated total count. The peak live count is used.

Source: Exhibit E, Table E.3.12.

I.1.4.3.1 Mainstem and Side-Channel Habitat

Adult salmon pass through this reach of the mainstem during spawning migration. Generally, the migration period extends from late May into September. The relative abundance of adult salmon in this reach is high because the entire Susitna salmon run must pass through the lower sections of the river to arrive at spawning grounds. Population estimates of the number of salmon that migrate to various escapement monitoring stations are given in Table I.1-5. Salmon-spawning habitat in the mainstem or side channels of the reach is limited and is comparable to the spawning habitat discussed for the Devil Canyon to Talkeetna reach. Of the six mainstem or side-channel spawning sites identified in 1981, chum salmon occupied six and coho salmon occupied one. No mainstem or side-channel spawning was observed for chinook or sockeye salmon. Mainstem and side-channel spawning habitat is probably restricted because of the lack of suitable spawning substrate and upwelling, which are two of the key factors determining substrate suitability for spawning.

Mainstem habitat also provides overwintering for chinook and coho juveniles, limited summer rearing habitat, and a migrating channel for smolt outmigration. Juvenile coho are less abundant than juvenile chinook and more often associated with tributary mouth sites.

Bering cisco and eulachon are anadromous species that use the mainstem as a migratory channel from Cook Inlet to their respective spawning areas. Bering cisco are abundant in the mainstem from August to October. Although spawning activity may occur throughout the reach between RM 30 and RM 100, only three spawning concentrations have been identified. Eulachon were observed in the lower 48 mi (76.8 km) of the reach in 1982 and in the lower 58 mi (92.8 km) in 1981.

All resident species found in the Susitna drainage except for lake trout were found in this reach or the mainstem. Lamprey were observed in this reach but not in other reaches of the Susitna River. Arctic grayling, rainbow trout, Dolly Varden, and round whitefish are resident fish that use the mainstem as a migratory channel to tributary spawning habitat and as overwintering habitat. Burbot and longnose sucker are present in the mainstem throughout the year and utilize the mainstem for overwintering, spawning, and juvenile rearing.

I.1.4.3.2 Slough Habitat

Chum, sockeye, and pink salmon adults occur in sloughs in this reach of the river, although no estimates of relative abundance by species or slough have been made. Factors that may contribute to the suitability of sloughs as spawning habitat are the same as previously discussed for the Devil Canyon to Talkeetna reach.

Slough habitat also serves as important rearing and overwintering habitat for juvenile chinook and coho salmon. Chinook juveniles are relatively abundant in slough habitat during winter and less abundant in summer. Juvenile coho are less abundant in slough habitat than in tributaries in this reach throughout the year. The importance of sloughs as juvenile overwintering and rearing habitat may be related to factors discussed previously for the Devil Canyon to Talkeetna reach.

The significance of slough habitat downstream from Talkeetna to resident fish is similar to that discussed for the reach between Devil Canyon and Talkeetna. Slough habitat in this reach is used as overwintering habitat for adult rainbow trout, grayling, and whitefish; year-round habitat for adult burbot and longnose sucker; and rearing habitat during late summer for juvenile whitefish, grayling, and rainbow trout. The importance of sloughs as overwintering habitat is related to the same factors as discussed previously for juvenile salmon species in the Devil Canyon to Talkeetna reach. No spawning sites were observed in the sloughs of this reach. Adult residents that are most abundant in slough habitat during summer include burbot, longnose, sucker, and rainbow trout.

I.1.4.3.3 Tributary Habitat

All of the salmon species present in the Susitna drainage have been observed in tributaries downstream from Talkeetna. The highest level of spawning for all salmon species in this reach occurs in the tributaries. Based on escapement counts and population estimates at monitoring stations along the mainstem, tributaries in this reach provide the majority of spawning habitat in the Susitna drainage for chinook, coho, and pink salmon.

Tributary habitat in this reach also supports rearing and summer feeding habitat for juvenile chinook and coho salmon. Sites associated with tributary mouths appear to provide particularly important rearing areas. Occurrence of age 0+ coho is particularly high at tributary mouth sites during summer. In addition, tributary mouth sites in these reaches appear to provide overwintering habitat for juvenile coho salmon.

All resident species except for burbot, longnose sucker, and lake trout were most abundant in and at the mouths of clear-water tributaries during summer. Information on winter distribution and abundance indicates that few resident fish overwinter in tributary habitat. Tributary habitat in this reach, similar to the Devil Canyon to Talkeetna reach, apparently provides spawning habitat, juvenile-rearing area, and summer feeding habitat for rainbow trout, arctic grayling, round whitefish, and Dolly Varden. In general, these fish migrate during spring (early fall for Dolly Varden) from the mainstem or slough habitat to clear-water tributaries to spawn. Once spawning is completed, fish move into favorable tributary habitat for rearing and summer feeding. As freeze-up begins, fish migrate from tributaries to the mainstem or deeper pools near the mouths of tributaries.

I.1.4.4 Streams of the Access Routes and Transmission Corridors

The portion of the Denali Highway between Cantwell and the Watana Access Road crosses 10 streams in the Jack River and Nenana River drainages. From the Denali Highway to Watana, the road will cross Lily Creek, Seattle Creek, and Brushkana Creek, as well as numerous unnamed streams. Fish species present in these streams include grayling, northern pike, burbot, whitefish, and sculpin. Of these species, the tributary streams would contain at least grayling and sculpin.

The upper reaches of Deadman Creek will be crossed and paralleled by the Watana access road. This creek is a tributary of the Susitna River and is considered important grayling habitat. Between the Watana and Devil Canyon damsites, the access road will cross Tsusena Creek and cross and parallel Devil Creek. The streams contain grayling and may contain cottids, whitefish, longnose sucker, and Dolly Varden.

The road will cross the Susitna River approximately 2 mi (3 km) below the Devil Canyon dam site. Salmon and probably grayling, whitefish, cottids, and longnose sucker occur in the vicinity of the crossing. The habitat in this reach of the Susitna is considered relatively nonproductive compared to reaches farther downstream.

The railroad between Devil Canyon and Gold Creek will cross and parallel Jack Long Creek and will cross Gold Creek. Jack Long Creek contains small numbers of pink, coho, chinook, and chum salmon. Gold Creek has been documented to contain chinook, a few coho, and pink salmon. Three unnamed tributaries of the Susitna River will also be crossed. These streams most likely do not contain fish because of their steep gradients, but they are considered important sources of clear water to sloughs 19 and 20, which are salmon spawning areas.

With respect to transmission lines, at least 27 major salmon streams, including Willow Creek, Kashwitna River, Talkeetna River, Chulitna River, and Indian River, will be crossed by the intertie and, presumably, by the additional lines to be built in the right-of-way in conjunction with the Susitna Hydroelectric Project. The streams contain grayling, rainbow trout, Dolly Varden, and cottids in addition to salmon.

South of Willow, the transmission line will be routed between the Susitna River and the Parks Highway for much of its length. It will cross Fish Creek and the Little Susitna River as well as many unnamed streams. The Little Susitna is a productive fish river and contains coho, pink, chinook, chum, and sockeye salmon, as well as rainbow trout, Dolly Varden, and grayling. Fish Creek is known to support chinook, sockeye, pink, and coho salmon and rainbow trout. Many of the unnamed tributaries to the Susitna River most likely provide salmon spawning habitat.

An underwater crossing will be used to cross the Knik Arm. The transmission line will then proceed east and south to the University power substation. Knik Arm serves as a migration corridor for five species of Pacific salmon as well as other anadromous species such as Dolly Varden, Bering cisco, eulachon, and lamprey. The transmission line will skirt Otter Lake, which is stocked with rainbow trout, and will cross Fossil and Ship creeks. Fossil Creek is not considered a fish stream. Ship Creek supports populations of pink, chum, coho, sockeye, and chinook salmon as well as Dolly Varden and rainbow trout, but because of the heavy development along its reaches, it is not considered prime fish habitat. Planned construction of a diversion wier for a power plant intake will block upstream movements of anadromous fish prior to construction of the transmission line.

North of Healy, the transmission line will cross at least 50 creeks and rivers including the Nenana and Tanana rivers. These are two of Alaska's major rivers and provide habitat for salmon, grayling, whitefish, suckers, burbot, cottids, northern pike, and inconnu. Panguinge Creek has been documented to contain coho salmon, Dolly Varden, and grayling. The streams in the Little Goldstream vicinity are not considered to be important fisheries habitat because of their steep gradients. While many of the streams go dry in the summer, some do support grayling populations near their mouths.

I.1.5 Fisheries

I.1.5.1 Commercial

Figure I.1-4 shows the ADF&G upper Cook Inlet salmon harvest statistical areas. The upper Cook Inlet commercial fishery harvests mixed stocks (Table I.1-7). With the exception of sockeye salmon, the majority of upper Cook Inlet salmon production originates in the Susitna drainage. The Susitna River is considered the most important salmon-producing system in upper Cook Inlet; however, the quantitative contribution of the Susitna River to the commercial fishery can only be approximated because of (1) the high number of intradrainage spawning and rearing areas; (2) the lack of data on other known and suspected salmon-producing systems in upper Cook Inlet; (3) the lack of stock separation programs (except for sockeye salmon) (ADF&G 1982b); and (4) overlap in migration timing of mixed stocks and species in Cook Inlet harvest areas. The salmon stocks spawning in the Susitna River drainage also contribute to the commercial fishery in lower Cook Inlet, although data are not available to estimate percent contributions.

Further discussion of the socioeconomic aspects of the commercial salmon harvest is contained in Appendix N.

I.1.5.1.1 Chinook

Since 1954, the commercial catch of chinook salmon in upper Cook Inlet has averaged 19,500 fish (Table I.1-5). Since 1964, the opening date of the commercial fishery has been June 25, and the Susitna River chinook salmon run begins in late May and peaks in mid-June. Thus, the majority of chinook have already passed through the area subject to commercial fishing. Estimates of chinook salmon escapement in the reach above Talkeetna were 10,900 fish in 1982 (Table I.1-5). This represented 22.0% of the chinook escapement past Sunshine Station (Figure I.1-4).

I.1.5.1.2 Chum

The upper Cook Inlet chum salmon catch has averaged approximately 614,000 fish annually since 1954 (Table I.1-7). The 1981 and 1982 estimates of chum salmon escapement in the reach above Talkeetna were 20,800 and 49,100 fish (Table I.1-5). These represented 7.9 and 11.4%, respectively, of the estimated chum escapement past Sunshine Station (Figure I.1-4).

I.1.5.1.3 Coho Salmon

Since 1954, the upper Cook Inlet coho salmon commercial catch has averaged approximately 230,000 fish (Table I.1-7). The 1981 and 1982 estimates of coho salmon escapement in the reach above Talkeetna were 3300 and 5100 fish (Table I.1-5). These represented 16.7 and 11.1%, respectively, of the estimated coho escapement past Sunshine Station (Figure I.1-4).

I.1.5.1.4 Pink Salmon

The upper Cook Inlet average odd-year harvest of pink salmon since 1954 is about 124,000 fish, with a range of 12,500 to 554,000, while the average even-year harvest is approximately 1,701,000 fish, with a range of 484,000 to 3,232,000 (Table I.1-7). The estimates of pink salmon escapement in the reach above Talkeetna were about 2300 fish in 1981 and 73,000 in 1982 (Table I.1-5). These represented 4.6 and 16.5%, respectively, of the pink escapement past Sunshine Station (Figure I.1-4).

I.1.5.1.5 Sockeye

The commercial sockeye harvest has averaged approximately 1,114,000 fish annually in upper Cook Inlet over the last 28 years (Table I.1-7). The estimated sockeye escapement in the reach above Talkeetna was 4800 fish in 1981 and 3100 in 1982 (Table B-5). These represented 3.6 and 2.0%, respectively, of the estimated sockeye escapement past Sunshine Station (Figure I.1-4).

I.1.5.1.6 Stock Separation

The applicant has prepared a report focusing on the feasibility of assessing the Susitna River contribution to the commercial salmon fishery in upper Cook Inlet through a stock identification program (ADF&G 1982b). The report includes an examination of salmon harvest data for the Cook Inlet commercial fishery and a review of literature on upper Cook Inlet fishery programs and stock identification techniques. The two recommendations in the report are:

1. "Develop an inventory system to determine characteristics (timing, length, weight, age) of salmon runs to west side systems of upper Cook Inlet. Should the west-side systems not be considered, the actual contribution by the Susitna River drainage will be misrepresented.

Table I.1-7. Commercial Catch of Upper Cook Inlet Salmon in Numbers of Fish by Species, 1954 - 1982[†1]

Year	Chinook	Sockeye	Coho		Pink	Chum	Total
1954	63,780	1,207,046	321,525		2,189,307	510,068	4,291,726
1955	45,926	1,027,528	170,777		101,680	248,343	1,594,254
1956	64,977	1,258,789	198,189		1,595,375	782,051	3,899,381
1957	42,158	643,712	125,434		21,228	1,001,470	1,834,002
1958	22,727	477,392	239,765		1,648,548	471,697	2,860,129
1959	32,651	612,676	106,312		12,527	300,319	1,064,485
1960	27,512	923,314	311,461		1,411,605	659,997	3,333,889
1961	19,210	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	296,037	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	4,780	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	14,792	2,054,020	192,975		544,184	1,233,733	1,049,704
1978	17,303	2,622,487	219,234		1,687,092	571,925	5,118,041
1979	13,738	924,415	265,166		72,982	650,357	1,926,658
1980	12,497	1,584,392	283,623		1,871,058	387,078	4,138,648
1981	11,548	1,443,294	494,073		127,857	842,849	2,919,621
Average	19,548	1,114,408	229,684	even-	1,701,026	614,384	2,891,894
				odd-	124,459		
1982[†2]	20,636	3,237,376	777,132		788,972	1,428,621	6,252,737

[†1]Data are graphed in Figure 3.1.4-3.

[†2]ADF&G preliminary data.

Source: Exhibit E, Table E.3.3.

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. These 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".

Based on research by Bilton (1971), Grant et al. (1980), McGregor (1983), and Okazaki (1981), it is the judgment of the FERC staff that a stock identification program designed to assess the Susitna River contribution to the commercial salmon fishery in upper Cook Inlet is not likely to be very successful for any of the five species. We predict that overlap in the frequency distributions for the possible morphometric, meristic, and biochemical characters will be so great that, in a sample of salmon from mixed stocks in Cook Inlet, the ability to correctly classify Susitna River salmon will be so low as to be of limited value.

I.1.5.2 Sport

Recent increases in population and tourism in Alaska have resulted in a growing demand for recreational fishing. Recreational fishing is now considered a significant factor in total fisheries management, especially in Cook Inlet where commercial and noncommercial user conflicts have developed (Mills 1980). The Susitna River and its major salmon and resident fish-producing tributaries provide a multispecies sport fishery easily accessible from Anchorage and other Cook Inlet communities. In 1978, the Susitna River and its primary tributaries accounted for over 124,000 angler days of sport fishing effort, about 10% of the total angler days in Alaska (Mills 1980). In 1981, over 102,240 angler days were expended in the Susitna Basin, representing about 7% of the total angler days in Alaska (Mills 1982).

The sport fish harvests for 1978 through 1981 from the Susitna basin, based on mailing surveys to a sample of licenses, are shown in Table I.1-8 (Mills 1979, 1980, 1981, 1982). The figures represent the sport fishing harvest throughout the Susitna basin and include an area that is larger than that which would be affected by the proposed project (see Figures I.1-11 to I.1-13 for locations of major tributaries listed in Table I.1-8).

The 1978 and 1981 estimated sport catches of arctic grayling represent about 28 and 33%, respectively, of the estimated grayling harvest in south-central Alaska. The estimated sport catch of rainbow trout represents about 13 and 10% of the entire state harvest in 1978 and 1981, respectively. The 1978 and 1981 Susitna sport harvest of pink salmon represents about 39 and 13% of the total estimated sport harvest for south-central Alaska; the harvest of coho represents about 18 and 10%; and the harvest of chinook represents about 11 and 19%.

I.1.5.3 Subsistence

Although salmon form an important resource for many Susitna basin residents, subsistence fishing within the Susitna basin is currently an unquantified harvest. The Division of Subsistence of the Alaska Department of Fish and Game serves as a research group with responsibility to gather data on resource uses; to provide these data to the Boards, wildlife agencies, and the public; and to advise decision-making bodies on the adoption of regulations and plans that affect subsistence uses. The Division does not manage subsistence fisheries, does not issue permits, and has no enforcement authority. However, the Division is collecting information in the Susitna River basin that will permit better quantification and understanding of present levels of subsistence fishing.

The Division's report (Foster 1982) on use of chinook salmon by residents of Tyonek on the west side of Upper Cook Inlet is a good example of the type of study that is needed for a number of other sites, and not just sites involving subsistence fishing by natives. Foster's results demonstrate the important role that the utilization of chinook plays in the ongoing life of the village. Numbers of chinook harvested ranged between 1500 and 2000 for the years 1980-1982; 10 to 15% as many sockeye were also harvested.

I.1.5.4 Salmon Enhancement Plan

The Cook Inlet Aquaculture Association and the Alaska Department of Fish and Game (1981) have developed a Cook Inlet Regional Salmon Enhancement Plan, 1981-2000. The underlying principles for this plan are as follows:

- Enhancement of the salmon resource in any significant and lasting fashion will depend on a careful balance of management for the wild stocks and the orderly introduction of supplemental production.

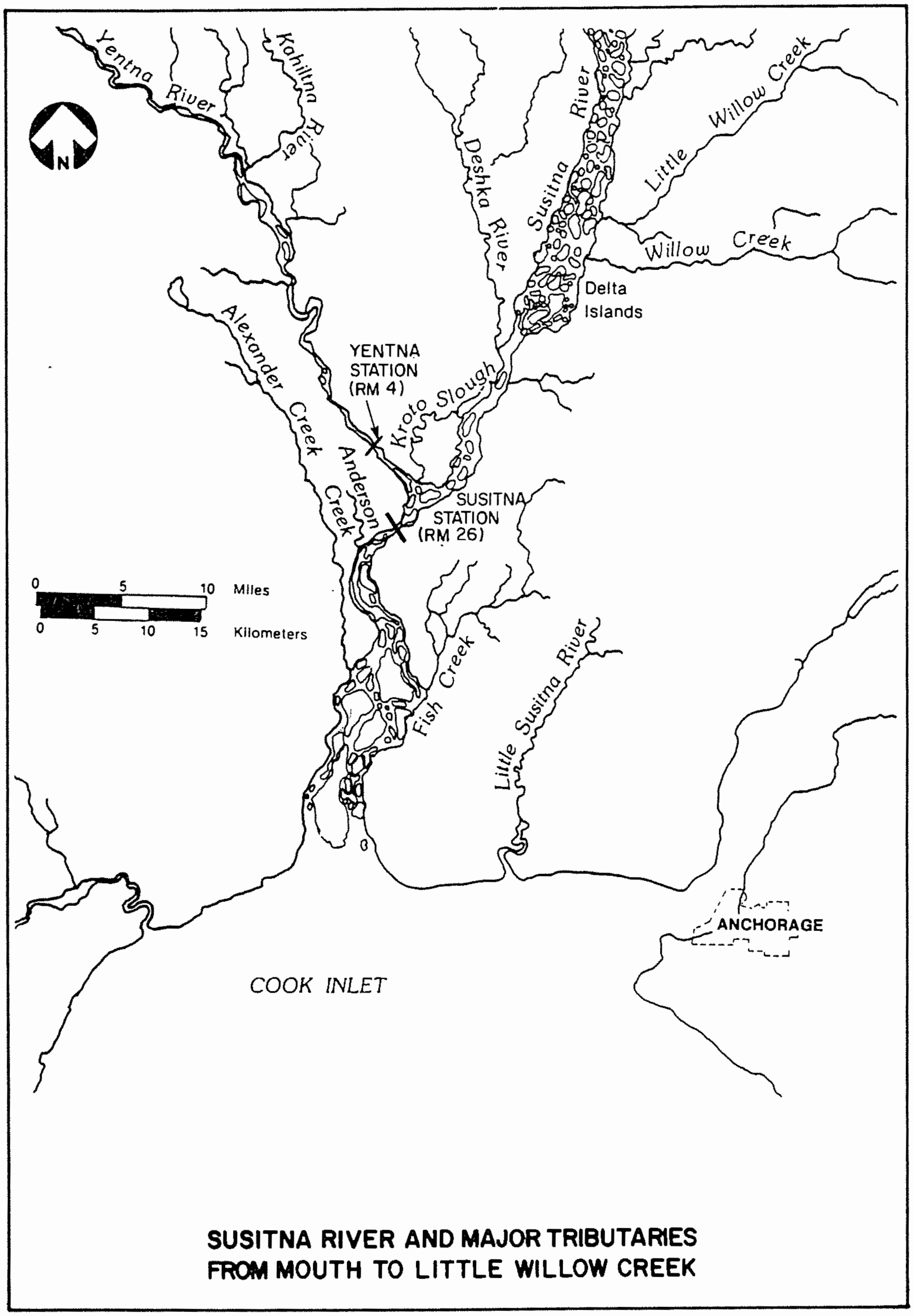


Figure I.1-11. Susitna River and Major Tributaries from Mouth to Little Willow Creek. Source: Exhibit E, Figure E.3.4.

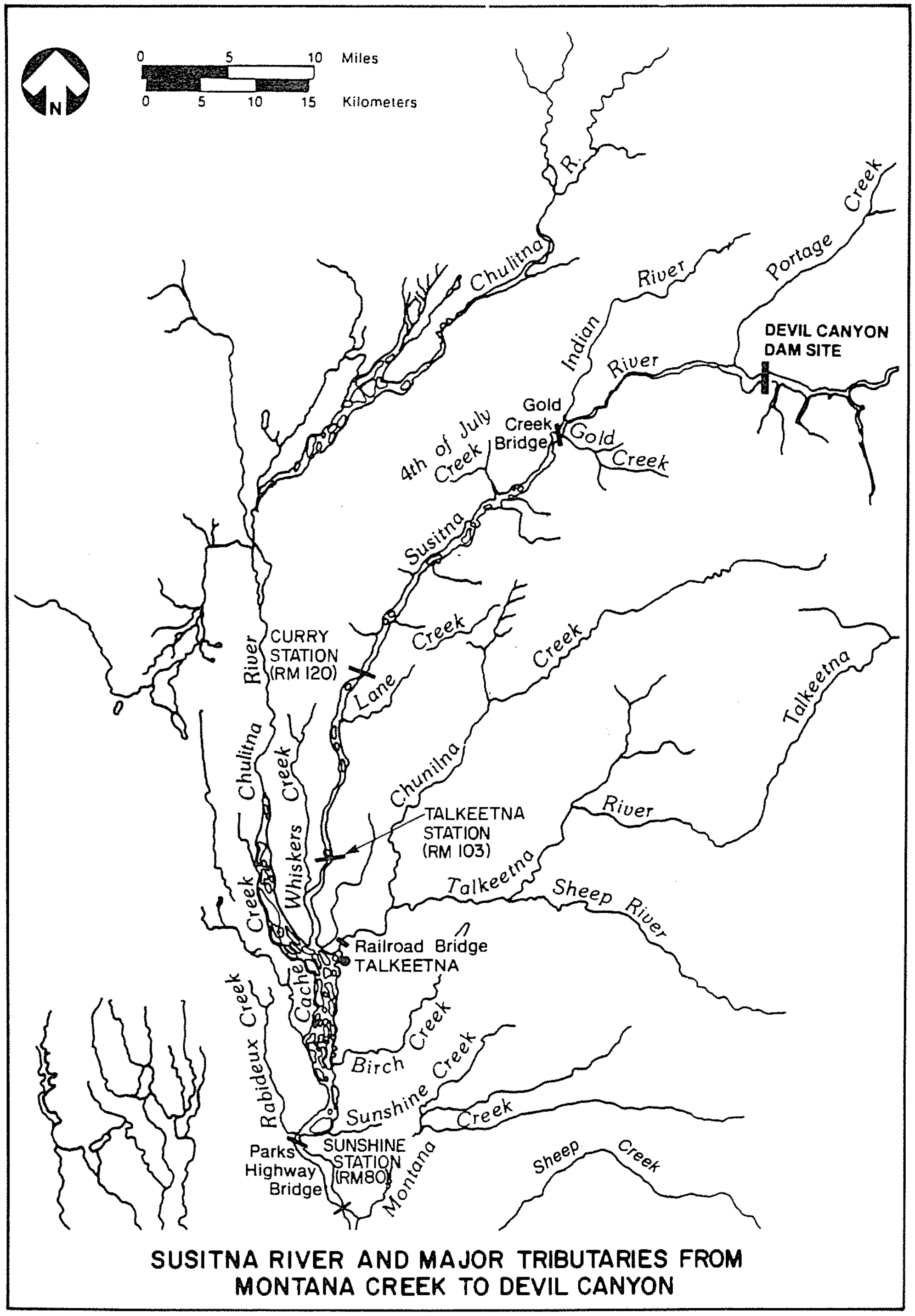
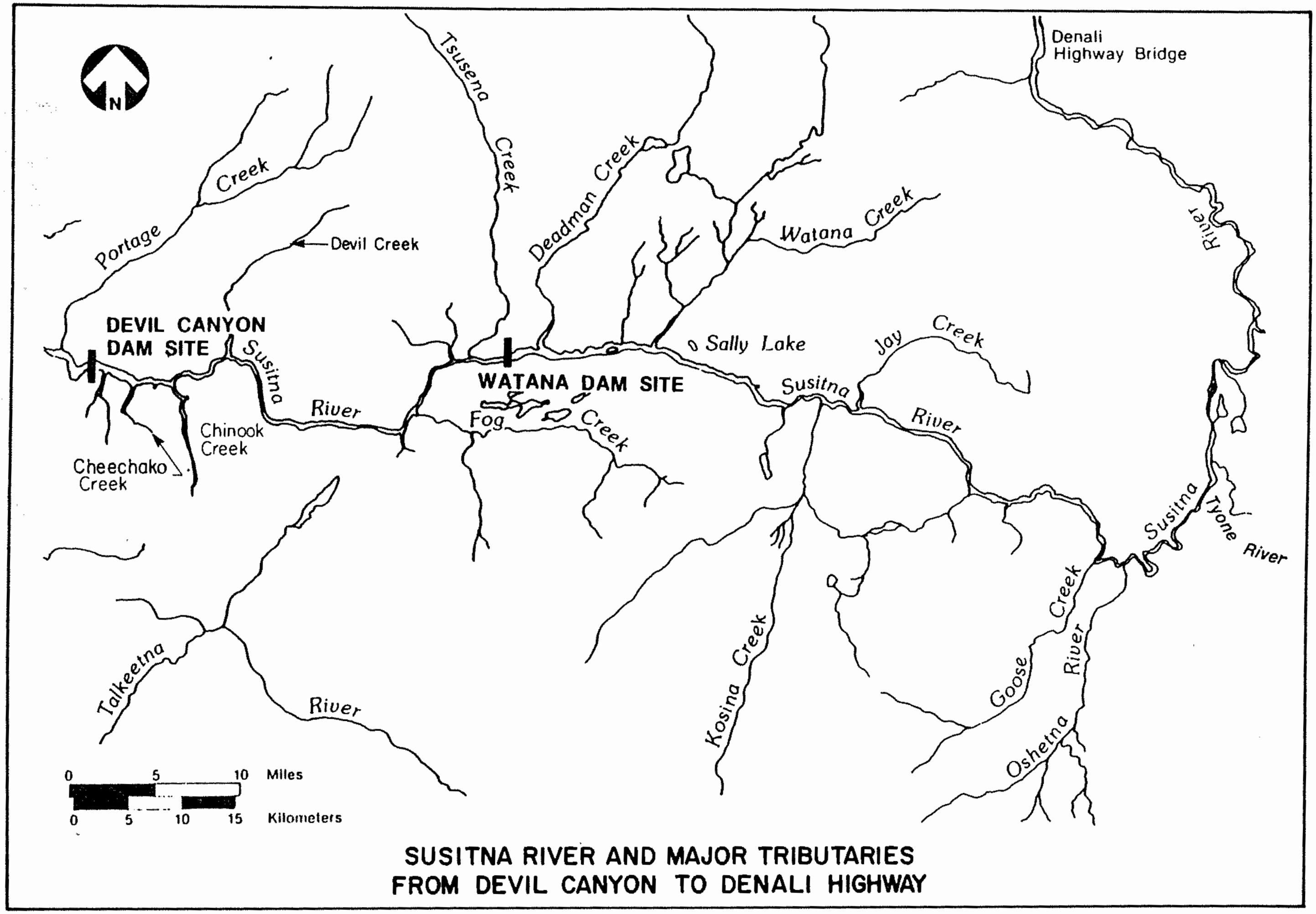


Figure I.1-12. Susitna River and Major Tributaries from Montana Creek to Devil Canyon. Source: Exhibit E, Figure E.3.5.



SUSITNA RIVER AND MAJOR TRIBUTARIES FROM DEVIL CANYON TO DENALI HIGHWAY

Figure I.1-13. Susitna River and Major Tributaries from Devil Canyon to Denali Highway.
Source: Exhibit E, Figure E.3.6.

Table I.1-8. Susitna Basin Sport Fish Harvest and Effort by Fishery and Species - 1978, 1979, 1980 and 1981

Locations	Days Fished	1978[†1]									
		KS	SS	RS	PS	CS	RT	DV	LT	GR	BB
Willow Creek	22,682	47	905	56	18,901	2,458	913	280	0	208	9
Caswell Creek	--										
Montana Creek	25,762	408	2,451	85	15,619	4,429	1,193	633	0	958	9
Sunshine Creek	--										
Clear (Chunilna) Creek	5,040	12	2,200	28	2,074	1,912	1,501	1,817	0	859	27
Sheep Creek	11,869	256	478	14	6,981	1,697	470	108	0	461	18
Little Willow Creek	5,687	0	151	28	3,142	1,015	334	63	0	334	0
Deshka River	9,111	850[†2]	1,798	0	697	0	3,634	0	0	579	0
Lake Creek	8,767	326[†2]	2,212	254	2,833	1,015	2,721	154	36	2,115	45
Alexander Creek	6,914	769[†2]	2,401	183	1,146	215	2,640	136	0	1,871	0
Talachulitna River	732	12[†2]	88	141	31	234	0	235	0	99	0
Lake Louise, Lake Susitna, Tyone River	13,161	0	0	0	0	0	0	0	2,522	2,278	2,947
Others	14,970	163	2,388	56	3,994	2,692	1,519	2,739	877	3,770	208
1978 total	124,695	2,843	15,072	845	55,418	15,667	14,925	6,165	3,435	13,532	3,263

[†1]KS = chinook salmon, SS = coho salmon, RS = sockeye salmon, PS = pink salmon, CS = chum salmon, RT = rainbow trout, DV = Dolly Varden, LT = lake trout, GR = arctic grayling, and BB = burbot.

[†2]Chinook less than 20 in.

Source: Exhibit E, Table E.3.6.

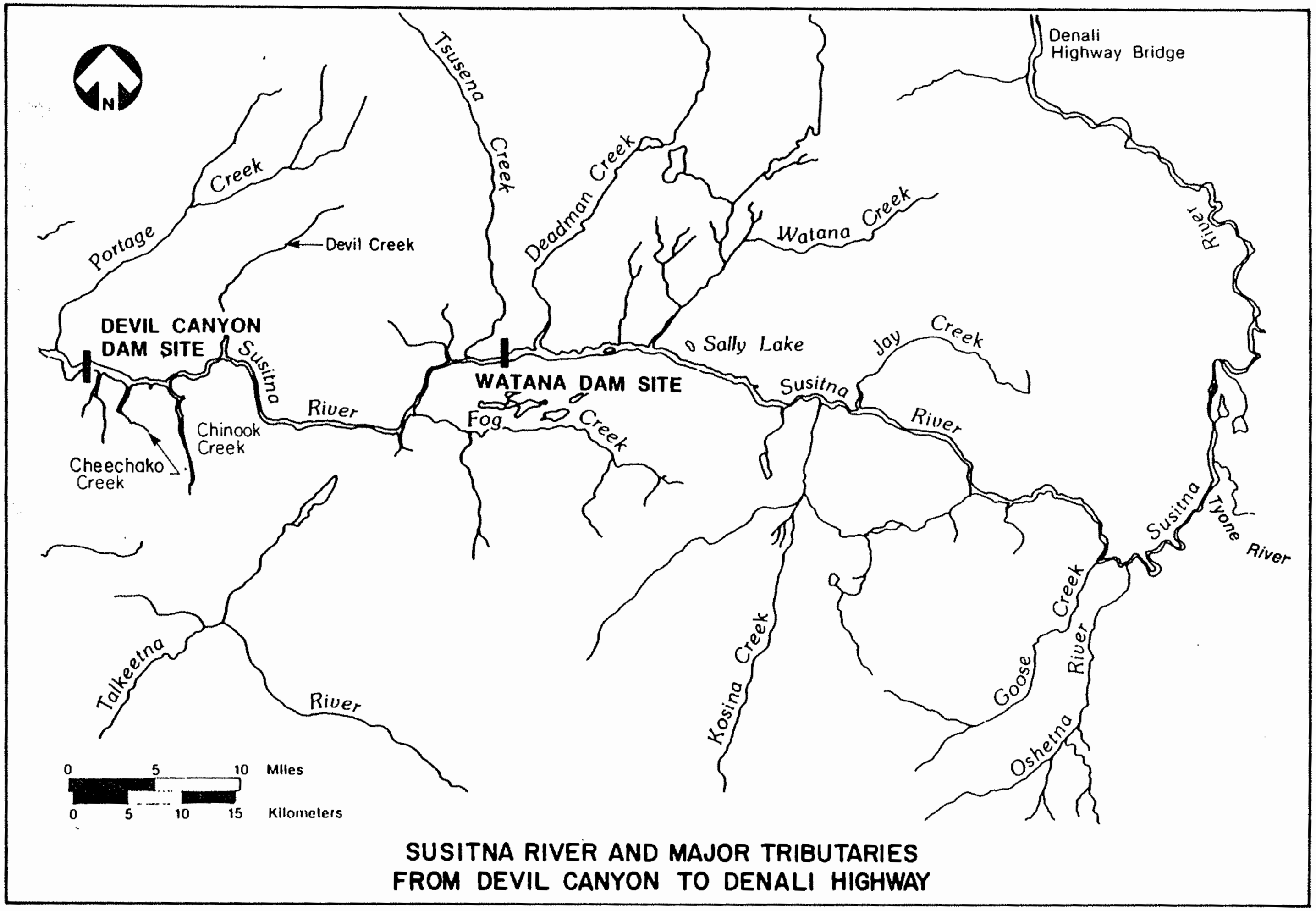


Figure I.1-13. Susitna River and Major Tributaries from Devil Canyon to Denali Highway.
Source: Exhibit E, Figure E.3.6.

Table I.1-8. Susitna Basin Sport Fish Harvest and Effort by Fishery and Species - 1978, 1979, 1980 and 1981

Locations	Days Fished	1978[†1]									
		KS	SS	RS	PS	CS	RT	DV	LT	GR	BB
Willow Creek	22,682	47	905	56	18,901	2,458	913	280	0	208	9
Caswell Creek	--										
Montana Creek	25,762	408	2,451	85	15,619	4,429	1,193	633	0	958	9
Sunshine Creek	--										
Clear (Chunilna) Creek	5,040	12	2,200	28	2,074	1,912	1,501	1,817	0	859	27
Sheep Creek	11,869	256	478	14	6,981	1,697	470	108	0	461	18
Little Willow Creek	5,687	0	151	28	3,142	1,015	334	63	0	334	0
Deshka River	9,111	850[†2]	1,798	0	697	0	3,634	0	0	579	0
Lake Creek	8,767	326[†2]	2,212	254	2,833	1,015	2,721	154	36	2,115	45
Alexander Creek	6,914	769[†2]	2,401	183	1,146	215	2,640	136	0	1,871	0
Talachulitna River	732	12[†2]	88	141	31	234	0	235	0	99	0
Lake Louise, Lake Susitna, Tyone River	13,161	0	0	0	0	0	0	0	2,522	2,278	2,947
Others	14,970	163	2,388	56	3,994	2,692	1,519	2,739	877	3,770	208
1978 total	124,695	2,843	15,072	845	55,418	15,667	14,925	6,165	3,435	13,532	3,263

[†1]KS = chinook salmon, SS = coho salmon, RS = sockeye salmon, PS = pink salmon, CS = chum salmon, RT = rainbow trout, DV = Dolly Varden, LT = lake trout, GR = arctic grayling, and BB = burbot.

[†2]Chinook less than 20 in.

Source: Exhibit E, Table E.3.6.

Table I.1-8 (Cont'd)

Locations	Days Fished	1979[†1]									
		KS	SS	RS	PS	CS	RT	DV	LT	GR	BB
Willow Creek	18,911	459	462	94	3,445	582	1,500	618	0	1,654	18
Caswell Creek	3,710	156	624	0	100	9	282	91	0	354	0
Montana Creek	22,621	312	1,735	346	2,472	745	1,536	527	0	791	9
Sunshine Creek	3,317	10[†2]	774	157	700	55	382	264	0	0	45
Clear (Chunilna) Creek	5,125	312	1,248	31	645	355	1,373	827	0	1,045	9
Sheep Creek	6,728	10	462	31	2,418	682	573	127	0	645	64
Little Willow Creek	5,171	0	262	141	745	118	345	336	0	1,091	0
Deshka River	13,236	2,811	973	0	109	0	3,182	0	0	1,463	82
Lake Creek	13,881	1,796	2,671	440	882	136	4,527	164	9	1,963	109
Alexander Creek	8,284	712	1,560	79	236	45	1,182	182	0	745	145
Talachulitna River	2,185	293	125	47	100	55	0	155	0	664	45
Lake Louise, Lake Susitna, Tyone River	12,199	0	0	0	0	0	0	0	2,618	2,936	2,363
Others	12,639	39	1,997	220	664	1,245	3,472	909	472	4,918	282
1979 total	128,007	6,910	12,893	1,586	12,516	4,072	18,354	4,200	3,099	13,342	3,171

[†1]KS = chinook salmon, SS = coho salmon, RS = sockeye salmon, PS = pink salmon, CS = chum salmon, RT = rainbow trout, DV = Dolly Varden, LT = lake trout, GR = arctic grayling, and BB = burbot.

[†2]Chinook less than 20 in.

Source: Exhibit E, Table E.3.6.

Table I.1-8. (Cont'd)

Locations	Days Fished	1980[†1]									
		KS	SS	RS	PS	CS	RT	DV	LT	GR	BB
Willow Creek	29,011	289	1,207	83	23,638	989	1,168	636	0	1,868	0
Caswell Creek	4,963	215	1,124	77	1,663	19	154	83	0	353	26
Montana Creek	19,287	559	2,684	257	8,230	571	854	167	0	655	13
Sunshine Creek	5,208	132	1,534	116	2,408	225	193	39	0	0	39
Clear (Chunilna) Creek	4,388	172	661	6	622	385	950	751	0	1,348	32
Sheep Creek	8,041	45[†2]	430	9	6,362	648	385	83	0	725	45
Little Willow Creek	8,190	32[†2]	494	77	6,420	270	353	122	0	1,156	0
Deshka River	19,364	3,685	2,290	0	689	0	4,305	0	0	1,817	224
Lake Creek	8,325	775	2,351	267	2,101	69	2,144	121	9	1,972	0
Alexander Creek	6,812	1,438	999	52	809	121	1,945	353	0	1,145	0
Talachulitna River	2,542	121	491	112	276	17	379	982	0	1,713	0
Lake Louise, Lake Susitna, Tyone River	10,539	0	0	0	0	0	0	0	2,609	4,477	6,612
Others	12,216	45[†2]	2,234	257	3,403	1,455	2,658	790	267	4,854	212
1980 total	138,886	7,389	16,499	1,304	56,621	4,759	15,488	4,127	2,876	22,083	7,203

[†1]KS = chinook salmon, SS = coho salmon, RS = sockeye salmon, PS = pink salmon, CS = chum salmon, RT = rainbow trout, DV = Dolly Varden, LT = lake trout, GR = arctic grayling, and BB = burbot.

[†2]Chinook less than 20 in.

Source: Exhibit E, Table E.3.6.

Table I.1-8. (Cont'd)

Locations	Days Fished	1981[†1]										
		KS[†2]	KS	SS	RS	PS	CS	RT	DV	LT	GR	BB
Willow Creek	14,060	144	441	747	77	2,797	1,533	1,475	249	0	1,188	48
Caswell Creek	3,860	77	172	901	38	335	0	326	38	0	144	0
Montana Creek	16,657	239	422	2,261	182	1,782	805	1,111	240	0	891	0
Sunshine Creek	3,062	57	0	968	220	958	125	249	10	0	57	115
Clear (Chunilna) Creek	3,584	86	287	422	29	19	57	1,226	1,418	0	996	0
Sheep Creek	6,936	0	0	326	105	1,236	987	201	57	0	872	0
Little Willow Creek	3,845	0	0	29	67	604	192	374	48	0	623	0
Deshka River	13,248	738	2,031	632	0	19	0	3,631	10	0	1,255	96
Lake Creek	6,471	163	632	1,035	211	412	48	2,874	67	19	1,600	29
Alexander Creek	6,892	278	843	891	67	57	10	2,290	287	0	1,130	29
Talachulitna River	1,378	57	0	240	172	29	0	0	0	0	479	0
Lake Louise, Lake Susitna, Tyone River	14,397	115	0	0	0	0	0	0	0	4,093	4,892	5,292
Others	7,850	277	0	939	115	412	450	3,851	814	287	7,089	57
1981 total	102,240	2,748	4,828	9,391	1,283	8,660	4,207	13,757	3,238	4,399	21,216	5,666

[†1] KS = chinook salmon, SS = coho salmon, RS = sockeye salmon, PS = pink salmon, CS = chum salmon, RT = rainbow trout, DV = Dolly Varden, LT = lake trout, GR = arctic grayling, BB = burbot.

[†2] Chinook less than 20 in.

Source: Exhibit E, Table E.2.6.

- Concentrated research efforts are necessary to build the type of information base that will support an increased salmon resource base and allow appropriate and effective management of it.

- Sustained long-term support of adequate staffing and project budgets on the part of the state and the fishermen will be required to realize the ambitious goals set out in the plan.

- The goals for this plan are given in Table I.1-9, where the numbers are for all five salmon species combined. A target harvest in the year 2000 of 12,000,000 salmon seems quite optimistic, but to the extent this plan is successfully implemented, it will counterbalance tne effects of increasing fishing pressure predicted in Sec. I.2.1.3.2.

Table I.1-9. Goals of the Cook Inlet Regional Salmon Enhancement Plan for Even-Year and Odd-Year Runs

	Present 1971-1980 Averages	Projected 1990 Status	Projected 2000 Status	Residual Gap	Target 2000 Status
Even-year run					
Harvestable fish	4,078,000	6,892,000	10,091,000	1,909,000	12,000,000
Nonharvestable fish	1,770,000	2,984,000	4,113,000	955,000	5,068,000
Run strength	5,848,000	9,876,000	14,204,000	2,864,000	17,068,000
Odd-year run					
Harvestable fish	3,810,000	6,092,000	9,091,000	2,909,000	12,000,000
Nonharvestable fish	1,720,000	2,584,000	3,613,000	1,455,000	5,068,000
Run strength	5,530,000	8,676,000	12,704,000	4,364,000	17,068,000

Source: Cook Inlet Regional Planning Team (1981).

I.2 ENVIRONMENTAL IMPACTS

This appendix section discusses the analytical processes used for estimating impacts of the Susitna project and its alternatives on the aquatic resources described in Sec. I.1 of this appendix. The attached environment and expected impacts are summarized in text Secs. 3.1.4 and 4.1.4, respectively.

Current uncertainty over the accuracy of modeling reservoir and river temperatures, ice processes, and changes in river morphology lends uncertainty to discussions of aquatic impacts. Nonetheless, we have taken projections by the applicant, tempered them with our own judgments about what probably constitutes typical changes due to the project, and conducted our fisheries and aquatic ecological analyses in as quantative a manner as possible. Despite the direction of most preapplication studies to the Talkeetna to Devil Canyon reach, fisheries impacts will not cease at the junction with the Chulitna River. To the extent possible with existing data, we have extended our analysis to Cook Inlet.

I.2.1 Watana Development

I.2.1.1 Plant Communities

Watana construction (including building of cofferdams, in-channel dredging, and deforestation) will introduce additional silt into the Susitna, but the quantities are estimated (Sec. 4.1.3.2) to be nominal compared to already high levels in the open water construction season. No detectable impact is anticipated to aquatic plant communities downstream of Watana which are poorly developed under present silt loadings. Aquatic plants are also poorly developed in clear-water seasons in winter due to ice and light limitation, and thus would be little affected by increased silt.

Effects of reservoir filling on downstream reaches will be similar to those of construction (silt) and operation (see section below). As the reservoir is filled, poorly developed benthic algae of the inundated river will be progressively replaced by an equally poor plankton population in the new reservoir which will be turbid due to both river inflows and erosion of banks.

During later stages of filling and normal reservoir operation, the major consequences of impounding the Susitna River with Watana Dam will be reduction in summertime turbidity and stabilization of flows (see Sec. 4.1.3.2), changes that the FERC staff judges could significantly increase benthic aquatic plant productivity and thus food availability for invertebrate and fish fauna. Turbidity in summer will remain at levels that will restrict light penetration, however, and thus inhibit maximal primary production. High stream turbidity has a negative effect on photosynthesis (by limiting light penetration) and on development of stream periphyton (by scour and covering rocky substrates), which reduces benthic productivity in general; flooding has a similar effect (Welch 1952, Hynes 1970). Information is available in the literature on the effects of hydroelectric development on benthic plant production below dams. The results can be used to consider what effects decreased turbidities and stabilized flows downstream of Watana Dam might have on benthic plant production and utilization (Iwamoto et al. 1978, Sorenson et al. 1977, Ward and Stanford 1979, Murphy et al. 1981). Specific information on the beneficial effects of dams in glacial systems on periphyton is available from the U.S. northwest (Graybill et al. 1979), Canada (Fredeen 1977), and Scandinavian studies (Heggberget in press).

Increased benthic algae production on the submerged riverbed will occur concurrently with a decrease in wetted surface area due to reduced summer flows during both filling and operation of Watana dam (Sec. 4.1.3.1). Although the balance is difficult to quantify, the staff believes that there will be a net increase in aquatic plant productivity similar to that seen at other glacial hydropower sites. Because of the overwhelming influences of the unregulated Chulitna and Talkeetna rivers on both flow and turbidity downstream of the confluences in the open water season, the FERC staff feels that no detectable change in aquatic plant communities will result. Any changes that do occur from the input of clear Susitna River water will likely be toward increased productivity.

Within Watana Reservoir, phytoplankton production in general is expected to be moderately low due to oligotrophic water quality (Sec. 4.1.3.2) and seasonally high silt loading. Settling silt will probably carry algal cells with it, effectively stripping much of the potential population (Avnimelech et al. 1982). Plankton abundances should peak in spring when turbidity is lowest, and be dominated by diatom species, as is typical of most cool lakes and reservoirs. Stratified flows caused by temperature differences within the reservoir, and affected by outlet gate location, may create reservoir detention times that vary seasonally in a complex manner and that significantly influence the development of phytoplankton communities.

I.2.1.2 Invertebrate Communities

Incremental increases in silt during Watana Dam construction that are within the range of natural variation can be expected, as for benthic algae production (Sec. I.2.1.1), to have minimal impact on benthic invertebrate communities in the Susitna River. Reservoir filling can be expected to have effects similar to those resulting from reservoir operation (below), with the exception that cold temperatures in summer will limit the anticipated benefits derived from progressively reduced silt loads. Depending on the degree of bank erosion and the rapidity with which river sediment settles in the new reservoir, turbidities during filling may continue to inhibit benthic invertebrates downstream. In the reservoir, the poorly developed benthic invertebrate community in the Susitna, and the higher populations found in clear-water tributaries, will be removed by the inundation. There will be gradual replacement of these faunas by benthic species typical of reservoirs and by reservoir zooplankton.

During later periods of filling and during operation of Watana Dam, a reduction in summertime turbidity and stabilization of river flows can be expected to be beneficial to the development of benthic invertebrate communities in the Susitna River downstream of the dam site (Hill 1972; Bjorn et al. 1977; Rosenberg and Wiens 1978). Despite losses of wetted surface (Sec. 4.1.3.1), the staff anticipates a net increase in benthic invertebrates. Sediment loads impact benthic invertebrate populations in three ways: indirectly, by reducing primary production (Sec. I.2.1.1; e.g., Hynes 1970; Ward and Stanford 1979); by clogging respiratory surfaces and/or dislodging organisms (Iwamoto et al. 1978); and by creating deposits of sand and silt in the interstices of the substrate which reduces accessibility of microhabitats and limits intragravel waterflow (Cordone and Kelly 1961; Iwamoto et al. 1978; Sorenson et al. 1977). In particular, the composition of fines less than 0.850 mm diam (typical of glacial streams) may be especially significant (Iwamoto et al. 1978).

Available studies show changes in the faunal composition, diversity, biomass, and/or abundance of the benthos in areas downstream of impoundments (e.g., Geen 1974; Ward 1976; Ward and Stanford 1979; Graybill et al. 1979), although it is difficult to determine specific causes of the changes, such as reduced sediment loads. The FERC staff believes silt load to be the preproject limiting factor for invertebrates in the Susitna. Benthic production downstream of Watana can be expected to increase after the water clears due to completion and filling of Watana Dam. This result would be anticipated based on differences in benthic populations reported between the glacially turbid Sauk River and the nearby impounded Skagit River, Washington, (Graybill et al. 1979). Species that filter reservoir-derived plankton (e.g., hydropsychids) may be important in the reaches from Watana to Devil Canyon, whereas species more typical of clear-water tributaries may dominate elsewhere. Increased winter turbidity is expected to have negligible impact when compared to low preproject benthic populations.

Because of the dominating influences of high turbidity levels and flow fluctuations in the Chulitna and Talkeetna rivers, regulation of the Susitna is not expected to result in any significant increase in benthic invertebrate populations downstream of the confluence of the three rivers.

Zooplankton can be expected to develop in the Watana Reservoir, and this community may be an important supplement to invertebrates in the Susitna River below the dam. In the Skagit River, Washington, reservoir-derived copepods and cladocerans were important constituents of juvenile salmon stomach contents downstream, becoming the dominant food item in April (Graybill et al. 1979). Watana Reservoir is expected to be oligotrophic, however (Sec. 4.1.3.2), so zooplankton populations may not be extensively developed.

The sparse riverine community of benthic invertebrates in the reaches of the Susitna to be inundated by the Watana Reservoir is expected to be replaced by an equally sparse community of Oligochaetes, chironomids, pisid clams, and benthic cladocerans such as those observed in Scandinavian glacially fed reservoirs (Grimas 1961, Grimas and Nilsson 1965). Biomass will be restricted by large fluctuations in water elevation (affecting littoral zones) and heavy sedimentation rates (affecting deep zones). The maximum benthic biomass can be expected immediately below the drawdown limit. Populations of animals normally abundant in the littoral zones of Arctic lakes (e.g., Gammarus lacustrus and many gastropods and insect larvae) will not develop there, but will occur in smaller numbers below the drawdown limit. Filter-feeding pisid clams and chironomids that normally inhabit profundal zones of Arctic lakes will be kept at low levels, even in the zone immediately below drawdown, by inflowing glacial silt and sediments eroding from the regulated area. The uniform rate of emergence of insects from normal Arctic lakes through the open water season (reflecting a high species diversity) will not develop in Watana Reservoir due to the general paucity of littoral species; instead there will be a few heavy emergences (Grimas 1961). This timing is important for fish food supply. High organic contents of flooded soils can be expected to foster benthic cladocerans in areas with moderate turbidity, but these populations should diminish after the first decade as this organic matter is oxidized and/or buried by silt. There should be a generally higher abundance of bottom animals in the vicinities of clear-water tributaries than in the main Susitna channel.

I.2.1.3. Fish Communities

I.2.1.3.1 Construction Phase

Construction of Watana Dam, from site preparation through reservoir filling, will impact fishery resources primarily through additions of silt, elimination of riverine habitat for resident species (much of which is converted to lake habitat), changes in downstream temperature, and reductions in summer flows.

Silt addition during construction of Watana Dam is judged to be a minor increase to an already high glacial silt load in most of the open water season (Sec. 4.1.3.2). Entry of eroded bank materials (where heaviest particles will deposit) and impacts to riverine fish populations beyond the local construction site are expected to be minor. Freeze-up and restricted construction activity in winter will prevent siltation during the normal clear-water months. Diminished silt loading as construction proceeds and the reservoir fills will have a generally positive effect on downstream fish populations, as detailed below under the operation phase.

Degradation and loss of spawning habitat below Watana Dam during construction of the dam itself due to increased turbidity and siltation will be minimal and localized to the first several miles below the dam site. No loss of salmon-spawning habitat is anticipated since, except for chinook during summer droughts, salmon do not spawn upriver of Devil Canyon.

As the reservoir fills, riverine habitat now utilized by resident fishes will be permanently lost at the dam construction site and permanently transformed to lake habitat between the dam and just downstream of Vee Canyon. The alteration will include lower reaches of several tributary streams. The most upstream reach of the reservoir to about the Oshetna River will lie in the regulated zone and will remain riverine during months of reservoir drawdown (winter, spring) and become lacustrine when the reservoir is storing water (summer, fall). Characteristics of the reservoir's anticipated fish populations are discussed under reservoir operation (below).

The FERC scoping process revealed concern that water quality alterations caused by impoundment of the river by Watana Dam (and later, Devil Canyon) could cause significant disorientation of adult spawners in the years immediately following closure. This disorientation might prevent a salmon from successfully locating the Susitna River at the confluence with the Chulitna River or the sloughs and tributaries used for spawning. The ability of salmon to return to the stream of their origin is well known, although in the Susitna River this homing is normally accomplished with a fairly large degree of preliminary wandering (ADF&G 1981b, 1983b). Experiences at other hydroelectric projects on Pacific coastal rivers suggest that this potential problem may be minimal, even though quantitative methods to evaluate it are not available. Migrations into tributaries more than a few kilometers downstream of new dams are usually not interrupted. Furthermore, salmon runs to watersheds cut off by a new dam typically congregate at the dam base for several years following closure until the stock is depleted. This congregation indicates successful upstream homing to the vicinity of the dam despite any changes in water quality imposed by the new reservoir.

During filling of Watana Reservoir, temperatures in the Susitna above Talkeetna may be sufficiently low in June-September to retard entry of migrating adult salmon. Salmon have been known to delay upstream migrations until appropriate temperatures have been reached (Bell 1973). Minimum temperatures reported for active migration of northern salmon stocks are 41°F (5°C) for pink salmon in Russia, 39°F (4°C) for coho and chinook, 36.5 to 39.2°F (2.5-4°C) for sockeye, and 34.7°F (1.5°C) for chum, although most stocks studied in lower latitudes show higher [43-45°F (6-7°C)] minimum migration temperatures. The requirements of Susitna River stocks are unknown. The FERC staff has estimated that midsummer temperatures of the Susitna could be near 41 to 43°F (5-6°C) at the confluence with the Chulitna [based on 39°F (4°C) release temperature and the rate of warming from sun and tributaries expected by the applicant]. This contrasts with normal migration temperatures in the Susitna of above 50°F (10°C), although the Chulitna commonly has summer temperatures in this range (Table I.2-1). Greater milling of fish at the confluence can be expected, with large numbers of adults choosing the warmer Talkeetna rather than their natal Susitna.

Pink, chum, and coho salmon spawning areas in the mainstem between Watana Dam and Talkeetna are expected to be adversely affected by the flows proposed in the filling schedule for Watana Reservoir (Sec. 4.1.1.4.1). These spawning areas are generally small, isolated areas on the river margins or behind velocity barriers. Lateral areas are more susceptible to changes in flow. The quality of these habitats will be degraded through reduced depth and velocity; some areas may be completely dewatered. In addition, some mainstem habitat still suitable for spawning during the summer will be dewatered in the early fall since fall flows at Gold Creek drop rapidly under the filling schedule. This dewatering of spawning habitat may result in a decreased percent hatch of developing embryos, although salmon tend to spawn in areas of groundwater upwelling which may not be dewatered at the lowered river stages in the fall.

Decreased mainstem flows will result in decreased depths and velocities in some side-channel habitat and complete dewatering of other side-channel habitat. This is expected to alter or eliminate the availability or suitability of some of the currently used spawning habitat. It is unlikely that new spawning areas will become available in side-channels under the filling flows. Side-channel habitats with a streambed elevation at their upstream end that is low enough to convey water during the low flows used in the reservoir filling process are currently expected to have substrate that is too large for spawning. It is unlikely that the substrate in these areas would change in a time span as short as the filling schedule. Thus, the use of these areas by spawning fish would continue to be limited by substrate.

Slough habitats between Watana Dam and Talkeetna are expected to be of the spawning habitat type most significantly affected by filling flows. In the absence of mitigation measures, filling flows are expected to cause access problems for returning adult chum and sockeye salmon. Analyses by FERC staff indicate that there will be acute access limitations during filling flows in seven out of seven sloughs above Talkeetna in July and in five of these seven sloughs in August and September (Appendix H) (Sec. 4.1.1.4.2). For salmon that do gain access, the spawning area within the sloughs will be reduced in area because of lower mainstem flows. Analyses by FERC staff indicate that for nine sloughs above Talkeetna the reduction in wetted surface area during filling flows will be 58% in July, 40% in August, and 10% in September (Sec. 4.1.1.4.2). In addition, a reduction in mainstem discharge may reduce the amount of upwelling or the area influenced by upwelling, resulting in reduction or elimination of spawning habitat (Sec. 4.1.3.2). Finally, under filling flows, increased beaver activity and lack of dam removal by spring/summer high flows are expected to inhibit use of upstream slough habitats for spawning.

Table I.2-1. Change in Potential Summer Growth of Juvenile Salmon in the Talkeetna-to-Mouth Reach Due to Filling of Watana Reservoir and Operation of Watana and Devil Canyon Dams†[1]

Month	Preproject	Watana Filling	Watana + Devil Canyon Operation
Temperatures (av °F/°C) in lower Susitna			
June	51.8/11	43.7/6.5	44.1/6.7
July	52.7/11.5	44.4/6.9	45.1/7.3
August	51.8/11	45.1/7.3	46.0/7.8
September	45.5/ 7.5	42.1/5.6	42.8/6.0
Accumulated June-September growth (g)	4.28	1.79	2.00
Reduction from preproject growth (%)		58	53

†[1]Calculations were based on assuming growth at mainstem temperatures and estimating temperatures by simple dilution. Accumulated growth was calculated on the basis of an initial 0.2-g fry that developed at weight-specific rates published for sockeye salmon. Average monthly temperatures for the reach were calculated from average temperature and flow data for the Chulitna and Talkeetna rivers and the projected minimum flows in the Susitna River during filling and operation of both dams. Temperatures for the Susitna River assume maximum downstream warming from release temperatures (4°C during filling). Warming from Talkeetna to the mouth has not been considered, but would change little due to the project.

Source: FERC staff.

If unmitigated, these impacts will reduce the number of spawning chum, sockeye, and pink salmon in the sloughs above Talkeetna, especially during the second and third year of filling. Under a worst-case scenario in which all slough spawning is lost, the applicant estimates that the total salmon run entering the Susitna River would be reduced by an estimated 11,840 chum; 9,200 sockeye, and 3,550 pink salmon, based on 1981 and 1982 escapement data (see Exhibit E., Sec. 2.3.2(b)[ii], Slough Habitat, and Table E.3.1.2).

These estimates assume harvest to escapement ratios of 2.2:1; 3.0:1; and 3.8:1 for chum, sockeye, and pink salmon, respectively (Friese 1975).

The FERC staff has reservations about this application of the ratios from Friese (1975). These ratios are presented in Appendix IV of Friese (1975), which has the following introduction:

> "The Alaska Department of Fish and Game has been requested to assign monetary values to the Susitna River salmon stocks by the Corps of Engineers. These figures will provide a basis for mitigation actions. Total escapement figures are not available for this system and it is therefore difficult to assign a value to the salmon populations. The following has been compiled by Commercial Fisheries staff biologists to partially fulfill the request. It must be emphasized that final figures are only estimates based on feelings of biologists familiar with the Susitna Basin area and do not represent facts."

In addition, the reasoning and data upon which the ratios are based are not provided. Another difficulty is that there apparently is some confusion concerning the definition of the ratio, which Friese (1975) labels "return/spawner." The applicant in Appendix E interprets this to mean "harvest/escapement," whereas Grogan (1983) interprets this to mean "total run/escapement" and claims the applicant has made an error.

Tributary habitats between Devil Canyon and Talkeetna are not expected to be directly affected during the filling of Watana Reservoir, except for Jack Long, Sherman, and Deadhorse creeks (see Sec. 4.1.3.1). Trihey (1983) indicates that accessibility of tributaries to adult salmon is not likely to be a problem at the filling flows, especially at Portage Creek and Indian River, which are the two most productive salmon tributaries upriver of Talkeetna. However, the amount of spawning in tributary habitat may be reduced because the numbers of adult salmon reaching the tributary mouths may be reduced.

Below Talkeetna, flow reductions may reduce the area of spawning habitat, since this habitat tends to be located on the lateral margins of the mainstem and in side-channel areas. Most salmon-spawning areas in the mainstem are located in broad or braided segments that are more sensitive to changes in flow. Small changes in stage near the threshold value necessary to overtop the upper end of the braided channels can potentially result in large changes in the availability of spawning habitat within the braided area.

Salmon and Bering cisco spawning habitats may be subject to change, since they occur primarily in the upper portion of this segment from RM 75 to 81. Eulachon spawning areas would be subject to the least amount of change, since they occur in the lower part of the reach, RM 45 to 58.

Spawning in sloughs and tributaries below Talkeetna is not expected to be significantly affected during filling of Watana Reservoir.

During filling, the normal winter ecology of salmonids will likely persist into summer in the Devil Canyon to Talkeetna reach of the Susitna River due to the abnormally cold [39.2°F (4°C) releases from Watana. A hypolimnetic discharge of 37°F (4°C) at Watana (Sec. 4.1.3.2) would warm during downstream flow through solar heating and tributary inflow, but this will be insufficient to even approach normal summer temperatures.

The winter ecology of young salmonids has been intensively studied outside of Alaska and the results offer indications of what could happen in the Susitna during the three-year filling period. Chinook and Coho that overwinter in freshwater as fry typically change from territorial defense and feeding activity to hiding in cover or in deep water as the temperature drops below about 41°F (5°C) (Hartman 1965; Chapman and Bjornn 1969; Bustard and Narver 1975a,b). At the maximal rates of river warming projected by the applicant in June (Exhibit E., Fig. E.2.176), this 41°F (5°C) threshold for normal fish behavior is estimated to be reached at the mouth of Devil Canyon, while at Talkeetna, river temperatures are estimated to be slightly above 42.8°F (6°C). These estimates have high uncertainty, since the FERC staff extrapolated from thermal modeling conducted for reservoir release temperatures other than 39.2°F (4°C), and the rate of summer heating expected by the applicant has been questioned by the staff (Sec. 4.1.3.2). The whole reach of river from Watana to Talkeetna would appear to be in a grey zone of uncertainty for fish behavior 39.2 to 42.8°F (4-6°C) between winter inactivity and normal, territorial feeding behavior. During months before and after June, when river heating would be less, the zone of induced "overwintering" would clearly be large. Even if fish do feed, growth rates at these temperatures are low, and FERC staff calculations (Sec. I.2.1.3.2, Growth-Temperature Relationships) show little accumulated body weight (less than one-quarter of the normal June-Sepetember growth increment). The degree to which slough temperatures will provide warm water refuges for young fish and allow more normal growth is highly uncertain.

It is likely that there will be an insignificant amount of salmon fry growth in the Devil Canyon to Talkeetna reach during the summers of Watana filling. This effect will be felt by resident fishes also, and differently by each of the five salmon species. Chum and pink salmon that emerge from redds in spring, emigrate rapidly in normally cool flows of early summer, and depend on lower river and estuarine rearing for much of their juvenile growth would be affected minimally. Sockeye apparently also leave the reach above Talkeetna rapidly and would show minimal effect. Coho and chinook, however, rear for a year or more in the river environment before descending to the ocean, and use the mainstem for overwintering. Thus, more than one year-class would be in the river during abnormal summer temperatures. They would be located there as a result of overwintering behavior the previous winter, and they would depend on summer rearing for attaining sizes appropriate for emigration. They would be affected most severely. The extent to which warmer sloughs and tributary mouths would provide enough suitable, alternative habitat to a nonwarming mainstem is difficult to judge.

Downstream of the confluence with the Chulitna and Talkeetna rivers, growth rates of juvenile salmon and resident species will also be suppressed by cool temperatures. The FERC staff estimates a reduction in accumulated June-September growth in this reach by about 50 to 60% compared to potential growth at preproject temperatures (Table I.2-1). These calculations take into account the contributions to the anticipated mainstem temperatures and flows by each of the three rivers. As in the Devil Canyon to Talkeetna reach, the impact would be greatest to chinook, coho, and sockeye salmon and resident species, with minimal effects to the spring-emigrating pink and chum salmon, and would be ameliorated to an unknown extent by fish concentrating in warmer sloughs.

I.2.1.3.2 Operation Phase

Numerous issues have arisen regarding maintenance of fish populations, especially salmon, in the Susitna River with the Susitna hydroelectric project. This section emphasizes those issues, which are organized according to major life stages of anadromous fish.

Upstream Migration and Spawning of Salmon

Between Devil Canyon and Talkeetna, the primary impacts on salmon spawning during the operation phase of the proposed project will be similar to, but less severe than, those discussed for the construction phase.

The decreased summer flows will cause access problems for adult salmon entering slough spawning habitats and will reduce the area of suitable spawning habitat within the sloughs. Analyses by FERC staff indicate that for nine sloughs above Talkeetna the frequency of occurrence of acute access limitations during operation of Watana will be 63% in July, 52% in August, and 56% in September. These analyses also indicate a reduction in wetted surface area in nine sloughs of 53% in July, 36% in August, and 9% in September (Sec. 4.1.1.4.2). Some of the present side channels will become sloughs under the summer flow regime; however, adequate information is not currently available to permit an analysis of the extent to which this change may provide new spawning habitat.

If unmitigated, and assuming that access to and availability of suitable spawning habitat are currently limiting salmon production, decreased summer flows will reduce the number of chum, sockeye, and pink salmon spawning in the sloughs upstream from Talkeetna. The worst-case scenario would be total loss of slough spawning habitat in this reach, with an estimated reduction in the total run size for these three species, as discussed for the construction phase (Sec. B.2.1.3.1).

Tributary habitats between Devil Canyon and Talkeetna are not expected to be directly affected during operation of the Watana project, except for Jack Long, Sherman, and Deadhorse creeks (see Sec. 4.1.3.1); salmon have not been observed spawning in any of these three creeks. Trihey (1983) indicates that accessability of tributaries to adult salmon is not likely to be a problem during June through September during the operation phase, especially at Portage Creek and Indian River, which are the two most productive salmon tributaries upriver of Talkeetna.

Downriver from Talkeetna (as compared to upriver), operation of Watana alone is expected to have less of an impact on spawning in all habitat types because the primary water-related variables influencing spawning (i.e., flow, temperature, turbidity, and siltation) will be changed to a lesser extent relative to preproject conditions (see Sec. 4.1.3.1). For example, the total wetted surface area of Rabideaux Slough near Sunshine will be decreased by only 22% on average in June and July (see Sec. 4.1.3.1 on Physical Habitat Availability).

Temperature changes from river to tributary. Temperature differences between a tributary and a mainstem migration corridor have been known to delay spawning migrations (e.g., Major and Mighell 1966), and this effect has been suggested for the Susitna River after mainstem temperatures have been altered. Review of available temperature predictions for the Susitna, with Watana Dam operating and the circumstances of reported migration effects elsewhere, indicates little potential for impeded migration from the Susitna into tributary streams. Documented migration blockages have been the result of tributary temperatures exceeding upper avoidance temperatures (Coutant 1977) rather than being due to the differential of temperature with the mainstem. This situation contrasts with the changed thermal relationships at the Susitna River, where tributary temperatures will not be raised but where will be some reduction of mainstem temperatures in early summer. Thermal regimes of both tributaries and mainstem will remain in the normal physiological and behavioral range during normal reservoir operation.

Gas supersaturation. Supersaturated dissolved gases in water (Sec. 4.1.3.2) are generally lethal to salmonid fishes when saturation values reach about 110% of surface atmospheric pressure (National Academy of Sciences/National Academy of Engineering 1973). Cone valves proposed for the outlet facilities to dissipate momentum should reduce the likelihood of supersaturation values exceeding 110%. There are no similar controls proposed for the spillway. Infrequent use of the spillway can be expected to cause extensive fish mortalities in the river downstream at least to the Chulitna confluence. Because water pressure at depth compensates physically for supersaturation, flood flows should provide additional depth in which migrating adults can find refuge. At greatest risk would be juvenile fishes that frequent shallow shoreline zones.

Potential salmon enhancement above Devil Canyon. Because the Susitna River and its tributaries upstream of Devil Canyon are naturally inaccessible to salmon migrations (except for rare incursion to tributaries immediately upstream during drought flows in June-August), the desirability of intervention to enhance migrations has been explored. The Alaska Department of Fish and Game's Fisheries Rehabilitation, Enhancement, and Development (FRED) Division assessed feasibility and costs of such enhancement. Although the internal reports have not been made available, the conclusion was reached that upriver expansion above Devil Canyon of anadromous salmon populations was not practicable. Reduced summer flows with Watana Dam operating could remove the barrier of turbulent flows in Devil Canyon and provide permenant access for adult salmon to Chinook, Cheechoko, Devil, Tsusena, and numerous smaller creeks. This change would open a watershed area to tributary salmon spawning that would be approximately equal in size to both Indian River and Portage Creek.

Incubation

During the July-April period, salmon eggs are incubating in gravels of sloughs and of some side channels. Changes in river flow and temperature during this time can be expected to have some impact on incubation success. The principal sources of impact are physical dewatering and reduced intergravel water flow derived from the mainstem (which are treated in Appendix H) and biological changes in incubation rate and emergence timing caused by altered temperatures and smothering of eggs by silt (as discussed below).

Redd dewatering. Operation of Watana Dam has been planned to avoid a power-peaking mode of hydroelectric generation which would require frequent changes in the amount of water released through turbines to the free-flowing Susitna River. Short-term, rapid fluctuations in downstream flow have been of concern at other hydroelectric sites, especially for impacts on developing salmon eggs, embryos, and alevins in river gravels. When salmon spawn during a sustained high discharge, subsequent reduction of flow may expose spawning beds and dewater redds. The FERC staff has reviewed field studies at several hydroelectric sites in the U.S. which have examined the effects of dewatering redds (Witty and Thompson 1974; Stillwell et al. 1977; Bauersfield 1978; Parametrix et al. 1979; McMullin and Graham 1981) and experimental studies of dewatered artificial redds containing chinook salmon. These studies have identified differing vulnerability to damage among developmental stages (Becker et al. 1982 and unpublished data). Because the Sustina River is used for mainstem and slough spawning by all Pacific salmon species except chinook, power peaking would have put spawning areas at risk. The proposed limitation of releases to the river to those of a base-load operation constitutes an effective fish conservation measure compared to a peaking mode of operation. Some redd dewatering may occur in winter above Sherman during reservoir operations. There, normal ice cover is not expected to form due to warm reservoir releases, and preproject ice damming will not be available to flood certain spawning sloughs. The amount of salmon production affected will be small, amounting to fewer than 100 spawning adults.

Egg incubation rates at altered temperatures. The large storage volume of Watana Reservoir will cause outlet temperatures during operation to be warmer than normal (preproject) in the fall and winter incubation period, although the mean annual river temperature with Watana alone will be about the same as preproject. Development rates are temperature-dependent and are important for salmon because premature emergence and early emigration induced by abnormally warm temperatures have been shown to reduce survival to the adult stage (Vernon 1958; Taylor 1980), whereas abnormally low temperatures can prevent normal development. A major factor in reduced survival of early emerging fry is believed to be their encounter with cold temperatures, inadequate seasonal food development, and high predation rates in the estuarine and marine environments (Gilhousen 1962). Earlier-emerging fry tend to be smaller than later-emerging ones in laboratory studies and field collections (Graybill et al. 1979), which may make them more vulnerable to many sources of mortality.

The staff has evaluated the incubation period of salmon eggs using cumulative "temperature units" or degree-days from the literature (where a daily temperature unit equals 1°C above freezing for a 24-h period) and regression equations published by Wangaard and Burger (1983) for incubation rate versus temperature for Susitna stocks of chum and sockeye salmon. Although temperature unit characterization is not completely satisfactory [see, for example, objections by Battle (1944) and Marr (1966), and evidence of compensatory rate changes that tend to minimize effects of altered temperatures found by Graybill et al. (1979)]. It has proven useful in hatchery management (Piper et al. 1982), laboratory investigations (e.g., Olson et al. 1970), and impact assessments of hydroelectric projects (Graybill et al. 1979). Temperature units to hatching and emergence are available for each salmon species, based largely on hatchery experiences in Oregon, Washington, and British Columbia (Table I.1-3). The Susitna stocks of chum and sockeye conform reasonably well to the published summaries, although the regression equations for incubation rates have allowed the most detailed predictions.

Accurate estimates of altered thermal conditions in salmon redds are difficult to obtain because of the complex, site-specific interactions between surface river water, mainstem infiltration, and groundwater discharge (Sec. 4.1.3.2 and 4.1.3.3). Fish spawn in areas of upwelling, although it is not clear whether the attractant is intergravel water flow, thermal differences, or relative paucity of cementing silt. In general, thermal patterns of potential water sources for incubation are: slough surface temperatures similar annually to the mainstem 32 to 55°F (0-13°C); the mainstem infiltration temperature cycle reduced in amplitude 32 to 46°F (0-8°C) compared to mainstem river water with a time lag greater in areas further from the river water source; and deep groundwater upwelling with a temperature fairly constant [36 to 39°F (2-4°C)] due to slow movement of interstitial water and averaging of summer and winter percolation by thermal retention of the gravel (Acres 1983). Although field studies are under way to characterize flow and thermal patterns in areas used for spawning, present relationships remain incompletely understood (Trihey 1982). With altered river flow, the relative contributions of the thermally different sources to a spawning area may change. (See Sec. 4.1.3.2 for a further discussion of groundwater temperatures.) Considering the uncertainties in estimating actual incubation temperatures, the preliminary analysis has focused on altered mainstem river temperatures [as was done by Graybill et al. (1979)] and the potential shifts in incubation rate patterns that they would cause. In addition, we used a typical slough temperature pattern as described by Wangaard and Berger (1983). As more complete data on actual redd temperatures become available, the analyses can be extended.

The major potential incubation impact of the Susitna project is acceleration of development rates by warmer temperatures in autumn months (Figure I.2-1; Table I.2-2. Under general river temperature regimes predicted by the applicant, corrected for warming and/or cooling as discharges traverse the Devil Canyon to Talkeetna reach, early-spawning pink and chum salmon (mid-July) could complete development to the emergence stage by mid- to late October with Watana alone, rather than early spring. Later pink and chum spawning and even early spawning of slower-developing sockeye and coho are less affected and are predicted to emerge more normally in late winter to spring. These projected effects reflect rapid egg and embryo development that would ocur at the prolonged summer-like river temperatures in September and early October that are maximum for early spawners. The long-term impacts to chum and pink salmon populations can only be estimated with additional studies to determine more realistic temperatures for spawning gravels throughout the incubation season. In the worst-case scenario in which there is loss of all chum and pink salmon that incubate in the sloughs, the total run to the Susitna River would be reduced by an estimated 11,840 chum and 3,550 pink salmon (see Exhibit E, Sec. 2.3.2 (b) [ii], Slough Habitat).

The impact would be considerably less for later-spawning fish. Chum salmon spawned on August 15 at mainstem temperatures such as those that could occur downstream of Watana near Sherman could complete yolk absorption by mid-May compared to an abnormally protracted early August completion at preproject mainstem temperatures (normal emergence from slough gravels is in April according to field data) (Figure I.2-2). This is still delayed, however, compared to incubation rates in the warmer waters of a typical slough.

During winter, ice that forms while the river is at higher than historic flows can be expected to cause staging that will overtop side sloughs used for salmon spawning (mostly chum and sockeye). This overtopping would decrease temperatures in slough gravels in which salmon eggs incubate and lengthen the time required for emergence. The significance for salmon would depend on the time of year when it occurred. Overtopping early in winter would retard development to the greatest extent. Cessation of overtopping in the spring, and reversion to groundwater temperatures, would also influence emergence timing. Figure I.2-2 illustrates two overtopping scenarios; a late November overtopping could extend incubation into late May or June. If overtopping ceases in March or April as warmer reservoir surface water is released from project dams, then the changes in emergence timing could be insignificant.

Effects of silt on incubation. Incubation mortality has been identified as the most important factor governing year class strength of pink salmon in southeast Alaska streams (McNeil 1968) and of sockeye salmon in Cedar River, Washington (Stober et al. 1978), and it is undoubtedly of major importance for all salmon. Siltation is the principal nemesis of incubating eggs in river gravels, as several studies have shown an inverse relationship between the amount of the sediment in spawning gravels and emergence success of salmon and trout fry (Bjornn 1969; Phillips et al. 1975; McCuddin 1977; Tappel 1981). Winter silt loads from operating the Susitna reservoirs have the potential of reaching levels detrimental to downstream redds. The predam pattern of high turbidities in open water seasons and clarity during freeze-up will be altered by the large storage capacities of the two reservoirs (see Sec. 4.1.3.2).

Quantitative data on embryo survival under various levels of water turbidity are available from experimental research related to mining (e.g., Shaw and Maga 1943) and forestry practices, but the uncertainties of project alterations due to the Susitna project make quantitative evaluations tenuous. Analogies with existing glacial lakes such as Eklutna suggest that residual turbidity from operation in winter will not be detrimental. There, the

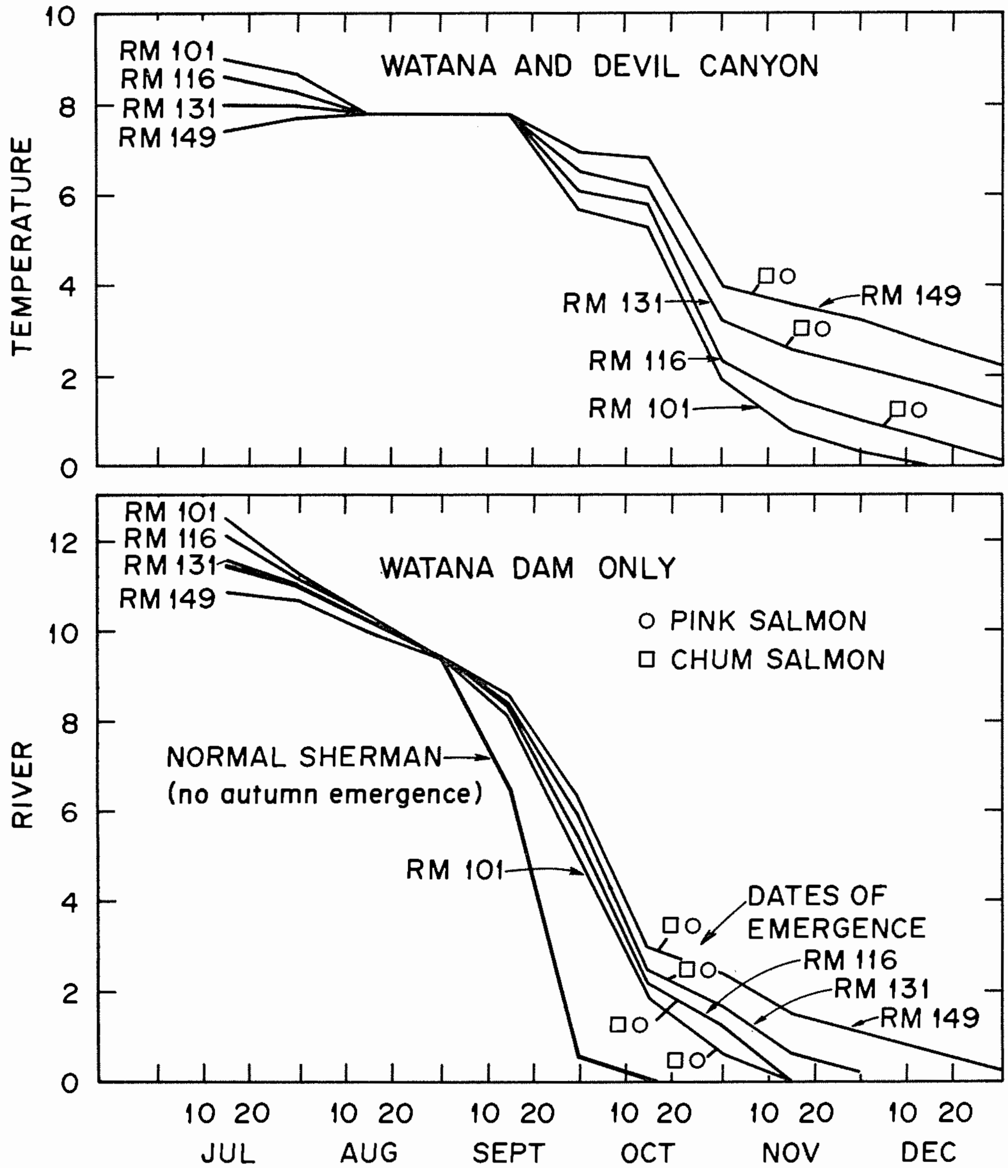


Figure I.2-1. Predicted early emergence of pink and chum salmon spawned on July 15 at four locations in the Susitna River between Devil Canyon outlet (RM 14a) and the Chulitna junction (RM 101). Watana alone (lower) and Watana and Devil Canyon (upper).

Table I.2-2. Dates Estimated for Emergence of Salmon Fry that Experience July-April Temperatures Projected for the Susitna River at Several Locations Between Devil Canyon and the Chulitna River Confluence. Temperatures were not Projected after April 30

	Temperature Profiles, Watana Only †[1]					Temperature Profiles, Watana and Devil Canyon †[1]				
Starting date	Preproject at Sherman	RM 101 (Confluence)	RM 116	RM 131 (Sherman)	RM 149 (Devil Canyon)	Preproject at Sherman	RM 101 (Confluence)	RM 116	RM 131 (Sherman)	RM 149 (Devil Canyon)
July 15										
Pink	*	10/29	10/21	10/19	10/17	*	4/15	12/5	11/14	11/7
Chum	*	10/29	10/21	10/19	10/17	*	4/15	12/5	11/14	11/7
Sockeye	*	*	*	*	*	*	*	*	4/2	1/17
Aug. 15										
Pink	*	*	*	*	*	*	*	*	4/29	2/5
Chum	*	*	*	*	*	*	*	*	4/29	2/5
Sockeye	*	*	*	*	*	*	*	*	*	*
Coho	*	*	*	*	*	*	*	*	*	4/30
Sept. 15										
Chum	*	*	*	*	*	*	*	*	*	*
Sockeye	*	*	*	*	*	*	*	*	*	*
Coho	*	*	*	*	*	*	*	*	*	*
Oct. 15										
Coho	*	*	*	*	*	*	*	*	*	*

†[1] = after 4/30.

Source: FERC staff; Temperature units derived from Piper et al. (1982).

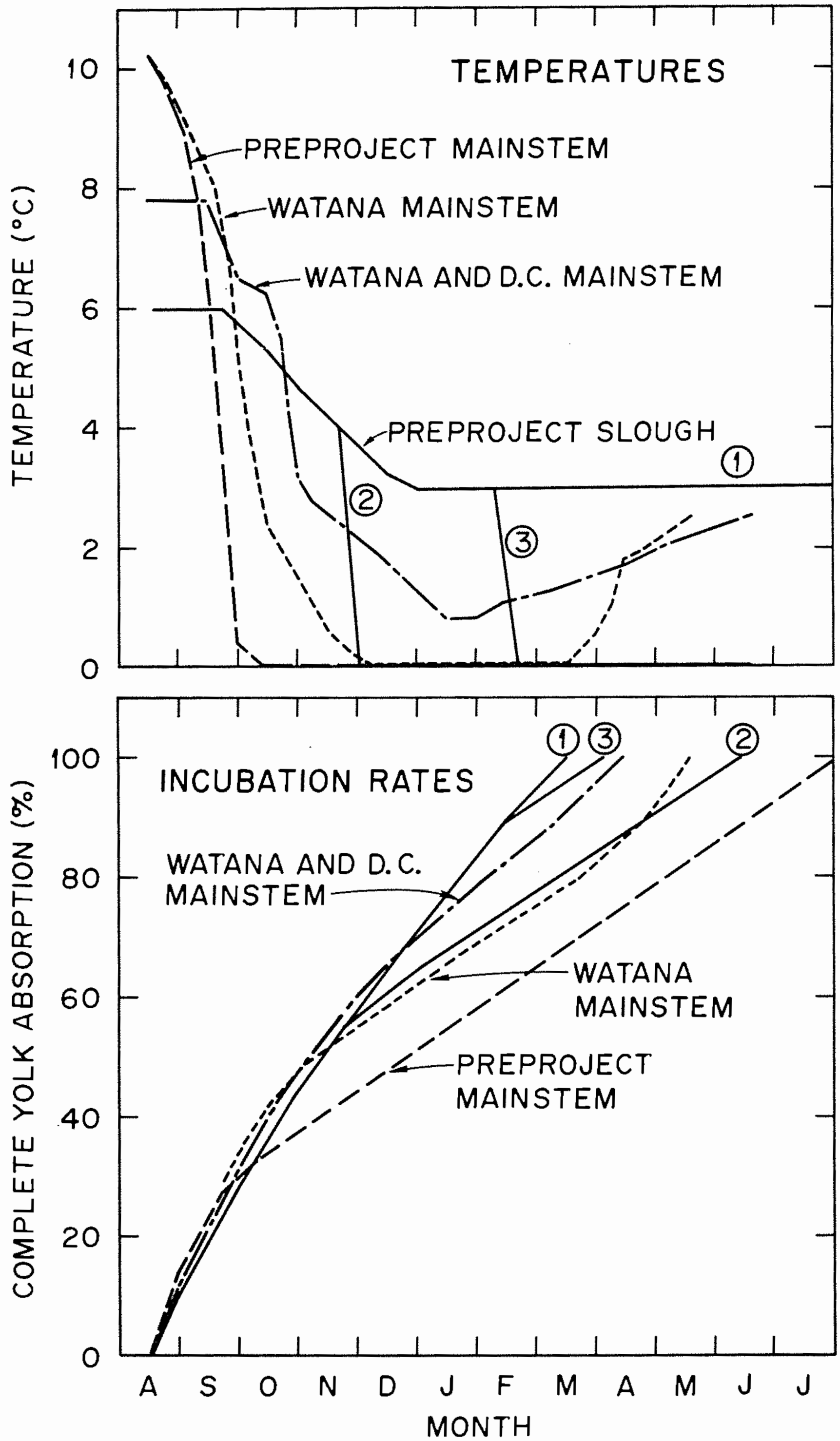


Figure I.2-2. Incubation rates for chum salmon spawned on August 15 under different temperature scenarios. (a) preproject mainstem at Sherman, (b) Sherman mainstem with Watana Dam alone, (c) Sherman mainstem with Watana and Devil Canyon dams, (d) intergravel in a preproject slough, (e) and slough intergravel at two overtopping dates, November and February. Mainstem temperatures were developed by the staff from the application. Slough temperatures and regression equations for incubation rate modeling were those of Wangaard and Berger (1983).

Cook Inlet Aquaculture Association has built a salmon hatchery at the power tunnel tailwater. Turbidities remain higher than in normal stream water in winter, and some deposition of fine silt on the chum and coho eggs incubated experimentally in 1980 and 1981 was observed, but emergence success was high (98.4% in 1982-83) even for hatchery standards (CIAA 1983a, 1983b). The FERC staff believes Eklutna will be representative for turbidity retention and winter release at the Susitna project.

There would be negative impacts on incubating salmon eggs in side channels and overtopped sloughs if there is heavy erosion of banks, islands, and gravel bars under winter operational conditions of elevated river flows and ice staging (Sec. 4.1.3.2). Such channel reconfiguration may occur only in the first few years of operation. The degree of impact is speculative at present, but would likely amount to localized losses of redd production. The impacts on overall populations may be minor.

Juvenile Rearing

Growth-temperature relationships. Fish growth is temperature-dependent, and alteration of river temperatures below the Susitna project dams will cause some change in growth rates that are physiologically possible. The expectation of changed growth is of particular concern for juvenile salmon of all five species that develop in the river for varying lengths of time prior to and during their seaward migration. It is known that larger fish at time of entrance to the ocean have a higher likelihood of surviving to adulthood (Foerster 1954; Levanidov 1964; Kanidyev et al. 1970; Taylor 1980).

The possible magnitude of change in potential growth rate of young salmon has been calculated (Figure I-2-3) for temperature patterns projected by the applicant at downstream locations in the Devil Canyon to Talkeetna reach. For purposes of this analysis, several assumptions relating to both temperatures and fish growth were made. Temperature patterns between May and November were derived from figures in the application for four representative locations spaced about equidistant in the Susitna River between Devil Canyon and the confluence with the Chulitna River: (1) River Mile (RM) 149 just below the canyon, RM 131 near Sherman, RM 116 near Lane, and RM 101 near the confluence. Consideration of several locations was advisable because water released from the dams will warm or cool in transit downriver, depending on the time of year and the discharge temperature (a factor considered in temperature projections by the applicant). Because the applicant's thermal models were not run uniformly through the entire open-water period, however, some judgment was required to generate a typical postproject operational pattern for all four stations. Similarly, variations in temperature caused by short-term weather patterns were smoothed for the applicant's predicted temperatures and measured values. In some cases, the FERC staff estimated temperature changes markedly different from those projected by the applicant; in those cases, the resulting differences in growth patterns are identified. For fish growth, there were several assumptions: (1) an increase in weight could occur only at temperatures above 37.4°F (3°C), (2) all five salmon species would exhibit the well-established pattern of weight-specific growth at different temperatures demonstrated for sockeye salmon (Brett 1974), (3) growth started at 0.2 g, and (4) all fish would feed to satiation (thus demonstrating growth potential under the various thermal regimes uncomplicated by limited food supply, which will be discussed separately). For each thermal pattern, Figure I.2-3 shows cumulative wet weight during the growing season, in a manner recommended by the National Academy of Sciences/National Academy of Engineering (1973) for evaluating long-term thermal effects on fish growth.

The results indicate little alteration of currently achievable growth under mainstem temperatures when Watana Dam alone is in place. With Watana Dam alone, retention of warm water in the river in autumn (due to storage in Watana Reservoir) generally compensates for somewhat delayed (but similar) summer peak temperatures in determining the cumulative annual growth of those species that remain all year (chinook, coho). If chum, pink, and sockeye salmon continue to migrate out of this reach of river by the end of July, their growth could, however, be reduced by nearly 30%. Calculations were also made for the Talkeetna to mouth reach, where it is reasonable to conclude that there will be reduction in growth of similar or lesser magnitude. Thermal modeling by FERC staff has questioned whether warmer waters will persist in the river in the autumn (Sec. 4.1.3.2); if temperatures do not remain warm, then annual growth for chinook and coho salmon would be reduced.

Whereas these calculations have used weight-specific growth data for sockeye salmon (because they are most complete), hatchery managers have long realized that there are quantitative differences in the way temperature controls growth of each species (Burrows 1963). For example, sockeye grow faster between 40°F (4.4°C) and 60°F (15.6°C) than chinook, although the growth rates of chinook accelerate more rapidly with temperature increases in this range. For every 10 degree rise in this range, food consumption increases 45% in sockeye and 60% in chinook. Altered temperatures, and thus growth rates, in the Susitna following dam construction would likely favor the species most capable of growing best in cooler water (which appear to be sockeye and pink salmon).

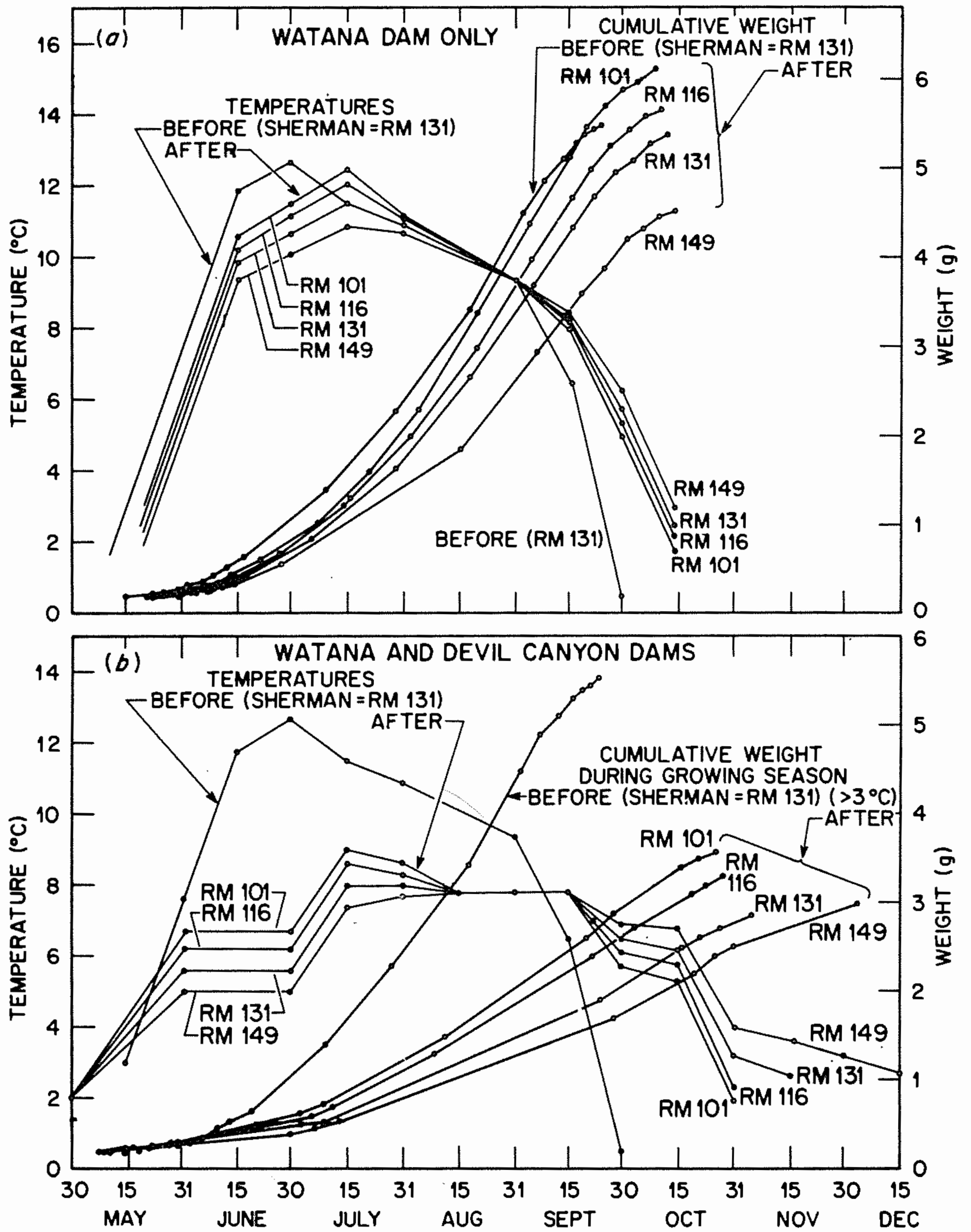


Figure I.2-3. Temperature and cumulative growth for representative juvenile salmon in the Susitna River between Devil Canyon and Talkeetna, before and after the project.

Food availability. Major consequences of impounding the Susitna River will be reduction in summertime turbidity and stabilization of flows, changes that could significantly increase benthic productivity and thus food availability for fish fauna (see Sec. 4.1.3.2 and Appendix I, Sec. B.2.1.2). Changes in fish populations below dams have been documented in a number of instances (e.g., Spence and Hynes 1971b; Ward and Stanford 1979) and include changes in faunal composition, diversity, and abundance. However, specifically linking changes in invertebrate populations with changes in fish populations has proven difficult (Spence and Hynes 1971a). Evidence that changes in fish populations could occur in the Susitna comes from studies of other subarctic hydroelectric developments. Following reduction in glacial turbidity in the River Skjoma, Norway, there was an increased production of algae, increased density and growth rate of presmolt Atlantic salmon (Salmo salar), and a more rapid commencement of seaward emigration by the older fry (Heggberget in press). Part of this effect may, however, have been due to simultaneous increase [4 to 7°F (2-3°C)] in summer temperature. Huntsman (1948) also observed that increased growth of algae leads to increased density of presmolt streamdwelling salmon in Canada.

Decreased summer flows in Norwegian streams due to hydroelectric development also caused increased densities of bottom invertebrates (Koksvik 1977). In the United States, Graybill et al. (1979) demonstrated that a decrease in water-level fluctuations below a dam on the Skagit River, Washington, led to better benthic production, better utilization of aquatic insects by salmon fry, fewer empty stomachs, and better growth.

Zooplankton originating in an upstream reservoir can be an important supplement to food resources for downstream salmonids, and may become important in the postimpoundment Susitna. In the Skagit River, Washington, reservoir-derived copepods and cladocerans were important constituents of chinook and coho salmon stomach contents, becoming the dominant food item in April (Graybill et al. 1979). Reduced turbidity could directly affect fish feeding by increasing the efficiency of sight feeders as shown in experiments by Noggle (1978), although this effect could be detrimental to small chum and pink salmon that could be fed upon by older chinook and coho or resident fishes such as rainbow trout and Dolly Varden.

The degree to which increased fish food availability per unit area in the Susitna during project operation will offset the effects of a decrease in wetted perimeter and reduced water temperatures is a matter of speculation without quantitative studies of the present condition and more thorough predictions about changes. Because thermal changes with Watana alone are relatively small, it is likely that overall productivity of the Susitna from the dam to Talkeetna will rise and juvenile salmon production should increase. Undoubtedly, reduction in turbidity and flow stabilization offer important management opportunities for Susitna River salmon.

Debris dams and juvenile salmon habitat. Woody debris (trees, stumps, logs, brush) in the present Susitna creates small pools and backwater areas at certain locations used by young salmon for resting and feeding. Blockage of upstream sources of this debris and reductions in peak flows that erode wooded riverbanks could lead to depletion of such debris in the river by progressive washout downstream, and thus degradation of rearing habitat. The importance of woody debris in salmonid nursery streams has been reviewed recently by Bryant (1983). He concluded that unless there is clear blockage of either upstream or downstream migration, debris damming within a stream channel benefits rearing habitat and the debris should be left in place. Quantitative data are not available for either the significance of debris for sustaining salmon habitat in the Susitna or the quantities in the various reaches below the dam sites that are derived from sources above them. A speculative appraisal suggests that sufficient debris is available from tributaries (e.g., Portage Creek, Indian River) and wooded riverbanks to provide adequate juvenile habitat. No effects should be discernable below Talkeetna where the Chulitna and Talkeetna rivers are heavily laden with woody debris.

Winter ecology of young salmonids. Elevation of winter temperatures in the reaches downstream of the dams will be a project modification that may affect the behavior and survival of overwintering fishes. The temperature alteration will be most pronounced close to a dam outlet and it will be moderated downstream by low air temperatures and cold tributary inflows (see Sec. 4.1.3.2). The winter ecology of young salmonids has been the subject of intensive study outside of Alaska, and the results offer indications of what could happen in the Susitna when Watana Dam is in operation. The species that overwinter in freshwater as fry typically change from active feeding and territorial defense to hiding in cover or in deep water as the temperature drops below about 41°F (5°C). (Hartman 1965; Chapman and Bjornn 1969; Bustard and Narver 1975a,b).

If 41°F (5°C) threshold for inducing behavioral changes is germane to Susitna populations (currently untested), then even the most elevated temperatures in winter will still be below it, and a normal annual behavior cycle will occur. The pronounced lag in autumnal cooling projected by the applicant, however, will delay onset of inactivity. When compared to preproject Susitna River temperatures at Sherman, the delay of onset of 41°F (5°C) would be about 10 to 20 d (depending on distance downstream) with Watana Dam alone (Figure I.2-3). The significance of such delays is unclear, but it could be positive (through prolonged time for feeding and growth) or negative (through added time for predation). If the balance of food intake and energy requirements of maintenance metabolism during winter hiding is crucial to overwintering survival of young salmon in the Susitna, as it is for some other fish species elsewhere (Shuter et al. 1980), then an increased period of feeding activity and growth would be a definite advantage.

Fry stranding by fluctuating flows. A common problem below hydroelectric dams is mortality of juvenile salmonids by stranding when flows are reduced diurnally (Thompson 1970; Phinney 1974; Bauersfeld 1978). Factors influencing the magnitude of such mortalities are biological (e.g., the seasonal abundance of each species in shallow water areas), physical (the topography and substrate composition of the channel), and operational (magnitude, time of day, and rate of flow fluctuation). Field studies (e.g., Graybill et al. 1979) have indicated that shoreline-feeding species, particularly chinook salmon, are especilly vulnerable, whereas pink and chum (which emigrate rapidly in the main channel) are less affected.

The Susitna project as currently conceived will not introduce peaking power water fluctuations to the river below Devil Canyon; there will instead be stabilization of naturally occurring freshet flows in summer. Any mortalities currently caused by stranding following freshets should be reduced.

Salmon Emigration

Temperature and spring migration of salmon smolts. Generally warmer winter temperatures in the Susitna River below Watana Dam may mean an earlier breakup of river ice, warmer river temperatures earlier in the season, and potential advancement of the timing of smolt out-migration. Because the timing and variability of normal river temperatures, ice break-up, and beginning of smolt emigration are still poorly characterized for the Susitna, estimation of impacts is speculative and based on what has been observed elsewhere.

The break-up of ice cover in the spring is probably an important timing cue for the initiation of some migrations. Ice may block migration prior to break-up, and there would be a physiological advantage to moving to feeding areas as soon as possible in the spring. Most research showing correlations of out-migration with ice break-up has involved sockeye salmon (Burgner 1962a,b; Brannon 1972; Hartman et al. 1967; Foerster 1937; Groot 1965). Short-term elevations of temperature stimulate pulses of migration and cool temperatures decrease migration (Hartman et al. 1967). That temperature rise can stimulate out-migration has been confirmed with behavioral experiments. Chum fry, coho fry and smolts, and sockeye smolts all switch from positive rheotaxis (orientation upstream) to negative rheotaxis in response to sudden increases in temperature when tested in small circular tanks (Hoar 1951; Keenleyside and Hoar 1955). However, temperature is obviously not the only factor timing the migration. Coho smolt migration seems to be initiated by lunar control of thyroxine levels (Grau et al. 1981). Similar mechanisms may occur as backup timing systems in all salmon species.

It seems reasonable to conclude that advancement of river temperatures in spring may have a concomitant advancement in out-migration of juvenile salmonids. This advancement could be detrimental for the populations involved if negative effects of early entrance to cold coastal waters seen by Gilhousen (1962) and Taylor (1980) hold for Susitna River stocks.

Salmon Population-Level Effects

Shifts in relative abundance among salmon species. Potential shifts may occur in relative abundance of the five salmon species due to different directions or degrees of response to dam-induced environmental changes. Such shifts could be important for fisheries in both the river and in Cook Inlet and might be avoided if deemed disadvantageous.

The five species have partitioned the aquatic environment in innumerable ways so that all five coexist. Some partitioning is obvious, such as chinook utilizing tributaries for spawning exclusively, whereas sockeye and chum frequently spawn in sloughs. Pink and chum make a rapid smolt emigration in spring and summer, while coho, chinook, and probably sockeye (from Talkeetna to the mouth) remain in the river for one or more years. More subtle differences among species exist as well, such as in growth responses to temperature levels, in food resources used, or types of cover selected. As the numerous features of the environment fluctuate from year to year, the relative advantage for one species shifts to another, back and forth, with a general cyclic, "dynamic dis-equilibrium" of relative population sizes being established that is characteristic of the river system. Hutchinson (1953, 1961) theorized about such dynamic influences that kept closely interacting species from excluding one or the other through competition. Subsequent experimentation has shown that random environmental fluctuations could maintain diversity in stream communities (Patrick 1975) and in communities of lake plankton (reviewed by Hutchinson 1975). Differences in temperature-dependent growth rates and their effects on relative survival of two closely related warm-water fishes have been reported (Coutant and DeAngelis 1983).

Differences in effects among salmon species are sufficiently clear for some sources of change to project changes in relative abundance (see previous section). Other are not well enough quantified to give much guidance regarding relative advantages/disadvantages of the environmental changes to be induced by the Susitna project. Some that are quantified, such as difference in growth rates at different temperatures, may not be quantitatively germane to Susitna stocks. It is apparent that environmental partitioning is somewhat different in major ways in the Susitna than elsewhere. For example, chinook in the Susitna are tributary spawners, whereas in other systems (e.g., the Columbia River) they utilize mainstem sites. More subtle characteristics of the Susitna species balance no doubt differ from those of other areas as well. Currently, it appears that stocks of chum and sockeye salmon could be the most severely impacted by operation, due to potential loss of spawning in sloughs. Pink may be severely impacted by reservoir filling and fail to recover due to the short life cycle. As the project impacts to environmental features become better defined and quantified, and as the fish populations are better understood, clearer projections about relative advantages may be made. The state of basic knowledge and ecological theory related to competitive processes makes most predictions speculative at this point.

See Sec. I.2.2, Summary of Environmental Impacts on Salmon Populations, for a discussion of the expected long-term trends in salmon populations and effects of changes in abundance of salmon stocks on fisheries. This discussion includes consideration of the construction phase and operation phase of Watana development and Devil Canyon development together.

Watana Reservoir Fish Fauna

A large number of studies have documented characteristic changes in fish fauna of rivers when they are dammed for hydroelecteic purposes. Migratory species (either anadromous or having extensive riverine movements) generally disappear, pelagic species increase dramatically if they are present in the watershed (usually in small lakes that are flooded), and certain littoral zone predatory game fish such as pike expand.

Habitat potential for fish in Watana Reservoir is limited by cold temperatures, low productivity, high silt loads in summer months, and large drawdown that will prevent development of a littoral zone (Sec. 4.1.3.2). Studies in Scandanavia (e.g., Grimas and Nilsson 1965) provide useful analogies with what can be expected in Watana and Devil Canyon reservoirs. Grayling have effectively colonized new Scandanavian reservoirs especially near tributary mouths where they depend heavily on terrestrial insects for food. Char (Arctic char, Salvelinus alpinus, found in Scandinavia, to which the Dolly Varden is closely allied and may be the same species; Krueger 1981b) differentiated rapidly in Scandinavian lakes into discrete populations that exploit different food sources, including benthic invertebrates and pelagic zooplankton (ISACF 1980). Resident Dolly Varden in tributaries in the impoundment reach should find the reservoir to be an excellent wintering lake, comparable to lakes generally utilized elsewhere in its range (Krueger 1981b). Whitefish have remained important in some Scandanavian reservoirs but have declined in others, particularly as the reservoirs have aged. Burbot have remained. The species that regularly formed denser populations were roach and perch (pelagic species for which there are no current analogs in the upper Susitna) and northern pike. Introduced species, lake and rainbow trout, which are already present in the Susitna, have become important in European alpine lakes and reservoirs.

The applicant evaluated the annual drawdown cycle of Watana Reservoir in relation to fish spawning. Winter dewatering and spring flooding (Sec. 4.1.3.1) are both of concern for successful reproduction in the reservoir. Grayling will spawn in flowing water of tributaries during the low-water period of May and June, and embryos below about elevation 2133 ft (646 M) will be inundated before hatching and likely killed. Humpback whitefish and burbot spawn in the reservoir generally at depths less than 20 ft (6 M) in October-December. Reservoir drawdown in winter will dewater embryos. Lake trout also spawn in the reservoir, but at depths of 3 to 110 ft (0.9 to 33 m) in September-October; later, deeper spawning areas will survive winter drawdown. Dolly Varden eggs, which are laid in tributaries in the fall, will not be affected by the drawdown cycle. Rainbow trout, not evaluated by the applicant, will likely be restricted in a manner similar to grayling.

In addition to year-around resident fishes, Watana Reservoir is expected to provide important new overwintering habitat for fishes that occupy tributaries and the Susitna upstream of the Oshetna River.

Kokanee (landlocked sockeye salmon) is the most abundant fish in many large subalpine lakes and reservoirs of western North America, and it could provide a valuable salmonid fish species for Devil Canyon and Watana reservoirs and tributaries above Devil Canyon. The fish are primarily lake-dwellers and spawn in autumn, both along lake shores and in tributary streams. The large Kokanee are valuable sport fish, and the juveniles are the major pelagic prey species for other large sport fish such as Kanloops rainbow and lake trout (Northcote 1972; Fraley and Graham 1982; Sport Fishing Institute 1983). The Kokanee are largely pelagic plankton feeders, utilizing cladoceran zooplankters Bosmina and Daphnia. Attempts to supplement their available planktonic food in several lakes through introduction of Mysis relicta, a large planktonic crustacean, met with negative results as the Mysis itself depleted Bosmina and Daphnia populations on which small Kokanee depend (Morgan et al. 1978). This experience paralleled that observed in Scandinavian lakes in which Mysis was introduced (Hanson and Lindström 1979). Establishment and maintenance of a Kokanee population in Watana Reservoir could provide a pelagic component of the fauna comparable to the Scandinavian roach and a viable alternative to ADF&G FRED Division proposals to open the upper Susitna to anadromous salmon stocks through fish passage facilities at Devil Canyon. Limiting factors would be the capability of the turbid Watana Reservoir to sustain zooplankton and impaired reproduction along the reservoir shoveline (although the upper Susitna and tributaries should provide abundant spawning habitat).

I.2.2. Devil Canyon Development

I.2.2.1. Plant Communities

Because the turbid Sustina River will have been clarified and its flow regulated by Watana Dam, silt additions during Devil Canyon construction can be expected to have some impact in the Devil Canyon to Talkeetna reach through scouring and shading of periphyton algae on submerged rocks. The effects should be of short duration and of little lasting significance for the riverine ecosystem. There should be no detectable changes below the confluence with the turbid Chulitna River. Reservoir filling will inundate riverine algal communities below Watana and replace them with planktonic algae derived mostly from Watana Reservoir. Downstream of Devil Canyon Dam, filling should have no noticeable impact on benthic algae beyond small changes in wetted surface area that are within normal river variability.

Devil Canyon operation should have only a small incremental impact on the Susitna River downstream, compared to riverine conditions when Watana Dam operates alone. Reduced summer temperatures (compared to both preproject and Watana alone conditions) can be expected to somewhat reduce productivity of benthic alage, but production should still exceed pre-Watana levels due to low turbidity. A short reach between dam and powerhouse will be dewatered (about 1000 m) and removed from production.

No detectable changes in aquatic plant communities are expected below the confluence of the Chulitna River when Devil Canyon Dam commences operation, due to the overwhelming effects of turbidity in the unregulated Chulitna and Talkeetna rivers and the changes in turbidity and flow in the Susitna already caused by Watana Dam.

The short residence time for water in Devil Canyon Reservoir (Sec. 4.1.3.1) nearly ensures that the phytoplankton community will be composed of populations derived largely from Watana Reservoir, although additional development can occur in the increasingly clear Devil Canyon Reservoir water. Diatom species are expected to dominate. Stratified flows from Watana outlet to the Devil Canyon outlet may lengthen retention times for some isolated water masses and allow populations independent of Watana contributions to develop seasonally.

I.2.2.2. Invertebrate Communities

Silt from Devil Canyon construction will temporarily affect benthic invertebrates in the river for several miles downstream of the site, but it is unlikely that they would be reduced to pre-Watana low levels. Reservoir filling will rapidly remove riverine benthos in the reservoir reach and replace it with a less productive planktonic invertebrate community derived from Watana Reservoir. No detectable impact from filling is anticipated on invertebrates below the local zone at the dam.

With sediment loads already reduced and flows stabilized in the Susitna River by Watana Dam, addition of Devil Canyon Dam will principally affect timing and rates of development of invertebrates due to reduced summer temperatures and increased winter temperatures. Overall benthic invertebrate productivity in this reach is likely to be significantly lower than that with Watana Dam alone, but still much higher than before the project. Additional time for plankton development in the reservoir should further stimulate filter-feeding benthos in the Susitna downstream of the dam. Lack of ice scour in the reach between Devil Canyon and Sherman will protect and enhance populations there.

Improvements in water clarity and flow stability, and reduction in temperatures in the Susitna River above the Chulitna confluence, are expected to be masked by the influences of the other rivers that will continue to suppress potential benthic invertebrate development. Because benthic populations are low, increased turbidity in winter is not expected to cause noticeable impacts.

Zooplankton within Devil Canyon Reservoir is expected to be dominated by additions from Watana. Further reductions in turbidity and isolation of some water masses during periods of stratified flow could allow zooplankton increases.

I.2.2.3 Fish Communities

I.2.2.3.1 Construction Phase

As at Watana Dam, construction will preempt a short reach of river bottom fish habitat for the dam itself [about 1100 ft (3540 m) between cofferdams); introduce silt to the river during several construction periods including placement of cotterdams, dredging for construction materials, and clearing of the reservoir area; and convert creek and riverine habitat to reservoir habitat in the impounded reach. Resident and anadromous fishes are expected to be impacted more strongly by sediment addition from Devil Canyon construction than was the case for Watana because of fish community adaptation to the more silt-free conditions after Watana filling. Any detectable sediment impact is expected to be small and of short duration, however.

Filling Devil Canyon reservoir will inundate about 32 mi (53 km) of mainstem Susitna habitat and 11 mi (18 km) of tributary habitats. The riverine species community will shift to a lacustrine assemblage (see Sec. I.2.2.3.2, while the applicant estimates that loss of clear-water tributary habitat in Tsusen and Fog creeks will eliminate about 1200 grayling longer than 8 in (20 cm). Temperature estimates were not available for the Susitna downstream of the project during the two-stage filling process (Sec. 4.1.3.2. Assuming a summer filling period (to coincide with maximum inflow to Watana Reservoir), and considering the effects of Devil Canyon operation on temperatures of the river downstream (see I.2.2.3.2), one can assume a marked decrease in summer river temperature during filling and impacts to fish similar to those during operation.

Devil Canyon Reservoir will be filled in a matter of three months. The filling of this reservoir is not expected to result in any additional impacts on spawning habitat or spawning success.

Degradation and loss of spawning habitat below Devil Canyon Dam during construction of the dam itself due to increased turbidity and siltation will be minimal and localized to the first several miles below the dam site. There is essentially no suitable spawning habitat immediately downriver from the Devil Canyon Dam site (RM 152.0) until Portage Creek at RM 149.

I.2.2.3.2 Operation Phase

Operation of Devil Canyon and Watana dams together will have some additional negative impact on salmon in the Susitna River downstream of the project from that of Watana Dam alone. This is due largely to the altered temperature regime, which will be markedly cooler in summer with both dams operating and somewhat warmer in winter. Post project stream flows under the operation of Watana and Devil Canyon dams would be similar to those under operation of Watana Dam alone. Most of the impacts related to habitat availability would already have occurred under the startup and operation of Watana Dam. There will be an additional loss of approximately 1.5 mi (2.5 km) of river habitat between the dam and the powerhouse outlet, of which about 3300 ft (1000 m) may be dry and the remainder converted to backwater.

Salmon Spawning Habitat

The most significant downstream environmental impact resulting from the operation of Devil Canyon Dam may be the change in winter water temperature regime, which may, based on the applicant's modeling, cause the ice front to form between Talkeetna (RM 99) and Sherman (RM 130), instead of between Sherman (RM 130) and Portage Creek (RM 149) as with Watana alone. The river stage in the open-water reach will be lower than the stage present under an ice cover. Thus, some mainstem, slough, and side-channel habitat used for spawning during the period June through September will be dewatered during the winter, potentially resulting in the freezing of eggs incubating in these dewatered habitats. This impact will be somewhat ameliorated, however, since salmon tend to select zones of groundwater upwelling which will not freeze. The dependence of groundwater upwelling on river stage is discussed in Sec. 4.1.3.2.

With Watana and Devil Canyon both operating, summer flows are only slightly lower than with Watana alone (Sec. 4.1.1.4.1), and thus access problems for adult salmon entering slough spawning habitats and reductions in area of suitable spawning habitat within the sloughs are only slightly greater than with Watana alone. Analyses by FERC staff indicate that for nine sloughs above Talkeetna the frequency of occurrence of acute access limitations will be 67% in July, 54% in August, and 55% in September. These analyses also indicate a reduction in wetted surface area in nine sloughs of 55% in July, 39% in August, and 0% in September (Sec. 4.1.1.4.2).

Gas Supersaturation

Without cone valves, Devil Canyon Dam is projected (Sec. 4.1.3.2) to create supersaturated conditions downstream in excess of the 110% lethal limit for most aquatic life (NAS/NAE 1973) for over 70% of the years when summer flow of hydropower turbines is augmented with discharge water. Cone valves should reduce or eliminate these high levels. Without cone valves proposed by the applicant, or a similar mitigative measure, high mortalities are expected downstream of the project. These conditions could persist to the Chulitna confluence and have severe consequences for the fishery amounting to nearly complete loss of fishery resources. With cone valves, these should be insignificant mortality.

Egg Incubation Rates at Altered Temperatures

The thermal effects on egg incubation estimated for Watana Reservoir alone (Sec. I.2.1.3.2) will be somewhat reduced with both dams in operation in spite of additional prolongation of warm temperatures into the late autumn by Devil Canyon Dam. Early-spawning pink and chum salmon could produce emerging fry in November-December with both dams in operation (Figure I.2-1, Table I.2-2). Later spawning fish would be more affected than with Watana alone (Figure I.2-2). For late spawners, the projected winter mainstem temperatures more closely approximate preproject slough temperatures, which may aid success, especially for mainstem or side-channel redds.

Growth-Temperature Relationships for Juvenile Rearing

Potential growth of juvenile salmon downstream of Devil Canyon and Watana dams shows marked decreases when both are in operation (Figure I.2-3, Table I.2-1). Summer peak temperatures are reduced to well below the optimal growth temperature of salmon (near 59°F or 15°C), and the prolonged release of abnormally warm water in autumn does not compensate for lost growth. Annual growth could potentially reach only about 50% of preproject levels. Species that emigrate in midsummer could accumulate only about one-third of their normal riverine growth increment. Whereas the modest changes in growth with Watana Dam alone (Sec. I.2.1.3.2) would probably be undetectable, the more striking changes associated with both dams operating could have important implications for survival of the emigrating juvenile salmon. If the FERC staff's conclusion is correct that autumn temperatures will fall more rapidly than the applicant estimated, then the reduction in annual growth from mainstem temperature changes will be greater. Below the Chulitna confluence, reduced summer flows in the warmer Susitna River will cause the lower Susitna River to be cooler than preproject or with Watana Dam alone. A simple dilution model using monthly average water temperatures and flows for the Susitna, Chulitna and Talkeetna (Table I.2-1) suggests that potential June-September growth of juvenile salmon could be reduced by about one-half compared to preproject conditions. All of these estimated effects would be ameliorated by fish congregation in the sloughs which would be somewhat warmer than the mainstem.

Food Availability

The markedly increased availability of food for juvenile salmon anticipated following reduction in turbidity and stabilization of flows in the Susitna by Watana Dam may be reduced by Devil Canyon Dam. Summer temperature reduction (Sec. 4.1.3.2 and Figure I.2-3) may be sufficiently severe to retard growth of benthic food organisms.

Winter Ecology of Young Salmonids

The most pronounced winter warming of the Susitna will occur in the Devil Canyon to Talkeetna reach after both Watana and Devil Canyon dams are in operation (See Sec. 4.1.3.2). Midwinter temperatures are expected by the applicant to remain near 36°F (2°C) in Devil Canyon, with eventual freezing between Sherman and Talkeetna. Assuming that a 41°F (5°C) threshold for inducing overwintering behavior applies to Susitna populations (Sec. I.2.1.3.2), then (as with Watana alone) the most elevated temperatures in winter will be below it and a normal behavioral cycle will occur. The pronounced lag in autumnal cooling with both dams, however, will delay onset of winter inactivity about 30 to 40 d (depending on distance downstream from the dam) (Figure I.2-3). As noted for Watana operations, the significance of this delay is unclear, but it may be beneficial for overwintering survival of chinook and coho salmon.

Reservoir Fish Community

Devil Canyon Reservoir will offer favorable habitat to fish populations, although low productivity levels are anticipated due to cool temperatures and nutrient limitation. Dolly Varden, Arctic grayling, rainbow and lake trout, burbot, whitefish, and longnose suckers are anticipated, paralleling trends projected for Watana Reservoir (Sec. I.2.1.3.2). Drawdown [about 50 ft (15 m)] in August and September to maintain minimum river flows downstream will affect shoreline spawning in summer. Turbidity levels less than in Watana Reservoir should aid development of fish populations.

Dependence of Year-class Strength on Flow and Temperature Regimes

Changes in the flow and temperature regimes downriver of the two dams have been identified in the previous sections of this appendix as having potentially negative impacts on the salmon stocks utilizing the Devil Canyon to Talkeetna reach of the Susitna River for spawning and rearing. In this section historical flow, temperature, and commercial catch data for the years 1950-1982 are analyzed to determine if there has been an obvious influence of low flows in summer or of low or high temperatures in summer or winter on year-class strength for any of the five salmon species. Specifically, three reasonable hypotheses are as follows:

(1) Is there a tendency for year-class strength to be below average for those year classes experiencing lower than average flows during the spawning period July through September? The most direct way in which low flows could reduce year-class strength is to restrict access to spawning sites to such a point that spawning sites become limiting. If this did occur, chum and sockeye salmon are the two species most likely to be adversely affected since these are the two species that spawn primarily in slough habitat.

(2) Is there a tendency for year-class strength to be above (below) average for those year classes experiencing warmer (colder) than average temperatures during the critical growth period of June through August after hatching (i.e., the summer of the year after spawning)? Growth during this first summer is particularly critical for chum and pink salmon that out-migrate that first summer, since larger smolts have a higher probability than smaller smolts of surviving and returning as adults to spawn. Although juvenile chinook, coho, and sockeye remain in freshwater through two or more summer growth periods, even for these three species growth over the first summer will tend to be positively correlated with subsequent survival.

(3) Is there a tendency for year-class strength to be above (below) average for those year classes experiencing warmer (colder) than average temperatures during the first winter after hatching? This hypothesis applies only to chinook, coho, and sockeye, since chum and pink out-migrate before the first winter after hatching. Survival from cold kills over this first winter can be quite variable from year to year, depending on the temperature regime during December through March, thus resulting in a corresponding variability in year-class strength.

The nature of the historical data available requires that certain assumptions and compromises be made to perform analyses to test the above three hypotheses. The best index of year-class strength for the five species of salmon is the commercial catch data for upper Cook Inlet. These data are available for the years 1954-1982 (Table I.1-7). Susitna River stocks are thought to contribute the majority of the salmon (except for sockeye) to this fishery, although certainly there are other stocks that spawn in other rivers draining into upper Cook Inlet. Since the fishery catches are comprised of an unknown mixture of stocks, it is appropriate to view the catch data as average indices of year-class strength for all the salmon stocks spawning in the various rivers draining into upper Cook Inlet, of which the Susitna River is the largest and most important.

A second assumption made concerning the use of catch data as indices of year-class strength is that for each species the fishery operates primarily on a single age class in any one year and that it is the same age class every year. For pink salmon this assumption is in reality a fact. For the other four species, the majority of the salmon caught are typically of the same age (age 4 for chum and coho, and age 5 for chinook and sockeye). This assumption appears to be least valid for chinook (ADF&G, 1983a), with age ranging from 3 to 6 years.

Data for average monthly flow for the years 1950-1981 at Gold Creek and Susitna Station were used for the analysis to evaluate hypothesis (1). We are assuming that these flows are reasonable relative indexes for the flows in the other salmon rivers draining into upper Cook Inlet. A similar assumption will be made for the temperature data, both water temperature at Gold Creek and air temperature at Anchorage.

For each species, using the appropriate lag between year of flow that would affect access of spawners to sloughs and year of catch of the progeny by the commercial fishery, the analysis to evaluate hypothesis (1) consisted of comparing the mean commercial catch for low-flow years with that for high-flow years. There were no statistically significant differences at $P = 0.05$ level), indicating that over the range of flows occurring from 1950 to 1981 there is no strong evidence that year-class strength for any of the five species is adversely affected by low flows during spawning (Table I.2-3). An important caveat for this analysis is that the average flows at Gold Creek for the low-flow years (column headed Q1) are all above 12,000 ft^3/s (340 m^3/s), whereas the proposed project flows at Gold Creek during July, August, and September are 6,480, 12,000, and 9,300 ft^3/s (183, 340, and 263 m^s/s), respectively, for an average flow of 9,260 ft^3/s (260 m^3/s). There is no sound basis for judging the validity of extrapolating the results of this analysis to these lower flows.

Summary of Environmental Impacts on Salmon Populations from Both Dams

This discussion of the expected long-term trends in salmon production and effects of changes in abundance of salmon stocks on fisheries includes consideration of both the construction and operation phases of Watana and Devil Canyon developments.

Considering the potential cumulative impact of changes in flow, temperature, and turbidity regimes on all stages of the salmon life cycle from migration of adults through out-migration of smolts, the staff expects that salmon production above Talkeetna for all five species will be greatly reduced during the second and third years of filling of Watana Reservoir. However, the lost production in this reach for these two years is likely to be at least partially offset by increased production in other systems due to salmon that normally would have continued to migrate up the Susitna River, selecting the warmer water of the Talkeetna River.

All five salmon species would be expected to increase their use of this reach of the Susitna River again when Watana starts operating, although the rate of return to higher production levels will vary among the five salmon species depending on the life cycle and on the strength of the year classes returning in the years immediately following the filling of Watana. In the case of pink salmon, no imprinted adults may be available to come back since both odd-year and even-year stocks will be impacted during the second and third years of filling, and thus recovery to higher production levels is likely to take more years.

It is not possible to assess whether the Susitna Hydroelectric Project will result in an average, long-term decrease or increase in populations of salmon currently spawning in the Susitna River basin. However, it is likely that there will be at least short-term decreases in salmon stock sizes due to construction of Watana and Devil Canyon dams and filling of Watana Reservoir due to substantial changes in flow, temperature, and turbidity regimes. Based on the staff's analysis, the magnitude of any decrease, especially in light of the various mitigation measures to be implemented (Sec. 5.3), will not be great. No combination of impacts has been projected that would reduce by as much as 50% any of the five salmon populations spawning in the Susitna River and its tributaries above its confluence with the Talkeetna and Chulitna rivers, although the chum, sockeye and pink stocks are likely to be more affected than the chinook and coho salmon stocks. Conversely, it is not reasonable to expect that the proposed project, even in combination with extensive mitigation measures will result in an increase, by as much as 50%, of any of these five salmon populations.

It is not possible to quantify the direct impact of the project on the commercial, sport, or subsistence fisheries, except that, other factors being equal, changes in catch will be approximately proportional to decreases or increases in the size of the spawning stocks.

Other factors, however, will not be equal, with and without the project. As discussed in Sec. 4.1.8, the project will tend to promote economic and population growth. These changes, in turn, will inevitably increase fishing effort by the commercial and sport fisheries, and probably the subsistence fishery as well. The effect of this increased fishing effort is relatively easy to predict, based on case histories for numerous other fish stocks all over the world. Increasing exploitation will eventually result in decreasing fishery resources unless there is increasing intervention of fishery management practices. This long-term and indirect impact of the project is likely to mask any direct impacts of the project on downstream habitat and the size of the fish populations this habitat can support.

Mercury Levels in Fish in Watana and Devil Canyon Reservoirs

Increases have been observed in mercury concentrations in fish in 10 newly impounded reservoirs in northern Manitoba that cannot be attributed to atmospheric or industrial sources (Bodaly and Hecky 1979, 1982; Bodaly et al. 1984). These observed increases in methyl mercury in fish associated with the flooding of soil raises concerns about the potential for postimpoundment increases in mercury levels in fish in Watana and Devil Canyon reservoirs to levels that present a public health risk, particularly for subsistence fishermen who may consume these

Table I.2-3. Analysis to Test the Hypothesis for Each of Five Salmon Species that There is a Tendency for Year-Class Strength to be Below Average for Those Year Classes Experiencing Lower than Average Flows During the Spawning Period July through September†[1]

Species	Station	N1	Q1	C1	N2	Q2	C2	MAXMINQ	T
A.	The lowest 25% of the flows versus the highest 25% of the flows.								
Chinook	Gold Creek	8	15,604	14,685	7	23,807	13,013	1.52570	-0.2841
Chinook	Susitna	8	84,883	16,958	7	119,435	14,270	1.40705	-0.4962
Sockeye	Gold Creek	8	15,604	1,070,251	7	23,807	1,062,252	1.52570	-0.0282
Sockeye	Susitna	8	84,883	834,384	7	119,435	1,398,928	1.40705	1.7272
Coho	Gold Creek	8	15,337	321,186	8	23,626	209,282	1.54046	-1.2840
Coho	Susitna	8	84,883	244,493	8	118,650	229,888	1.39781	-0.2152
Pink (even)	Gold Creek	4	15,656	1,705,368	4	22,768	2,095,292	1.45427	0.6842
Pink (even)	Susitna	4	85,441	1,441,078	4	123,225	1,964,697	1.44222	0.9131
Pink (odd)	Gold Creek	4	15,710	136,661	3	24,420	30,467	1.55442	-1.3205
Pink (odd)	Susitna	4	87,246	256,962	3	118,813	39,644	1.36182	-1.5448
Chum	Gold Creek	8	15,337	789,369	8	23,626	533,893	1.54046	-1.3856
Chum	Susitna	8	84,883	732,245	8	118,650	540,001	1.39781	-1.4826
B. The lowest 10% of the flows versus the highest 50% of the flows.									
Chinook	Gold Creek	3	13,663	10,627	14	22,462	18,434	1.64400	0.7819
Chinook	Susitna	3	77,434	8,509	14	114,381	14,715	1.47714	0.9735
Sockeye	Gold Creek	3	13,663	954,965	14	22,462	1,193,902	1.64400	1.0056
Sockeye	Susitna	3	77,434	697,208	14	114,381	1,270,975	1.47714	1.4343
Coho	Gold Creek	3	13,523	388,392	15	22,284	207,283	1.64786	-1.8791
Coho	Susitna	3	77,434	134,862	15	113,680	224,500	1.46809	1.2286
Pink (even)	Gold Creek	2	15,273	1,779,075	7	21,374	1,807,083	1.39946	0.0381
Pink (even)	Susitna	2	83,056	1,035,320	7	116,502	1,827,776	1.40269	1.1065
Pink (odd)	Gold Creek	2	12,948	185,992	6	23,666	78,507	1.82777	-0.9349
Pink (odd)	Susitna	2	77,717	68,652	6	117,129	101,165	1.50712	0.3653
Chum	Gold Creek	3	13,523	827,757	15	22,284	508,099	1.64786	-1.6261
Chum	Susitna	3	77,434	623,215	15	113,680	530,832	1.46809	-0.5847

†[1]Elaboration of column headings:

Species: Pink (even) = pink salmon spawning in even-numbered years; pink (odd) = pink salmon spawning in odd-numbered years.

Station: Sites for flow measurements are Gold Creek and Susitna Station.

N1 is the number of years in the sample of low-flow years; N2 is the number of years in the sample of high-flow years.

Q1 is the average flow (ft^3/s) for the sample of low-flow years; Q2 is the average flow for the sample of high-flow years. In both cases, the flow used for each year is the average of July, August, and September mean flows.

C1 is the average commercial catch (numbers of salmon) in upper Cook Inlet for the sample of low-flow years; C2 is the average commercial catch for the sample of high-flow years.

MAXMINQ = Q2/Q1.

T is the _t_-test statistic calculated from the sample data. It is compared with one-tailed tabulated _t_ values for (N1 + N2 - 2) degrees of freedom to determine the probability of observing a _t_ value this large or larger if the null hypothesis of equal commercial catches for low-flow and high-flow years is true.

Conversion: To convert from cubic feet per second to cubic meters per second, multiply by 0.028831.

Source: FERC staff.

fish on a sustained basis. The basis for concern is that the reported increases occurred coincidently with flooding and were related to the flooded terrestrial area, suggesting that the soil was the source of the elevated mercury. Because mercury levels in fish from nearby unflooded lakes did not increase, atmospheric fallout was eliminated as a cause of the problem. Mercury levels in predatory fish species from all of the flooded lakes were near to, or exceeded, the Food and Drug Administration's "action level" of 1.0 ppm (μg/g) fresh weight of mercury in the edible portion of fish flesh. It was hypothesized that the increased mercury levels in fish were due to bacterial methylation of naturally occurring mercury in newly flooded soils and suspended sediments. Based on the reported postimpoundment increases of mercury in fish in northern Manitoba, it appears likely that mercury levels will increase in fish after impoundment in Watana and Devil Canyon and that monitoring of mercury levels in fish from these impoundments will be necessary.

I.2.3 Access Routes

I.2.3.1 Plant Communities

Increased turbidity and siltation associated with stream crossings by access routes will result in some degradation and loss of habitat utilized by benthic algae and periphyton. These impacts will be due to reduced light penetration, scouring, and sediment covering suitable substrate. Some changes in species composition may occur locally. Although these types of impacts cannot be completely avoided, they can be limited to the immediate vicinity [e.g., 100 yard (100 m)] of stream crossings. Given the limited information currently available from the applicant concerning the plant communities in these streams and the number, location, and design of the actual crossings, it is not possible to quantitatively estimate the absolute or relative amount of stream habitat that will be degraded or lost, but it is not expected to be great. These impacts will occur primarily during the construction phase when the stream crossings are being built.

I.2.3.2 Invertebrate Communities

Increased turbidity and siltation associated with stream crossings by access routes will result in some degradation and loss of habitat utilized by invertebrates. This impact will be due to both the direct effects of scouring, clogging of feeding mechanisms by silt, and covering of suitable substrate by sediment and the indirect effects on the availability of plant food for invertebrates because of local reductions in the size and productivity of plant communities. Some changes in species composition may occur locally. Although these types of impacts cannot be completely avoided, the impacts can be limited to the immediate vicinity [e.g., 100 yard (100 m)] of stream crossings. Given the limited information currently available from the applicant concerning the number, location, and design of the actual crossings, it is not possible to quantitatively estimate the absolute or relative amount of stream habitat that will be degraded or lost, but it is not expected to be great. These impacts will occur primarily during the construction phase when the stream crossings are being built.

I.2.3.3 Fish Communities

There are two environmental impacts to be assessed for fish communities in streams and lakes in the vicinity of the access routes. The greatest source of adverse impact on fish communities will be the increased accessibility of these streams and lakes to fishing pressure via the network of access routes. As an example, the Watana access road will cross Brushkana, Lily, Seattle, and Deadman creeks as well as other small, unnamed streams. These creeks are clear-water streams and many are inhabited by grayling. Deadman Creek, in particular, is known for its abundant and trophy-sized grayling. The reach of Deadman Creek between the falls and Deadman Lake is considered prime grayling habit. By subjecting this stream to increased fishing pressure, many of the larger, older fish will be removed from the population, altering the age structure and possibly reducing reproductive potential. A similar impact may occur to other grayling streams in the area. Another impact associated with access roads and railroads, as identified by the applicant and the various agencies concerned with fishery resources, is the effect on resident fish populations, grayling in particular, of increased turbidity and siltation associated with stream crossings. The bases for this concern are that there will be numerous (approximately 100) stream crossings and that increased turbidity and siltation are likely to result in degradation and loss of habitat, especially habitat currently used for spawning and rearing of juveniles. The streams of concern are described in Secs. 3.1.4.5 and I.1.

Fish will tend to avoid areas where in-stream work is being conducted, areas contaminated by petroleum products, or areas experiencing excessive turbidity and siltation. Barriers to fish movements and migrations may be created when streams are diverted, flumed, or blocked during installation of drainage structures. Fish can also be prevented from moving upstream if drainage structures are incorrectly installed. Pumping of water from streams can adversely affect local populations by entraining juvenile fish. Clearing will remove overhanging vegetation that provides cover for fish.

The applicant's approach to minimizing increases in turbidity and siltation is evaluated in Sec. 4.1.3.2. Although these types of impacts cannot be completely avoided, the impacts can be limited to the immediate vicinity [e.g., 100 yard (100 m) of stream crossings. Given the limited information currently available from the applicant concerning the number, location, and design of the actual crossings, it is not possible to quantitatively estimate the absolute or relative amount of stream habitat that will be degraded or lost, but it is not expected to be great. These impacts will occur primarily during the construction phase when the stream crossings are being built.

I.2.4 Power Transmission Facilities

I.2.4.1 Plant Communities

Increased turbidity and siltation associated with stream crossings by transmission corridors will result in some degradation and loss of habitat utilized by benthic algae and periphyton. These impacts will be due to reduced light penetration, scouring, and sediment covering suitable substrate. Some changes in species composition may occur locally. Although these types of impacts cannot be completely avoided, they can be limited to the immediate vicinity [e.g., 100 yard (100 m)] of stream crossings. Given the limited information currently available from the applicant concerning the number, location, and design of the actual crossings, it is not possible to quantitatively estimate the absolute or relative amount of stream habitat that will be degraded or lost, but it is not expected to be great. These impacts will occur primarily during the construction phase when the stream crossings are being built.

I.2.4.2 Invertebrate Communities

As for plant communities, increased turbidity and siltation associated with stream crossings by transmission corridors will result in some degradation and loss of habitat utilized by invertebrates. This impact will be due to both the direct effects of scouring, clogging of feeding mechanisms by silt, and sediment covering suitable substrate and the indirect effects on the availability of plant food for invertebrates because of local reductions in the size and productivity of plant communities.

I.2.4.3 Fish Communities

The same two environmental impacts on fish communities identified for access routes (Sec. 4.1.3.5.3) must also be considered for the power transmission facilities. Because the vegetation along the transmission corridors is kept relatively low, hikers and all terrain vehicles can use the corridors as trails. This will result in greater numbers of fishermen being able to reach areas that previously experienced little or no fishing pressure. This effect will be more acute in areas where the new transmission route diverges from existing roads and transmission lines, such as south of Willow and north of Healy. The second source of impact on fish communities will be increased turbidity and siltation associated with stream crossings (see Sec. 4.1.3.5.3). The applicant's approach to mitigation of this impact is evaluated in Sec. 2.1.8. Although increases in turbidity and siltation cannot be completely avoided, the impacts can be limited to the immediate vicinity [e.g., 100 yard (100 m)] of stream crossings.

REFERENCES FOR APPENDIX I

Acres American, Inc. (Acres). 1983. Slough Hydrogeology Report (Draft). Prepared for Alaska Power Authority, Anchorage, AK.

Avnimelech, Y., B.W. Troeger and L.W. Reed. 1982. Mutual flocculation of algae and clay: evidence and implications. Science 216:63-65.

Alaska Department of Fish and Game (ADF&G). 1981a. Adult Anadromous Phase 1 Final Species/Subject Report. Susitna Hydro Aquatic Studies. Anchorage, AK.

Alaska Department of Fish and Game (ADF&G). 1981b. Phase 1 Final Draft Report, Adult Anadromous Fisheries Project. Susitna Hydro Aquatic Studies, 1981. Anchorage, AK. (Prepared for Alaska Power Authority).

Alaska Department of Fish and Game (ADF&G). 1981c. Phase 1 Final Draft Report, Aquatic Habitat and Instream Flow Project. Volume I. Anchorage, AK. (Prepared for Acres American, Incorporated).

Alaska Department of Fish and Game (ADF&G). 1981d. Phase 1 Final Draft Report, Juvenile Anadromous Fish Study on the Lower Susitna River. Susitna Hydro Aquatic Studies, 1981. Anchorage, AK. (Prepared for Acres American, Incorporated).

Alaska Department of Fish and Game (ADF&G). 1981e. Phase 1 Final Draft Report, Resident Fish Investigation on the Lower Susitna River. Susitna Hydro Aquatic Studies, 1981. Anchorage, AK. (Prepared for Acres American, Incorporated).

Alaska Department of Fish and Game (ADF&G). 1981f. Phase 1 Final Draft Report, Resident Fish Investigation on the Upper Susitna River. Susitna Hydro Aquatic Studies. Anchorage, AK. (Prepared for Acres American, Incorporated).

Alaska Department of Fish and Game (ADF&G). 1982a. Phase 1 Final Draft Report, Aquatic Studies Program. Susitna Hydro Aquatic Studies. Anchorage, AK. (Prepared for Acres American, Incorporated).

Alaska Department of Fish and Game (ADF&G). 1982b. Phase 1 Final Draft Stock Separation Feasibility Report, Adult Anadromous Fisheries Project. Susitna Hydro Aquatic Studies. Anchorage, AK. (Prepared for Alaska Power Authority).

Alaska Department of Fish and Game (ADF&G). 1983a. Synposis of the 1982 Aquatic Studies and Analysis of Fish and Habitat Relationships. Susitna Hydro Aquatic Studies, Phase II Report, Anchorage, AK. 152 pp. plus appendices.

Alaska Department of Fish and Game (ADF&G). 1983b. Adult Anadromous Fish Studies, 1982. Susitna Hydro Aquatic Studies, Phase II Report, Vol. 2 (2 parts). Anchorage, AK. 239 pp. plus appendices.

Alaska Department of Fish and Game (ADF&G). 1983c. Resident and Juvenile Anadromous Fish Studies on the Susitna River Below Devil Canyon, 1982. Susitna Hydro Aquatic Studies, Phase II Report, Vol. 3 (2 parts). Anchorage, AK. 277 pp. plus appendices.

Alaska Department of Fish and Game (ADF&G). 1983d. Aquatic Habitat and Instream Flow Studies, 1982. Susitna Hydro Aquatic Studies, Phase II Report, Vol. 4 (2 parts). Anchorage, AK. 267 pp. plus appendices.

Alaska Department of Fish and Game (ADF&G). 1983e. Upper Susitna River Impoundment Studies, 1982. Susitna Hydro Aquatic Studies, Phase II Report, Vol. 5. Anchorage, AK. 150 pp. plus appendices.

Alt, K.T. 1973. Contributions to biology of the Bering cisco (Coregonus laurettae) in Alaska. J. Fish. Res. Board Can. 30:1885-1888.

Bakkala, Richard G. 1970. Synopsis of Biological Data on the Chum Salmon, Oncorhynchus keta (Walbaum) 1792. FAO Species Synopsis No. 41. U.S. Fish Wildl. Serv., Bureau Comm. Fish. Circ. 315. Washington, DC. 89 pp.

Barrett, B.M. 1974. An Assessment of the Anadromous Fish Populations in the upper Susitna River Watershed Between Devil Canyon and the Chulitna River. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage, AK. 56 pp.

Battle, H. I. 1944. The embryology of the Atlantic salmon (Salmo salar Linnaeus). Can. J. Res. Sect. D. 22(5):105-125.

Bauersfeld, K. 1978. Stranding of Juvenile Salmon by Flow Reductions at Mayfield Dam on the Cowlitz River, 1976. Wash. Dept. Fish., Tech. Rep. No. 36. 36 pp.

Bechtel Civil and Minerals, Inc. 1983. Chakachamna Hydroelectric Project Interim Report. Prepared for Alaska Power Authority, Anchorage, AK.

Becker, C.D. 1973. Food and growth parameters of juvenile chinook salmon Oncorhynchus tshawytscha in central Columbia River. Nat. Oceanic Atmops. Admin. (U.S.) Fish. Bull. 71(2):387-400.

Becker, C.D., D.A. Neitzel and D.H. Fickeisen. 1982. Effects of dewatering on chinook salmon redds: Tolerance of four developmental phases to daily dewaterings. Trans. Am. Fish. Soc. 111:624-637.

Bell, Milo C. 1973. Fisheries Handbook of Engineering Requirements and Biological Criteria. Fisheries Engineering Research Program. U.S. Army Corps of Engineers, North Pacific Division, Portland, OR. 34 chapters.

Bernard, D.R., G. Oliver, W. Goshert and B. Cross. 1983. Comparison of Scale Patterns from Sockeye Salmon Sampled from Different Rivers within the Susitna River Watershed in 1982. Alaska Department of Fish and Game, Division of Commercial Fisheries, Statewide Stock Biology Group, Anchorage, AK. 22 pp.

Bilton, H.T. 1971. Identification of major British Columbia and Alaska runs of even-year and odd-year pink salmon from scale characters. J. Fish. Res. Board Can. 29:295-301.

Bjornn, T.C. 1969. Salmon and Steelhead Investigations - Embryo Survival and Emergence Studies. Idaho Dep. Fish. Game Completion Rep. No. F-49-4-7. 11 pp.

Bjornn, T.C., M.A. Brusven, M.P. Molnau, J.H. Milligan, R.A. KLlamt, E. Chacho and C. Schaye. 1977. Transport of Granitic Sediment in Streams and its Effects on Insects and Fish. For. Wildlife and Range Exp. Stn. Completion Rep. Water Resour. Res. Inst. Proj. B-036-IDA. Univ. of Idaho, Moscow. 44 pp.

Bodaly, R.A. and R.E. Hecky. 1979. Post-impoundment Increases in Fish Mercury Levels in the Southern Indian Lake Reservoir, Manitoba. Fish. Marine Serv. Manuscr. Rep. No. 1531. Department of Fisheries and Environment, Winnipeg, Manitoba, Canada. 15 pp.

Bodaly, R.A. and R.E. Hecky. 1982. The Potential for Mercury Accumulation in Fish Muscle as a Result of the Proposed Peace River Site C Reservoir. Report prepared by Canada Department of Fisheries and Oceans for British Columbia Utilities Commission, Vancouver, British Columbia.

Bodaly, R.A., R.E. Hecky and R.J.P. Fudge. 1984. Increases in Fish Mercury Levels in Lakes Flooded by the Churchill River Diversion, Northern Manitoba. Draft report, Freshwater Institute, Canada Department of Fisheries and Oceans, Winnipeg, Manitoba. 22 pp.

Bovee, K.D. 1978. Probability of Use Criteria for the Family Salmonidae. FWS/OBS-78/07. Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Fort Collins, CO.

Brannon, E.L. 1972. Mechanisms controlling migration of sockeye salmon fry. Int. Pac. Salmon Fish. Comm. Bull. 21.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus Oncorhynchus. J. Fish. Res. Board Can. 9(6):265-323.

Brett, J.R. 1971. Energetic responses of salmon to temperature: a study of some thermal relations in the physiology and freshwater ecology of sockeye salmon. Am. Zool. 11:99-113.

Brett, J.R. 1974. Tank experiments on the culture of pan-size sockeye (Oncorhynchus nerka) and pink salmon (O. gorbuscha) using environmental control. Aquaculture 4:341-352.

Bryant, M.D. 1983. The role and management of woody debris in west coast salmonid nursery streams. North Am. J. Fish. Manage. 3:322-330.

Burgner, R.L. 1962a. Studies of red salmon smolts from the Wood River Lakes, Alaska, IN S.Y. Koo (ed.), Studies of Alaska Red Salmon. Univ. of Washington Press, Seattle.

Burgner, R.L. 1962b. Sampling red salmon fry by lake trap in the Wood River Lakes, Alaska, IN S.Y. Koo (ed.), Studies of Alaska Red Salmon. Univ. of Washington Press, Seattle.

Burrows, R.E. 1963. Water temperature requirements for maximum productivity of salmon, pp. 29-38. IN E.B. Eldridge (ed.), Water Temperature-Influences, Effects, and Control. Proc., 12th Pacific Northwest Symposium on Water Pollution Research. U. S. Public Health Service, Corvallis, OR.

Bustard, D.R. and D.W. Narver. 1975a. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 32:667-680.

Bustard, D.R. and D.W. Narver. 1975b. Preferences of juvenile coho salmon (Oncorhynchus kisutch) and cutthroat trout (Salmo clarki) relative to simulated alteration of winter habitat. J. Fish. Res. Board Can. 32:681-687.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams with special reference to food and feeding, pp. 153-176. IN T.G. Northcote (ed.), Symposium on Salmon and Trout in Streams, H.R. MacMillan Lectures in Fisheries. Institute of Fisheries, Univ. of British Columbia, Vancouver.

Cook Inlet Aquaculture Association (CIAA). 1983a. Eklutna Hatchery - 1979 Idea Becomes 1983 Reality. CIAA Smolts 6:4-5.

Cook Inlet Aquaculture Association (CIAA). 1983b. Eklutna hatchery complete a series of "firsts." CIAA Smolts 7:1,7.

Cook Inlet Regional Planning Team. 1981. Cook Inlet Regional Salmon Enhancement Plan, 1981-2000. Cook Inlet Aquaculture Association, Goldatna, AK.

Cordone, A.J. and D.W. Kelley. 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish Game 47:189-228.

Coutant, C.C. 1977. Compilation of temperature preference data. J. Fish. Res. Board Can. 34:739-745.

Coutant, C.C., and D.L. DeAngelis. 1983. Comparative temperature-dependent growth rates of largemouth and smallmouth bass fry. Trans. Am. Fish. Soc. 112:416-423.

Dauble, D.D., R.H. Gray, and T.L. Page. 1980. Importance of insects and zooplankton in the diet of 0-Age chinook salmon Oncorhynchus tshawytscha in the central Columbia River. Northwest Sci. 54(4):253-258.

Foerster, R.E. 1954. On the relation of adult sockeye salmon (Oncorhynchus nerka) returns to known smolt seaward migrations. J. Fish. Res. Board Can. 11:339-350.

Foerster, R.E. 1937. The relation of temperature to the seaward migration of young sockeye salmon (Oncorhynchus nerka). J. Biol. Board Can. 3:421-438.

Foster, D. 1982. The Utilization of King Salmon and the Annual Round of Resource Uses in Tyonek, Alaska. Technical Paper No. 27, Alaska Department of Fish and Game, Division of Subsistence, Anchorage, AK.

Fraley, J.J., and P.J. Graham. 1982. The Impact of Hungry Horse Dam on the Fishery of the Flathead River - Final Report. Montana Department of Fish, Wildlife and Parks, Kalispell, MT.

Fredeen, F.G.H. 1977. Some recent changes in black fly populations in the Saskatchewan River system in Western Canada coinciding with the development of reservoirs. Can. Water Resour. J. 2(3-4):90-102.

Friese, N.V. 1975. Preauthorization Assessment of Anadromous Fish Populations of the Upper Susitna River Watershed in the Vicinity of the Proposed Devil Canyon Hydroelectric Project. Cook Inlet Data Report No. 75-2. Alaska Department of Fish and Game, Anchorage, AK.

Geen, G.H. 1974. Effects of hydroelectric development in Western Canada on aquatic ecosystems. J. Fish. Res. Board Can. 31:913-927.

Gilhousen, P. 1962. Marine factors affecting the survival of Fraser River pink salmon, pp. 105-111. IN N.J. Wilimovsky (ed.), Symposium on Pink Salmon. H. R. MacMillan Lectures in Fisheries. Univ. of British Columbia, Vancouver.

Grant, W.S., G.B. Milner, P.Krasnowski and F.M. Utter. 1980. Use of biochemical genetic variants for identification of sockeye salmon (Oncorhynuchus nerka) stocks in Cook Inlet, Alaska. Can. J. Fish. Aquat. Sci. 37:1236-1247.

Grau, E.G., W.W. Dickhoff, R.S. Nishioka, H.A. Bern, and L.C. Folmar. 1981. Lunar phasing of the thyroxine surge preparatory to seaward migration of salmonid fish. Science 211:607-609.

Graybill, J.P., R.L. Burgner, J.C. Gislason, P.E. Huffman, K.H. Wyman, R.G. Gibbons, K.W. Kurdo, Q.J. Stober, T.W. Fagnan, A.P. Stayman and D.M. Eggers. 1979. Assessment of the Reservoir-Related Effects of the Skagit Project on Downstream Fishery Resources of the Skagit River, Washington. FRI-UW-7905. Final Report by Fisheries Research Institute, Univ. of Washington, or City of Seattle, Washington. pp. 602.

Grimas, U. 1961. The Bottom Fauna of Natural and Impounded Lakes in Northern Sweden (Ankarvattnet and Blasjon). Rep. No. 42:183-237. Institute of Freshwater Research, Drottningholm, Sweden.

Grimas, U. and N.A. Nilsson. 1965. On the Food Chain in Some North Swedish River Reservoirs. Rep. No. 46:31-48. Institute of Freshwater Research, Drottningholm, Sweden.

Grogan, R.L. 1983. Subject: Susitna Hydroelectric Project Application. Letter to Mr. Larry Crawford, Alaska Power Authority, dated November 18, 1983, from the Office of the Governor, Office of Management and Budget, Division of Governmental Coordination, Juneau, AK.

Groot, C. 1965. On the orientation of young sockeye salmon (Oncorhynchus nerka) during their seaward migration out of lakes. Behaviour Suppl. 14.

Hale, S.S. 1981a. Freshwater Habitat Relationships, Threespine Stickleback (Gasterosteus aculeatus). Alaska Department of Fish and Game, Habitat Division, Anchorage, AK. 46 pp.

Hale, S.S. 1981b. Freshwater Habitat Relationships, Chum Salmon (Oncorhynchus keta). Alaska Department of Fish and Game, Habitat Division, Anchorage, AK. 93 pp.

Hale, S.S. 1981c. Freshwater Habitat Relationships, Round Whitefish (Prosopium cylindraceum). Alaska Department of Fish and Game, Habitat Division, Anchorage, AK. 18 pp.

Hanson, M. and T. Linstrom. 1979. Suorva - en reglerad sjodar fisken inte har fordvargats (Suorva: A lake reservoir with char and whitefish of good size). Information Bull. No. 4. Institute of Freshwater Research, Drottningholm, Sweden.

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22:1035-1081.

Hartman, W.L. 1971. Alaska's Fishery Resources. The Sockeye Salmon. Fishery Leaflet 636. U.S. Department of Commerce, Washington, DC.

Hartman, W.L., W.R. Heard and B. Drucker. 1967. Migratory behavior of sockeye salmon fry and smolts. J. Fish. Res. Board Can. 24:2069-2099.

Heard, W.R. 1966. Observations on Lampreys in the Naknek River System of Southwest Alaska., Vol. 2. (as cited in the application).

Heggberget, T.G. (in press). Populations of presmolt Atlantic salmon (Salmo salar L.) and brown trout (Salmo trutta L.) before and after hydroelectric development and building of weirs in the River Skjoma, North Norway. Proc. Second Int. Symp. on Regulated Streams, Oslo, Norway. 1982.

Hill, D.M. 1972. Stream Faunal Recovery after Manganese Strip Mine Reclamation. PhD Dissertation. Virginia Polytechnic Institute and State Univ., Blacksburg.

Hoar, W.S. 1951. The behavior of chum pink and coho salmon in relation to their seaward migration. J. Fish. Res. Board Can. 8:241-263.

Huntsman, A.G. 1948. Fertility and fertilization of streams. J. Fish. Res. Board Can. 7:248-253.

Hutchinson, G.E. 1953. The concept of pattern in ecology. Proc. Nat. Acad. Sci. 105:1-12.

Hutchinson, G.E. 1961. The paradox of plankton. Am. Nat. 95:137-145.

Hutchinson, G.E. 1975. Variations on a theme by Robert MacArthur, pp. 445-459. IN M.L. Cody and J.M. Diamond (eds.), Ecology and Evolution of Communities. Belknap Press, Harvard University, Cambridge, MA.

Hynes, H.B.N. 1970. The ecology of running water. Univ. of Toronto Press. 555 pp.

ISACF. 1980. Proceedings of the First ISACF Workshop on Arctic char, 1980. ISACF Information Series No. 1. Institute of Freshwater Research, Drottningholm, Sweden.

Iwamoto, R.N., E.O. Salo, M.A. Madej and R.L. McComas. 1978. Sediment and Water Quality: A Review of the Literature Including a Suggested Approach for Water Quality Criteria. EPA 910/9-78-048, Univ. of Washington, Fisheries Research Institute, Seattle, WA.

Kanidyev, A.N., G.M. Kostyunin and S.A. Salmin. 1970. Hatchery propagation of the pink salmon and chum salmons as a means of increasing the salmon stocks of Sakhalin. J. Ichthyol. (English translation of Voprosy Ikhtiologii) 10:249-259.

Keenleyside, M.H.A. and W.S. Hoar. 1955. Effects of temperature on the responses of young salmon to water current. Behaviour 7:77-87.

Koksvik, J.I. 1977. Ferskvannsbiologiske og hydrografiske undersokelser i Saltfjell - Svartisomradet. Del II. Saltdalsvassdraget. K. Norske Vidensk. Selsk. Mus. Rapp. Zool. Ser. 1977-16.

Krueger, S.W. 1981a. Freshwater Habitat Relationships, Pink Salmon (Oncorhynchus gorbuscha). Alaska Department of Fish and Game, Habitat Division, Anchorage, AK. 40 pp.

Krueger, S.W. 1981b. Freshwater Habitat Relationships, Dolly Varden Char [Salvelinus malnea (Walbaum)]. Alaska Department of Fish and Game, Habitat Division, Anchorage, AK. 38 pp.

Krueger, S.W. 1981c. Freshwater Habitat Relationships, Arctic Grayling (Thymallus arcticus). Alaska Department of Fish and Game, Habitat Division, Anchorage, AK. 65 pp.

Kruse, T. 1959. Grayling of Grebe Lake, Yellowstone National Park, Wyoming. U.S. Fish Wildl. Serv. Fish. Bull. 59:305-351.

LaPerrier, J. and R. Carlson. 1973. Thermal Tolerances of Interior Alaska Arctic Grayling. Report No. IWR-46. Institute of Water Resources, Univ. of Alaska, Fairbanks. 36 pp.

Levanidov, V.Ya. 1964. The relationship between the size of fingerling Amur autumn chum (Oncorhynchus keta infrasp. autumnalis Berg) and their survival. J. Ichthyol. (English translation of Voprosy Ikhtiologii) 4:658-663.

Major, R.L. and J.L. Mighell. 1966. Influence of Rocky Reach Dam and the temperature of the Okanoghan River on the upstream migration of sockeye salmon. U.S. Fish. Wildl. Serv. Fish. Bull. 66(1):131-147.

Marr, D.H.A. 1966. Influences of temperature on the efficiency of growth of salmonid embryos. Nature 212(5065):957-959.

McClane, A.J. 1965. McClane's Standard Fishing Encyclopedia. Holt, Rinehart, and Winston, New York. 1072 pp.

McCuddin, M.E. 1977. Survival of Salmon and Trout Embryos and Fry in Gravel Sand Mixtures. Univ. of Idaho, Moscow. 30 pp.

McGregor, A.J. 1983. A Biochemical Genetic Analysis of Pink Salmon (Oncorhynchus gorbuscha) from Selected Streams in Northern Southeast Alaska. Informational Leaflet No. 213. Alaska Department of Fish and Game, Anchorage, AK.

McLean, R.F. and K.S. Delaney. 1978. Alaska's Fisheries Atlas, Vol. II. Alaska Department of Fish and Game, Anchorage, AK.

McMullin, S.L. and P.J. Graham. 1981. The Impact of Hungry Horse Dam on the Kokanee Fishery of the Flathead River. Montana Department of Fish, Wildlife and Parks, Kalispell, MT.

McNeil, W.J. 1968. Survival of pink and chum salmon eggs and alevins, pp. 101-117. IN T.G. Northcote (ed.), Symposium on Salmon and Trout in Streams. Univ. of British Columbia, Vancouver.

McNeil, William J. and Jack E. Bailey. 1975. Salmon Rancher's Manual. Nat. Marine. Fisheries Service Northwest Fisheries Center, Auke Bay Fisheries Laboratory, Auke Bay, AK. 95 pp.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of Northwestern Canada and Alaska. Fish. Res. Board Can. Bull. 173, Ottawa. 381 pp.

Mills, M.J. 1979. Alaska Statewide Sport Fish Harvest Studies, 1979. F-9-11, SW-I. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Vol. 20. Juneau, AK.

Mills, M.J. 1980. Alaska Statewide Sport Fish Harvest Studies, 1980. F-9-12, SW-I. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Vol. 21. Juneau, AK.

Mills, M.J. 1981. Alaska Statewide Sport Fish Harvest Studies, 1980 Data. F-9-13, SW-I. Alaska Department of Fish and Game, Federal Aid in Fish Restoration and Anadromous Fish Studies, Vol. 22. Juneau, AK.

Mills, M.J. 1982. Alaska Statewide Sport Fish Harvest Studies. F-9-14, SW-I. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Vol. 23. Juneau, AK.

Morgan, M.D., S.T. Threlkeld and C.R. Goldman. 1978. Impact of the introduction of kokanee (Oncorhynchus nerka) and oppossum shrimp (Mysis relicta) on a subalpine lake. J. Fish. Res. Board Can. 35(12):1572-1579.

Morrow, J.E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publ. Co., Anchorage, AK. 248 pp.

Murphy, M.L., C.P. Hawkins and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Am. Fish. Soc. 110:469-478.

National Academy of Sciences/National Academy of Engineering. 1973. Water Quality Criteria-1972. EPA.R.73.033. U. S. Environmental Protection Agency, Washington, DC.

Noggle, C.C. 1978. Behavioral, Physiological and Lethal Effects of Suspended Sediment on Juvenile Salmonids. MS Thesis. Univ. of Washington, Seattle. 87 pp.

Northcote, T.G. 1972. Kootnay Lake: man's effect on the salmonid community. J. Fish. Res. Board Can. 29(6):861-865.

Okazaki, T. 1981. Geographical distribution of allelic variations of enzymes in chum salmon, Oncorhynchus keta, populations of North America. Bull. Jpn. Soc. Sci. Fish. 47:507-514.

Olson, P.A., R.E. Nakatani and T. Meekin. 1970. Effects of Thermal Increments on Eggs and Young of Columbia River Fall Chinook. BNWL-1538. Battelle, Pacific Northwest Laboratory, Richland, WA.

Parametrix, Inc., D. Chapman, and T. Welsh. 1979. Vernita Barsspawning Survey, 1978-79. Document 79-1221-36F. Grant County Public Utility District, Ephrata, WA.

Patrick, R. 1975. Stream communities, pp. 445-459. IN M.L. Cody and J.M. Diamond (eds.), Ecology and Evolution of Communities. Belknap Press, Harvard Univ., Cambridge, MA.

Phillips, R.W., R.L. Lantz, E.W. Claire and J.R. Moving. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104(3):461-466.

Phinney, L.A. 1974. Further Observations of Juvenile Salmon Strandings in the Skagit River, March 1973. Washington Department of Fisheries, Olympia, WA. 34 pp.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCrasen, L.G. Fowler and J.R. Leonard. 1982. Fish Hatchery Management. U.S. Fish and Wildlife Service, Washington, DC.

Rosenberg, D. and A. P. Wiens. 1978. Effect of sediment on macro benthic invertebrates in a Northern Canadian River. Water Res. 12:753-763.

Scott, W.B. and E.J. Crossman. 1973. Freshwater Fishes of Canada. Fish. Res. Board Can. Bull. 184. Ottawa. 966 pp.

Seymour, A.H. 1956. Effects of Temperature on Young Chinook Salmon. PhD Dissertation, Univ. of Washington, Seattle. 127 pp.

Shaw, P.A. and J.A. Maga. 1943. The effect of mining silt on yield of fry from salmon spawning beds. Calif. Fish Game 29(1):29-41.

Shuter, B.J., J.A. MacLean, F.E.J. Fry and H.A. Regier. 1980. Stochastic simulation of temperature effects on first-year survival of small mouth bass. Trans. Am. Fish. Soc. 109:1-34.

Sorenson, D.L., M.M. McCarthy, E.J. Middlebrooks, and D.B. Parcella. 1977. Suspended and Dissolved Solids Effects on Freshwater Biota: A Review. EPA-600/3-77-042. Ecol. Res. Series. Environmental Protection Agency, Washington, DC. 64 pp.

Spence, J.A. and H.B.N. Hynes. 1971a. Differences in benthos upstream and downstream of an impoundment. J. Fish Res. Board Can. 28:35-43.

Spence, J.A. and H.B.N. Hynes. 1971b. Differences in fish populations upstream and downstream of a mainstream impoundment. J. Fish. Res. Board Can. 28:45-46.

Sport Fishing Institute. 1983. Pend Oreille Lake Kokanee Restoration Program. SFI Bulletin No. 344:7.

Stillwell, F.P., J.K. Atkins, M.D. Evenson, R.D. Ewing, and J.J. Martin. 1977. Determination of Salmonid Egg Mortality Resulting from Closure of Lost Creen Dam, September 1, 1976-April 30, 1977. Information Report Series, Fisheries 77-9. Oregon Department of Fish and Wildlife, Research Section, Corvallis, OR.

Stober, Q.J., R.E. Marita and A.J. Hamalainen. 1978. Instream Flow and the Reproductive Efficiency of Sockeye Salmon. Fisheries Research Institute, Unov. of Washington, Seattle. 124 pp.

Tack, S. 1973. Distribution, Abundance and Natural History of the Arctic Grayling in the Tanana River Drainage. F-9-6. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress, 1972-1973, Vol. 14. 34 pp.

Tappel, P.D. 1981. A New Method of Relating Spawning Gravel Size Composition to Salmonid Embryo Survival. MS Thesis. Univ. of Idaho, Moscow.

Taylor, S.G. 1980. Marine survival of pink salmon fry from early and late spawners. Trans. Am. Fish. Soc. 109:79-82.

Thompson J.S. 1970. The Effect of Water Flow Regulation at Gorge Dam on Stranding of Salmon Fry in the Skagit River, 1969-1970. Suppl. Prog. Rep., Power Dam Studies. Management and Research Division, Washington Department of Fish, Olympia, WA. 46 pp.

Thompson, K. 1972. Determining stream flows for fish life, pp. 31-50. IN Proceedings, Instream Flow Requirement Workshop. Pacific Northwest River Basin Commission, Vancouver, WA.

Trihey, E.W. 1982. 1982 Winter Temperature Study. Open file report for Acres American, Inc., Buffalo, NY.

Trihey, E.W. 1983. Preliminary Assessment of Access by Spawning Salmon into Portage Creek and Indian River. Prepared for Alaska Power Authority, Anchorage, AK. 63 pp. plus appendix.

Vernon, E.H. 1958. An Examination of Factors Affecting the Abundance of Pink Salmon in the Fraser River. Int. Pac. Salmon Fish. Comm. Prog. Rep. No. 5, New Westminister, British Columbia.

Wangaard, D.B. and C.V. Burger. 1983. Effects of Various Water Temperature Regimes on the Egg and Alevin Incubation of Susitna River Chum and Sockeye Salmon. U.S. Department of Interior, Fish and Wildlife Service, National Fishery Research Center, Alaska Field Station, Anchorage, AK. 43 pp.

Ward, J.V. 1976. Effects of flow patterns below large dams on stream benthos: a review, pp. 235-253. IN J.F. Orsborn and C.H. Allman (eds.), Instream Flow Needs. American Fisheries Society, Bethesda, MD.

Ward, J. and J.A. Stanford (eds.). 1979. The Ecology of Regulated Streams. Plenum Press, New York. pp. 398.

Welch, S. 1952. Limnology, 2nd rd. McGraw Hill Book Company, Inc., New York. 538 pp.

Wilson, W.J., E.W. Trihey, J.E. Baldridge, C.D. Evans, J.G. Thiele and D.E. Trudgen. 1981. An Assessment of Environmental Effects of Construction and Operation of the Proposed Terror Lake Hydroelectric Facility, Kodiak, Alaska. Instream Flow Studies. Univ. of Alaska, Arctic Environmental Information and Data Center, Anchorage, AK.

Witty, K. and K. Thompson. 1974. Fish stranding surveys, pp. 113-120. IN K. Bayha and C. Koski (eds.), Anatomy of a River. Pacific Northwest River Basins Commission, Vancouver, WA.

Wojcik, F. 1954. Spawning habits of grayling in interior Alaska. Report No. 2 by the Alaska Game Commission, Juneau, AK, for the U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.

Wojcik, F. 1955. Life history and management of the grayling in interior Alaska. MS Thesis. Univ. of Alaska, Fairbanks. 54 pp.