A Hydrologic Reconnaissance of the Susitna River Below Devil's Canyon

Environaid
October, 1974
Juneau

DAN BISHOP

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
P. O. BOX 1668 - JUNEAU, ALASKA 99801

March 18, 1975

Mr. J. V. House, Administrator
Alaska Power Administration
P. O. Box 50
Juneau, Alaska 99802

Dear Mr. House:

I am enclosing for your information the report "A Hydrologic Reconnaissance of the Susitna River Below Devil's Canyon," October 1974. The report was prepared by our consultant, Dan Bishop of Environaid, Juneau, under Contract Number 03-4-208-302.

I understand that your office will reprint a limited number of copies for your internal use and for information of others involved in current studies of the potential Susitna River hydroelectric project.

Sincerely,

Harry L. Rietze

Harry L. Rietze
Director, Alaska Region

Environaid

A Land-Water Resource Consultant Group

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October 31, 1975

Mr. Harry L. Rietze
Director, Alaska Region
National Marine Fisheries Service
P.O. Box 1661
Juneau, AK 99802

Dear Mr. Rietze:

The report, A Hydrologic Reconnaissance of the Susitna River Below Devil Canyon, is submitted herewith to fulfill contract No. 03-4-208-302 which I made June 19, 1974, with the National Marine Fisheries Service of NOAA.

Sincerely,

Dan Bishop

Daniel M. Bishop

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A HYDROLOGIC RECONNAISSANCE OF THE SUSITNA RIVER BELOW DEVIL'S CANYON DAMSITE...examining physical features that may be altered

As stated in the original proposal, this work was to provide information on present and future (regulated) physical characteristics of the Susitna River below Devil's Canyon. Available information was to be gathered and selected field work done during summer, 1974. The subsequent analysis was to concentrate on features relating to the fishery resource habitat. Particular attention was to be given to the Susitna River above Talkeetna because this portion of the river is apt to be most changed and it appears to have more available river-related information. The work was to be a careful reconnaissance focusing the problem, indicating the present state of knowledge, and reaching conclusions as to where problems or opportunities may lie.

Specific Objectives originally identified were:

A. Stream temperature
B. Stream velocity
C. Suspended sediment, and
D. Re-grading of the Susitna River profile.

To these I have added a brief discussion and review of springflows in the river bottom as they may be influenced by regulation of the river.

This work does not attempt to evaluate impacts on resources from possible physical changes; rather it should lead to selection of possible impacts that may be important in managing the river's resources and need further investigation.

A. Stream Temperature

Impoundment of the Susitna River will alter the temperature of water discharged below Devil's Canyon dam. This change will reflect the heating and stratification characteristics of the reservoir behind the dam as well as the design of turbine intake facilities at the dam. These factors are not part of this work though they will ultimately relate to downstream conditions.

The purpose of temperature work described in this report is to assemble and display information known on the middle river's present temperature regime and to project how this regime may change below the dam.

1. Figure 1 shows estimates of the surface water temperatures of the Susitna River at Gold Creek and of the Chulitna and Talkeetna tributaries at their gaging stations. This figure represents a body of miscellaneous temperature measurements made over a period of years (also included are daily temperature measurements of the Susitna during the summer of 1957) and hence are more limited in their use than continuously recorded temperatures. Nevertheless, the data provide a meaningful characterization. There is indication that the Susitna and particularly the Talkeetna begin to warm earlier in the spring than the Chulitna, evidently reflecting the smaller percent of glacial headwaters. The Susitna at Gold Creek reaches considerably higher surface water temperatures than the Chulitna and possibly higher than the Talkeetna.

2. Surface water temperature measurements were made during part of July on the Little Susitna (a clear water river), the Susitna River at Gold Creek and at Sherman Creek, the Chulitna River at the gaging station, and the Talkeetna River immediately above the mouth.

These continuous records have been plotted from maximum and minimum values in Figure 2. Diurnal patterns are evident in all streams, particularly in the Chulitna and Little Susitna rivers. The Talkeetna pair of thermographs recorded a pattern suggesting the influence of springflows. This is possible at the site where the recorders were installed but was not indicated by any evidence of surface flow or clearer water next to the bank. As was suggested in Figure 1, the Susitna River reaches higher maximum daily temperatures than the Chulitna or the Talkeetna.

One objective of these measurements was to compare the heating of a clearwater river (Little Susitna) with the Susitna. For that reason two stations were used on each of these rivers. Differences between maximum temperatures and between minimum temperatures for these respective pairs of stations are shown in Table 1.

Table 1: Temperature differences between two stations on the Little Susitna and between two stations on the Susitna River.

	Little Susitna River		Susitna River	
Date	max lower sta - max upper sta	min lower sta - min up sta	max lower sta - max upper sta	min lower sta - min up sta
7-14	.3 deg. F	--	--	--
-15	.6	.6	--	--
-16	.4	.4	--	--
-17	.0	.2	.5	--
-18	.5	.5	.3	0.0
-19	.3	.0	no maximum	1.2
-20	.2	.4	" "	1.2
-21	.2	.2	" "	.9
-22	.1	.2	.9	1.0
-23	.2	.4	.2	.8

There is a distance of about 1.3 miles between the upper and lower stations on the Little Susitna and six miles on the Susitna River between Gold Creek and Sherman. Each of these

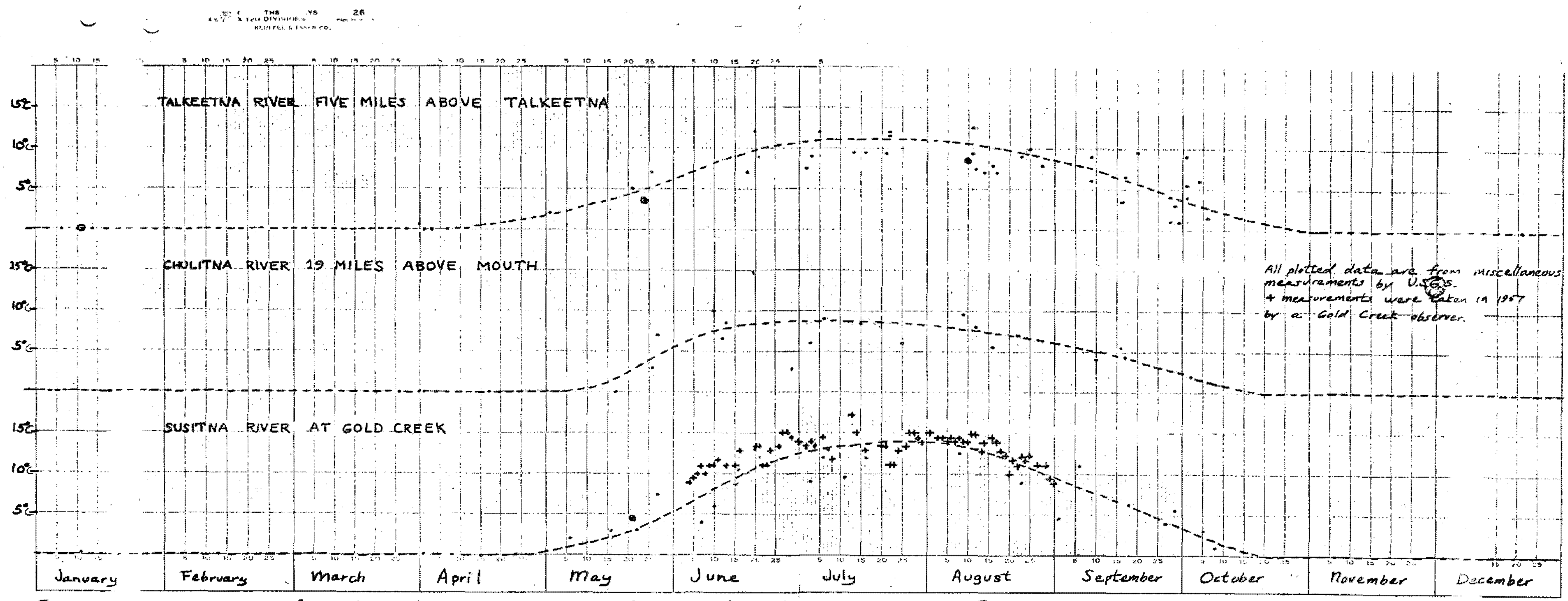


Figure 1 : Estimated Annual Water Temperature Curves for Three Susitna Rivers.

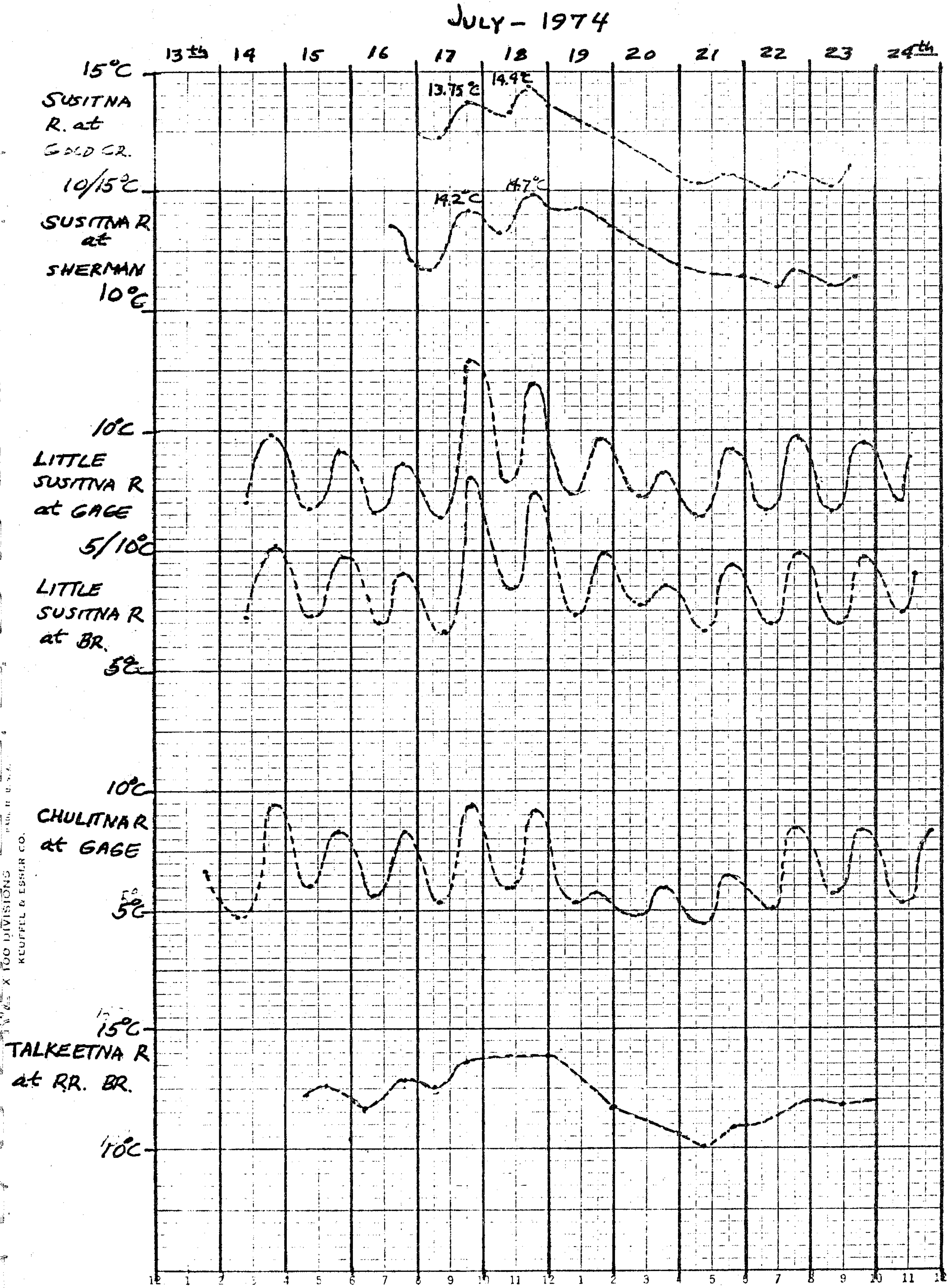


Figure 2: Measured Temperatures of Three Susitna Rivers and of Little Susitna River.

pairs of stations was located immediately below a USGS stream gaging station. The plan of study was to obtain comparative measurements as shown in Table 1 and then to study the temperature change in each of the respective sections of stream according to the method developed by Edinger and Geyer (1965). The Little Susitna proved to be unsuited to this analysis because the stream was subject to shading from streamside vegetation and was moving so turbulently (gradient about 200 ft. in a mile) that much of the heat being absorbed by the stream was probably by air-water mixing.

Analysis of the measured six mile section of the Susitna River proved interesting and instructive in terms of future change in the temperature regime. Edinger and Geyer provide comprehensive and rigorous theory to determine the rate at which a streamflow changes temperature. This rate depends upon volume and area of streamflow and upon meteorological features--dewpoint temperature, wind velocity, and solar radiation. The work does not provide for variation in albedo or re-radiation characteristics according to differing water surface characteristics.

Between Gold Creek station (river mile 119) and Sherman (river mile 113) the widths measured on the 1962 photographs are as follows, and have also been reduced according to the regression shown on Figure 8 of Section B. Average width is 559 ft. Stream area is 559(5280)(6) = 17,700,000ft.^{2} on 18 July.

River mile	Width at 25,900 cfs	estimated width at 17,300 cfs (18 July)
119	360 ft.	343 ft.
118	415 "	395 ".
117	790 "	753 "
116	.835 "	787 "
115	615 "	586 "
114	480 "	457 "
113	410 "	391 "

Stream discharge during 18 July, the date selected for calculation, was 17,300 cfs or 1,494,720,000 ft^3/day.

From Edinger and Geyer the equation developed to solve for predicted temperature at the lower end of a measured section is:

$$T_2 = T_1 \, e^{-r2} + E + Ee^{-r2}$$

T_1 = mixed water temperature, deg. F at beginning of temperature section.

T_2 = mixed water temperature, deg. F at end of measurement section.

e = 2,71828, base of Natural Logarithm

r2 = K · Area/ 62.4(disch., ft^3 per day.

K = average surface heat exchange coef. in BTU's/ft^2/day/deg. F, and depends on wind, dewpoint temp., and T_1. a graphical approximation of K is provided by Edinger and Geyer, and indicates a K = 85BTU/ft^2/day/deg. F for conditions on 7/18/74.

E = Equilibrium temperature toward which water temperature is approaching.

E = $T_d + H_s/K$, where T_d = dewpoint temperature (46 deg. F on 7/18/74)

H_s = gross solar radiation in BTU's/ft^2/day/deg. F (1608 BTU/ft^2/day/deg. F on 7/17/74)

For the situation on the Susitna River, July 18th:

$$r^2 = \frac{85(17,700,000)}{62.4(1,494,720,000)} = .016; \text{ and } e^{-.016} = .985$$

$$E = 46 \text{ deg.} + 1608/85 = 65 \text{ deg. F.}$$

Thus, the temperature, T_2, at the lower end of the measured section of the river = T_1 (.985) + 65 deg. F - 65(.985). When the temperature at the beginning of the section is 56.5 (the maximum on 7/18/74) the temperature projected for six miles downstream at Sherman = 56.5(.985) + 65 - 65(.985) = 56.6 deg. F.

This projected temperature compares with a measured value of 56.8 deg. F. The magnitude of error is sufficiently small to suggest that the methodology may be of use in evaluating present and projected temperature conditions in the river between Devil's Canyon and the Talkeetna-Chulitna confluence.

3. Suspended sediment concentration in the Susitna may influence the heating characteristic of the river. We explored this factor through library research at the University of Alaska at College and also by measurements made in Juneau of heating in clear and in silty water samples.

Stan Justice, graduate student with the University of Alaska's Environmental Engineering Department reports:

> "Little is known about the effects of sediment on temperature changes in water. Several professionals at the University of Alaska were questioned but none could say for certain what the effects would be or provide any references.

"Water has a specific heat of 1.00 cal/gm/deg. C and soil has a specific heat of 0.2 cal/gm/deg. C; sediment-laden water therefore has a lower specific heat than does clear water even though soil or silt is about 1.6 times heaver than water.

"For example, if a solution is one-tenth percent suspended sediments, its specific heat would be: C_p = (1.00 cal/gm/deg. C)(0.999) + (0.2 cal/gm/deg. C (.001) = 0.9992 cal/gm/deg. C, and its density would be: e = (1.00gm/cm^3)(0.999) + (1.6gm/cm^3)(0.001) = 1.0006 gm/cm^3. The calories required to heat a cubic meter one degree are: (1m^3)(10^{6}cm^3/m^3)(10^{6}cm^3/m^3) (1.0006gm/cm^3)(0.9992cal/gm/deg.C = 0.9998·10^{6}cal/deg.C compared to 1.0000 calories required to heat a cubic meter of distilled water. With identical heat input conditions the temperature of silty Susitna water will rise slightly faster (0.02%) than the temperature of clear water.

"The depth of short wave radiation penetration will obviously be decreased by silty water. The effect of this will be to increase heating at the surface and decrease it at depth. The high surface temperatures will cause an increase in evaporation which removes heat by the formula: $Q_e = 0.34u(e_w - e_a)0$, where u = wind velocity, e_w = vapor pressure for water and e_a = vapor pressure for air. (Delay 1966)

"Another effect of high surface temperatures is to increase long wave radiation as described by the classical Stefan-Boltzmann equation: $\phi_{rw} = 0.97KT_w^4$, where $K = 1.71 \cdot 10^{-6}$kcal/m^2-k^{4}day and T_w = absolute temperature of water, ^{o}k (Parsons, 1971). This will also cause an increased loss of heat with increase in surface water temperature.

"Albedo is the ratio of reflected short wave radiation to incident short wave radiation. For clear water it varies from 0.03 to 0.04 (Eagleson, 1970), but no data could be found on the albedo of silty water. It can be assumed that soil particles disrupting the water surface will cause the albedo of silty water to be less than that of clear water. But what is the effect of silt below the surface? When looking at glacial streams from the air, they appear grey-white while clear streams are dark in color; apparently the particles reflect at least visible light and probably some nonvisible light as well. Pivovarov (1973) writes that "the effect of water transparence on albedo may be considerable" but he does not quantify his statement.

"Several people contacted suggested that the sediment's color will have an effect upon heat absorption and reflectance. Darker sediment will absorb more than lighter sediment but again there is no quanification.

"Short wave radiation is transmitted to and heats the bottom of clear, shallow water masses. Because this energy is re-radiated out into the water, it has the same effect on temperature as short wave radiation entering shallow, silty water.

"Because heated surface water is mixed with the mass in a turbulent river like the Susitna, any effects due to the decrease in light penetration are apt to be eliminated. There should be no loss of heat due to higher evaporation and long wave radiation in silty river water. In a river the primary factors affected by the sediment load are lowering of specific heat and change of albedo.

"Before heavy silt laden water sinks below clear water in a reservoir, increased surface heating and the change of albedo and specific heat probably influence the temperature regime. In the silt-free reservoir radiant energy is absorbed in the first few meters, eliminating the effects of surface heating. The clear water surface has a higher albedo and specific heat, thus decreasing the heating rate.

"Extensive investigation of the sediment load's effect on solar heating is needed. Turbid water samples should be collected and examined for specific heat, albedo, and light penetration. Although more difficult, field investigation should also be made of free flowing rivers."

Measurements were made in Juneau during August, 1974 to explore the heating of four kinds of fresh water held in 20 liter plastic buckets and exposed to the sun. This work is summarized below:

Kinds of water:

A = 20,400 ml of Auke Lake water with evident organic staining.

TW = 20,300 ml of tap water from drilled well. Clear.

C = 20,600 ml of Chulitna River water. Sample taken on 24 July at main hwy. bridge, near gaging station. Based upon other sediment samples in records, this water's sediment concentration is in the magnitude of 1000 mg/l.

TA = 20,400 ml of mixed waters from the Talkeetna and Mendenhall Rivers. Rough estimate of sediment concentration is 100 to 300 mg/l.

Containers:

White plastic garbage cans with 20 liter capacity.

Top diameter at water surfaces was 31.8 cm., with a surface area of 794 cm^2.

Measurements:

Temperature measurements were taken with a Yellow Springs Electronic thermometer, reading to 0.01°C. Measurements were taken at 1, 3, 6, 10 and about 12 inches below the water surfaces. The 1-inch measurement depth represents 17.1% of the volume; 3-inch = 23.1%; 6-inch = 29.3%; 10-inch = 23.1%; and 12-inch = 7.3%. These percentages were used as weighting values to determing weighted average temperatures for the respective measurements.

Results:

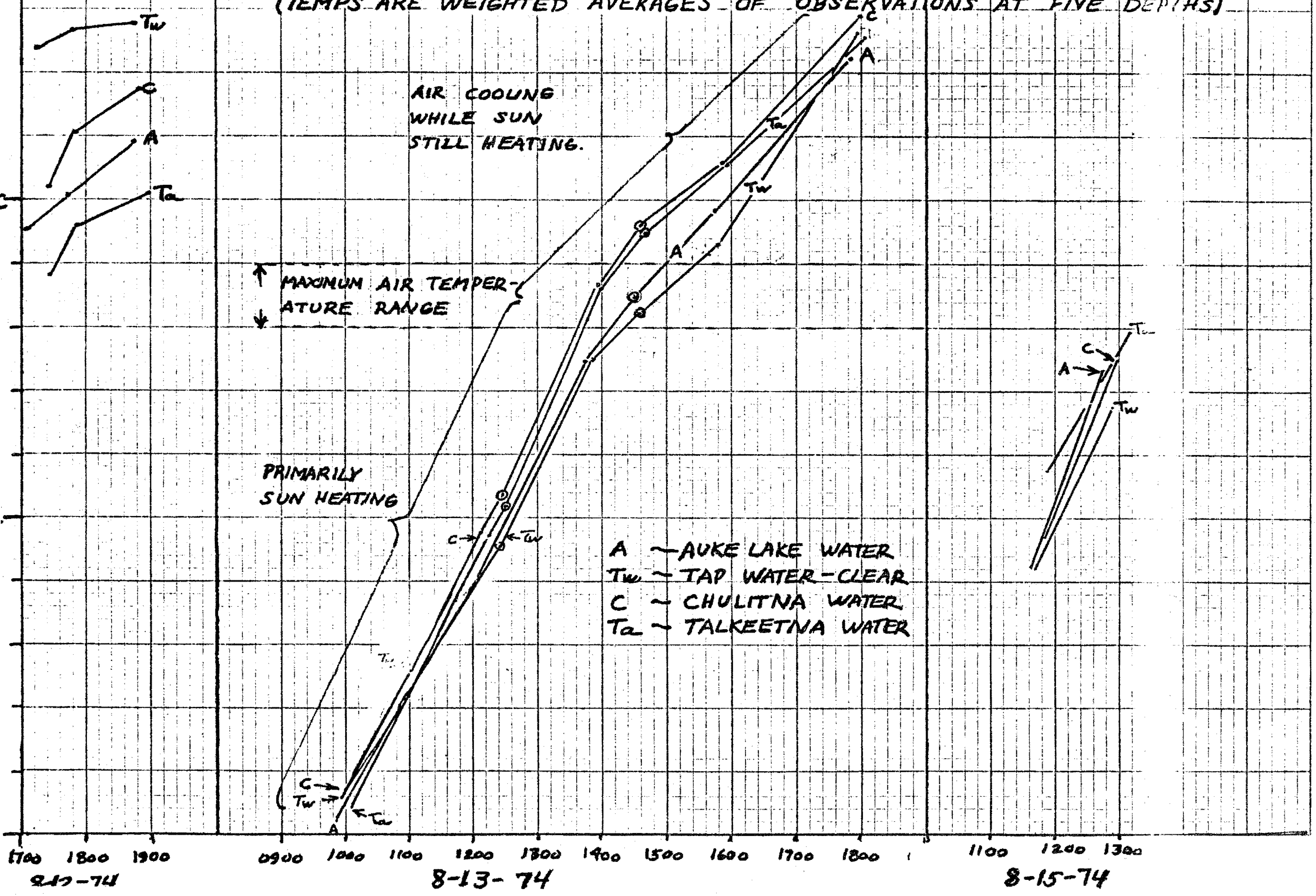
Shown in Figures 3 and 4, summarize the respective heating patterns.

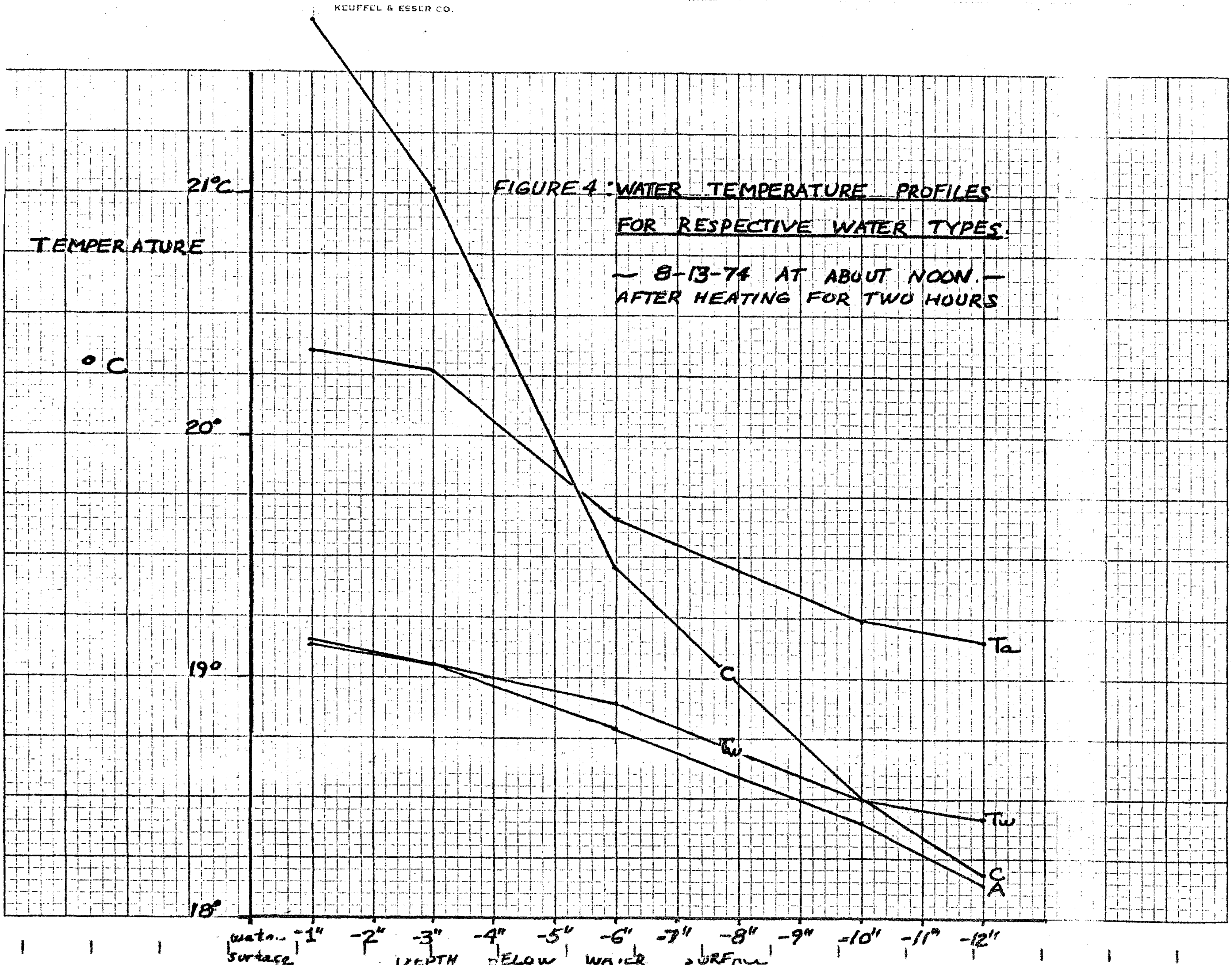
Conclusions pertinent to reconnaissance:

1. With ambient air temperatures above water temperatures, the average water temperatures in containers of sedimented water (Chulitna, Talkeetna) rose 17-20% faster than clear

FIGURE 3: HEATING PATTERNS WITH FOUR WATER TYPES

(TEMP'S ARE WEIGHTED AVERAGES OF OBSERVATIONS AT FIVE DEPTHS)




KEUFFEL & ESSER CO.
FIGURE 4: WATER TEMPERATURE PROFILES FOR RESPECTIVE WATER TYPES.
— 8-13-74 AT ABOUT NOON. — AFTER HEATING FOR TWO HOURS
TEMPERATURE
°C
21°C
20°
19°
18°
water surface
-1"
-2"
-3"
-4"
-5"
-6"
-7"
-8"
-9"
-10"
-11"
-12"
DEPTH BELOW WATER SURFACE
Ta
C
Tw
Tw
C
A

tap water; there was little difference in the average heating of Chulitna and Talkeetna waters. The organically stained water of Auke Lake may heat faster than tap water.

2. Rate of heat loss to the atmosphere at high temperatures (above ambient air temperatures) was evidently lower for clear tap water than for sedimented or organically stained waters. I presume this was due to differing rates of back radiation.

3. Sedimented water develops a much steeper temperature profile with depth in a quiet container than clear water. The more heavily sedimented water of the Chulitna stratified much more strongly than the Talkeetna water.

4. Estimates will be made of July temperatures of the Susitna River at Gold Creek and at river mile 91 near Chase for conditions of natural and regulated flows, respectively. These estimates will indicate the effect of changes in volume of flow and channel heating characteristics on expected temperatures. The effect of suspended sediment on water heating is not included here. Assumptions used in these estimates are as follows:

<u>River Discharge</u>:

Section of River	Unreg. July Flow	Reg. July Flow
Devil's Canyon to Gold Creek	23,825 cfs	13,648 cfs
Gold Creek to River mile 91	25,000	14,800

River Area:

(a) length:

Devil's Canyon to Gold Creek = 15 river miles = 79,200 ft.

Gold Creek to river mile 91 1/ = 28 river miles = 146,840 ft.

1/ River mile 91 is near Chase and is about ten river miles upriver from Talkeetna. This is the southernmost river coverage of the Talkeetna air photography. The Susitna flight does not reach this far north.

(b) width.

The regulated July discharges used for the two respective sections of stream were as follows: Devil's Canyon to Gold Creek: 13,648 cfs; Gold Creek to river mile 91: 14,800. Adjusted widths were developed for these reduced flows in the following manner:

As discussed further in Section D, width of the regulated Susitna at bankful flow is estimated at about .715 present width at bankful flow. This reduction is based on a relation relating stream width to the square root of discharges having similar return intervals. This factor has also been applied to the average widths, 565 and 493 ft. generated in Table 2, suggesting that a regulated flow of 25,000 cfs below Gold Creek will have an average channel width of 404 ft. and a regulated flow of 23,825 cfs above Gold Creek will have an average width of 352 ft.

Further, small reductions in width are then made based upon the local channel form at Gold Creek (Figure 9) which suggests a rate of reduction in width proportional to discharge $^{(.11)}$.

Table 2: Average width of the Susitna River as taken from 1962 photos and adjusted for average July flow conditions.

River mile location	Width on 1962 photos	Adjusted widths Gold Creek to river mile 91	River mile location	Width on 1962 photos	Adjusted widths Devil's Canyon to Gold Creek
91	520 ft.	404 ft.	120	420 ft.	417 ft.
92	560 "	543 "	121	480 "	477
93	415 "	403 "	122	620 "	6 ,
94	615 "	624 "	123	800 "	793 "
95	675 "	685 "	124	630 "	634 "
96	415 "	422 "	125	415 "	420 "
97	625 "	636 "	126	820 "	829 "
98	520 "	527 "	127	520 "	526 "
99	515 "	523 "	128	420 "	425 "
100	630 "	639 "	129	520 "	526 "
101	620 "	629 "	130	310 "	314 "
102	270 "	269 "	131	300 "	304 "
103	370 "	369 "	132	400 "	405 "
104	590 "	588 "	133	210 "	213 "
105	470 "	469 "			
106	830 "	828 "			
107	610 "	608 "			
108	600 "	598 "			
109	720 "	718 "			
110	720 "	718 "			
111	370 "	369 "			
112	730 "	728 "			
113	360 "	359 "			
114	415 "	414 "			
115	790 "	788 "			
116	825 "	823 "			
117	615 "	613 "			
118	480 "	479 "			
119	410 "	409 "			

Streamflows varied by very considerable amounts during the several days of photography used. This was accounted for. The average July discharges used were: Devil's Canyon to Gold Creek: 23,825 cfs; Gold Creek to river mile 91: 25,000.

565 ft. average width

493 ft. ave. width

The 404 ft. width is reduced to 380 ft. for 14,800 cfs and the 352 ft. width is reduced to 328 ft.

Estimates of widths are thus:

	un-reg. July flow	reg. July flow
Devil's Canyon to Gold Creek	493 ft.	328 ft.
Gold Creek to River mile 91	565 ft.	380 ft.

Resultant stream areas for the test sections:

	un-reg. July flow	reg. July flow
Devil's Canyon to Gold Creek	39,100,000	25,990,000
Gold Creek to River mile 91	83,400,000	56,100,000

Equilibrium Temperature Calculation:

$$E = \text{dewpoint temperature} + \frac{\text{Gross solar rad., BTU's per day}}{K}$$

Gross solar radiation in BTU's/ft^2/day - an average July value was taken from the solar radiation tables for Palmer, Alaska, published by the University of Alaska (Branton, et. al., 1972). They indicate 390 Lys/day = 1440 BTU's/ft^2/day.

Dewpoint temperature: The 7/18/74 condition where a dewpoint of 46°F was used has also been taken here.

K, the heat exchange coefficient, gives the net rate at which heat is lost or gained by a body of water for a unit temperature difference. In these determinations 85 BTU's/ft^2/day/$^\circ$F has been used, assuming a wind speed of about 5 mph and an equilibrium temperature of about 60°F. This value is derived from tabular data in Edinger and Geyer (1965).

E. Equilibrium Temperature, thus = $46^{\circ}F + 1440/85 = 61^{\circ}F$.

T_1, temperature at the upper end of the measurement section: a range of assumed values have been used ($50-60^{\circ}F$) and are tabulated with respective generated temperatures (T_2) for the lower ends of the test sections.

The assumed values shown above have been used in the Edinger-Geyer equation described in (2) above. These calculations are not shown, but generate the following values:

	Temp. T_1 at upper end	Est. of T_2, water temp at lower end	
		unregulated	regulated
Devil's Canyon to Gold Creek	$50^{\circ}F$	$50.3^{\circ}F$	$50.4^{\circ}F$
	52	52.2	52.3
	54	54.1	54.3
	56	56.1	56.2
	58	58.1	58.1
	60	60.0	60.0
Gold Creek to river mile 91	50	50.5	50.6
	52	52.5	52.5
	54	54.3	54.4
	56	56.2	56.3
	58	58.2	58.2
	60	60.1	60.1

5. Water temperatures below the Susitna-Chulitna-Talkeetna confluence can be estimated from respective river temperatures above the confluence and their volumes of flow.

$$T_{mixed} = T_{Susitna}\left(\frac{\text{Susitna flow}}{\text{combined flow}}\right) + T_{Chulitna}\left(\frac{\text{Chulitna flow}}{\text{combined flow}}\right) + T_{Talkeetna}\left(\frac{\text{Talkeetna flow}}{\text{combined flow}}\right)$$

Calculations have been made for combined temperatures on 15 June, 15 July, and 1 September, because these times appear to define points in the temperature curve best.

a. Before regulation:

June 15: $T = 9.4\left(\frac{28,000}{63,000}\right) + 8.0\left(\frac{22,900}{63,000}\right) + 9.0\left(\frac{12,100}{63,000}\right) = 8.8^{\circ}C$

July 15: $T = 13.6\left(\frac{24,600}{61,600}\right) + 8.7\left(\frac{26,400}{61,600}\right) + 11.0\left(\frac{10,600}{61,600}\right) = 11.06^{\circ}C$

Sept. 1: $T = 9.6\left(\frac{36,400}{88,000}\right) + 6.1\left(\frac{34,500}{88,000}\right) + 8.6\left(\frac{17,100}{88,000}\right) = 8.5^{\circ}C$

b. After regulation: 1/

June 15: $T = 9.5\left(\frac{13,700}{48,700}\right) + 8.0\left(\frac{22,900}{48,700}\right) + 9.0\left(\frac{12,100}{48,700}\right) = 8.67^{\circ}C$

July 15: $T = 13.7\left(\frac{14,200}{51,200}\right) + 8.7\left(\frac{26,400}{51,200}\right) + 11.0\left(\frac{10,600}{51,200}\right) = 10.53^{\circ}C$

Sept. 1: $T = 9.7\left(\frac{29,200}{80,800}\right) + 6.1\left(\frac{34,500}{80,800}\right) + 8.6\left(\frac{17,100}{80,800}\right) = 7.94^{\circ}C$

6. Summary: The preceeding work indicates that the Susitna above Talkeetna will produce only small rates of temperature change because it is such a large and fast-moving river. Loss of suspended sediment will influence heating and cooling of the river and its bottom as discussed. This influence, particularly as it will relate to the river water, is thought to be small. Alteration of the flow regime will not influence summer temperature as much as might be expected because as summer discharge is

1/ regulated temperature calculations here assume very small changes in Susitna River temperatures.

decreased (favoring increased temperatures), the width/depth ratio is also decreased (reducing surface area and therefore acting to reduce heating). Increased late Fall and Winter discharges, still with the reduced width/depth ratio, will conversely favor reduced rates of cooling. Release of colder water below the dam will increase summer heating rate in the river; conversely, warmer waters during winter will produce higher water cooling rates.

In summarizing possible effects of river regulation on downstream temperature conditions, the temperature of waters discharged below the dam as well as the winter temperature regime have not been included in this work. They were not considerations of the original proposal. However, these two features will influence some of the interactions which have been examined. To enhance the usefulness of a summary, assumptions on released water temperatures have been included in the matrix shown in Table 3.

In considering the effect of regulating the Susitna on water temperatures downstream of the Chulitna-Talkeetna confluence, the size of the regulated flow as compared to that of the tributary rivers plays a key role. Calculations shown in A-5 illustrate this relationship. In this fashion, it can be shown that the warmer winter flows of the regulated Susitna may dominate the river for some distance downstream because the regulated winter flows are much larger than those of the tributary rivers. Similarly, the somewhat depressed temperatures of the regulated Susitna during summer months will exert reduced influence on the downstream temperatures because the regulated summer flows are reduced.

Table 3: Matrix of factors summarizing the regulated stream temperature regime in the Susitna River between Devil's Canyon dam and Talkeetna. The temperatures shown for the Susitna immediately downstream from the dam are assumed.

	Nov - May	1 May-15 June	15 June-15 Sept	15 Sept-1 Nov
Temperature of streamflows released below Devil's Canyon dam.	34-36°F (+2 to 4°F)	34-40°F (similar to unreg regime)	40-55°F (-2 to 6°F)	50-36°F (reduced rate of change)
	Summary of influences on the stream temperature regime produced by other changes in the river following reg.			
Change of channel width/depth ratio.	width/depth reduction; reduced cooling rate.	width/depth reduction; reduced rate of temp. change.	width/depth reduction; reduced rate of heating.	width/depth reduction; reduce rate of cooling.
Change of streamflows discharged with regulation of river.	increase in flow reduce rate of river cooling	relative reduction in flow favors stream heating.	reduced flow favor heating.	not much change from natural flow. No impact.
Change of suspended sediment concentration below dam.	no sediment naturally	reduced sediment concentration means more bottom heating; less diurnal fluct.	reduced sediment; possibly small reduction in heating; more bottom heating; less diurnal fluct.	reduced sediment; possibly small reduction in surface water heating.
Expected temperature conditions in Susitna above Talkeetna.	Much incr. in cooling rate immed. below dam due to 2-4°F increment above freez; more open chan. thinner ice; earlier break-up	transitional; little change in river temp. warmer str. margins; less diurnal fluct.	cooler; 2-6°F smaller diurnal fluctiation.	transitional, from 2-4°F cooler at 15 Sept. to 2-4°F. warmer 1 Nov. delay of ice formation.

B. <u>Stream Velocity</u>

This section is to describe and evaluate Susitna River velocities and related streamflows under natural and regulated conditions, respectively. Portions are also used in other sections; conversely, this section used information discussed further in later sections. USGS records, both published and unpublished (stream discharge measurement data) from their Anchorage subdistrict office have been used. Printout sheets received from the U.S. Army Corps Engineers showing monthly regulated and unregulated flows below Devil's Canyon dam were also used.

1. The annual hydrographs under present and under regulated flow conditions are shown in Figure 5 for the Gold Creek station. The annual hydrographs, natural and regulated for flows below Talkeetna are shown in Figure 6.

These serve to describe the general flow regime, natural and regulated. Change in hydrograph together with major alteration of the total sediment flow downriver and changes in the pattern of water temperatures released below the dam represent the prime movers in altering the river regime below the dam.

From Figure 5 it is evident that the Susitna above the Chulitna confluence will have a Fall-Winter regulated flow generally two to five times the present normal pattern. To compensate for this October through April increase in regulated flow, the high runoff months, May through August will have flows reduced by as much as half (June).

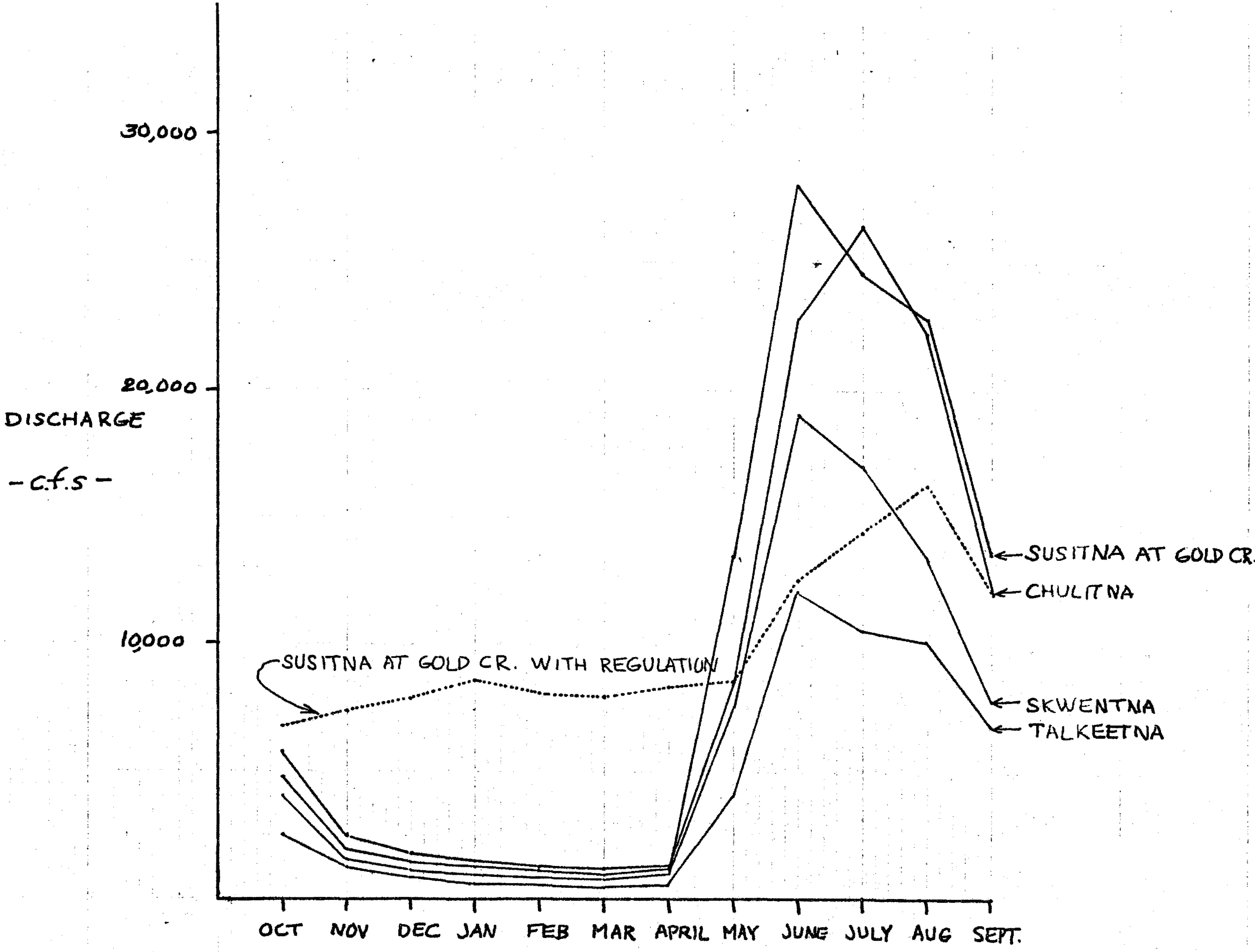


FIGURE 5 : ANNUAL HYDROGRAPHS OF FOUR SUSITNA RIVERS

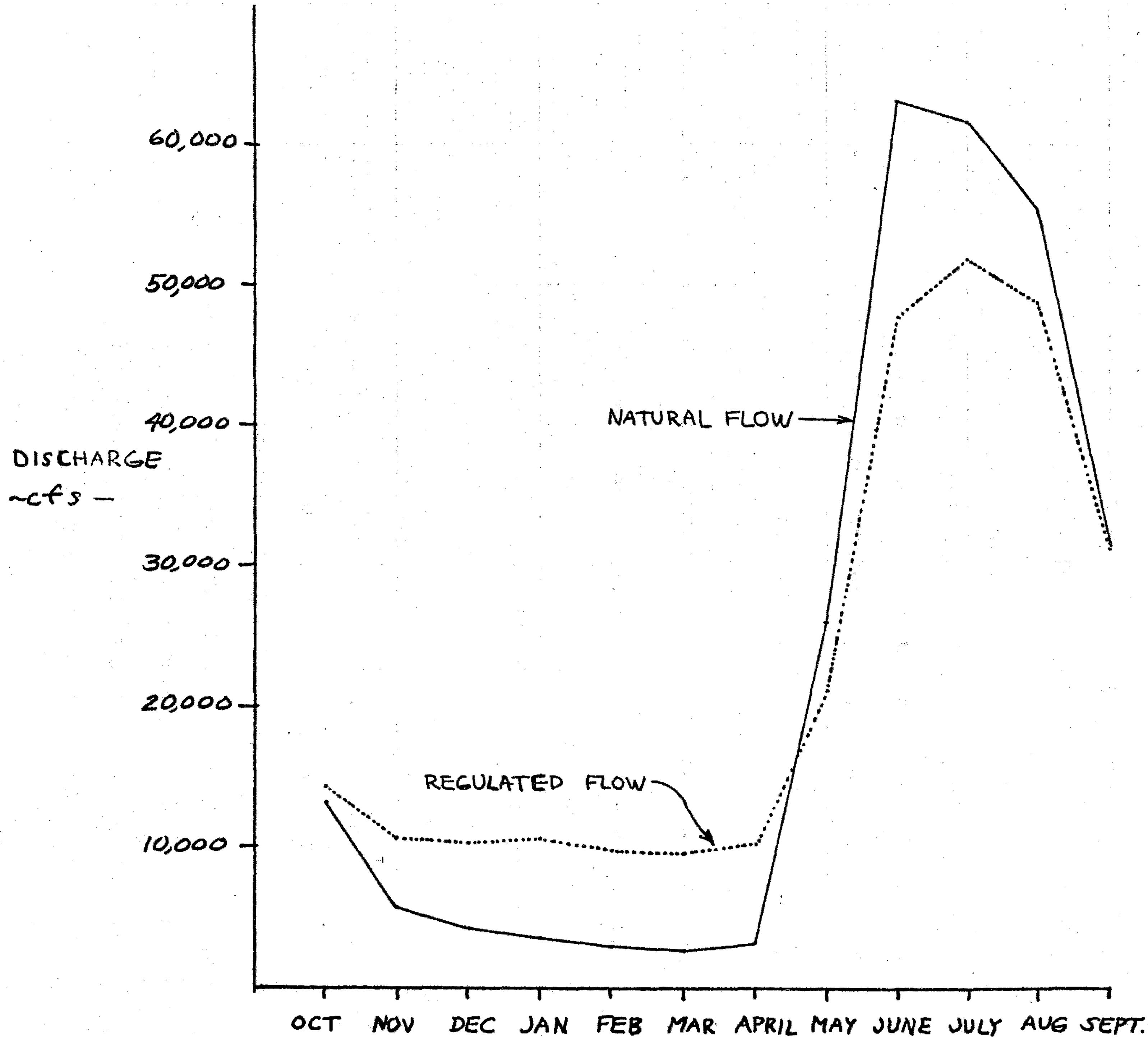


FIGURE 6 : ANNUAL HYDROGRAPH OF SUSITNA BELOW TALKEETNA

Values of Figure 5 for the Susitna, and those used for Figure 6 are made with the assumption of the Denali storage dam also in operation on the river. With this degree of regulation it appears evident that water will often pass over the spillway from June through August and probably into September as well. Construction of the Watana-Vee dams would totally regulate the river eliminating the spillage suggested in Figure 5. (From telephone conversation on 8/8/74 with Mr. Gary Flightner, Hydrologist, U.S. Army Corps Engineers).

2. Flow duration curves for the Susitna family of rivers have been developed and are shown in Figure 7. The duration curve for the regulated Susitna at Gold Creek is also shown in Figure 7.

The ordinates of these curves were expressed in terms of percent of average flow rather than in volume of flow, cfs. By doing this, the curves are comparable in character.

The curves of natural flows suggest that the Susitna at Gold Creek is somewhat less prone to higher flows than other Susitna tributaries. The Talkeetna, by contrast, evidently experiences larger peak flows more frequently.

The regulated Susitna is projected to maintain flows within 25% of average flow (9,843 cfs) about 80% of the time. These average conditions do not, however, demonstrate conditions for a particular year.

The monthly flows for August and September are particularly pertinent examples inasmuch as this interval includes spawning periods. The average Gold Creek flow for August is about 22,800 cfs; for September about 13,650 cfs. Regulated flows for August and September will be about 16,260 and 12,130 cfs respectively. In 1969 the August flow dropped to 8,879 cfs and the September flow to 5,093 cfs. The former flow represented about 39% of the present average for the month and the latter 22.3%. The Corps of Engineers' programmed estimate of what average regulated flow would have been for August and September of 1969 is approximately 6,224 cfs and 6,528 cfs for the respective months. The August regulated flow represents 38.3% of average and the September flow 53.8%.

The record of unregulated flows at Gold Creek compared with the projected regulated flows indicates the following occurrence of flows less than 9,000 cfs over the 24 years of record:

No. of years having monthly average $<$ 9,000 cfs

	August	September
Unregulated flow	1	5
Regulated flow	2	9

It appears that regulation of flows will increase the occurrence of low streamflow conditions during late summer periods. Further, more comprehensive examination of size and frequency of late summer low flows is warranted.

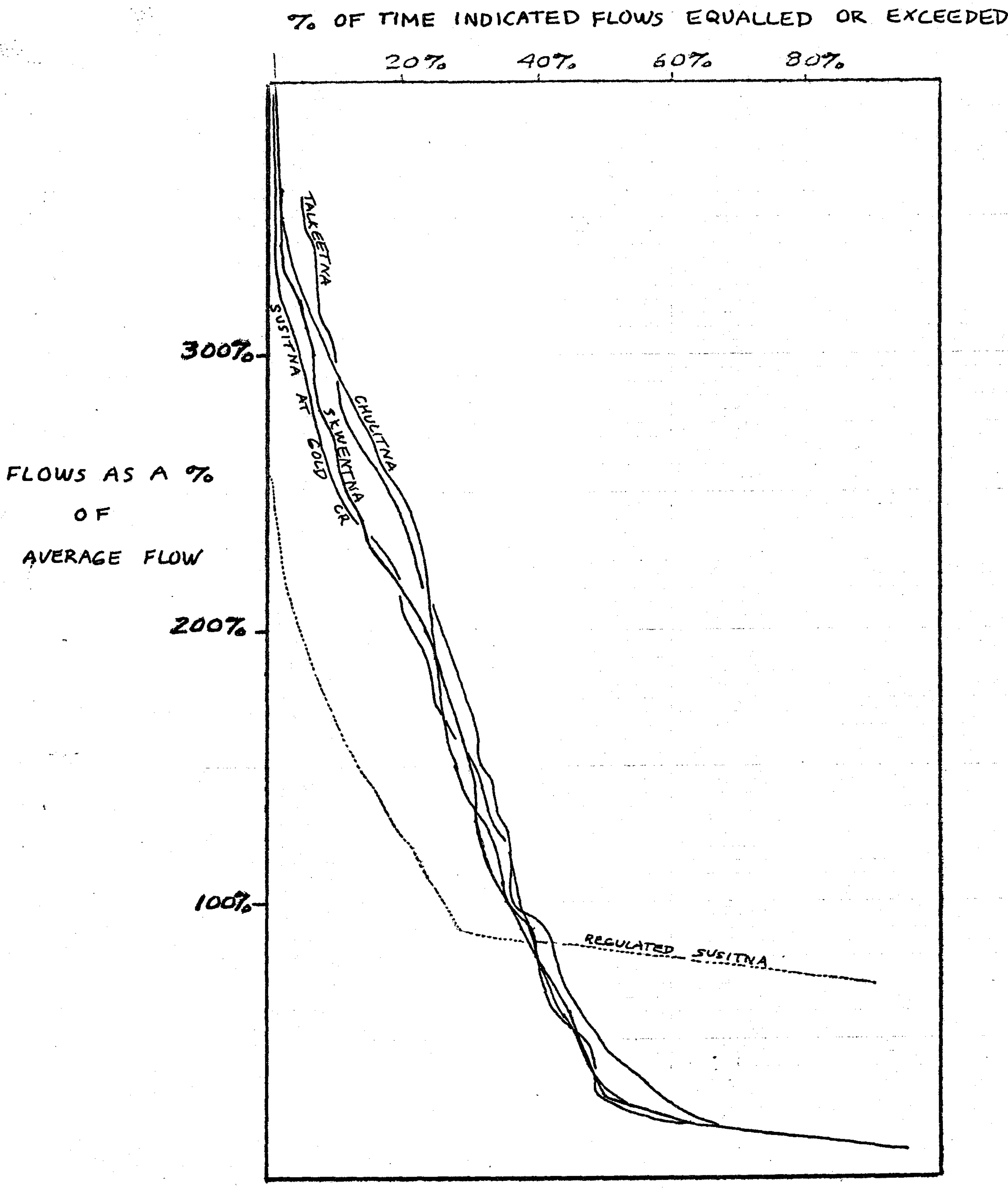


FIGURE 7: FLOW DURATION CURVES FOR FOUR SUSITNA RIVERS

3. The distribution of flow velocities within three measurement sections taken on the Susitna at Gold Creek are shown in the isometric diagrams of Figure 8. These diagrams suggest the magnitude and the distribution of velocities within narrower channel reaches. The three discharges selected for examination represent low, intermediate and high discharge conditions at the Gold Creek station. Only the lowest dischargemeasurement indicates any significant cross-sectional area with velocities suitable for resident fish. While velocities at other river sections above Talkeetna may not be as severe as the Gold Creek station, the indication is that their velocities, too, are limiting to resident fish.

4. Observation of surface velocity conditions were made at four points along the Susitna River. River perimeter material was photographed at nine locations and also suggests the high range of stream velocities to be expected.

Drift velocity was measured about 75 feet out from the river's east bank. These measurements are summarized in Table 4 below:

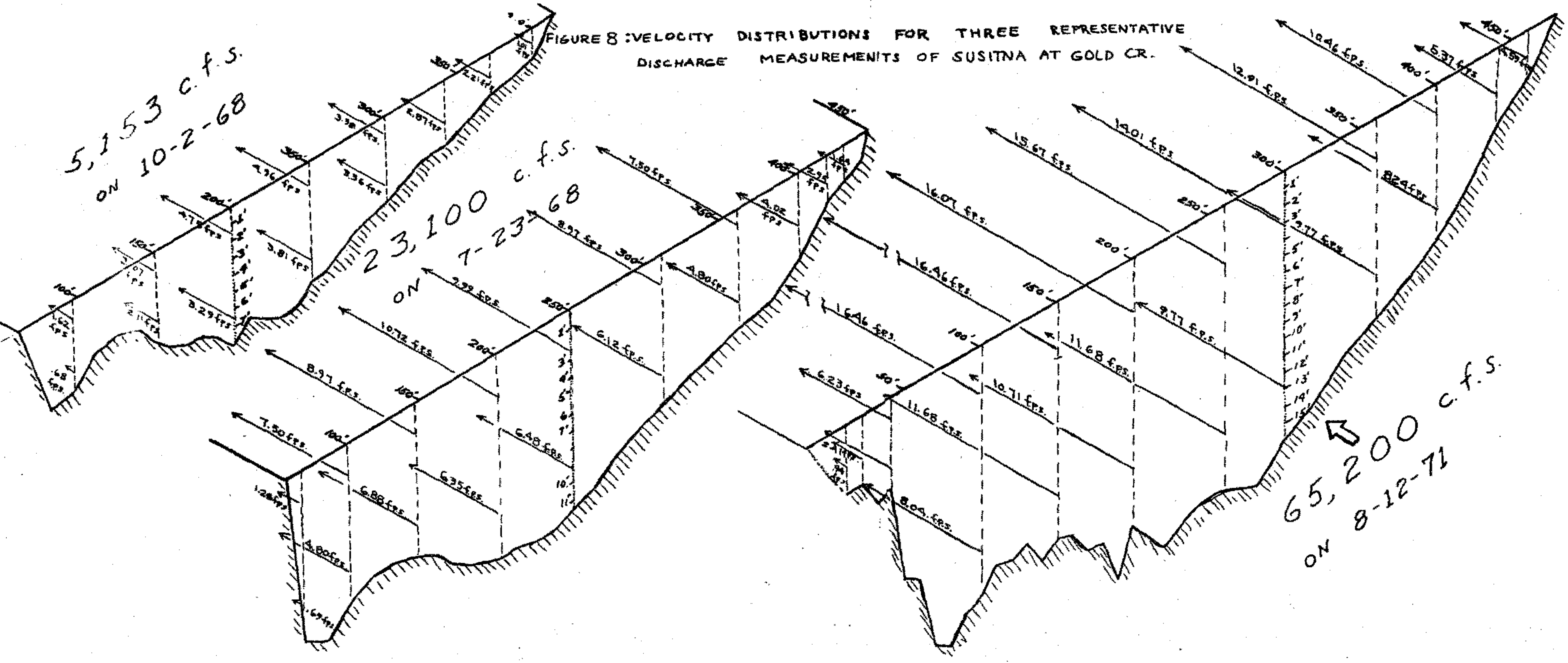
Table 4: Surface velocities measured at four stations about 75 feet of the east bank.

River mile location	Date	Surface velocity feet per second	Flow at Gold Creek	Average flow velocity at Gold Creek
76½	7/21/74	2.8 fps	20,320	6.5 fps
82½	7/21/74	6.5	20,320	6.5
90¼	7/20/74	5.1-5.7	19,900	6.4
109½	7/18/74	5.7-8.5	17,300	5.9

Photographs of river perimeter material at nine locations on the river are summarized in Table 4. Photos are included in the appendix material with the exception of the stream perimeter at Gold Creek which is shown in Plate 1.

Plate 1
Stream perimeter material on Susitna River at Gold Creek.

FIGURE 8: VELOCITY DISTRIBUTIONS FOR THREE REPRESENTATIVE DISCHARGE MEASUREMENTS OF SUSITNA AT GOLD CR.



8-12-71-65,2..
7-23-68-23,1..
10-2-68-5,153

Table 5 Summary of photos of Susitna perimeter material, and of tributary streambed material suggesting maximum flow velocities of the river or of respective tributaries.

Photo Plate Number	River Mile Location	Description	Stream material size range	Suggested limit of flow velocities *
A-1	76¼	Susitna near Birch Creek.	2-3 inches	8.2-8.8 fps
A-2	82½	Flood-flow depository on beaver dam	2-4 inches	8.2-10.5 fps
A-3	82½	Susitna above Billion slough	1-4 inches	5.2-10.5 fps
A-4	90¼	Susitna near Chase	2-6 inches	8.2-12 fps
A-5	92¼	Susitna above tributary	2-3 inches	6.9-8.8 fps
A-7	92¼	Glacial till--derived streambed rubble in tributary	12 + inches	16.4 + fps
A-9	96¼	Lane Creek		
A-10	96¼	Susitna above Lane Cr.	3-4 inches	8.8-10.5 fps
A-13	99 1/3	McKenzie Creek		
A-15	99 1/3	Susitna above McKenzie Cr.	3-5 inches	8.8-11.5 fps
A-16	100¼	Portage Creek		
A-17	103	Susitna near Curry	3-6 inches angular	8.8-12 fps
Plate 1	119	Susitna at Gold Creek	6-12 inches angular	12-16.4 fps
A-22	121	Indian River		
A-20	121	Susitna below Indian R.	2-6 inches	8.2-12 fps
A-24	131¼	Portage River		

* estimates of shearing velocities are adapted from Mamak, (1958).

The velocities suggested in Table 5 indicate the maximum range of flow velocities found next to the stream bottom. In some cases, however, the streambed also includes remnant material that has seen little movement since the last glacial advance and retreat. This is true in the tributary at river mile 92¼ (Plate A-7, Photo Appendix). It is also true of the glacial erratics seen in the Susitna channel between Chase and Lane Creek (see Plate A-4, Photo Appendix).

The velocity and bedload observations provided here are very limited. They appear, however, to provide a reasonable representation of conditions seen in the aerial photographs (above river mile 91) and on the ground. There is little if any tendency of the present unregulated Susitna to decrease in velocity between Gold Creek and the Talkeetna-Chulitna confluence. The Susitna above Gold Creek is somewhat faster than below Gold Creek.

5. River discharge-measurement information from the Gold Creek station on the Susitna was used to develop regression curves showing how average velocities, widths and depths at this site vary with stream discharge. These curves, shown in Figure 9, can be used with the annual hydrograph (Figure 5) to suggest the range of channel conditions that presently occur during seasons of the year. Used with the flow duration curves of Figure 7, an appreciation can be developed for the percent of time specific channel conditions are apt to occur. It is reasonable to expect similar channel relations at numerous other of the more confined

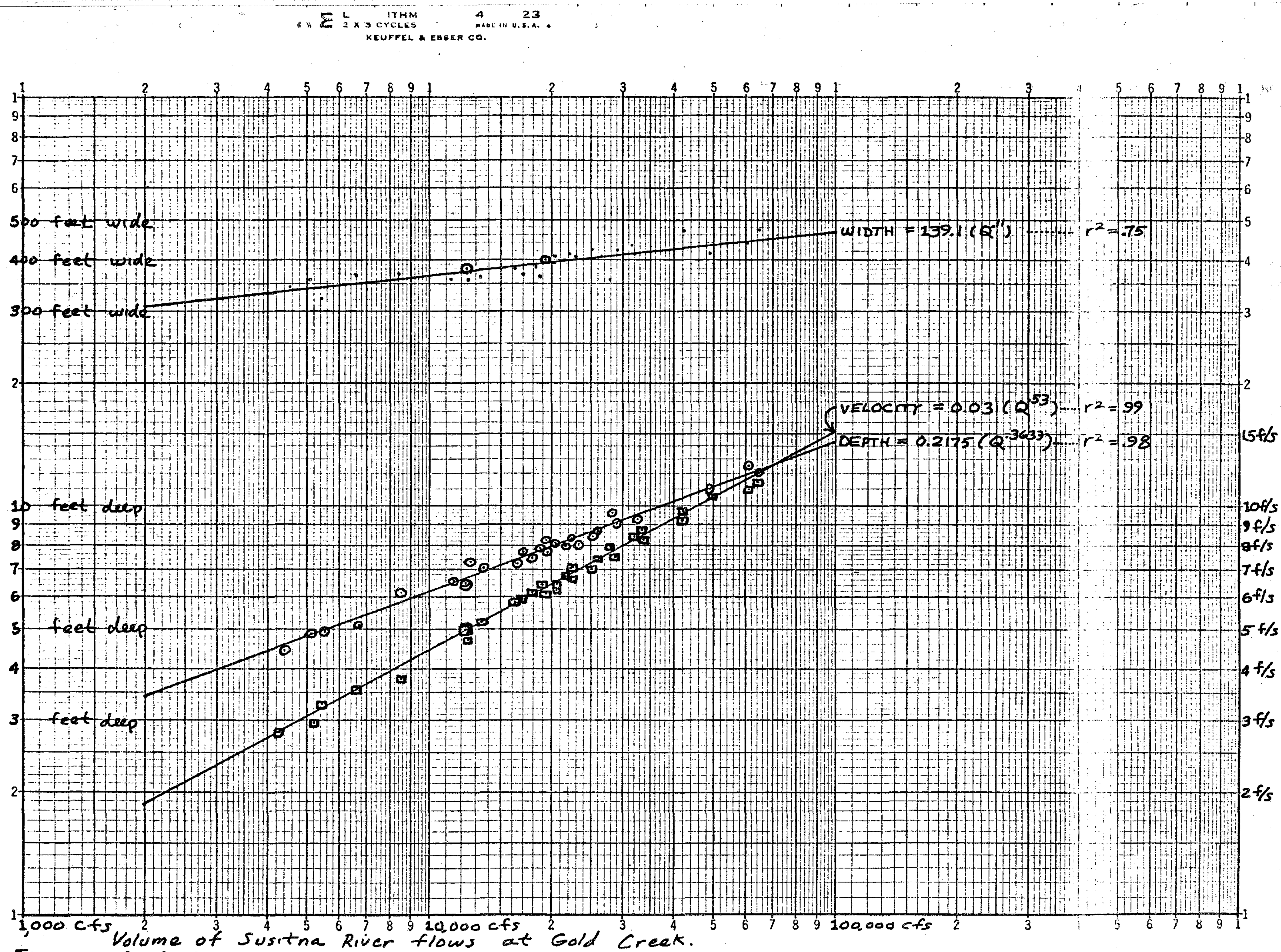


FIGURE 9: DEPENDANCE OF WIDTH, DEPTH, AND VELOCITY CONDITIONS OF THE SUSITNA AT GOLD CREEK TO VARIED LEVELS OF DISCHARGE

channel situations between Talkeetna and Devil's Canyon. The relationships of Figure 9 are not recommended for use in providing approximations of the relations between w, width, v, velocity and <u>regulated</u> discharge. As discussed further in Section D, the river under a regulated regime will form new channel relationships with discharge. In particular, the width relation is apt to be much altered; this in turn will be a factor in changing velocity conditions.

6. Reduction of flows of specific recurrence interval will affect velocity conditions. For example, if the two-year return peak flow (Q_2) of the Susitna River at Gold Creek is reduced from the present value of 49,300 cfs, to 25,000 cfs,[1] what would be the average velocity for the regulated Q_2?

Applying the velocity curve of Figure 9 indicates an average of 10.5 fps for the natural Q_2, 49,300 cfs.; again, applying the regression to the regulated Q_2 of 25,000 indicates 7.2 fps. But the channel will be altered by imposition of the regulated flow regime.

Adaption of a relation developed by Leopold and Maddock (1953) to this situation suggests that velocity will be altered according to the 1/10 power of comparable (same return interval) discharges for the two regimes.

---

[1]This appears in Figure 7 to be a reasonable figure, but lacking sufficient data is not the result of rigorous analysis.

Thus, $\frac{\text{bankful velocity for } Q_2 \text{, natural}}{\text{bankful velocity for } Q_2 \text{, regulated}} = \frac{Q^{.1} \text{, natural}}{Q^{.1} \text{, regulated}}$

Bankful velocity for Q_2 natural of Susitna at Gold Creek = 10.5 fps.

Hence, regulated bankful velocity = $\frac{10.5(25{,}000)^{.1}}{(49{,}300)^{.1}}$

$= 9.8$ fps

which is 9.8 - 7.2 = 2.6 fps greater than the velocity projected for 25,000 cfs under the present flow regime.

7. The effect of loss of suspended sediment on velocities of the Susitna is also of interest. The hydrologist Schoklitsch is reported by Jarocki (1957) to have investigated this problem, concluding

> "that in the case of intensive sediment transportation, water velocity determined by means of empirical formulas should be reduced 15-20 percent and in the case of big rivers (like the Danube or Rhine) even to 30 percent."

Vanoni and Brooks (1957) have shown that

> "muddy water has less resistance to flow than clear water and that the muddier the water (within reason) the less the resistance."

Their explanation is that

> "sediment particles dampen turbulence, hence the more particles of sediment, the less turbulence; hence the less resistance to flow."

This reduction in turbulence and resistance is evidently a result of increase in viscosity and would be particularly evident in streams with moderate to heavy loads of fine sediments. There is probably some reduction in turbulence in the Susitna during summer months as a result of its present sediment load, and conversely, some increase in turbulence of flow with the loss of suspended sediment by regulation.

8. Summary: Regulation will produce major changes of the river hydrograph above Talkeetna and very significant alteration of the river hydrograph below the Chulitna-Talkeetna confluence.

Flow duration pattern will be much evened out by regulation. However, regulation will evidently increase the occurence of low-flow events during late summer. This relation should be examined further.

Presently the river's velocities above Talkeetna appear too high for resident fishes in the mainstream. Reduction of summer high flows will reduce flow velocities more slowly than the rate presently indicated by discharge measurements at Gold Creek. Little improvement in habitat should be expected due to reduction in velocity in the river. Some improvement in habitat may occur in river reaches with large erratic boulders, dur to the possibility of increased turbulence and enlarged eddies.

C. Suspended Sediment

1. A suspended sediment rating curve supplied to me by the U.S. Army Corps Engineers has been converted from tons/day to parts per million and is shown as Figure 10. This conversion was made because fish are probably more interested in the quality of the water than the rate the reservoir fills with sediment.

It can readily be seen from studying Figures 5 and 10 together that during six months of the year (November to May) the river carries about 5 ppm or less suspended sediment while the river in October carries around 25 ppm and in September and May around 150 ppm. These are generalized values but they suggest present suspended sediment conditions in the river.

2. The size class distribution of suspended sediment in the Susitna at Gold Creek is displayed in Figure 11. Chulitna and Talkeetna suspended sediment size classes are also suggested by values summarized and averaged.

It may assist the reader in studying these curves to recognize that steepness of curve between two sediment size classes is in proportion to the volume of material contained between those classes.

A straight-line sloped curve would suggest equal distribution of size classes; concavity suggests a preponderance of larger particles; convex form suggests a majority of finer particles.

The Susitna load is fairly well distributed in size-classes except for the heavier flows that tend to produce larger pro-

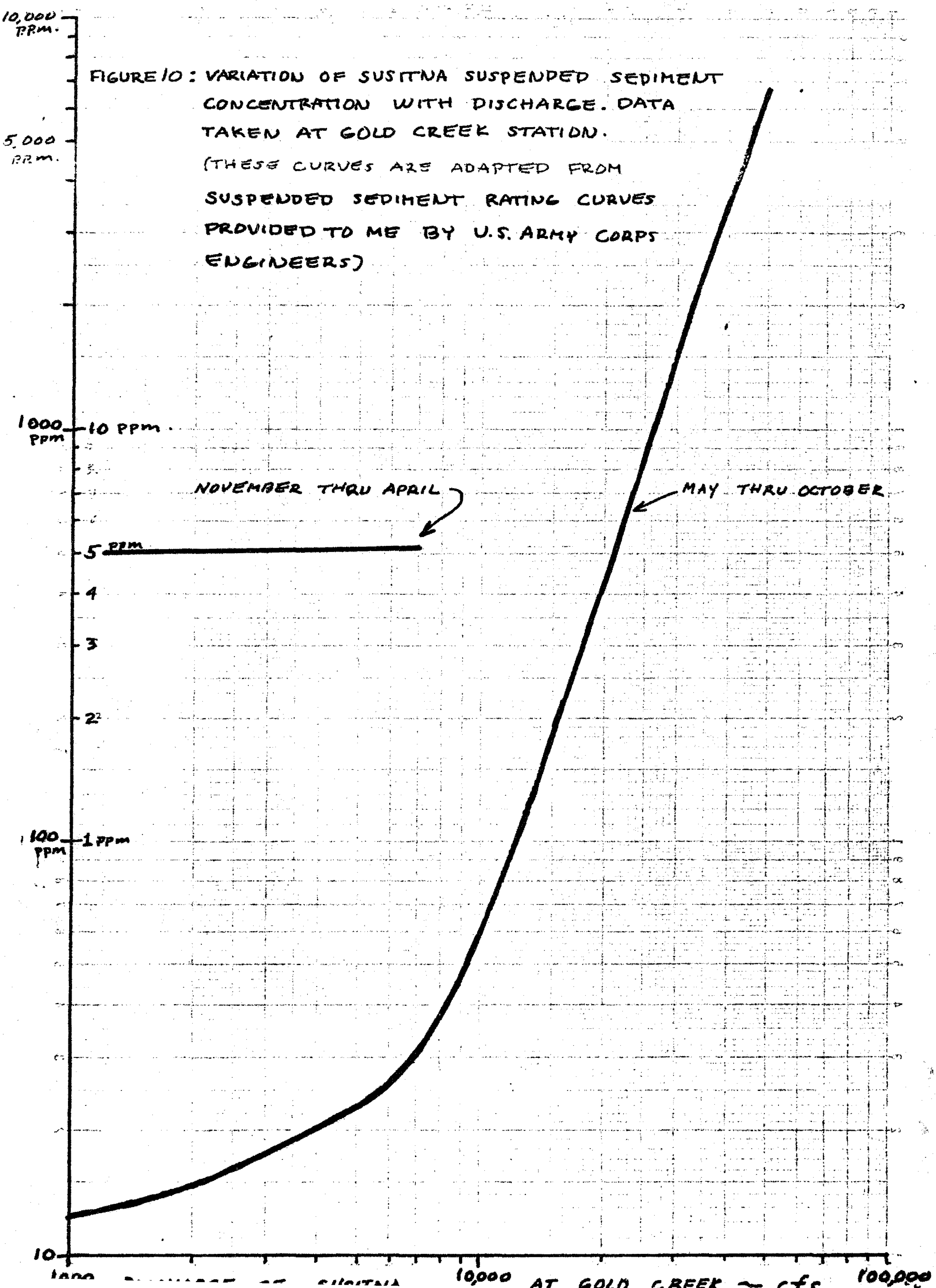
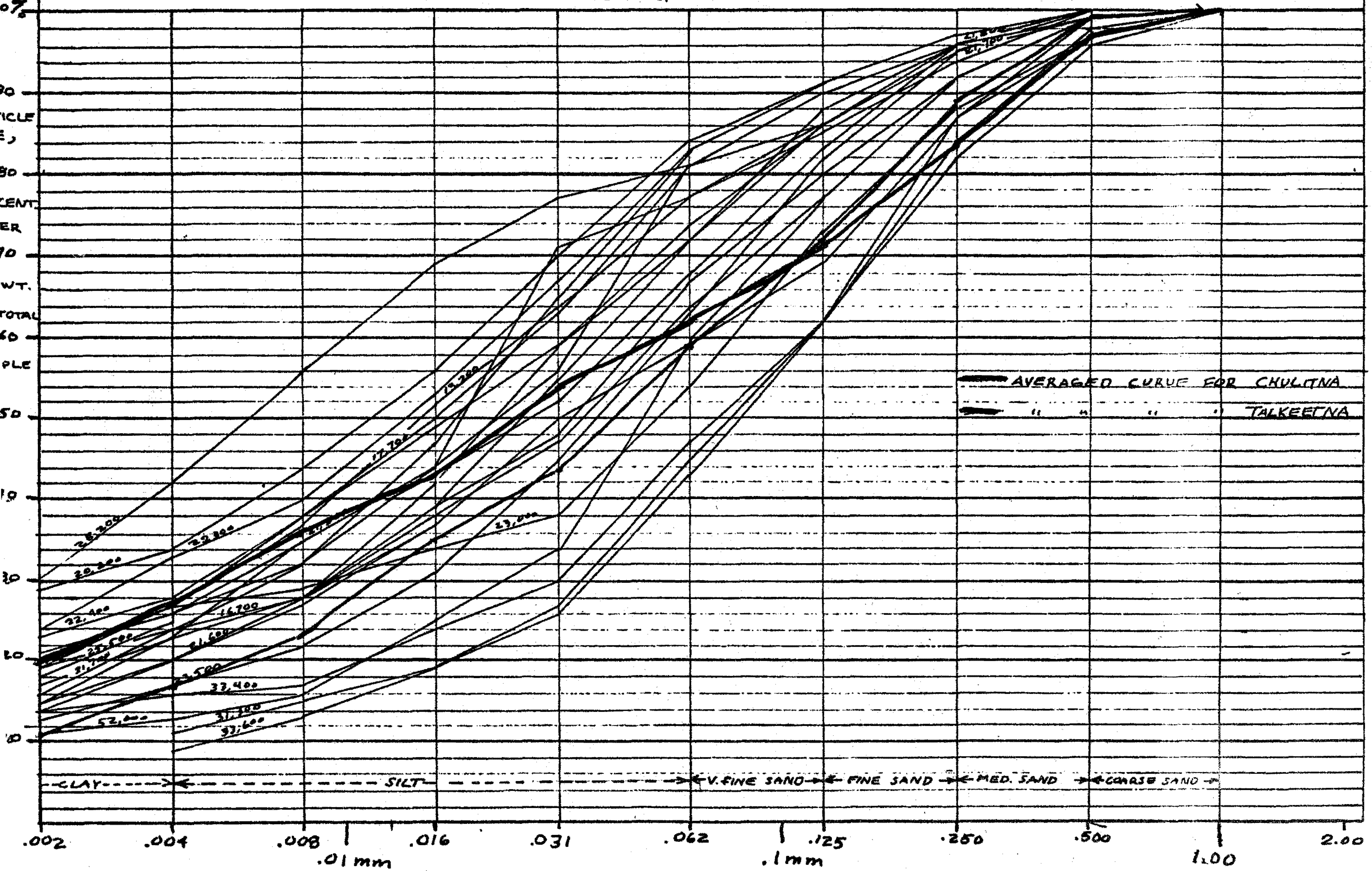


FIGURE 10: VARIATION OF SUSITNA SUSPENDED SEDIMENT CONCENTRATION WITH DISCHARGE. DATA TAKEN AT GOLD CREEK STATION.
(THESE CURVES ARE ADAPTED FROM SUSPENDED SEDIMENT RATING CURVES PROVIDED TO ME BY U.S. ARMY CORPS ENGINEERS)

FIGURE 11: SUSPENDED SEDIMENTS SIZE CLASSES FOUND IN SELECTED SAMPLES FROM SUSITNA AT GOLD CREEK.



portions of fine to medium sands. This increase in sands probably comes particularly from sediments picked up from the stream channel on higher flows.

While too much should not be made of the Chulitna and Talkeetna curves due to the averaging technique of summarizing, their results are interesting. The Chulitna curve suggests rather even distribution of sediment size classes with somewhat heavier proportions of medium to coarse sands. The Talkeetna curve suggests a somewhat low proportion of fine silts and clay with greater amounts of larger silts and fine sands.

If the regulation of the Susitna produces deposition in the Chulitna in and above its confluence with the Susitna (discussed in Section D), the suspended sand fraction may be reduced.

The Susitna clay-size fraction is apt to pass through the reservoir system. The Susitna values shown in Figure 10 suggest that 10-20 % of total May-October load as shown in Figure 9 may pass downstream after regulation. I presume this has been investigated by or for the Corps of Engineers. The data were not available to me.

D. <u>Change in Middle Susitna River's Form</u>

1. The Susitna valley was a major route of ice-flow to the sea 15,000 years ago. Recession of the ice left many forms and deposits now seen in the valley. Between Talkeetna and Devil's Canyon I saw occasional streamside banks of blue-glacial-till, dense deposits (Plate 2) with a full range of particle sizes

from much silt (and a little clay fraction ?) to large boulders. With these prominent bank deposits of till, large glacial boulders are evident in the stream channels, (Plate A-4, Photo Appendix) increasing gradient and turbulence.

Plate 2: Glacial till-slope along the R.R. at river mile 99½.

Abundant coarse-textured (up to cobbles and pebbles) deposits found along the stream have also been labeled glacial till material in <u>Soil Survey, Susitna Valley Area, Alaska</u>. (Schoephorster and Hinton, 1973). In the streamside typing done for this work I have grouped these deposits in with alluvial deposits because I saw no difference--at least as these deposits would influence the stream.

The de-glacial and post glacial periods left terraces marking climatic stops along the river valley's road to the present (see Wolman and Leopold, 1957). The land behind Sherman (Plate 3) offers an example of terrace deposits. Other more recent terraces are notable and have been indicated in the river map (Figure 12).

Plate 3: Terraced slope above Sherman.

An explanation for the terrace deposits suggests that they represent the river channel's stand for a considerable time at that elevation, indicating generally stable flows of water and sediment during that period. Subsequent de-grading action indicates that reduced volumes of water and/or sediment have been provided. I surmise that the middle Susitna valley in recent decades has been in a degrading period. The stage-discharge relations at the Gold Creek Station might possibly contain sufficient record to determine this.

The form and the behavior of the river is of course closely tied to the character of its perimeter lands. The valley above Chase as far as Indian River is not particularly symmetrical. The glacially scoured rock spur separating the lower Chulitna from the Susitna is relatively low and not as active a bedload producer as the east side of the river. Tributaries falling steeply from the Talkeetna Mountains, for example, Gold, Sherman, Curry, Portage, McKenzie Creeks carry heavy bedloads, not infrequently in torrent flows. The bedload material is large and generally angular in size as seen in the respective plates (see Photo Appendix). Downstream from these steep tributaries a blue-till-rich sector of the stream occurs from about Lane (river mile 97) to Chase (river mile 92); than a transitional sector between Chase and river mile 86 where the extensive alluvial flood plains and terraces begin to dominate.

2. Features of the river as seen on the aerial photos and in some locations as measured on the ground have been summarized in Table 6.

The Susitna between Talkeetna and Devil's Canyon is generally confined and is strongly braided only near the Chulitna confluence (Plates 4, 5, & 6). It exhibits a moderately sinuous to braided pattern and though it undoubtedly has the cross-over bars, riffles and pools commonly found on alluvial rivers, these are not recognizable on the aerial photographs because of the silt load. Measurements of these features of stream form have not been made for the Susitna. The photo widths shown in Table 6 are for the main flow of the river. In some cases the existing river channel includes areas that are covered by higher flows but not by intermediate or lower flows. The photo widths do not include these areas where they occur.

Plate 4:
Highly braided
Susitna River
below confluence
of the Chulitna
and Talkeetna
Rivers.

Plate 5:
Susitna River
valley viewed
upstream from
river mile 107.

Plate 6:
Downstream view
of Susitna River
valley with
Sherman Creek
in left foreground.

Table 6: Widths, gradients, velocities and shoreline types as seen on Talkeetna Mountains photography of the Susitna above Talkeetna. Photography made at several dates during summer, 1962. Widths from air photos; grades measured, July-1974, along water surfaces of east bank; drift velocities off east bank; shore types as described in D-2.

	River miles above mouth	Flow - cfs on date of photo-graphy	Photo width, -feet	Flow - cfs on date of gradient, vel., obs.	Energy gradient	Surface velocity 75 ft. offshore	Shore types *
	76½	no photo.	--	20,320	.0014	2.8 fps	T-T
	82¼	" "	--	20,320	.0008	6.5	T-T
	90¼	" "	--	19,900	.0022	5.1-5.7	T-T
near Chase	91	32,700	520 ft.				T-T
	92	"	560 "				T-G
below Lane	93	"	415 "				T-G
	94	23,000	615 "				T-G
	95	"	675 "				T-G
	96	"	415 "				T-T
	97	"	625 "				R-R
	98	"	520 "				T-R
	99	"	515 "				R-T
	100	"	630 "				R-R
	101	"	620 "				T-R
	102	25,900	270 ≠ x				T-R
Curry	103	"	370 ft.	18,820	.0003	--	R-F
	104	"	590 "				R-T
	105	"	470 "				R-T
	106	"	830 "				R-T
	107	"	610 "				R-T
	108	"	600 ≠				R-T
	109	"	720 ft.				R-T
	109½	"		17,300	.0020-.0023	5.8-8.5	

(continued)

	River miles above mouth	Flow - cfs on date of photography	Photo width, -feet	Flow - cfs on date of gradient, vel., obs.	Energy gradient	Surface velocity 75 ft. offshore	Shore types
	110	25,900	720 ft.				T-R
	111	"	370 "				R-T
	112	"	730 "				R-T
Sherman	113	"	360 "				F-F
	114	"	415 "				T-R
	115	"	790 "				T-R
	116	"	825 "				T-T
	117	"	615 "				T-T
	118	"	480 "				R-T
Gold Cr.	119	"	410 "	17,200	.0019	8-10	R-F
	120	"	420 "				T-T
Indian R.	121	"	480 "	17,200	.0011	--	F-R
	122	"	620 "				T-R
	123	"	800 "				T-R
	124	23,000	630 "				G-T
	125	"	415 "				G-T
	126	"	820 "				A-T
	127	"	520 "				A-F
	128	"	420 "				A-R
	129	"	520 "				G-T
Portage River	130	"	310 "		about .003 from APA Report		R-R
	131	"	300 "				R-R
	132	"	400 "				R-R
	133	"	210 "				R-R

* First letter refers to right shore facing downstream, Second letter refers to left shore.

Photo overlays have been made for features of the Susitna River between Talkeetna and Devil's Canyon as shown on the Talkeetna Mountains photo flight. These overlays have been joined into flight lines and are shown as Figures 12 a, b, and c.

The classification and nomenclature used on these maps is as follows:

<u>Shoreline characteristics adjacent to river</u>:

R = bedrock, predominantly shale, schists, graywackes.

T = river-built terrace or flood-plain deposits. Commonly includes coarse gravels and cobbles under a variable thickness of silts and sands.

A = alluvium, colluvium, or coarse clean glacial till. This material was not deposited by river action.

F = alluvial fans, commonly steep in stream gradient and built of coarse materials.

G = compacted glacial till with boulders and fine materials intermixed.

<u>Channel and river characteristics</u>:

bo = boulders in channel, generally indicating increase in gradient and turbulence.

 = fast water, often standing waves.

 = channel areas that the flows of the regulated river will not commonly flood.

S = springflows into the river itself or into small tributaries near to the river and in the valley bottom.

Some of these terms need additional description as to associated features:

R slopes to the river are often steep, yielding rotten rock to the streambed; they do not yield springflows although the meeting of bedrock and flood plain or terrace deposits often shows ponded areas.

T,A,F - springflows are often found where fans, terraces or flood plain meets the mainstream or its flood channel.

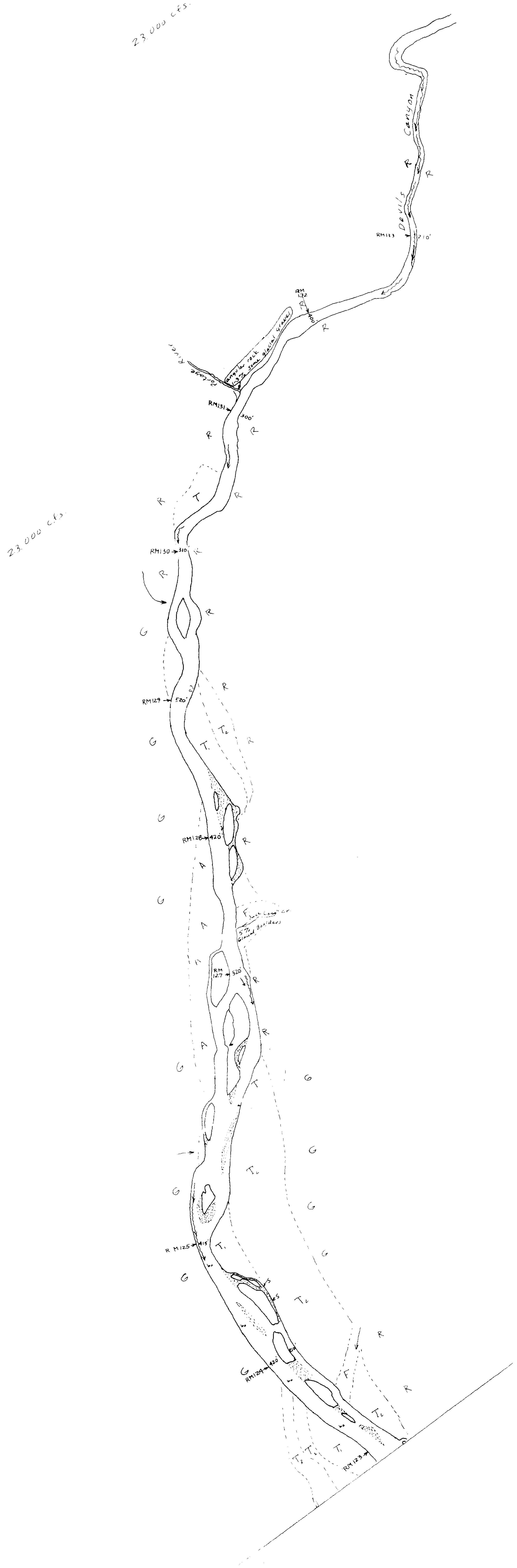
G is associated with boulders in the channels of the tributaries or the mainstream (see Plates A-4, A-7, Photo Appendix); does not produce springflows; is a likely sediment source.

- these flood channel areas will generally be abandoned by the river when it is regulated. Such interpretations that were made are in most cases fairly obvious on the photographs and, I think, are conservative (may underestimate) in identifying the area of channel reduction.

3. In the past when the Susitna River has received less water and/or sediment load, it has cut down to a new grade of balance leaving terrace formations. In this section we will investigate the extent to which a similar reaction will result from regulation of the Susitna at Devil's Canyon.

When the unregulated river experiences reduction of total flows of water and sediment, large peak flows still occur. When the river adjusts to reduced flows by degrading, it is because the load carrying ability of the river, particularly on higher flows, is (a) greater than the load supplied to the river, and (b) the velocities are sufficient allowing for the load being carried to also move and scour out in-place streambed materials.

With regulation of the Susitna's flows most of the suspended and all of the bedload sediments carried by the river through Devil's Canyon will be eliminated. But at the same time the peak flows



23,000 cfs.
Devils Canyon
R
RM 133
210'
RM 132
400'
angular rock 1-3% some glacial gravel
Portage River
RM131
300'
23,000 cfs.
RM130
310'
RM129
520'
RM128
420'
5% Glacial Boulders
RM 127
520'
RM125
415'
RM124
420'
RM123

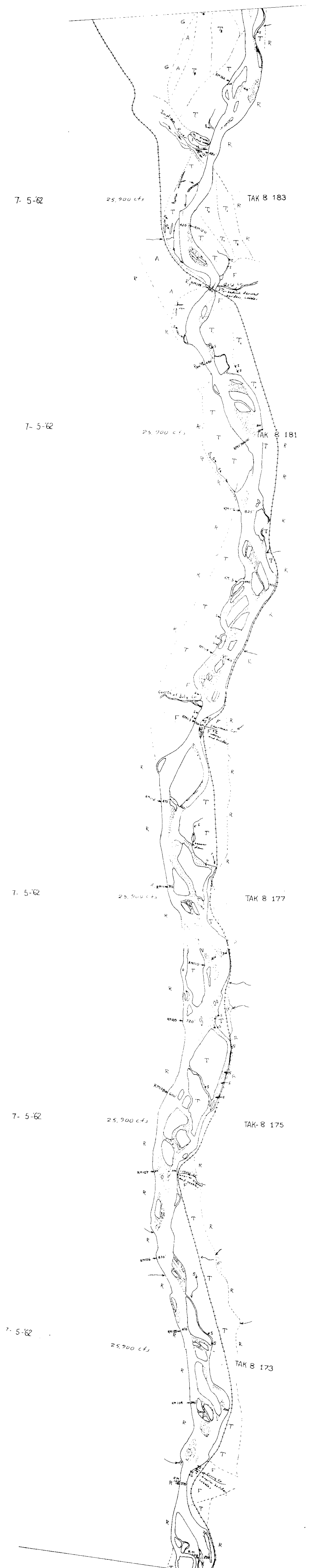


Figure 12 b

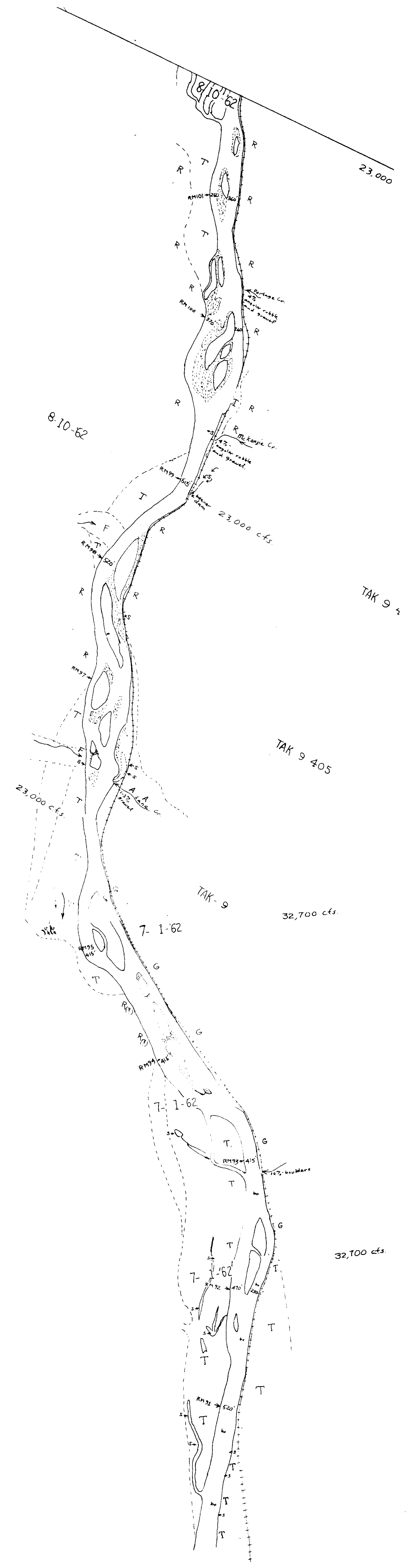


Figure 12 a.

commonly experienced below the dam are likely to be greatly reduced. These two alterations act in opposite directions with regard to river channel degradation.

The character of relevant information on the Susitna River relating to the degradation process is outlined below:

a) Flow: the two-year return period peak flow provides an estimate of discharge conditions that exercise control over the channel form at bankful stage. The Susitna River at Gold Creek presently indicates a Q_2 of 49,000 cfs.; the Q_2 of the river under regulation will depend to a large degree on how the dam system is managed and on the future of the Watana and Vee dams. I have selected 25,000 cfs for use here. This value may be high and thus tend to underestimate the regulating effect due to flow. The naturally occurring unregulated peak flows of greater return interval also are likely to bear on the river's ability to scour and degrade in that such flows probably have established the "floor" particle size in many portions of the river channel. It should be borne in mind when reviewing the velocity diagrams shown earlier in Figure 8 that the 65,200 cfs flow shown is not much larger than the Q_5 flow of 63,400 cfs. and that the former flow is capable of scouring particles up to about 4-6 inches in diameter (as estimated from tabular data provided in Mamak, 1958). Similarly, the Q_{25} of 88,100 cfs suggests scouring ability up to particle sizes of 6-8 inches diameter.

b) Sediment load in the mainstream at Devil's Canyon is to my knowledge not known. Measures of suspended loads in the river have been made (see Section C) but I have not found bedload estimates. It is probably reasonable to assume that bedload is one to two times as large as sediment load (S. A. Schumm, 1963).

The bedload fans at mouths of large tributaries such as Portage River, Indian River or smaller streams such as "Jack Long" Creek, Gold Creek, Sherman Creek, etc., indicate large sediment loads which under the present flow regime are rapidly entrained by the mainstream. The size material delivered to the mainstream ranges from boulders, cobbles, pebbles and gravel to particles that are sandsize and smaller. It is evident on the ground that some streams deliver a significant part of their load to the river through periodic torrent flows. Some estimation of particle size is provided in Table 5 and in the Plates of the Photo Appendix. However, I do not have a basis for assigning a bedload rate or for estimating the fractional percents of bedload provided through the river at Devil's Canyon versus bedload supplied by downstream tributaries. I have assumed in the tentative conclusions drawn below that a major part of the middle Susitna River's total sediment load will be eliminated by the Devil's Canyon dam.

c) Only one location between Gold Creek and Portage River appears to have the possibility of a rock floored stream bottom. That site is at river mile 130 just below the mouth of Portage

River. Rock occurs commonly along this 11 mile stretch of the river (Plate 7) but becomes closely confining on both sides of the river only at this point upstream.

Plate 7: Metamorphic rocks (schists, shales, graywackes) are common along the shoreline above Indian River.

Below Gold Creek only a rock margined reach at river mile 99.5 below McKenzie Creek approaches such a condition. This reach, however, is about twice as wide as the river mile 130 site.

I have used the information above in what I think is a reasonable and intuitive manner to reach some conclusions regarding possible degradation following regulation of the Susitna. More rigorous conclusions may be possible (see Gessler, 1971) but it is evident that sufficient data is not available at this time.

Conclusions Regarding Degradation:

Table 7 summarizes portions of the river between river mile 91 and Devil's Canyon that are likely to resist degrading action. I have assumed that narrow river sections such as Gold Creek have a sufficiently coarse and armored bottom to resist degradation. The re-supply of coarse bedload to reaches near sizeable tributary bedload sources will act to resist degradation. The river at or above mile 130 may be protected by bedrock under its channel. Other portions of the river, particularly in river miles 92-96, may contain sufficient remnant glacial boulders in the channel to armor the channel and prevent or limit downcutting. For several miles above the confluence of the Chulitna with the Susitna no downcutting will be likely because the sediment load of the Chulitna will act to establish a local base level (not included in Table 7 summary). Even in river locations where some downcutting is apt to occur it may be limited by formation of an armor coat during the degradation process. Livesey (1963) reports of "the experience downstream of Ft. Randall dam where 15 ft. of degradation were expected, but already after 3.5 ft. the bed became stable".

Degradation will begin upstream and and work down. The early downcutting will occur more rapidly than later in the process because the action is asymptotic in nature. The river may assume a more stepped longitudinal profile than presently with downcut areas limited to respective wider sections between reaches, narrow, armored, or otherwise protected.

4. Possible changes in channel form - width, depth, gradient, meander length, sinuosity - can be generally evaluated using principles of fluvial morphology. The pertinent assumptions made regarding the Susitna River have largely been stated in (3) above. In brief they are: (a) decrease in peak flows, (b) a major but undefined decrease in total sediment load below Devil's Canyon but with heavy bedload sediment loads still supplied by tributaries, (c) confining rock channels exist above river mile 130 and to some degree at river mile 99.5.

Basic to studies of alluvial river form is the concept of a valley and a river having features that are interrelated in cause and effect. Usually a river's flow, sediment loads, and to varying degrees its bedrock and geologic features, are causative, independent variables. Stream width, depth, gradient, meander pattern, and sinuosity are important dependent variables that interact to flow and load and with each other to produce a river and its valley.

Blench (1969) working from the Indian canal regime concepts developed essentially empirical formulae for estimating width (b), depth (d), gradient (S), and meander length (M_1). Independent variables he used are described functionally as follows:

<u>F_b, bed factor</u>, increases in proportion to a stream bottom's ability to resist shearing action; also increases with the rate of bedload passing through a stream channel.

<u>F_s, side factor</u>, increases in proportion to the ability of sides of a stream to resist erosion.

Table 7: Locations on air photography between river miles 90 and 130, where river channel will resist or limit downcutting.

Stable points on Channel	River Miles	Cause of Stability
near and above Chase	90-93	Till boulder zone will act to armor the channel
vicinity Curry Creek	103	Rock on west shore opposed by large and coarse bedloads from Curry Creek which probably is subject to torrent flows.
vicinity Sherman Creek	113	Sherman Cr. carries large, coarse bedload to the river, sometimes by torrent flow. Fourth of July Cr. on west shore also carries considerable bedload volume, though not as coarse. These loads will provide resistance to scour.
vicinity Gold Creek	119	Similar to Curry Creek, though no bedrock is evident.
vicinity Indian River	121	Rock on east shore opposed by bedload from Indian River though this bedload is dominantly gravel and hence susceptible to scouring.
below Portage River	130	Combination of coarse bedload from Portage River, plus possible bedrock floor will limit or prevent downcutting.

Q, bankful flow,

k, meander slope correction coef., accounting for the degree of head loss that may be associated with a flow pattern, straight, braided, meandering, etc. (not used below).

Blench's formulae are particularly canal oriented and may not be suitable for accurage determinations on rivers like the Susitna. However, a useful table derived from his work (1969) is shown below. I have indicated the likely changes in independent variables due to dam construction as well as the resultant changes predicted in channel form.

Independent Variable	Dependent Variables b	d	S	M_1
F_b - reduced	-	$\cancel{-}$	-	-
F_s - no change				
Q - reduced	-	-	$\cancel{-}$	-
k - undetermined				

Thus, using Blench's approach a decrease in channel width and meander length and little change in river depth or gradient conditions are predicted.

Schumm, (1971) working from a different perspective and with a differing set of independent-dependent variables, provides a similar summary of effects. His independent factors are Q, stream discharge (average or bankful); and Q_s, the bed material load. Dependents are channel width, b, depth, d, λ, meander length, $\underline{S}$, gradient; $\underline{P}$, channel sinuosity, and $\underline{F}$, the width/ depth ratio. The Susitna situation he summarizes as below:

$$Q^{-},\ Q_s^{-},\ = b^{-},\ d^{\pm},\ ^{-},\ S^{\pm},\ P^{+};\ F^{-}.$$

suggesting narrower channel, shorter meander length, greater sinuosity, reduced b/d ratio. The reduced b/d ratio further indicates that depth will remain constant or increase. Increase in sinuosity suggests that gradient will decrease.

5. The analysis of (4) above, is useful in indicating direction of change. Schumm further points to additional work he indicates will provide quantification for b, d, S, , P, F, (see Schumm 1971). This basis for quantification is built around $\underline{M}$, percent silts and clays in the perimeter forming the stream channel, and $\underline{Q}_m$, mean annual discharge. In the case of the Susitna, $\underline{Q}_m$ is a meaningless variable because mean annual discharge will remain essentially unchanged and thus does not provide a description of the effect of regulation of flow. $\underline{M}$ is probably not a meaningful variable either because the percent silts and clays is apt to be consistently very low.

The most useful quantitative relationships in the case of the Susitna appear to be those developed by Leopold and Maddock (1953), whose regressions relate mean annual or bankful discharges to width, depth, and velocity at respective stations along rivers. Their work, as well as that done by others, shows very general agreement that stream width for a given return-interval frequency of flow is proportional to the (discharge)$^{.5}$ found at a location along that stream; similarly, that depth is generally proportional to about (discharge)$^{.4}$, and mean velocity to about (discharge)$^{.1}$.

While strictly speaking this work does not include a basis for the comparison to be made for a situation as may occur on the Susitna, it appears sufficiently broad in application to warrant use.

<u>width</u>: at the present Q_2 (assumed bankful condition) of 49,300 cfs, width at Gold Creek is shown in the regression of Figure 8 at about 435 ft. For the regulated Q_2 flow assumed at 25,000 cfs, width would be:

$$\frac{435(25{,}000)^{.5}}{(49{,}300)^{.5}} = 310 \text{ ft.}$$

<u>depth</u>: (depth = x-sectional area ÷ width) At present Q_2, depth at Gold Creek = 11 ft.; depth at regulated Q_2, 25,000.

$$= \frac{11(25{,}000)^{.4}}{(49{,}300)^{.4}} = 8.4 \text{ ft.}$$

<u>velocity</u>: At present Q_2 mean velocity is about 10.5 fps. Velocity at regulated Q_2:

$$= \frac{10.5(25{,}000)^{.1}}{(49{,}300)^{.1}} = 9.8 \text{ fps.}$$

A comparison of present versus projected widths at 25,000 cfs suggests 125 ft. reduction, a very large change. Referring again to Figure 8, it is evident that the new depth for Q_2 of 25,000 cfs is virtually the same as that presently shown for this discharge. This is because Susitna depths at Gold Creek actually vary as the .36 power of discharge at that station, a very similar relation to the (.4) power found along the run of rivers. The large reductions projected for width, while depth remains fairly constant, are consistent with the predictions provided from Schumm in (4) above.

Mean velocity for the regulated Q_2 is indicated to drop from 10.5 fps to 9.8 fps when compared with the existing Q_2, but will be significantly higher than the original 25,000 cfs velocity of 7.2 fps.

The projections made above look fairly reasonable, though the width reduction appears somewhat greater than I would expect. In using the Leopold-Maddock relationships to project channel conditions in the regulated Susitna from present knowledge of channel and flow, we are projecting from one flow regime to a new and different one, but with unchanged channel material. The new regime will have greatly reduced peak flows; conversely more sustained and somewhat larger lower flows. The above projections of width, depth and velocity were made with the assumption that this change in regime will not greatly alter the nature of channels in unchanged bed materials.

6. Width, depth and velocity in a specific narrow type cross-section are related logarithmically to discharge in Figure 9. These curves represent present conditions.

The depth curve also provides, I believe, a reasonable estimate of variation in mean depth with change in <u>regulated</u> discharge at Gold Creek.

The slope of the depth curve can be used as a reasonable basis for drawing curves to estimate depth at other stream sections of generally similar form. To do this a discharge measurement is necessary at the point in question. This measurement provides a coordinate position for the depth curve to pass through.

I do not recommend use of the width or velocity curves for prediction of regulated channel conditions. The w/d value is likely to reduce; at the same time velocity relation in such reaches will also change.

7. Tributary streams will influence and be influenced by changes in the Susitna.

a. The Chulitna River, quite evidently, carries a large bed and suspended load to its confluence with the Susitna. From the general braided appearance of the Chulitna at its mouth <u>and</u> the extension of that condition several miles up the Susitna, it appears that this portion of the two rivers has a sediment transporting regime that could readily become depositional. The loss of the Susitna's peak flows, particularly during the sediment-loaded summer months, will significantly reduce velocity conditions at the confluence of the two rivers reducing both bed and suspended load-carrying abilities.

This action will favor deposition and related flooding in the flats of the Chulitna above its confluence. Deposition will begin at the mouth and work upstream. It will occur at a faster rate than the downcutting mentioned earlier, and will be limited upstream by the incised canyon of the Chulitna.

The form of the Susitna river for some distance upstream from the Chulitna may be influenced by deposition. A backwater reaction may act to prevent any downcutting in the river near the Chulitna, and may in fact produce deposition in that sector.

While the Talkeetna does not carry the sediment load of the Chulitna, it too may be influenced by regulation of the Susitna. The reaction would be particularly in response to the Chulitna's deposition of sediments acting to backwater the Talkeetna. Again, I expect the occurrence of floods on the Talkeetna to be somewhat stimulated (see also, U.S. Army Corps Engineers, 1972).

b. Portage River carries a significant bedload as shown by the fan at its mouth. Some further movement into the river of this fan may occur, but it will be limited because the river is narrow here. Since I do not expect significant downcutting in this portion of the river, similar resultant downcutting action on the Portage River bottom will be more a function of the effective lowering of the Susitna's water surface during high flows. This changed relation between mainstream and tributary peak flow condition will favor some downcutting adjustment at the mouths of tributaries. In the case of Portage River the bedload material at the mouth is very coarse and will make this process very slow.

c. Indian River is more apt than Portage River to experience downcutting at its mouth because it has a gravel bottom near the mouth. Again, this action will result particularly from relative lowering of the Susitna during peak flows. Downcutting action will stimulate an increase in bedload rate which will again stabilize at a later time.

d. Smaller tributaries such as Gold Creek, Sherman Creek, Fourth of July Creek, etc. will also be somewhat stimulated to cut down near their mouths and to produce an increase in bedload rate which will diminish as a new equilibrium is approached.

e. Tributaries fed by springs or ponded areas will downcut but at much slower rates. Differences produced in peak flow conditions as a result of regulating the Susitna will not develop to as large an extent here because springs are highly regulated in flow condition.

However, the type of erosive action seen in Plate A-14 (Photo Appendix) will continue at least to clean the spring source beds of finer material and to this extent some degrading action may be seen. Particularly pertinent work has been done on this problem by Clayton (1966 ?), who provides a basis for calculating size of particle moved by upwelling springflows. In some cases he shows that springs are capable of putting cobble-size particles into motion; the critical factor is piezometric gradient, (the water head which the spring outflow is capable of developing).

In summary I did not find springs in or near the Susitna Valley that appeared to have flows of high piezometric head; for that reason I do not expect particles much larger than sand to be in motion in spring beds except very near their juncture with the mainstream where high gradients can develop and thus significant downcutting occur.

This downcutting face will move toward the spring source but at an increasingly slow rate.

8. Flood channels and flood plains will be abandoned and vegetated after regulation of the river. Approximations of these areas are shown on the overlays of Figure 12. Based on the frequent evidence of seedlings and older new growth on such areas, (Plate 8) rapid vegetation may be expected. Species will be primarily cottonwood, alder and willow. The margins of spring-flow channels such as one shown in Plates 9 and 10 will be more narrowly confined with vegetation.

Plate 8: Abandoned flood channel areas will rapidly vegetate with cottonwood, alder and willow.

Plate 9: Springflow-fed secondary flood channels at river mile 104 3/4.

Plate 10: Flood Channel at river mile 107½ is fed by spring and small tributary flows.

E. Springflows

Springs occurring in or near the valley bottom probably come mostly from unconfined aquifers suggesting that only low pressures are available.

1. Three kinds of springs were identified in the middle Susitna:

   a) Discharges from the perimeter of beds of steep tributaries or from their fan deposits adjacent to the river: these flows are fairly constant in volume; water temperatures are conditioned by stream temperatures depending upon the distance of travel within the aquifer.

   b) Discharges fed by the river upstream: these are apt to be close to (downstream from) a significant drop in river gradient. They will, of course, occur through alluvial deposits.
   It should be borne in mind that head loss of flow in the river will always be much less than flow through an aquifer, thus limiting the springflow that may be expected. Volume of flow from such springs will depend directly upon the water level of the river upstream. Again, water temperature will be conditioned by distance of travel through the aquifer.

   c) Discharges dominantly from and through alluvium leading to the valley bottom, water source(s) not primarily from adjacent stream flows: Such ground-water flows are apt to be the most constant in discharge and in temperature. They may, however, fluctuate in volume as the valley ground-water level changes. If, for example, a drop in the Susitna produces a general lowering of valley bottom water-table, then the ground-water flow feeding the spring will not enter surface flow. This fluctuation will occur unless and to the extent that a channel is sealed and therefore a local water table is perched.

This type breakdown has been used in Table 8, which summarizes the springflows either seen on the ground or tentatively identified on the aerial photography.

2. Considering possible effects of regulation of the Susitna on springflow conditions, the river level has been pointed out earlier and observed last summer by ADF & G field crews as capable of influencing volume of spring flow discharges. By consulting Figure 6, as well as pertinent features of Section D, the summary shown below was constructed to indicate the direction of influence of river regulation on valley ground-water level and hence on the depth and surface discharge of springflows.

Month	Influence of river regulation on valley ground-water level (compared with existing relationship)
October	begin to increase groundwater levels
January	river regulation has greatest elevating effect on ground-water table.
Mid-April	end of elevating effect on water table; beginning of depressing effect.
June	greatest depressing effect on ground-water table
September	smaller potential influence on water-table; however, September evidently can be a drought month under a regulated regime indicating very significant depressing effect on dry years.

It is reasonable to conclude that during the months of October through March springflows may be enhanced in the river valley bottom; during the months May through mid-September these springflows may be depressed. The degree, the variability, and the years-timespan of these changes will require further work to establish.

Table 8: Summary of springflows seen on the ground or identified on aerial photos.

Location	Type (a) (b) (c)	Temperature Observations	Other Observations
L[2]-90-90 3/4	c		discharges into river
R-91½	a		
R-92¼	c		into small slough, an old channel
R-95½	c		into small flood channels
L-96½	a,c		
R-96½	a		
L-97½	a		
L-99 1/3	a		
R-101½	a		
L-103¼	a		from Curry Cr., discharges into river.
L-104 3/4	a,c		sizeable springflows into flood channels
L-105½	a,c		
L-108¼--½	a	17.1°C 11.4	from lake-fed stream; sizeable spring-channel flows.
L-109	a,c	8.1	into side channel near river
L-111¼	a,c	16.0	sizeable springflows into flood channels.
L-111½	b,c	7.5	
L-113	a	6.0	into short flood channel discharges into river.
R-114¼	c		
L-117 3/4	c		into flood channel
R-118½	c		
L-119	a		from Gold Cr., discharges into river.
L-119¼	c		into small side channel ponded area - abandoned channels
R-119 3/4	a		ponded area - abandoned channels
R-120½	c		
L-122½	a		
L-124½	c		into flood channel

[1]see text for description of springflow types identified.
[2]L= left side of river looking downstream; R = right side.

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Table A-1: Instantaneous Observations of River Temperatures During Field Visit

Date-Time	Location	Water Temperature
7-13-74-1745	Chulitna- River Mile 99½	5.9°C
7-13-74-1845	" " " 99	6.0°
7-25-74-1820	" " " 99	6.8°
7-14-74-1010	Little Susitna at Gaging Station	6.2°
7-24-74-1230	" " " " "	8.3°
7-14-74-1100	Little Susitna @ Edgerton Park Road Bridge	6.4°
7-24-74-1340	" " " "	8.9°
7-15-74-1750	Little Susitna @ Main Hwy. Br.	9.1
7-25-74-2030	" " " " "	10.8°
7-14-74-2130	Talkeetna River near R.R. bridge	11.6°
7-21-74-1000	" " " " "	9.4°
7-23-74-2035	" " " " "	10.8°
7-23-74-1230	Susitna R. @ Portage River	10.8°
7-17-74-1230	" " " Indian River	13.2°
7-23-74-0900	" " " " "	9.5°
7-17-74-0830	" " " Gold Creek	11.3°
7-23-74-1515	" " " " "	11.4°
7-16-74-1415	" " " Sherman	13°
7-17-74-1615	" " " "	14.2°
7-23-74-1530	" " " "	11.4°
7-18-74-1040	Susitna-river mile 109½	12.4°
7-19-74-1015	" (Curry) " 103	13.4°
7-19-74-1045	" (Portage Cr) 100¼	14.5°
7-19-74-1130	" (McKenzie Cr) 99 1/3	14.4°
7-19-74-1545	" (Lane Cr) river mile 96¼	14.4°
7-20-74-1100	" (above Chase) " 93	12.5°

Table A-2: Instantaneous Observations of Susitna Tributary Water Temperatures During Field Visit

Date-Time	River-Mile	Trib. Name?	Water Temp.	
7-23-74 10:20	131¼	Portage River	8.5°C	
7-23-74 13:00	127¼	"Jack Long" Creek	10.1°	
7-17-74 12:30	121	Indian River	11.5°	
7-16-74 19:00	119	Gold Creek	10.8°	
7-16-74 14:15	113	Sherman Creek	11.0°	
7-17-74 16:15	113	Sherman Creek	12.0°	
7-16-74 14:15	113	Spring flow into R.	6.0°	
7-17-74 16:30	113	" " "	8.6°	
7-17-74 18:30	111½	" " "	7.5°	
7-17-74 18:15	111¼	Clearwater flow in flood channel	16°	-from small lake-fed Cr. (shows algal growth)
7-18-74 10:40	109½	Spring flow along R.	8.1°	
7-18-74 11:30	108½	Spring entering lower end flood channel	11.4°	
7-18-74 14:00	108	Clear water flood channel	17.1°	
7-18-74 14:30	107	--	12.4°	
7-19-74 10:15	103¼	Curry Cr. (intermittent)	10.1°	
7-19-74 10:45	100¼	Portage Cr.	11.5°	
7-19-74 12:00	99½	McKenzie Cr. (spring flows also	10.0°	
7-19-74 12:45	98 3/4	Un-named (reported springfall)	11.6	
7-19-74 15:45	96¼	Lane Creek	9.1°	Springs just upriver.
7-20-74 11:00	92½	Un-named	10.4°	

Table A-3: Thermograph Installation Record, July 1974

Tape #	Station	Installation Date-Time	Installation Water Temp.	Installation Recorded Temp.	Total Time Error	Removal Date-Time	Removal Recorded Date-Time	Removal Water Temp.	Removal Recorded Temp.
12911	Susitna @ Gold Creek	17/July at 8:30	11.2°C	12.2°C	All times 1 hr slow	23 July at 15:15	23 July at 14:00	11.4°C	11.1°C
11916	Susitna @ Sherman	16/July at 14:15	13.°C	13.9°C	Gain 1¼ hr in 7 days	23 July at 15:30	23 July at 17:30	11.4°C	11.7°C
12925	Susitna @ Sherman	16 July at 14:20	13°C	13.3°C	All times 1 hr/10 min slow	23 July at 15:30	23 July at 16:30	11.4°C	11.1°C
12933	Little Susitna upper station	17 July @ 10:10	6.2°C	6.7°C	Gain 40 min in 10 days	24 July at 12:30	24 July at 14:00	8.3°C	7.8°C
12930	Little Susitna upper station	14 July @ 10:10	6.2°C	7.2°C	1½ hrs slow in 10 days	24 July at 12:30	24 July at 13:00	8.3°C	8.6°C
12931	Little Susitna lower station	14 July @ 10:30	6.4°C	7.2°C	5 1/3 hrs fast in ten days	24 July at 13:40	24 July at 21:00	8.9°C	8.6°C
12924	" "	"	6.4°C	7.5°C	3½ hrs slow in ten days	"	24 July at 16:30	8.9°C	9.2°C
12949	Chulitna River	13 July @ 18:45	6.0°C	6.7°C	6 hrs fast	25 July at 18:35	25 July at 24:00	6.8°C	6.7°C
12954	Chulitna River	13 July @ 17:40	5.9°C	6.7°C	bad record	25 July at 18:20	17 July at 7:00	6.8°C	3.6°C
12959	Talkeetna River	14 July @ 21:40	11.6°C	12.1°C	3½ hrs fast	23 July at 20:35	23 July at 21:30	10.8°C	10.3°C
12957		14 July @ 21:40	11.6°C	12.9°C	6½ hrs fast	"	24 July @ 2:00	10.8°C	11.1°C

Plate A-1: Perimeter of Susitna R. at about Birch Cr., river mile 76½.

Plate A-2: Bedload deposited on beaver dam in flood channel nr. Billion Slough, river mile 82½.

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Plate A-3: Perimeter of Susitna R. nr. Billion Slough, river mile 82¼.

Plate Ap4: Perimeter of Susitna R. below Chase, about river mile 90½.

Plate A-5: Perimeter of Susitna R. above trib. cr. at r. mi. 92½

Plate A-6: Upstream view of river from river mile 92½

Plate A-7: Tributary entering Susitna R.at river mile 92½. Glacial boulders prominent.

Plate A-8: Mouth of Lane Cr., river mile 96¼.

Plate A-9: Perimeter material, Lane Cr., river miâe 96¼/

Plate A-11: Beaver-dammed, springfed(reported pond-creek, river mile 98 3/4.

Plate A-10: Perimeter, Susitna R., above Lane Cr., river mile 96¼

Plate A-12: Mouth of McKenzie Cr., river mile 99 1/3. Bedload being rapidly trimmed off by the river.

Plate A-13: McKenzie Cr., river mile 99 1/3.

Plate A-14: Activerspringflow erosion along banks of river just above McKenzie Cr., river mile 99½.

Plate A-15: Susitna beach above Mckenzie Cr., river mile 99½.

Plate A-16: Perimeter, Portage Cr., river mile 100¼

Plate A-17: Perimeter, Susitna R., at Curry, river mile 103.

Plate A-18: Streambed rubble in dry creekbed, Curry Cr., river mile 103.

Plate A-19: Susitna R. above Curry Cr., river mile 103.

Plate A-20: Perimeter, Susitna R. below Indian R., river mile 121.

Plate A-21: Indian R. - Susitna R. confluence; larger mat'l, (foreground) is river deposited; smaller mat'l(middle) Indian R. deposition. Indian R. in background.

Plate A-22: Indian R. perimeter gravel at mouth.

Plate A-23: Portage R. near mouth, looking upstream, river mile 130.

Plate A-24: Portage R. shoreline looking downstream from ½ mile above mouth.

Plate A-25: Portage R. perimeter material on active bar near mouth.