Bedload Sediment Transport and Channel Morphology of a Southeast Alaskan Stream

by

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A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed June 2, 1982

Commencement June 1983

AN ABSTRACT OF THE THESIS OF

Margaret A. Estep for the degree of Master of Science
in Forest Engineering presented on June 2, 1982
Title: BEDLOAD SEDIMENT TRASNPORT AND CHANNEL MORPHOLOGY OF A SOUTHEAST ALASKAN STREAM
Abstract approved:
Paul Adams

This study was conducted at portions of Trap Bay Creek, a medium-sized third-order stream on Chichagof Island, Southeast Alaska, to 1) quantify short-term sediment transport and channel morphology changes, 2) relate measured sediment transport rates to the major hydrologic parameters that appeared to determine the mechanisms of sediment transport, and 3) evaluate how bedload transport can influence channel morphology. Morphologic characteristics were evaluated by means of plani-metric surveys and cross-sectional measurements made in July and August of 1980 and August of 1981. Bedload and suspended sediment data were collected during the Fall of 1980 along with data on streamflow and precipitation.

Morphologic evaulations indicated that the stream is a dynamic system and that it appeared to be widening and aggrading during 1980-81. Large organic debris, especially fallen trees, are important in stream morphology, especially above the zone of tidal influence. The tides, as well as human activity, probably contributed to recent

morphological changes in lower reaches of the channel.

Problems involved in processing suspended sediment samples resulted in a limited amount of suspended sediment data. However, data that were collected from one point on the stream indicated that suspended sediment concentrations were low, usually less than 5 $mg \cdot l^{-1}$, and did not exceed 90 $mg \cdot l^{-1}$ during an approximate 2 to 5-year return interval storm event. Under average storm conditions, therefore, suspended sediment transport appears to be supply limited and constitutes a small portion of total sediment transport.

Bedload sediment samples were collected from a short pool-riffle study reach during a total of ten storms with streamflow ranging from 0.01 to 1.26 $m^3 \cdot s^{-1} \cdot km^{-2}$. Bedload sediment transport ranged from 3.9 to 4400 $kg \cdot hr^{-1}$, with peak transport rates occurring during peak streamflow.

Regression relationships were developed between bedload transport, gravel-sized inorganic bedload transport, coarse particulate organic matter transport, two particle size diameter classes (D_{50} and D_{90}), and stream discharge during the ten storms. This analysis revealed that total inorganic bedload transport was more strongly related to discharge than was transport of the large size category, coarse particulate organic matter transport tended to be more strongly related to streamflow than bedload discharge, and that neither of the particle size diameters had any consistent relationship to streamflow.

Bedload transport during the ten storms was further evaluated in terms of the sampling sites that were used, i.e. riffles above and below a depositional area approximately 20 m in length. Transport

tended to be greater, in terms of amount transported, at the upper riffle for most of the storm events. The opposite was true during the largest storm of the season and a storm which occurred a week later. It may be that bedload sediment is transported past the upper riffle by lesser magnitude events and is temporarily stored in the pool. Transport out of the pool requires events of greater magnitude. Supply limitations also appear to determine bedload transport in Trap Bay Creek.

Keywords: Helley-Smith sampler, pool-riffle sequence, armor layer, coarse particulate organic matter, suspended sediment, Southeast Alaska.

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ACKNOWLEDGEMENTS

This study was made possible by a grant from the Pacific Northwest Range and Experiment Station through the Forestry Sciences Laboratory, Juneau, Alaska, obtained by Dr. Robert L. Beschta. Laboratory facilities were made available by the Forestry Sciences Lab and by the Department of Forest Engineering, Oregon State University, Corvallis.

I would like to thank Bob Beschta for help in all phases of the project, including building sampling bridges. I would also like to thank all of the folks in Juneau from the Lab and from the Alaska Department of Fish and Game - Sport Fish Division for all of their help and encouragement. Thanks, also, to John Adams of the Region X Supervisor's Office, and to the hydrologists from the Sitka Ranger Station, Tongass National Forest. Special thanks to Dick Orchard who saved me from the flood, and to Roy and Ede Sidle for providing housing, food and fellowship. Finally, thanks to my committee members for their comments and criticisms of this manuscript, and especially to Paul Adams for being an excellent substitute.

TABLE OF CONTENTS

APPENDICES

TABLE OF CONTENTS - continued

LIST OF FIGURES

LIST OF FIGURES - continued

LIST OF TABLES

LIST OF TABLES - continued

APPENDIX TABLES

Bedload Sediment Transport and Channel Morphology of a Southeast Alaskan Stream

I. INTRODUCTION

Bedload sediment transport in streams is a natural process that removes the relatively coarse-sized products of erosion from the site of weathering and moves them through the fluvial system. Bedload particles undergo further attrition and weathering during transport and may be altered so that they enter the suspended or dissolved load portion of the total load of the stream (Swanson _et al_. in press). The geology and geomorphology of a watershed and the climate, as it determines the amount and form of precipitation characteristic of an area, are the primary factors influencing the size distribution of particles and the total sediment load. In theory, the physical stability of a stream system is maintained by its characteristic fluvial sediment load (Committee on Erosion and Sedimentation, 1977). Increases or decreases in sediment load can initiate adjustments in channel form by upsetting the dynamic equilibrium that exists under the natural sediment regime, thus altering the physical and biological characteristics of the system (Heede, 1975; Park, 1976).

Many land-use activities that result in accelerated sedimentation are considered to act as sources of non-point pollution. Sedimentation in small streams represents an important non-point water quality problem in southeast Alaska (Beschta, 1979).

Forest management activities are only one of the many that may lead to accelerated erosion and alter the sediment regime of a stream system. In southeast Alaska, fish and timber are the two most important resources at the present time (Meehan, 1974). The fisheries resource is also the one most likely to be adversely affected by any increased sedimentation arising from timber harvest. Conflicts between timber harvesting and fisheries are an important problem for public land administrators (Beschta, 1979).

Research on sediment transport has largely been limited to the measurement and analysis of suspended sediment, i.e., inorganic material transported by the turbulence of the stream and maintained in the water column. This situation may reflect the relative ease of design and use, as well as the relatively high efficiency of samplers for the collection of this portion of the total sediment load. High levels of suspended sediment have been found to fill substrate interstices, and reduce cover and habitat for algae, aquatic insects, and small fish (Nuttal, 1972; Brusven, 1980). Fish and other aquatic populations may also be reduced or altered once suspended sediment is deposited. Deposition can reduce or block intergravel flow velocities which are necessary to maintain a sufficient supply of dissolved oxygen for the respiration of fish eggs and invertebrates, and for the removal of the waste products of metabolism of these organisms (Hynes, 1970).

Bedload sediment is defined as that portion of total sediment load that moves by sliding, rolling, or saltating on or near the streambed, moving at velocities that are less than that of the adjacent flow (Harris and William, 1971). This somewhat arbitrary definition makes it difficult to separate the suspended and bedload portions of total load. Rocks and gravel would fall into the bedload category, while sand-size particles could be transported in either mode, depending on flow conditions and particle density. Most field research on bedload transport has been conducted within the last forty years, yet little is known about its physical and biological relationships with the stream ecosystem. Land-use activities may have an effect on either the suspended or the bedload regime. A better understanding of bedload transport as it occurs under natural conditions is needed in order to comprehend the interactions between land use, sedimentation, and stream ecosystems.

Bedload studies in the field have generally been hampered by a lack of adequate sampling devices. The International Organization for Standardization (ISO) has not yet established standards for bedload samplers or for sampling methods. ISO has issued guidelines for bed material sampling, but the spacing or frequency of bedload sampling has not been specified. Very little is known about the factors that control the transverse variations of bed particle sizes at a given cross section or how these distributions vary with time and flow conditions (Nordin, 1981). The major problems involved in sampling bedload are: (1) There is no sampler that does not alter discharge or the streambed, or that is not selective in sampling certain particle sizes; (2) obtaining reasonable average values requires the collection of many samples because of the great temporal and spatial variations in bedload transport. A modified, hand-held, Helley-Smith pressure-differential bedload sampler was used in this study to intensively sample bedload transport during the high flow events of the Fall of 1980 in a third-order stream in southeast Alaska. Descriptions of this sampler and its use are available in the literature (Drufel et al., 1976; Emmet, 1979, 1981; Helley and Smith, 1971; Johnson et al., 1977; Beschta, 1981), and are discussed in the "Literature Review" section of this paper.

Background and Objectives of Study

This study was sponsored by the USDA-Forest Service, Forestry Sciences Laboratory (FSL), Juneau, Alaska, and conducted in cooperation with the Alaska Department of Fish and Game - Sport Fish Division (ADF&G) and the National Oceanic and Atmospheric Association - National Marine Fisheries Service (NMFS).

The Trap Bay watershed was the site of research and background data collection by the aforementioned agencies in the areas of benthic invertebrate, insect, and fish populations; water temperature and quality; precipitation and hydrology; and hillslope stability. Trap Bay Creek, a medium-sized third-order stream, and its tributaries are located on the northeastern end of Chichagof Island on the southeastern side of Tenakee Inlet. The area is part of the land designated for timber harvest in the Alaska Lumber and Pulp Company 1981-86 Timber Sale. Cutting units and the main haul road have been surveyed and staked out; two small tributaries to Trap Bay Creek drain cutting units. Details of the sale are available from William P. Gee, Forest Supervisor, Chatham Area, Tongass National Forest, P.O. Box 1980. Sitka, Alaska 99835.

The Watershed is moderately productive for pink salmon[1] and Dolly varden char; a small number of coho salmon also spawn here. Old growth Sitka spruce and western hemlock are the major commerical timber species. Timber production is moderately good, but much of the watershed is composed of very steep slopes of low-lying muskeg.

Sediment transport research included suspended and bedload sediment sampling on Trap Bay Creek during storm events from September through November, 1980. Channel characteristics were measured in August of 1980 and 1981.

Objectives of the research were:

(1) To quantify sediment transport rates, particularly the bedload component,

(2) To relate sediment transport rates to those major hyrologic parameters which appeared to determine the mechanisms of sediment transport,

(3) To evaluate how bedload transport influences channel morphology.

This study was an extension of a continuing research program on sediment transport processes in mountain streams that is being conducted by the Forest Engineering Department, Oregon State University, Corvallis, Oregon.

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[1] See Appendix 1 for a list of the scientific names of flora and fauna mentioned in this paper.

II. LITERATURE REVIEW

Forest Management Activities and Fluvial Transport Processes

Physical and chemical erosion processes are continuously at work at the earth's surface. The products of these processes are moved downslope by gravity, precipitation, wind, and biological activities, where they become available for transport by streams (Swanson, 1980). Once fragmental materials enter the stream system, bedload and suspended transport processes move particulate matter through the channels. Forest vegetation strongly influences nearly all elements of the soil/sediment routing system on slopes and in small streams (Swanson _et al._, in press).

The amount of sediment that is eroded, transported, or deposited in a stream is a function of many interrelated variables, including climate, soils, topography, vegetation, and land use. In an undisturbed steep forested watershed, solution transport, the transport of dissolved minerals, is the only perpetual transport mechanism. Where precipitation exceeds approximately 65 cm per year, solution transport can exceed particulate transport in terms of the volume of material exported per unit area (Clayton, 1981). In contrast to the generally perpetual transport of dissolved materials, periods of sediment movement range from frequent, low magnitude suspended transfer to infrequent, high magnitude debris torrent events (Swanson _et al._, in press). The capacity of a stream to transport the sediment supplied to it is a function of the hydraulic properties of the channel (O'Leary, 1980).

Surface erosion (splash, sheet, rill, and gully erosion) is a result of raindrop impact, thin film flow, or concentrated surface runoff over the watershed (Satterlund, 1972). It is rarely a problem on undisturbed vegetated watersheds where the vegetation acts as a buffer, absorbing energy from raindrops, and where the incorporation of organic matter into the soil helps to improve the soil structure and increase infiltration capacities. The highly permeable soils typical of southeast Alaska ensure that drainage is primarily by subsurface flow with little or no surface flow outside of established channels (Swanston, 1974). Dense vegetation and the thick organic layer present under the old growth forest are particularly effective in protecting the soil from surface erosion.

The dominant geologic processes that transport the products of weathering from the hillslope to the stream channel under forested conditions in the steep terrain of the Northwest are soil mass movements (Swanston, 1974). The entire soil mantle may be subject to the set of processes termed "creep," which includes rheological deformation and root throw (Swanson, 1980). Debris avalanches and debris flows occur on oversteepened slopes as a result of surface loading, increased soil water levels, removal of mechanical support, or a combination of all three (Swanston and Swanson, 1976). These types of mass movement are the most frequently occurring types of mass failure in southeast Alaska and involve the rapid downslope movement of soil, rock, and forest litter with relatively high water content (Swanston, 1974). Soil creep may contribute to the susceptibility of soil to sliding in critical areas (Swanston, 1974).

Debris flows and avalanches are usually initiated at the heads of, or within, shallow linear depressions on the valley side slopes (Swanston, 1974). These hollows serve to concentrate soil seepage and develop into surface drainages during major storms. In some instances, debris avalanches may deposit their load at the base of a slope where sediments can be supplied to the stream in small increments over long periods of time. Debris can also be carried directly into the stream, producing a temporarily heavy sediment load or, under certain conditions, initiating a debris torrent which can scour the channel and result in a large debris dam (Swanston and Swanson, 1976). In either case, the sediment regime of the stream will be disrupted and sediments may be deposited on and within spawining gravels where they can disrupt the flow of oxygen to fish eggs and alevins and block the emergence of fry (Chapman, 1961; Phillips, 1971).

Debris avalanches generally occur in relatively shallow, cohesionless soils in which the angle of internal friction, friction along the sliding surface, and slope gradient control internal soil strength and gravitational stress. Soil saturation and active pore-water pressure development during major storms can substantially reduce soil strength and decrease the critical angle of stability of the slope (Swanston, 1974). Timber harvest on oversteepened slopes can affect stability in two major ways. First, tree removal increases the amount of water stored in the soil through decreased evapotranspirational withdrawals. This increases the length of time that the soil is fully saturated by reducing the amount of water necessary to recharge the soil water deficit (Harr, 1976). Soil moisture levels may significantly affect seasonal rates of creep and slump-earthflow movement. Secondly, the anchoring of the soil mass to the parent material by tree roots is a major factor affecting the stability of oversteepened slopes. Maximum decreases in shear strength of anchoring roots occurs three to five years after cutting, and is probably the time when slopes are most susceptible to mass failure during major storm events (Swanston and Walkotten, 1974).

Sediment may also arise from the stream channel itself. The force of flowing water erodes the stream banks and bed, and this material may then be entrained, transported, or deposited by the streamflow. Sediment is stored in floodplains, alluvial fans, point bars, and in deposits associated with large organic debris (Swanson and Lienkaemper, 1978). Bed material transport reflects channel stability and determines gravel bed composition (Milhous and Klingeman, 1973; Beschta and Jackson, 1979). The removal of large organic debris from streams, either as part of the harvest or as part of a stream-cleaning operation, can result in the release of the equivalent of up to 15 years sediment previously stored behind the debris accumulations (Megahan, 1975).

A study conducted in western Oregon showed that road building and landing construction associated with timber harvesting can increase the occurrence of soil movement by 20 to 350 times its rate of occurrence in an undisturbed forest (Swanston and Swanson, 1976). Clearcutting can cause an increase of from 2 to 20 times over natural rates of occurrence. Increases in the sediment supply to a stream as a result of mass failures can cause changes in the diversity and productivity of insect life (Brusven, 1980), changes in the suitability of gravels for fisheries production (Chapman, 1961; Hall and Krygier, 1967), and over the long term, increased sediment production may reflect a loss in the productivity of forest soils (Curry, 1973).

Sediment in Streams

The understanding of sediment processes is at a qualitative level (Committee on Erosion and Sedimentation, 1977). Suspended sediment has been better quantified than has the bedload fraction of total load; suspended sediment measurement teachiques are well documented (Vanoni, 1975). However, both suspended and bedload transport need to be measured at the same time in order to adequately characterize the sediment regime of a stream. The bedload fraction may be small relative to the suspended load fraction, but its movement has a greater effect on channel characteristics. A lack of reliable sampling methods for bedload has been a major limitation in field studies; data analysis and comparison are further complicated by variations in research techniques (Edwards, 1979).

Sediment transport begins when the force of streamflow acting on channel materials exceeds the critical condition for motion. This concept of a critical tractive force, τ, was defined by Du Boys in 1879 as follows:

$$\tau = \gamma R S \qquad (1)$$

where, γ = specific weight of water

R = hydraulic radius

S = energy gradient.

Material that is entrained in the flow travels either as suspended or bedload sediment. Particles are suspended if the ratio of fall velocity, W, to shear velocity, $\overset{*}{v}$, is less than 0.8. They are transported as bedload if the ratio $W/\overset{*}{v}$ is greater than 0.8 and the Shields criterion for initial motion is met, which for fully developed flows is $\tau/\Delta\gamma d = 0.06$ (Nordin, 1981).

$$\tau = \rho g D S \tag{2}$$

where, ρ = fluid density
g = acceleration due to gravity
D = flow depth
S = slope of energy gradient
d = particle diameter
$\Delta\gamma = (\rho_2 - \rho)g$
ρ_2 = sediment density
$\overset{*}{v} = (\tau/\rho)^{\frac{1}{2}}$

In most streams, suspended load comprises a larger fraction of the total load then bedload. Most mountain streams are supply-limited in their suspended load, which is dependent on the amount of fines (silts, clays, very fine sands) present in or transported to the stream. The bedload supply, in contrast, is generally greater than the stream can transport. Thus, bedload transport occurs only during periods of high flow, and then only over relatively short distances.

Table 1 summarized the findings of several researchers on the percent of total load transported as bedload. It can be seen that for several streams in the Pacific Northwest, bedload comprises only about one to 25 percent of the total load transported at peak flows. This fraction may be somewhat larger for mountain streams and tends to

TABLE 1. Percent of Total Load Transported as Bedload During Peak Flows for Several Streams in the Pacific Northwest

Region	% bedload at peak discharge	Source
Idaho Batholith (Upper Salmon River)	1-10	Emmett, 1975
N. Coastal California (Van Duzen River)	9-15	Kelsey, 1977
Oregon Coast Range (Oak Creek)	1-26	Klingeman & Milhous, 1970
Oregon Coast Range (Flynn Creek)	2-17	Edwards, 1979

increase as discharge increases (Klingeman and Milhous, 1970).

Bedload transport is influenced by channel slope and roughness, particle size, and stream velocity and turbulence (Simons and Senturk, 1976). Changes in any one or several of these factors alter the transport capacity of the stream, and may result in aggradation or degradation of the channel. Furthermore, changes in the sediment supply due to increased erosion in the upper reaches of the watershed can result in general deposition of the sediment and aggradation along the lower channels (Leopold *et al.*, 1964).

Bedload Measurement and Prediction Techniques

Direct sampling and measurement methods were used for estimating bedload tranpsort up until the early 1940's, when Einstein introduced his empirical bedload equations (O'Leary, 1980). Development of numerous theoretical and empirical bedload equations followed. Attempts were made to construct bedload transport equations that would predict the maximum transport capacity of a stream for a given set of hydraulic conditions and sediment characteristics (Graf, 1971; Vanoni, 1975). A number of investigators have studied the applicability of these equations (Klingeman, 1971; Haddock, 1978). The models studied were found to inadequately represent high-energy mountain streams due to the supply limitations which arise from the flushing, deposition, and armoring of the streambed (Milhous and Klingeman, 1973; Haddock, 1978). Most empirical and theoretical equations have been developed from flume studies or for relatively constant conditions which are not characteristic of natural streams; thus they do not adequately represent the

the conditions under which natural sediment transport normally occurs. These problems have prompted a return to direct sampling techniques.

Of the bedload sampling devices developed prior to the 1940's, there are two categories of samplers which come close to meeting the three criteria for an ideal bedload sampler listed in the 1940 U.S. Federal Inter-Agency River Basin Report:

(1) The sampler must sample a definite portion of the moving water and solids.

(2) All the solids moving in the sampled portion must be collected.

(3) The sampler must have a secure contact with the bed surface and not disrupt upstream flow nor obstruct the entrance of particles.

These two samplers are the pressure differential and the vortex samplers, although problems have been observed with each type of sampler. The vortex sampler had been found to underestimate the actual bedload transport rate. It is especially inefficient for particle sizes of less than 4.75 mm in diameter and becomes more inefficient as discharge increases (Klingeman, 1971; Hayward and Sutherland, 1974). The pressure differential sampler may either over-or underestimate bedload tranpsort depending on which particular device is used (Hubell, 1964; Helley and Smith, 1971). An additional problem with the pressure differential sampler is that its use requires moving the device, which can further disrupt flow. Good contact with the streambed may not always be possible and local scour can occur at the point of placement (Helley and Smith, 1971).

Use of a vortex sampler requires that the device be installed in a uniform cross section of the stream. Installation costs are high and the vortex sampler is not transportable from place to place. Few researchers have used vortex samplers for these reasons (O'Leary, 1980). There have been four studies published so far in which the researcher(s) used a vortex sampler: Klingeman and Milhous (1970), Hayward and Sutherland (1974), O'Leary (1980), and Edwards (1979). The latter two included comparisons of vortex and Helley-Smith pressure differential sampler efficiencies.

The lack of a uniform, stable cross-section for installation, relatively high installation costs, and inaccessability of the research area made the use of a vortex sampler infeasible in this study. The Helley-Smith pressure differential sampler has been used in a number of studies of natural bedload transport and a slightly modified version of it was chosen for use in Trap Bay Creek.

Pressure differential samplers theoretically equalize the entrance velocity of the sampled portion of streamflow and that of the surrounding stream through a pressure drop created by the divergence of the exit walls of the sampler. As the velocity decreases at the downstream end of the sampler, the sediment in transport is deposited. The Dutch, or Arnheim, sampler was the most widely used model prior to the development of the Helley-Smith. The Helley-Smith sampler is a modified version of the Arnheim sampler and was designed for use by the U.S. Geologic Survey. It has a 7.6 cm^{-} square aperture and was designed to be used in flow velocities of less than or equal to three meters per second ($\text{m}\cdot\text{s}^{-1}$) (Emmett, 1981). Efficiency tests of the Arnheim and Helley-Smith overestimates by about 50% (Hubbell, 1964; Helley and Smith, 1971).

The variability in sampler efficiency was originally thought to be a function of the bed material used in testing, a 1.15 mm diameter sand, and the natural variability of bedload in time and space. In his 1971 report to Helley and Smith, Jobson[1] stated that he had found that the sampler tended to slide upstream a small distance while being raised from the bed, and would thus tend to scoop up additional sand. He concluded that the scooping tendency might be reduced by using larger gravel in efficiency tests, and the sampler would then give a better estimate of transport rates. More recent studies have shown that the overestimation of transport rates is a result of increased velocities at the orifice, while underestimation is a result of the clogging of the mesh collection bag on the sampler. The hydraulic efficiency of the sampler (the ratio of the mean velocity of water through the sampler to the mean velocity of water had the sampler not been there) was found to be about 1.54 (Emmett, 1981). Emmett (1981) also states that the sampling bag can be 40% filled with sediment which has a particle size larger than the mesh size without losing efficiency. However, smaller particles tend to plug the bag and are subsequently lost from the sample.

The problem of the clogging of the sampler bag was the subject of a 1981 study by Beschta. Both Beschta (1981) and Johnson *et al.* (1977) observed that fine sands and particulate organic matter tend to clog the mesh of the sampling bag. This reduces the effective flow

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[1] *IN*: Helley and Smith, 1971.

through area of the sampler,creating a back pressure at the orifice and reducing efficiency. Beschta (1981) showed that trapping efficiency of a standard collection bag (surface area 1950 cm^2, 0.2 mm mesh size) exposed to a 0.50 mm (average particle diameter) sand mixture in a flume was a function of the length of time of the sampling period. The use of a larger collection bag (6000 cm^2, 0.2 mm mesh) resulted in the efficiency remaining constant for sampling periods of up to eight minutes. Sampler efficiency would probably decrease for sampling periods longer than this, or if large amounts of particulate organic matter were in transport.

Studies of bedload transport have been made using the Helley-Smith sampler in the field as well. Molnau _et al_. (1975) used it in the Knapp and Cape Horn Creeks of the Central Idaho Batholith. These streams have beds consisting of sand and fine gravel. For Cape Horn Creek, the researchers found that bedload transport rates increased on the rising limb of the hydrograph, dropped sharply prior to the peak, and increased again on the falling limb. Molnau _et al_. (1975) explained this rising limb shift based on the tractive force theory[1]. The tractive force necessary to initiate bedload tranpsort was exceeded early in the snowmelt season,causing the increased transport on the rising limb. The drop in bedload transport was hypothesized to indicate that the stream had cleansed itself of all "transportable" sediment, that sediment deposited on the armor layer over the previous year or time since last critical discharge. Thus, although the

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[1] See pages 12 and 13 for explanation of tractive force theory.

tractive force increased further at the peak of the hydrograph, no increase in bedload transport could take place because of a lack of transportable sediment. In Knapp Creek, transport rates also increased on the rising limb of the spring melt hydrograph, but a second sharp increase occurred just prior to the peak of the hydrograph. Molnau et al. (1975) hypothesized that discharge had increased to the point where the tractive force was great enough to dislodge the armor layer, releasing sediment that had been trapped below it.

According to Beschta (personal communication), Molnau et al. (1975) based their hypothesis on a relatively few samples. Much of what they saw may actually have been sampling variability. In the following study by Emmett (1975), a ten-fold variation in peak bedload transport rates was common.

Emmett (1975) used a Helley-Smith sampler to collect bedload data for three streams of the upper Salmon River basin of Idaho. Although there were too few samples taken to detect differences in transport rates prior to or after the peak discharge, bedload transport was found to increase with increasing discharge. Measurements were taken in Slate Creek to obtain average minimum transport rates at the cross-sectional location where the maximum transport rates were observed. Over a three day period, the average rate of transport was approximately the same for the same discharge. Individual transport rates comprising these averages showed about a ten-fold variation, however. These variations were related to some hydraulic variables, but the relationships were not consistent.

Samples collected from the Snake and Clearwater Rivers in Idaho were used to estimate bedload transport rates in kilograms per meter width of channel per second ($kg \cdot m^{-1} s^{-1}$) (Emmett, 1976). This data was plotted against stream power, as defined by Bagnold (1977), also in $kg.m^{-1} s^{-1}$. This graph showed that one relationship was applicable for low values of stream power when coarse particles are not moving and fine particles are limited, and that another relationship was applicable at higher values of stream power when almost all bed materials are moving. At intermediate values of stream power, there is a break in the relationship. Emmett felt that the lack of intermediate sized gravels in the bed material of these two rivers (bimodal size distribution) led to this; the bed was either armored or moving.

The results of a field calibration conducted on the East Fork River, Wyoming, in 1979, were presented by Emmett (1981). Helley-Smith samples were compared with results obtained using a conveyor-belt sampler which was assumed to be 100% efficient. Transport rates of large particles, 8 to 16 mm in diameter and 16 to 32 mm in diameter, were too minimal to allow calibration for particle size ranges greater then 16 mm. Direct comparisons with results obtained using the conveyor belt could be made for particle sizes ranging from 0.5 to 16 mm. Emmet felt that the Helley-Smith sampler was 100% efficient for the 0.25 to 0.50 mm particle size class, but that data on particle sizes less than 0.25 mm should not be used and that data on particles larger than 16 mm should be treated with caution.

Using data from the East Fork River, Emmett (1981) quantified bedload transport in terms of the particle size classes as a percent of total load, and the rates of change of a given size class as the total bedload transport rate increased (Table 2). A least squares linear regression of the log transformed data was used to develop a power equation relating the bedload transport rate in each particle size class (Y) and the total bedload transport rate (X):

$$Y = aX^b \tag{3}$$

"b", the slope of the regression line, is the rate of change in percentage of total bedload in that particle size class.

The Helley-Smith sampler does pick up some suspended sediment, the absolute quantities of which depend upon the sizes of sediment in transport and the hydraulic conditions of flow (Emmett, 1981). However, the significance of material that can be transported as suspended sediment (less than 0.50 mm in diameter) decreases as the bedload transport rate increases. The rate of change values (exponent b) in Table 2 for suspended size particles are less than unity, indicating that the percentage of sediment in those size classes decreases as total bedload transport rate increases.

The significance of transport of particles in size classes ranging from 0.50 to 8.0 mm was found to be greatest and to increase as bedload transport increased (Table 2). The dominant particle size class was 0.50 to 1.0 mm. The greatest rates of change occur from the 2.0 to 4.0 mm size class, followed by the 1.0 to 2.0 mm and 4.0 to 8.0 mm size classes. At high bedload transport rates, the rate of change values combine with the mean percentage values such that the 1.0 to 2.0 and 2.0 to 4.0 mm size classes comprise the greatest percentage of total bedload. The median particle values or rate of change for the two coarsest particle size categories are not comparable

TABLE 2. Mean Percentage of Total Bedload in Each Particle Size Class (Y/X) and Rate of Change in Percentage (B) as Bedload Transport Rate Changes[1,2]

Particle size class, mm	Mean percentage of total bedload in particle size class (Y/X in %)	Rate of change in percentage of total bedload in particle size class (B)
0.06 - 0.12	0.35	0.727
0.12 - 0.25	3.24	0.599
0.25 - 0.50	22.80	0.698
0.50 - 1.00	26.84	1.050
1.00 - 2.00	20.07	1.213
2.00 - 4.00	10.61	1.344
4.00 - 8.00	3.45	1.193
8.00 - 16.00	0.89	0.867
16.00 - 32.00	0.65	0.367

[1] Data adapted from Emmett (1981).

[2] y = bedload transport rate in a given particle size class.
x = total bedload transport rate in a given particle size class.

to those for the smaller size categories because the largest particles move only at high transport rates. Thus, many of the low transport runs could not be included in the analysis for these size particles (log transformed regressions cannot include zero values) (Emmett, 1981).

Emmett (1981) concluded that the Helley-Smith sampler should not be used for measuring bedload transport rates for sediment of particle sizes which also are transported as suspended sediment; nor where the bag may become clogged with particles about equal in size to the size of the mesh, or with organic debris. Sampling efficiency probably also decreases as particle size approaches nozzle dimensions. Further, the sampler should not be used when irregularities in the stream bed preclude a reasonable fit between the sampler bottom and the bed.

Edwards (1979) conducted sediment transport research and used both a vortex sampler and a hand-held Helley-Smith sampler. The study was conducted on Flynn Creek, which drains a 2 km^2 undisturbed watershed in the Coast Range of western Oregon. The Helley-Smith sampler was found to be more efficient in this stream, where much of the bedload consists of sand-size material. The Helley-Smith sampler is also compatible with standard suspended sediment sampling techniques, and it can be modified to account for local sampling conditions. This is advantageous in Flynn Creek because of the variation in transport rates and types of material in transport. Edwards found such differences existed among three sites selected for bedload sampling, indicating that limited sampling at a single site may not adequately characterize bedload transport in this area.

Edwards (1979) also found that bedload transport occurred in relatively discrete pulses. Maximum bedload discharge did not always coincide with peak runoff. Although streamflow was found to be the principal variable controlling sediment transport, results indicated that supply limitations exist. Suspended sediment represents the greater portion of total load in Flynn Creek, yielding from four to ten times more sediment than was yielded as bedload during a 24-hour peak flow period. Both total suspended solids (TSS) and coarse particulate organic matter (CPOM) peaked early in the storm; however, pulses of CPOM discharge occurred during the recession and appeared to be related to streambed disturbances. Edwards concluded that channel morphology and in-stream obstructions may cause significant spatial and temporal variations in sediment transport. Bedload movement is important in regulating bed composition and particulate yields.

Another study by O'Leary (1980) in Flynn Creek used a vortex sampler as the primary device for sampling bedload tranpsort during storms. A hand-held Helley-Smith sampler was used to obtain samples composed of several cross-sectional subsamples, which provided supplemental information about bedload transport, and provided "test samples" which were used to measure equipment efficiency or variations in transport across the channel. Samples collected with the vortex sampler indicated that bedload discharge increased with increasing streamflow. Bedload transport rates also increased as the storm season progressed, even though streamflow was less than that of previous storms. O'Leary (1980) concluded that this may have been the result of exceeding some critical discharge necessary to initiate bedload transport. Regression analysis of streamflow and bedload discharge showed that significant ($p = 0.01$) differences existed between relationships developed for individual storms.

Helley-Smith samples obtained by O'Leary (1980) indicated bedload discharge rates greater than those indicated by the vortex sampler, except for one storm. This was again attributed to the greater efficiency of the Helley-Smith for material in the sand-size particle range. Intensive sampling with the Helley-Smith sampler showed that bedload transport rates fluctuated rapidly. O'Leary (1980) also found that when large amounts of organic material were in transport, bedload transport rates as estimated by the Helley-Smith samples tended to be low. However, there was no statistically significant regression relationship between percent organic matter and the bedload transport rate.

Another method that has been used to estimate bedload transport has been to measure changes in the channel morphology. This has been done by measuring cross-sectional profiles prior to and following the storm season or, in some cases, following individual storm events. Cross-sectional profiles and longitudinal morphometric surveys have been combined to show net channel changes over time (Leopold *et al.*, 1964; Dunne and Leopold, 1978; Edwards, 1980).

Various morphological characteristics have been used in attempts to predict sediment discharge (Rosgen, 1978; Marston, 1978; Dunne and Leopold, 1978). Marston (1978) used data on the morphometric characteristics of several streams in western Oregon to develop regression equations to predict streamflow and sediment yield. Rosgen (1978) shows how sediment rating curves can be used to predict changes in sediment yield following silvicultural activities. Both of these methods have limited usefulness, however, because of the large amount of data which must be collected and because the relationships tend to be site specific.

Tracers, in the form of marked rocks, have been used to relate discharge to the number and size of bedload particles moved during high flows (Leopold and Emmett, 1981). Rocks representing various size particle classes were collected from a streambed, marked, and replaced in a line along a riffle. The authors found that even when the computed shear stress was several times larger than the minimal value for motion as indicated by initial motion stress values derived from the Shields curve, only a small proportion of available rocks would actually be set in motion. Therefore, to move all rocks of a given size, it is necessary to have repreated flows which produce a competent shear stress. Leopold and Emmett (1981) stated, "If a gravel riffle is an expression of a kinematic wave as suggested by Langbein and Leopold, complete replacement of rocks in a zone of concentration requires a series of flow events of sufficient energy to move those rocks." Thus, although a riffle may represent the crest of a wave of bedload transport, bedload movement itself is a function of more than the shear stress resulting from streamflow.

Color-coded marbles were used by O'Leary (1980) to determine bed scour and fill, and average transport distances of bed material. Although the marbles were resistant to abrasion, so that the color would not come off, and they approximated bedload particles in size and density, difficulties arose in recovering them following the storm season. Three sizes of marbles were used in the study; percent recovery was significantly higher for large and medium-sized marbles than for small marbles. The method did show where bedload movement and channel changes occurred, but results obtained for transport in terms of distance moved and number of marbles moved may have been biased towards the larger marble sizes (O'Leary, 1980).

Problems associated with using "tracers" to determine transport distances tend to be related to recovery problems. Painted rocks are subject to abrasion and lose their markings. Even if this is not a problem, 100% recovery of tracers is often difficult. The use of materials to mark tracer particles may be one way to overcome these problems.

None of the methods available to evaluate bedload transport in streams is entirely satisfactory. Theoretical and empirical equations do not adequately characterize conditions occurring in natural streams. Direct measurement techniques utilize samplers that alter streamflow conditions, which leads to an over-or underestimation of bedload transport. Direct sampling techniques and measurements of changes in channel morphology are very labor intensive; large amounts of data are required to yield reliable results. However, the use of these various techniques will hopefully lead to a better understanding of sediment transport under natural conditions, and aid in the development of more suitable methods to evaluate changes in the sediment regime in streams.

III. WATERSHED DESCRIPTION

The Trap Bay watershed is located on the southern side of the Tenakee Inlet, on the northeastern side of Chichagof Island, between 57°44' and 57°45' north latitude and 135°00' and 135°02' west longitude (Figure 1). It is approximately 60 aerial miles SSW of Juneau, Alaska, and is 13.5 ~~ha~~ (5.2 mi^2) in area.

The climate is typical of the Alaska Panhandle and is a cool, moist maritime climate characterized by cloudy skies and little daily temperature variation. Cloudy skies occur on the average of 275 days per year, 43 are clear, and the remainder are partly cloudy (Harris _et al_., 1974). The relatively wide range in daily hours of sunshine during the year apparently reduces daily temperature fluctuations. During the summer, there is only a brief period of nighttime cooling, while during the winter, the low angle of the sun and reduced hours of sunshine result in little surface heating (Harris _et al_., 1974). The other major moderating influence on temperature is the sea. Waters of the Inland Passage are warmed by the Alaska current. Sea temperatures range from 12.8°C (55°F) in the summer to about 5.6°C (42°F) in the winter (Harris _et al_., 1974).

The watershed receives about 3410 mm (95 in) of precipitation per year, with nearly 40% occurring in October, and only 1% occurring in April, May, and June (Harris _et al_., 1974). Most precipitation occurs as steady, light to moderate rain, although there may be appreciable snowfall at higher elevations during the fall and winter.

Maximum precipitation is usually associated with prominent low pressure systems, called Aleutian Lows, which develop in, or cross,

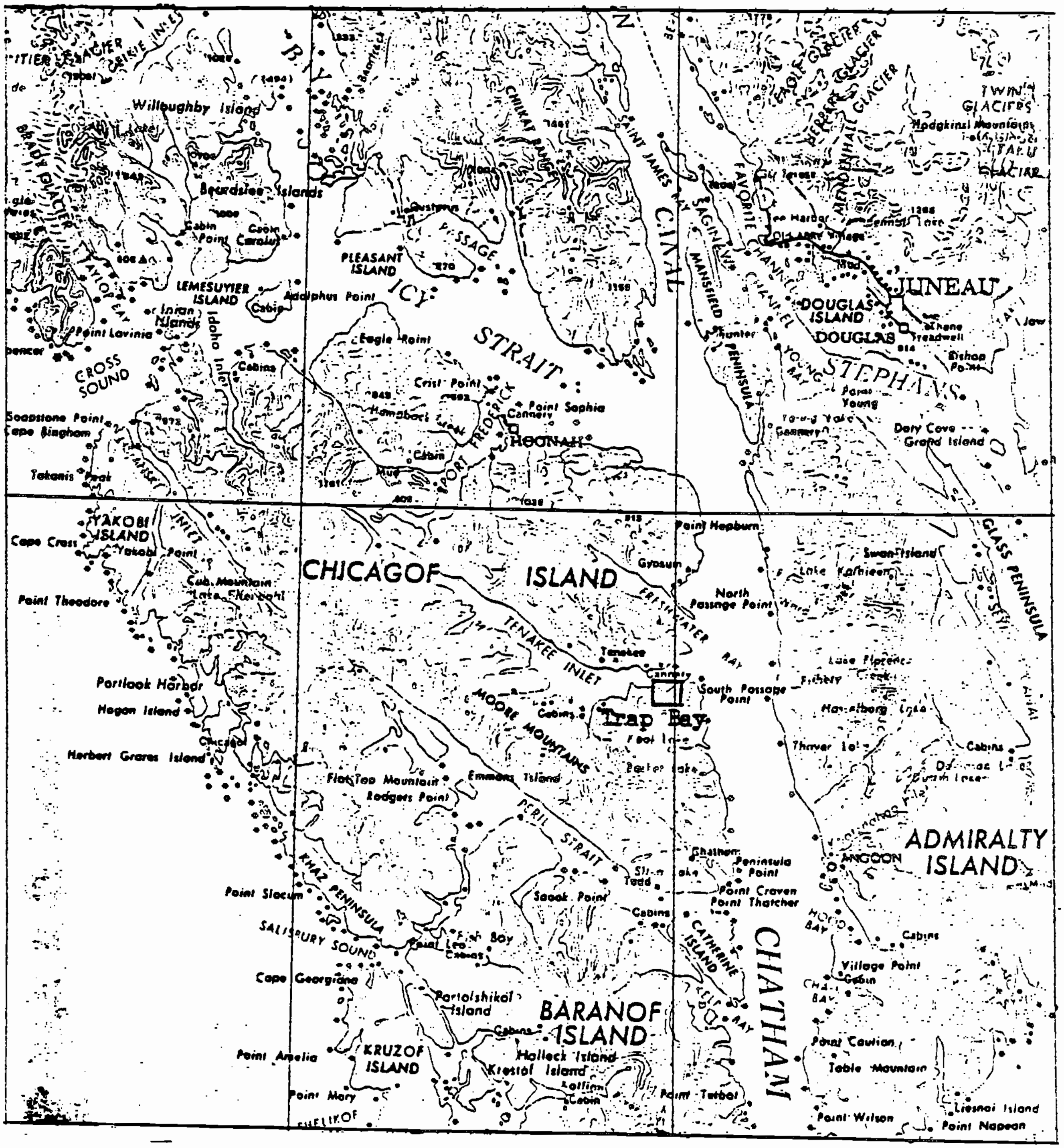

Figure 1. General map of Chicagof Island showing location of Trap Bay Watershed

the Gulf of Alaska (Harris et al., 1974). These systems follow a storm track along the Aleutian Island chain, the Alaska Penninsula, and the Gulf of Alaska. These areas are exposed to most of the storms crossing the north Pacific. Moist air masses moving in from the sea are lifted by the Coast Mountains, which interrupt surface air circulation, resulting in the large amounts of rainfall that soak the Panhandle.

Trap Bay Watershed is a glacial cirque valley bounded by serrate ridges and a horn peak at the southern end. Elevation ranges from sea level to a maximum of 1320 m (3870 ft). Detailed mapping and interpretation of the geologic history of southeast Alaska is still in the initial stages. In most glacial cirque valleys in the area, the bedrock plays a lesser role in soils development because it is often overlain by compact glacial till up to 451 m (1500 ft) in elevation (Harris _et al._, 1974). Soil formation began following the retreat of the last glaciers, which were associated with the Wisconsin advance; most mineral soils are derived from ablation till (Harris _et al._, 1974).

Climate is an important factor in soil development. High rainfall, cool temperatures, a short growing season, and moderately low soil temperatures all contribute to an accumulation of organic matter on the surface and within the soil (Harris _et al._, 1974). The organic mat on the surface, for example, may range from 15 to 25 cm in thickness.

Sidel and Swanston (1982) described the soils of a northwest facing slope on the eastern side of the watershed. Mid to upslope soils are 15 to 50 cm thick and are overlain by a wet, dense, organic layer which is about 20 cm thick. The Tolstoi soil series predominates in well-drained slope positions and the St. Nicholas series occurs in more poorly drained steep sites. The Kupreanof series occurs in lower and midslope reaches. These soils are moderately deep, well drained, and overlie weathered graywacke.

Soils common to similar areas of southeast Alaska contain approximately 10% organic matter and 12% iron oxides, both of which strongly attract and hold water (Harris et al., 1974). Thixotrophic properties are common in many southeast Alaskan soils as a result of the high organic and iron content in combination with high rainfall. Thixatrophy is a reversible gel-sol transformation in which the soil structure breaks down under stress.

Precipitation generally exceeds calculated evapotranspiration throughout the year. This, in combination with the many glacially-caused depressions and extensive impermeable soil layers, has resulted in the formation of large areas of organic soils. These are classified as Histosols and commonly called "muskegs" (Harris et al., 1974). Muskegs cover much of the lowland area of the watershed. They are composed of sedge or sphagnum peat, and support sedge, sphagnum, ericaceous species, and stunted lodgepole pine and western hemlock. Muskegs may help to regulate streamflow (Harris et al., 1974).

All mature mineral soils under timber have strongly spodic (Podzol B) horizons (Harris et al., 1974). Spodosols have developed under the spruce forest which covers the slopes and better drained lowland areas. The depth of tree rooting is largely confined to the thick organic mat and the upper 30.5 cm (12 in) of mineral soil where most plant nutrients are concentrated.

Vegetation is rich and abundant everywhere in the watershed except above treeline. I observed Sitka spruce, western hemlock, and scattered red-cedar and red alder in the forest. The understory consisted of blueberry, huckleberry, ferns and numerous vascular plants. Mosses and lichens covered every available surface. Dense thickets of salmonberry, ferns, skunk cabbage, and nettles alternated with alder clones and an occasional hemlock along the streambanks and in frequently inundated areas. Devils club was also found along streams, throughout the forest, and was particularly abundant in clearings and on steeper slopes where the soil becomes thin and rocky. A variety of grasses grew along the shorline, extending inland as far as the high tide line. Descriptions and geographic ranges of most woody species of the region can be found in Alaska Trees and Shrubs (Viereck and Little, 1972).

The watershed is characteristic of southeast Alaska with its steep slopes; shallow, highly permeable soils; and high rainfall. Slopes range from 5% in the valley to about 75% along the side of the ridges. The dense vegetation and thick organic layer effectively protect the soil from surface erosion. Soil drainage is primarily by subsurface flow; high soil permeabilities ensure that little surface flow occurs outside of established channels. Oversteepened slopes, those having a slope angle of greater than 30 degrees, are subject to creep which may contribute to the susceptibility of soil to sliding in critical areas (Swanston, 1974). Also, the watershed is in a zone of seismic activity, and is undergoing tectonic uplift following the last glacial retreat (Swanston, personal communication). Ongoing research which is being conducted by the Forestry Sciences Lab should provide more information on the contribution of mass failure to the sediment load of the drainage network, both under the virgin old-growth timber and following timber harvest.

Stream Characteristics

Trap Bay Creek is fed both by a spring originating in a cave on the eastern end of the watershed, and by a second-order stream draining the southern end of the watershed. Numerous small tributaries flow into these two branches and into the main stream itself. Several of these tributaries flow through muskegs which contribute large amounts of dissolved organic matter and result in discolored water.

Peak flows in the general region occur following the recharge of the soil moisture deficit during the fall rains, and also during early spring due to rain-on-snow events (Schmiege et al., 1974). Streamflow is at its lowest stages during the months of July and August when evapotranspirational demands are highest and precipitation inputs are relatively small. Lag time following precipitation varies with antecedent conditions; the hydrograph begins to rise approximately six hours after the onset of precipitation. Rapid fluctuations in streamflow are probably reduced to some degree by the regulating influence of the spring in the cave and by the muskegs.

In the upper reaches of Trap Bay Creek, channel form is primarily influenced by large organic debris in the channel and streamside vegetation. Pool-riffle sequences are generally a result of stable accumulations of debris against fallen trees which create settling basins and tend to obscure any natural systemic pool-riffle sequences. Large trees and root wads frequently create protected backwater areas that are important as habitat for fry during high flows (Swanson, 1980).

Downstream reaches are not as heavily influenced by the forest, but large organic debris continues to play a significant role in channel form. Streambanks become far less stable and are subject to frequent sloughing during high flows where the protection afforded by tree roots is no longer present. The downstream reaches are also affected by tides which vary from less than 0.3 m (1 ft) to more than 6.1 m (20 ft). The effects of 6.1 m tides extend nearly 1280 m (4200 ft) upstream and, when they occur in combination with high flows, can result in the flotation of otherwise stable debris.

Beaver activity is common along the lower 1890 m (6200 ft) of channel. Numerous piles of debris have been constructed which usually divert flow. A network of trails and slides also occurs along the stream which may contribute to localized areas of bank instability.

During the months of August through November, and especially during the major pink slamon run of late August, the streambed is disturbed by the spawning activities of the fish. Pink salmon redd construction redistributes large amounts of gravel and can change the streambed profile drastically in heavily used areas. Changes in the suspended sediment load during these period may result from this spawning activity.

The longitudinal profile of Trap Bay Creek closely parallels the valley gradient. The lower 1372 m (4500 ft) of stream channel has a relatively steady gradient of 0.25%. Gradient decreases to about 0.18% through a 168 m (550 ft) relatively straight section, and then begins to increase. This increase in gradient begins above the tidal influence zone. Gradient in a reach examined in this study, 1591 m to 1409 m (5218 to 5279 ft) upstream of the stream mouth, increased from 0.41% in 1980 to 0.81% in 1981 (see discussion of channel morphology in Results section).

The streambed is generally composed of small to medium cobbles, gravel and coarse sand, with silt and fine sands increasing in abundance in depositional areas. Gravel bars are numerous and obvious at low flows. Sections of the streambed are armoured by cobbles that range in size from one to several cm in diameter. Sand and gravel underlie and fill the interstices between the cobbles. In one short and relatively straight reach of the stream (1340 to 1522 m from the stream mouth) larger stones and boulders, ranging from 5 to more than 30 cm in diameter, compose part of the bed. They increase in size and number in the upstream direction, reaching a maximum in the vicinity of a USFS stream gage, which is located 1521 m (4990 ft) from the stream mouth.

The primary study site was located between 1590 and 1609 m from the stream mouth, and consisted of two riffles separated by a depositional area. It was selected because it was the only pool-riffle sequence close enough to camp to enable manual transport of equipment and materials, and it was only slightly affected by larger organic debris. There were several trees that had fallen across the stream along the study reach, but all appeared to have been in the same position for several seasons. Only one of these trees, located at the upper riffle, was actually on the streambed; this log was more than half buried in gravel and there was gravel accumulating upstream from it, so it appeared to be stable. The upper riffle was 13.7 m (45.1 ft) wide at bankfull. The lower riffle had a bankfull width of 12.6 m (41.4 ft). The depositional area was approximately 18 m (60 ft) long and 10.7 m (35.0 ft) wide.

A bridge was constructed across each of the riffles so that bedload samples could be obtained without disturbing the bed. Some riparian vegetation was cut down to accommodate construction. Bed materials in the study section were typical of the stream, with an increase in the proportion of sand and silt size particles in the depositional area.

Stream banks averaged 0.76 m (2.5 ft) high through the primary study section, ranging from 0.17 m (0.5 ft) to 1.22 m (4.0 ft). The left[1] bank appeared to be realtively stable due to the presence of the roots of salmonberry, alder, and hemlock. Some undercutting was occurring below the rooting depth of this vegetation. Control Creek, a tributary stream that entered the mainstream just below the foot of the upper bridge, had been dammed by beaver activity prior to 1979 (Hubbard, personal communication). It now joins the mainstream at two additional places: at the foot of the lower bridge, and 30.5 m (100 ft) downstream from the lower bridge. The diversion of Control Creek has

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[1] Left and right designate the side of channel relative to an observer facing in the downstream direction.

resulted in the year-round inundation of the lowland area adjacent to the mainstream and the accelerated erosion of the right bank.

IV. METHODS

Precipitation and Streamflow

Two weighing precipitation gages (Weather-Measure Model No. P511P Remote Recording Snow Gage) were installed on the watershed in the Spring of 1980. One was located in a natural clearing on a southwest facing slope at about 150 m (490 ft) in elevation. The other was located in a meadow, less than 400 m (1300 ft) from the stream, at an elevation of about 15 m (150 ft). Other studies have indicated that there may be signficant differences between precipitation falling on slopes and that received in valleys (Schmiege _et al._, 1974). Mechanical problems with the meadow gage made it impossible to determine if this might be the case at Trap Bay. A continuous record of rainfall during the sampling period was available from the slope gage, except for the rainfall of 24 September 1980, and was used to relate rainfall duration and intensity to storm runoff.

A water-level recording stream gage (Fischer-Porter Series 1540, Model No. 35-D; accuracy ± ½ count) was installed at the head of a chute, 1520 m (4990 ft) from the stream mouth, in July of 1980. This instrument recorded the water level at 15-minute intervals to the nearest 0.3 cm (0.01 ft) on a punch tape. It was set to punch at the same level as the stage indicated by a staff gage that was adjacent to it. Two additional metal staff gages were installed below each bridge to provide supplemental readings. The float-counterweight fell off the recording gage during the period from 11 October - 16 October, and during this time stage was determined from the staff gages.

A series of velocity measurements were made during September and October, 1980, using a Teledyne-Gurley Direct-Reading Current Meter. A regression equation was developed to relate stage to velocity for each of the cross-sections below the bridges. The stage-velocity relationship was then combined with determinations of the cross-sectional areas occupied by water at a given stage and stage-discharge relationships were developed. Regression relationships between stage at the recording gage and the estimated discharge at each of the cross-sections underneath the bridges allowed development of a stage-discharge curve for the entire stream.

Although there were insufficient on-site data available to use any of the commonly employed methods for evaluating the magnitude of storm events, equations have been developed for estimating mean monthly, mean annual, and peak flows of various return periods, based on certain characteristics of the watershed (Water Resources Atlas for Alaska, 1979). These equations are included in Appendix 2.

Channel Morphology

A theodolite survey of the thalweg was conducted during July and August, 1980, from the mouth of the stream (assumed to be sea level at station 0 at low tide mark on 22 July 1980) to 1646 m (6400 ft) upstream. Thalweg elevation, bankfull width, and the distance of the thalweg from the right bank were measured at 15.2 m (50 ft) intervals. Stakes were placed on the right bank to mark the point at which the measurements were taken. The location of large organic debris, gravel bars, and pools were also recorded and referenced to the stakes.

These features were plotted on a USGS topographic map (Sitka (C-4) Quadrangle, scale = 1:31,680).

During August and September, 1980, cross-sectional profiles were taken at an average of one every 45.7 m (150 ft) over the same extent of the stream covered by the theodolite survey, and additional stakes were used to mark their locations. Individual cross-sections were selected to be representative of each reach of channel. Also in August 1980, the depth of the thalweg relative to the water surface, stream width, and the distance of the thalweg from the right bank were measured at 0.6 m (2 ft) intervals along the 18.6 m (61 ft) reach where bedload sampling was conducted. Four cross-sectional profiles were taken within this reach.

The August, 1981, theodolite survey was restricted to a 259 m (850 ft) section of the stream, from 1387 to 1646 m upstream (stations 45 + 50 to 54 + 00 of the first survey). Cross-sectional profiles were also taken wherever stakes from the previous study could be found. The 0.6 m (2 ft) survey of the pool-riffle study reach was repeated. Large organic debris, pools, and gravel bars were remapped for the lower 1646 m of the stream.

Total Suspended Solids and Turbidity

Total suspended solids (TSS) includes inorganic sediments and fine to very fine organic matter (0.5 - 1.0 mm) that is tranported in suspension in the water column. TSS samples were collected during two 28-hr periods that coincided with portions of three storms during Fall, 1980. An automatic pumping sampler (Instrumentation Specialties

Co., Model 1392) was manually activated prior to each expected high flow event to obtain two subsamples at 30-minute intervals that were composited in each of the 28 sample bottles held by the machine. The ISCO sampler intake was located near the end of a chute, located approximately 1341 m (4500 ft) from the mouth of Trap Bay Creek (see Figure 18 for precise location). Samples were filtered through a $4.5 * 10^{-8}$ m glass-fiber filter, oven-dried at 100°C, and analyzed gravimetrically.

An attempt was made to determine turbidity of the TSS samples with a Hach Nephalometer. Unfortunately, a two-hour warm-up period is necessary to stabilize readings on the instrument, and this was not possible because the electrical source was a gas-powered generator. The initial attempts at turbidity analysis without a sufficient warm-up period yielded inconsistent and highly variable results.

Bedload Transport Measurements

Bedload samples were collected from the bridges at the pool-riffle study reach with a hand-held Helley-Smith pressure differential sampler during ten storm events during the fall and early winter of 1980. The sampler had a standard 7.6 cm square aperture but was fitted with a 6000 cm^2 surface area (0.2 mm mesh) collection bag instead of the standard 1950 cm^2 bag. This larger bag has been shown to reduce clogging and, thus, improve sampler efficiency (Johnson et al., 1977; Beschta, 1981).

Bedload sampling methods must account for the lateral variations in transport (Emmett, 1979). A composite sample was thus obtained by taking subsamples at equally spaced positions along each bridge at the two riffles. The upper bridge was marked at ten 0.61 m (2 ft) intervals; the lower bridge was marked at eight 0.46 m (1.5 ft) intervals. Depending on the ambient bedload discharge, the subsampling period ranged from 15 seconds to 1 minute. A sample was collected from a given bridge at intervals of from seven to 20 minutes during peak transport periods, depending upon how rapidly the sampler could be emptied and the water decanted from the samples. I was able to do this more quickly as the season progressed, and if sampling was conducted during the day. Samples were collected at hourly to bihourly intervals during the rising and/or falling limb of the hydrograph when bedload discharge was relatively low. The lower riffle cross-section was sampled immediately after the upper riffle cross-section had been sampled.

Bedload Sample Analysis

Figure 2 illustrates the bedload sample analysis procedure. Oven-dry sample weights were obtained with a Mettler P1210 top-pan balance (1200 g capacity), accurate to ± .01 g). Samples were burned at 320°C for 24 hours to eliminate organic matter and then reweighed. Most of the samples were dried and burned at the Forest Sciences Lab in Juneau; however, about half of them were burned and weighed at the Forestry Research Lab, Oregon State Univeristy, Corvallis. The same procedure and type of scale were used at both locations. The seiving and subsequent weighing were done at the Forestry Research Lab.

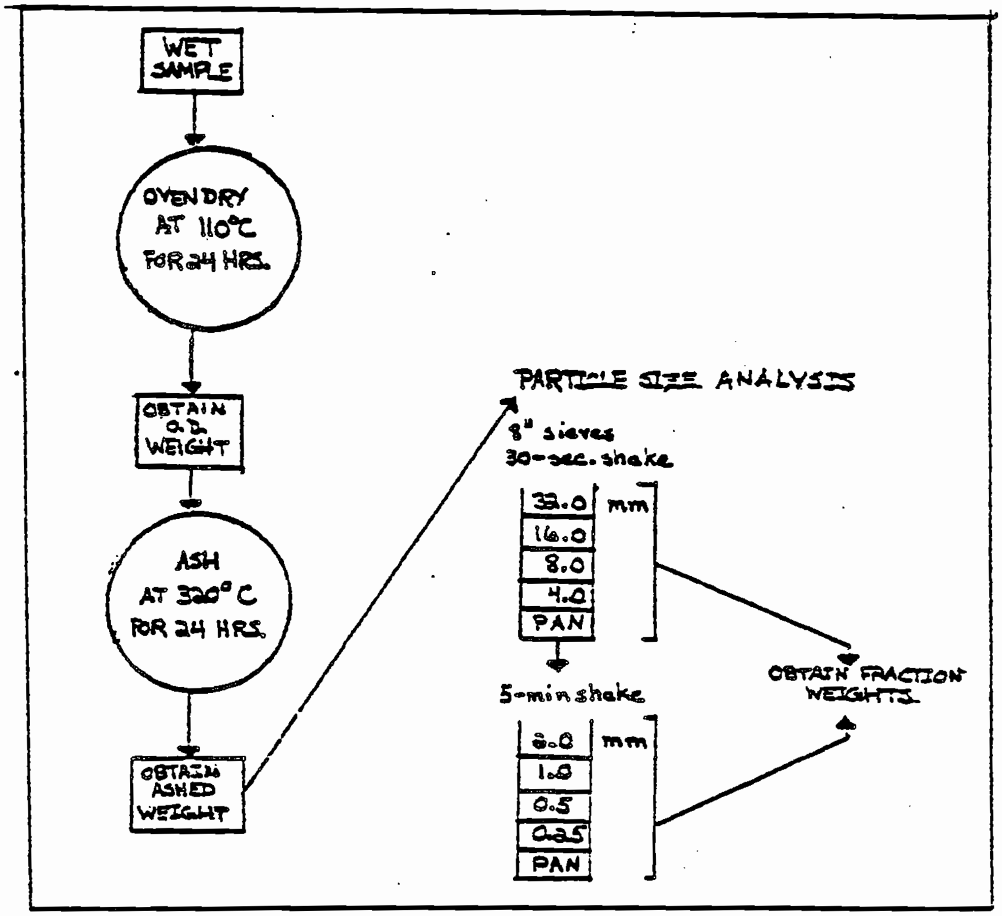

Figure 2. Flow chart illustrating bedload sample analysis procedure.

Calculation of Bedload Discharge

Total bedload discharge in kilograms per hour ($kg \cdot hr^{-1}$) were obtained by dividing the net oven-dry weight of each composite sample by the number of minutes the sampler was in contact with the bottom, multiplying by 60 $min.hr^{-1}$, and dividing by the fraction of the stream bottom covered by the sampler orifice (i.e., 7.6 cm/bottom width). Because of the temporal and spatial variability of bedload transport, the same rate of transport cannot be occurring at all points along the channel bottom at any given time. Therefore, the average of systematic traverses across the channel may be a better indicator of transport rates than individual measurements (Bagnold, 1977). However, this average does not provide an indication of the cross-sectional spatial variability in transport. The subsampling procedure does incorporate points representative of the varying transport rates across the channel and also provides an index to the average transport rate at a given discharge.

Particle size fractions were obtained by seiving (Figure 2) and were plotted as cumulative distributions of grain size diameter in mm versus percent of sample by weight finer than a given diameter. Seive sizes corresponded to the USDA soil-texture classification (Hillel, 1980) and this classification is used throughout this paper. Interpolation from the graphs provided estimates of the distribution characteristics such as D_{50} and D_{90}. D_{50}, the median particle size diameter, has been considered to be the simplest parameter to use in characterizing the effective grain size diameter (Bagnold, 1977). D_{90}, the diameter equalled or exceeded by 10% of the particles in the sample, is an index of the largest particle sizes in transport.

Emmett (1981) considers the Helley-Smith sampler to be 100% efficient for particles larger than 0.25 mm; therefore, the portion of each sample larger than this (medium-to coarse-sand and gravel) can be considered to represent total inorganic bedload in transport. The portion of material larger than 2.00 mm (gravel) excludes any material which might actually be suspended sediment (Edwards, 1979).

Sediment-discharge rating curves were developed using a power function of the form:

$$BLD = aQ^b \tag{4}$$

where, BLD is bedload discharge in $kg \cdot hr^{-1}$

Q is stream water discharge in $m^3 s^{-1} km^{-2}$

and a and b are regression coefficients.

This function was also used to develop relationships for total suspended solids. Beschta (personal communication) has found that this equation appears to relate bedload transport to discharge better than a linear regression equation. Scatter diagrams also indicated that there was a curvilinear relationship between discharge and sediment transport. This equation is similar in form to that given by Graf (1971) which relates sediment discharge to the actual and "critical" water discharge, except that no value of "critical" discharge is assumed. 'Critical' discharge is that necessary to initiate sediment transport (Graf, 1971).

The same type of equation was used to relate coarse particulate organic matter transport (CPOM), D_{50}, and D_{90} to water discharge. Rating curves of this type were developed for all data from all storms for each of these parameters. In order to examine the variability of bedload transport relationships between each of the riffles, between different storm events, and between the rising and falling limbs of the storm hydrographs, additional comparisons were developed using that data collected during the time and/or from the site of interest. All of the regression equations were tested for significance using an F-test for goodness-of-fit at alpha-levels of 0.10 and 0.05, and r^2 values were computed. Regression coefficients were tested for significance using the t-test at alpha-levels of 0.10 and 0.05. This test uses a null hypothesis of 'a' or 'b' = 0. Significance indicates that the coefficient(s) differ from zero (Neter and Wasserman, 1974).

Organic Matter

Both fine particulate organic matter (FPOM), 0 - 1.0 mm, and CPOM, >1.0 mm, which is in transport near the streambed is collected by the Helley-Smith sampler. No analysis of the size of organic particles was made. However, all organic matter is referred to as CPOM because the Helley-Smith is efficient only for particles in the upper range of FPOM.

It was not possible to use a furnace capable of achieving the standard burning temperture of 550°C for the determination of organic matter content (American Public Health Association, 1976). The large volume of the samples made it necessary to use a larger oven, and consequently a temperature of only 320°C, for a period of 24 hours. Some of the organic matter may not be completely eliminated at this temperature (Cummins, personal communication), but some of the weight loss of obtained using the 550°C temperature may be due to the loss of bound water from inorganic matter, particularly clay particles (Adams, 1980). Some bound water may even be lost at the 320°C temperature; however I noted that it frequently appeared that not all organic matter had been completely eliminated. Both Adams (1980) and Beschta (personal communication), however, consider the 320°C temperatrue to be adequate for providing an index to the relative CPOM content of sediment samples. The data presented here, therefore, do not represent absolute amounts of CPOM in transport, but can be considered to represent relative fractions. Work presently being conducted by R.C. Sidle at the Forestry Sciences Lab in Juneau may provide more information on the accuracy of the analytical procedure used for determining CPOM in this study.

Bed Composition

Bed surface particle size-distributions were estimated from random samples of surface particles using a procedure similar to that described by Dunne and Leopold (1978). Two 1 m^2 areas were delineated at each of the bridges and in the depositional area between the bridges. Surface particles were selected by taking a step within the area, reaching down and picking up a particle without looking, and measuring the particle and replacing it. The process was repeated 25 times within each area.

V. RESULTS AND DISCUSSION

Precipitation and Streamflow

Most precipitation during the 1980 study period occurred as long duration, light to moderate rainfall which did not result in an appreciable rise in streamflow. Ten storms occurred during this study period, at which time sediment sampling was conducted; data on precipitation was available for nine of these storms (Figures 3-10). Data limitations make it impossible to characterize storm events as to their relative intensity; there are no precipitation or streamflow records for this area other than those collected during this study. During the early part of the storm season, it was difficult to predict when rainfall would result in significant changes in streamflow and bedload transport. This is reflected in the fact that bedload sampling was conducted during the 23 and 24 September storms, both of which were relatively low magnitude events (c.f. Figures 3-10). Peak flows of greater than 2.0 $m^3 s^{-1}$ were required to produce appreciable bedload movement and it was difficult to determine whether rainfall would result in peak flows of this magnitude.

Peak flows generally had a lag time of about four hours following the onset of precipitation, depending on the rainfall intensity and antecedant conditions. Lag time varied from less than one hour to more than five hours (Figures 3-10). Storm flows had a duration of as much as ten hours and usually lasted more than six hours. This made it difficult for me to continue to collect samples over the entire event. Therefore, I made an attempt to intensively sample the peak of

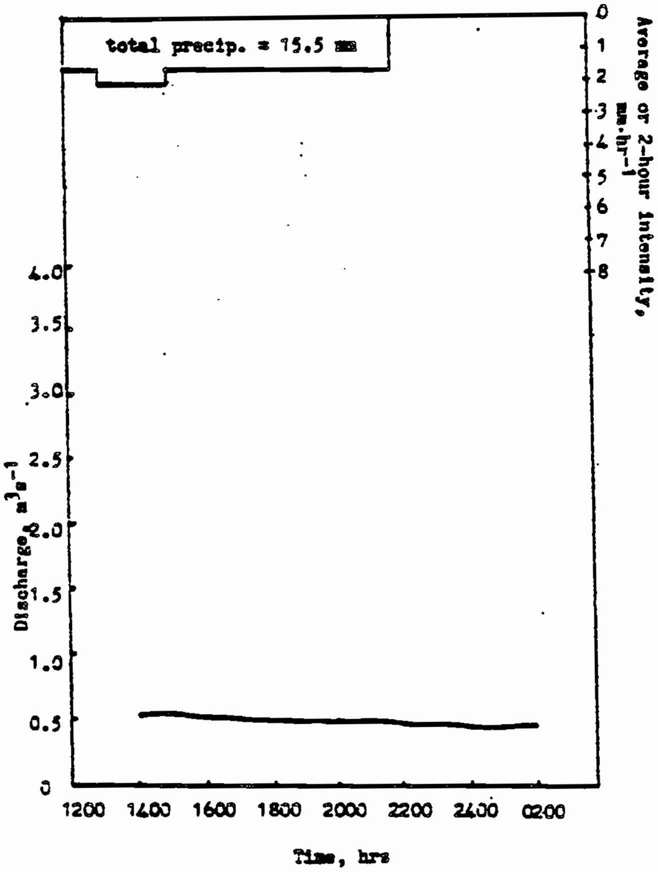

Figure 3. Precipitation intensity and duration and the resultant hydrograph for the 23 September 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

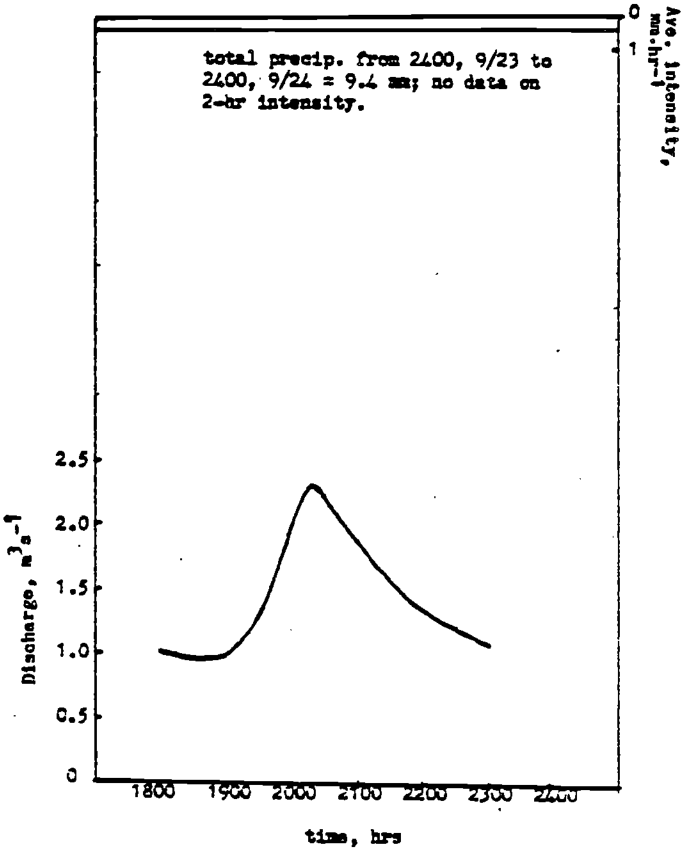

Figure 4. Precipitation intensity and duration and the resultant hydrograph for the 24 September 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

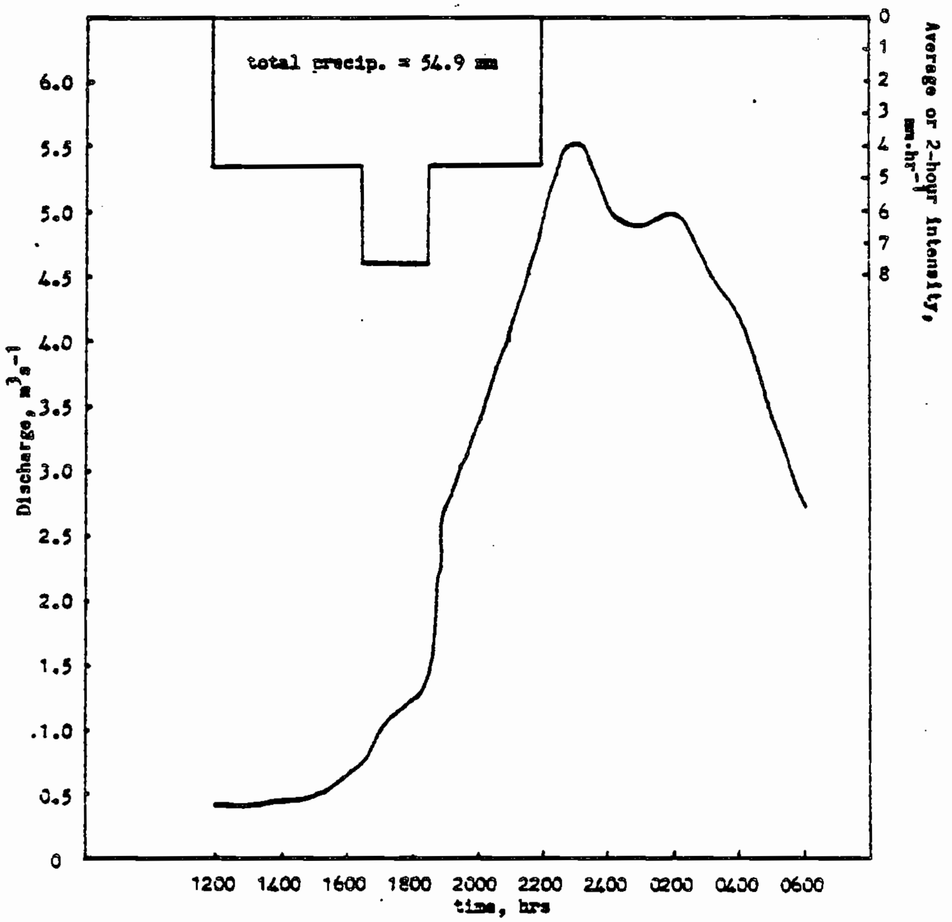

Figure 5. Precipitation intensity and duration and the resultant hydrograph for the 28 September 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

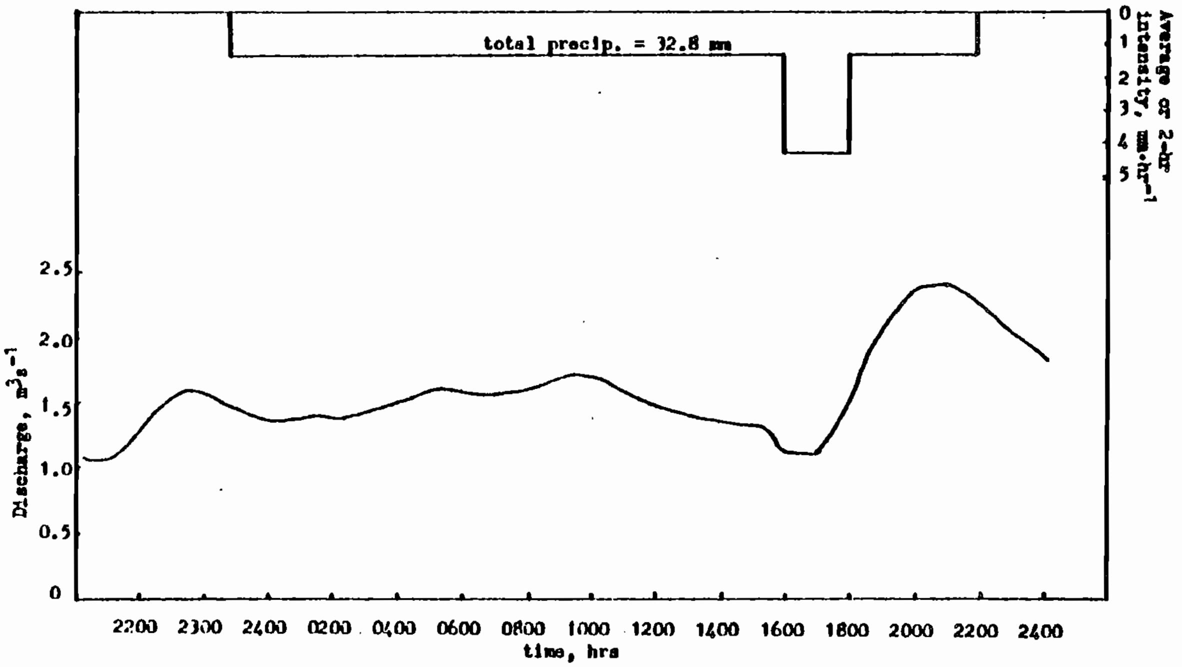

Figure 6. Precipitation intensity and duration and the resultant hydrograph for the Sept. 30 - 1 Oct. 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

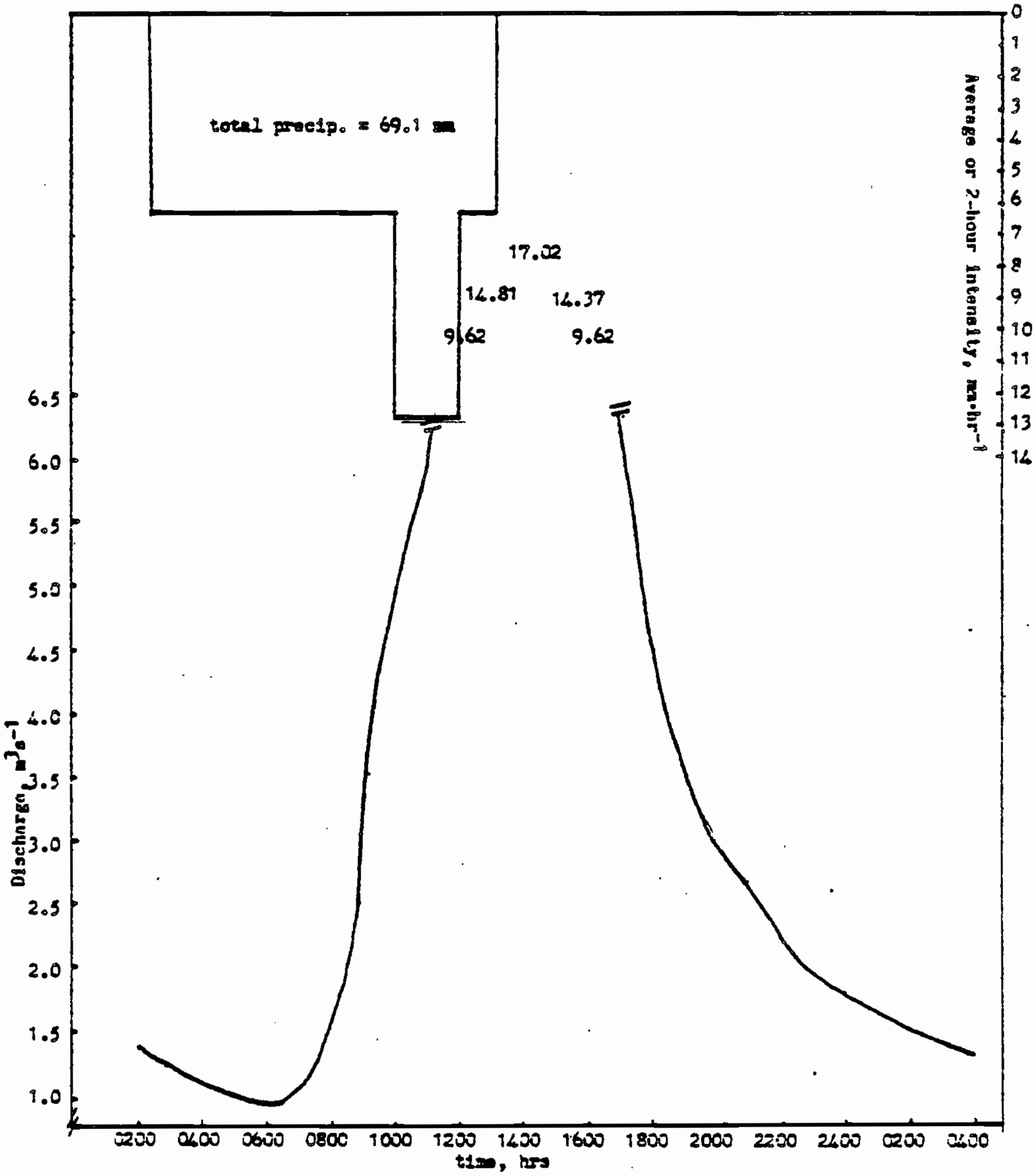

Figure 7. Precipitation intensity and duration and the resultant hydrograph for the 1 October 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

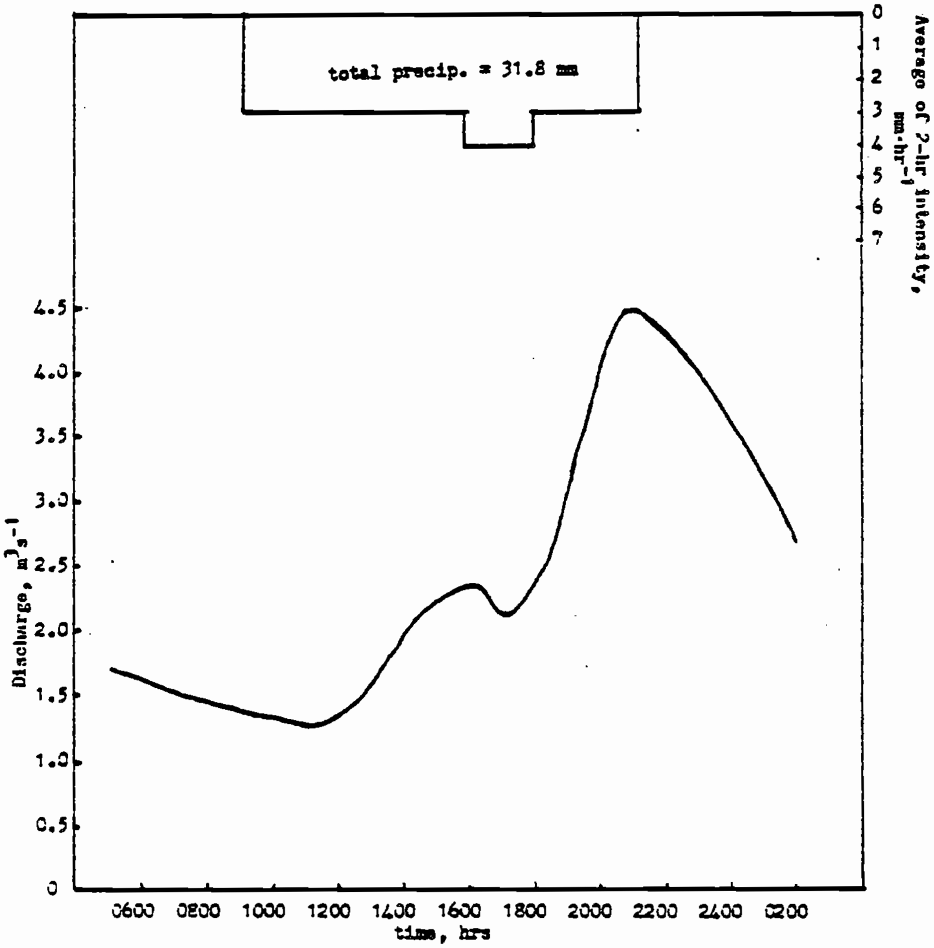

Figure 8. Precipitation intensity and duration and the resultant hydrograph for the 2 October 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

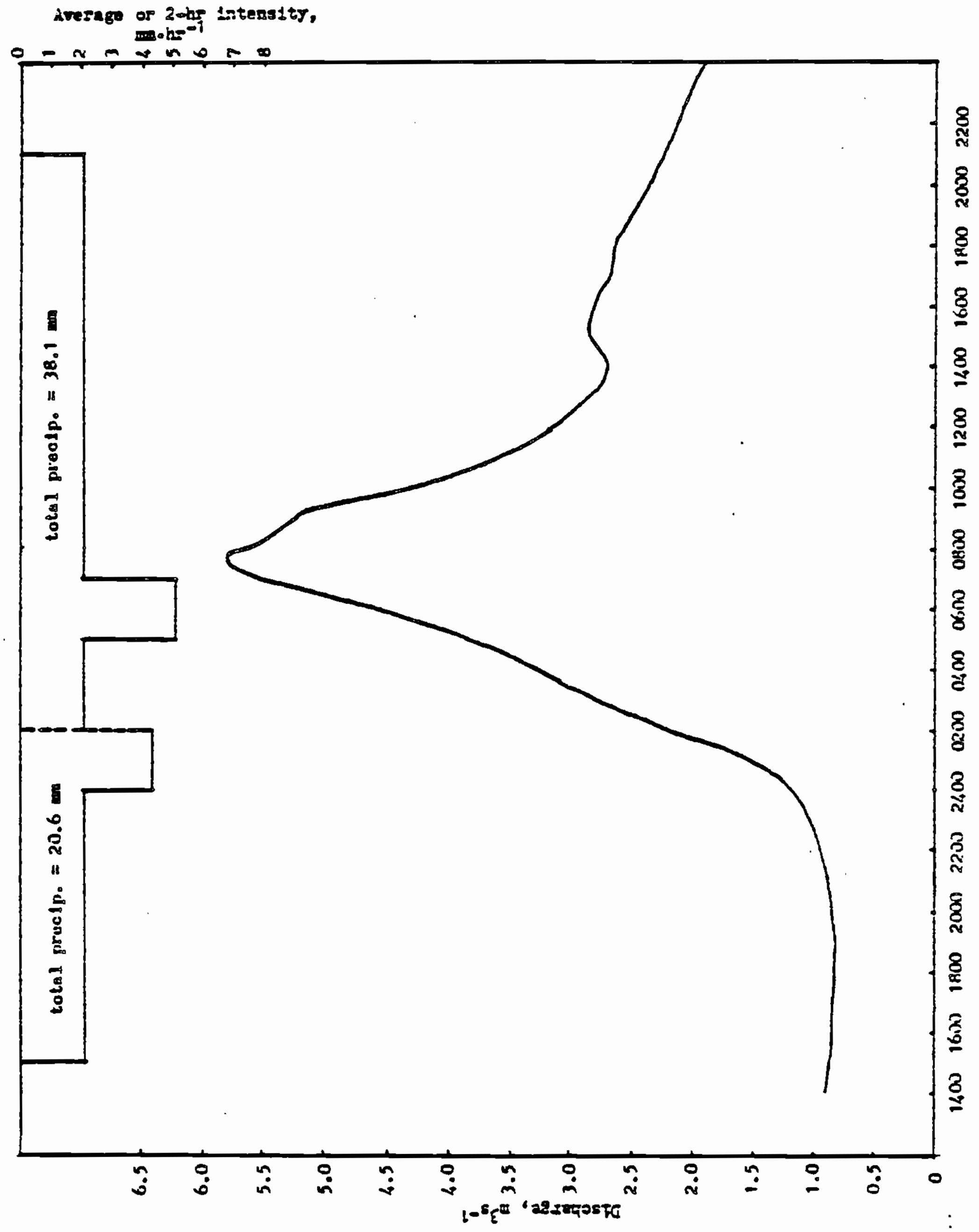

Figure 9. Precipitation intensity and duration and the resultant hydrograph for the 5 October 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

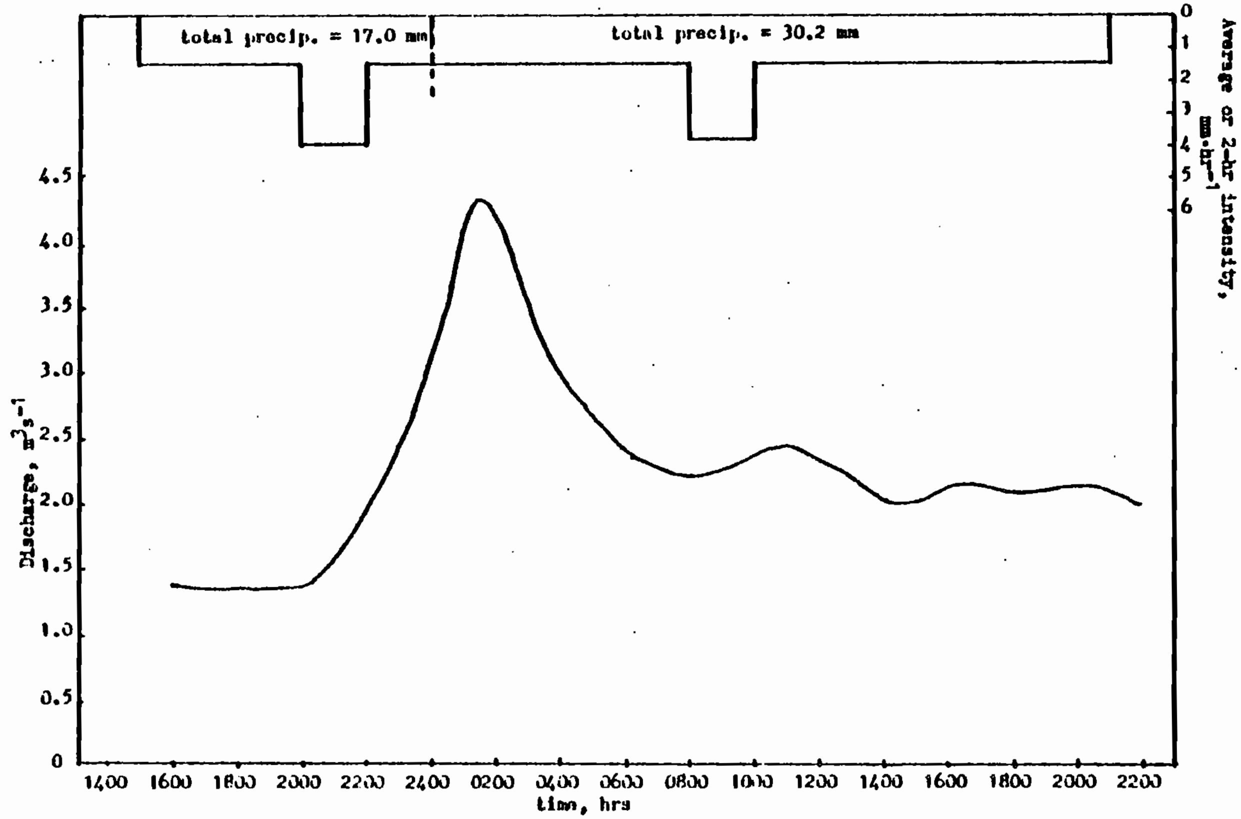

Figure 10. Precipitation intensity and duration and the resultant hydrograph for the 7 October 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

the hydrograph, and to take samples at less frequent intervals on either the rising or falling limb.

Figures 3-10 show the time of duration, average intensity and 2-hour maximum intensity of precipitation, and the resultant hydrographs for the nine storms during which bedload was sampled. Data were incomplete for the event of 24 September, and there were no data available on rainfall for the 16 and 18 October events. The figures show that the peak of the hydrograph generally occurs at two to four hours after the period of most intense rainfall. Also, because most rainfall is of light to moderate intensity, the hydrograph often begins to recede while it is still raining.

The great point-to-point variation in precipitation that characterizes this region makes it impossible to compare or relate rainfall received in one area to that received at a nearby location. Inghram (1979) attempted to fill in missing precipitation data for the Kadashan drainage area, which is west of Trap Bay, using regression relationships developed from the relatively complete records of the Kadashan base station and Tenakee Springs. He found that the method was unsatisfactory because of the resulting low r^2 values, the variability in the number of days per month for which there was precipitation data, and the general unreliability of the data. Inghram also found that precipitation and discharge comparisons were unsuccessful. He felt that there are too many factors involved on a watershed to draw a useful correlation between precipitation and streamflow.

The Water Resources Atlas for Alaska (1979) lists equations that can be used to estimate streamflow based on selected watershed characteristics. These equations were used to estimate expected streamflow for various return periods and average monthly flows for August through November (Appendix II). All events except the 1 October storm appear to have had return periods of less than two years, based on these equations, whereas the 1 October event had a return period of between two and five years (Table 3).

The stream gage operated continuously for the entire month of September. Mechanical problems resulted in incomplete records for the other months. The estimated mean monthly discharge for September from the equations of the Water Resource Atlas is 1.26 m^3s^{-1} (44.4 cfs). Actual mean monthly discharge was 0.57 m^3s^{-1} (20.3 cfs). However, it is not possible to determine whether September, 1980, was relatively dry, or whether the estimate is too high.

More data on both streamflow and precipitation are needed before the relative magnitude of flow events can be determined. The 1 October event was produced by only moderately heavy rainfall (Figure 12), yet discharge exceeded that of all other events by an order of magnitude. The flooding and channel changes accompanying this storm were much greater than those of any of the other events.

Streamflow at each of the sampling sites was related to the streamgage readings by regression of the staff gage readings (one was located downstream from each of the bridges) against the readings of the streamgage. Assuming that there was no change in the volume of water being discharged between the study reach and adjacent to the streamgage, the area occupied by water at a given stage was determined at each of the riffles and related to the stage readings at the

TABLE 3. Measured peak flows and estimated recurrence intervals for Fall, 1980, storms, Trap Bay Creek, Chichagof Island, Alaska

Date	Discharge $m^3s^{-1}km^{-2}$	 ft^3s^{-1}	Estimated recurrence interval[1], years
23 September	0.046	21.9	<2
23 September	0.147	70.6	<2
28 September	0.417	199.5	<2
30 Sept. - 1 Oct.	0.170	81.2	<2
1 October	1.254	600.4	2-5
2 October	0.330	158.2	<2
5 October	0.424	203.1	<2
7 October	0.139	66.4	<2
16 October	0.664	317.8	<2
18 October	0.167	79.8	<2

478.8

$1\ m^3$

streamgage. The resulting rating curve used to relate the recorded stage to volumetric discharge is illustrated in Figure 11.

Bed Composition

The streambed of Trap Bay Creek consists of particles derived from igneous bedrock and ablation till. Past glaciation has accelerated the breakdown of the relatively resistant bedrock, thus increasing the proportion of bed material in smaller size classes. There is a wide range of particle sizes, the larger of which may exceed 10 cm in diameter. Larger particles are usually angular but those derived from glacial deposits are often somewhat rounded. Much of the surficial material is made up of small to medium-sized particles which range from less than one to several cm in diameter. This non-cohesive material is underlain by alluvium and ablation till, both of which may contain large amounts of colloidal-sized particles and silt.

Results of surface-particle size distribution sampling are presented in Table 4 and Figure 12. There does not appear to be a significant difference between the riffles and the pool except that the median particle size in the pool and lower riffle was slightly larger than that in the upper riffle, with that of the lower riffle being the largest. Time of sampling must be considered in interpreting these results. Sampling was conducted in late August; the armor layer could have been well-developed over the whole reach. Differences in bed composition may not have been evident in surface material because of the churning of the gravels by pink salmon, although this reach is not

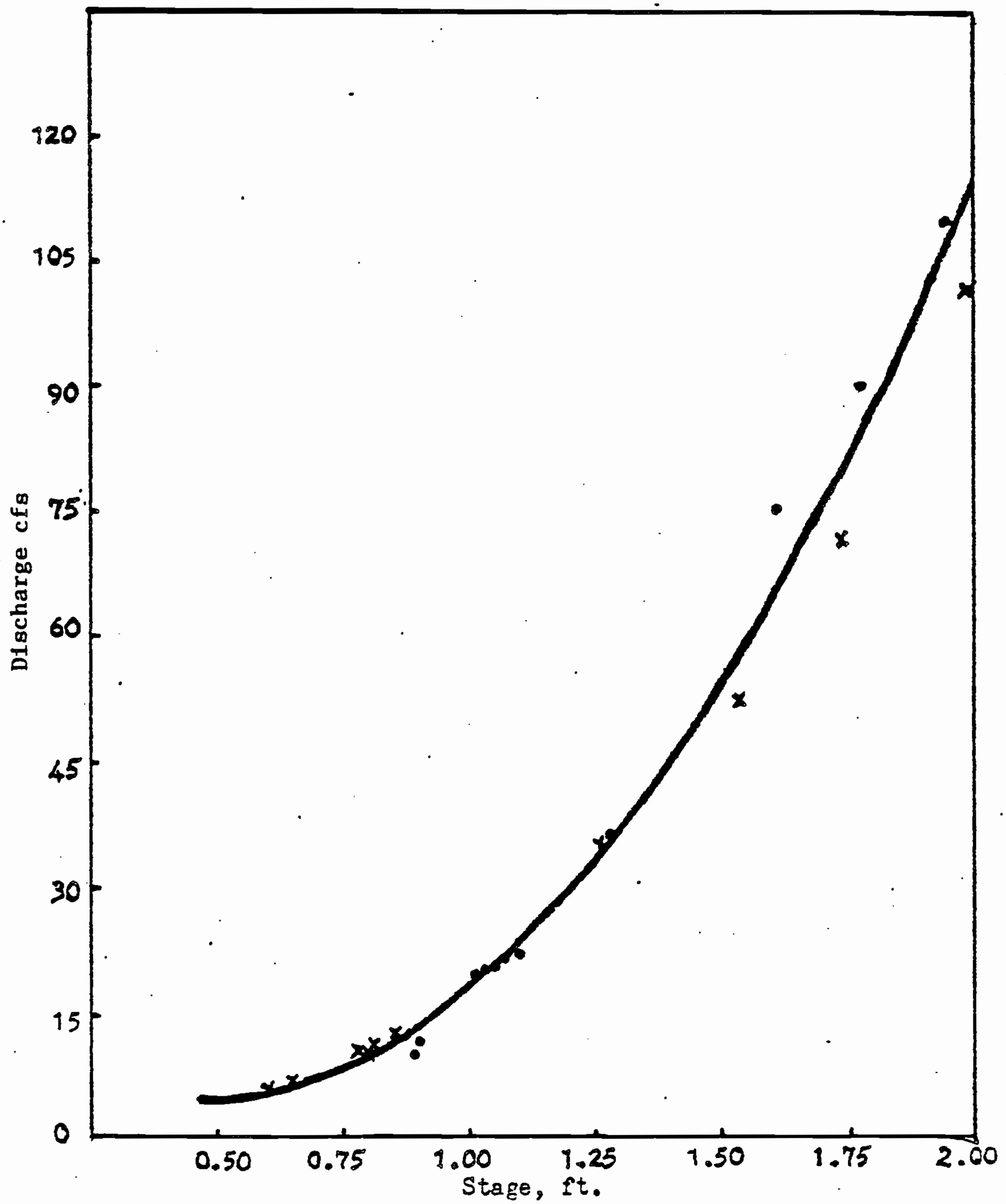

Figure 11. Stage-discharge[1] rating curve for Trap Bay Creek, Chicagof Island, Alaska

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[1] To convert from feet to meters, multiply by 0.3048, to convert from cfs to m^3s^{-1} multiply by 0.028.

heavily used by fish. It is evident, however, that the largest percentage of surface particles (about 50%) is composed of coarse sand, with most of the remainder (about 45%) being gravel.

Channel Morphology

The thalweg survey was only repeated for a 259 m (850 ft) section of channel in 1981; both the 1980 and 1981 surveys were conducted in mid-August. Results are presented in Figures 13 and 14. Overall channel gradient in 1980 was 0.25%. Gradient decreased from 0.24% in the resurveyed section to 0.17% from 1980 to 1981, while stream width remained about the same. The resurvey of the pool-riffle study reach, where measurements were made at 0.61 m (2 ft) intervals, showed that no major changes in bankfull width had occurred from 1980 to 1981 (Figure 14). However, gradient in this section nearly doubled, going from 0.41% to 0.81%, as a result of aggradation at the upstream end and degradation at the downstream end.

The greatest changes in thalweg elevation and location took place upstream from a chute (Figure 13), except for some aggradation and a shift of the thalweg towards the right (looking upstream) near the lower end of the chute (Station 45 + 00). This chute appears to be relatively stable, probably because of the material which underlies it. Boulder-sized material becomes apparent at about 122 m (400 ft) from the upstream end of the chute, and increases in size and abundance in the upstream direction. The tidal influence zone reaches as far up as the chute, but does not appear to reach the stream gage. The lack of extreme fluctuations due to tides may contribute to

TABLE 4. Size Distributions of Particles Selected at Random From the Armor Layer of the Study Reach, Trap Bay Creek, Chicagof Island, Alaska

Class Size cm	no. of particles in class	% of total	cummulative % finer	D_{50}	D_5	D_{95}
			lower riffle			
0.25	1	2	0			
0.25	3	6	2			
0.50	11	22	8			
1.00	6	12	30	2.43	0.44	4.30
2.00	24	48	42			
4.00	5	10	90			
			upper riffle			
0.25	1	2	0			
0.25	3	6	2			
0.50	10	20	8			
1.00	17	34	28	1.66	0.44	4.40
2.00	15	30	62			
4.00	4	8	92			
			pool			
0.25	2	4	0			
0.25	1	2	4			
0.50	12	24	6			
1.00	10	20	30	2.00	0.39	4.80
2.00	17	34	50			
4.00	8	16	84			

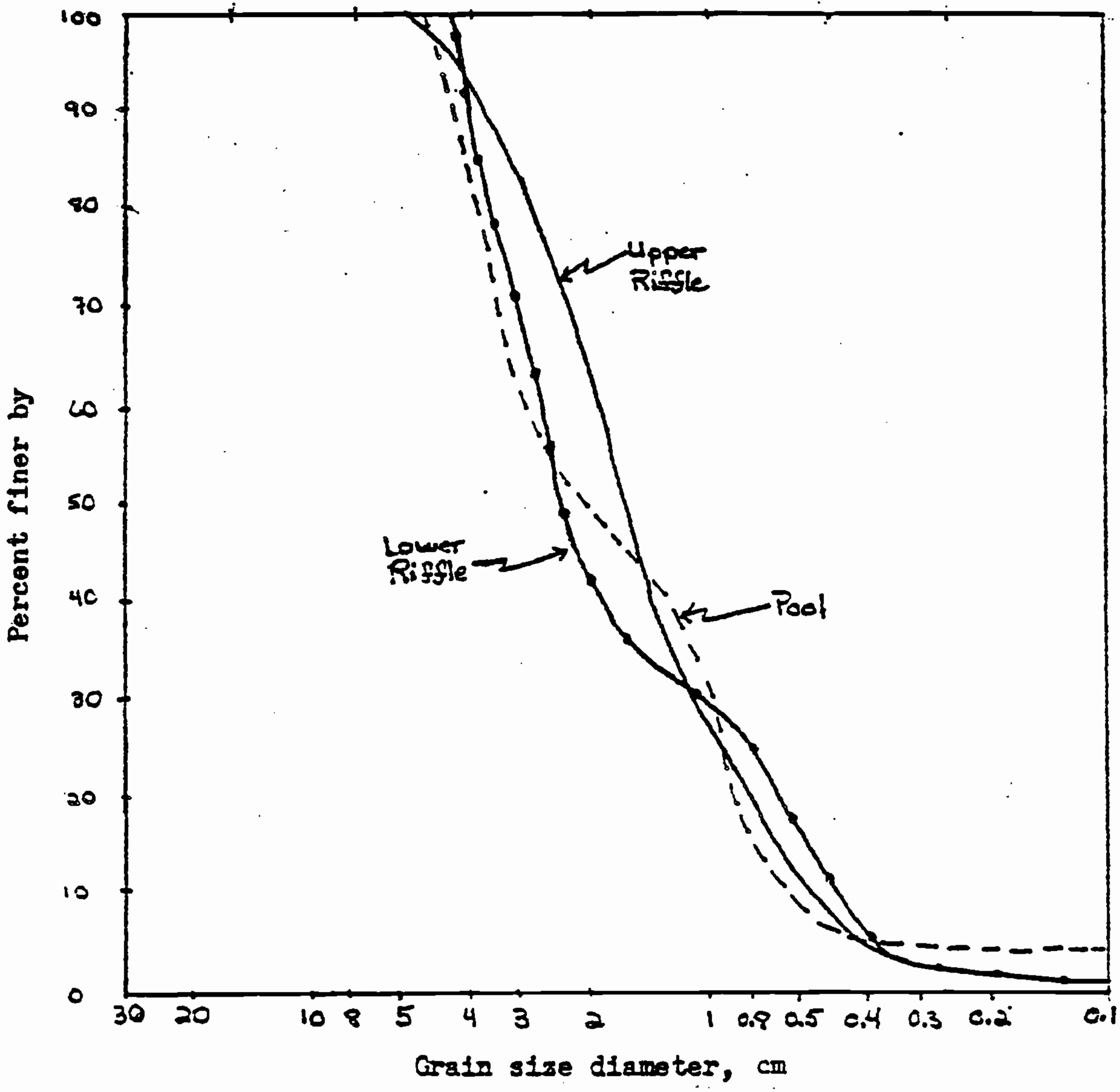
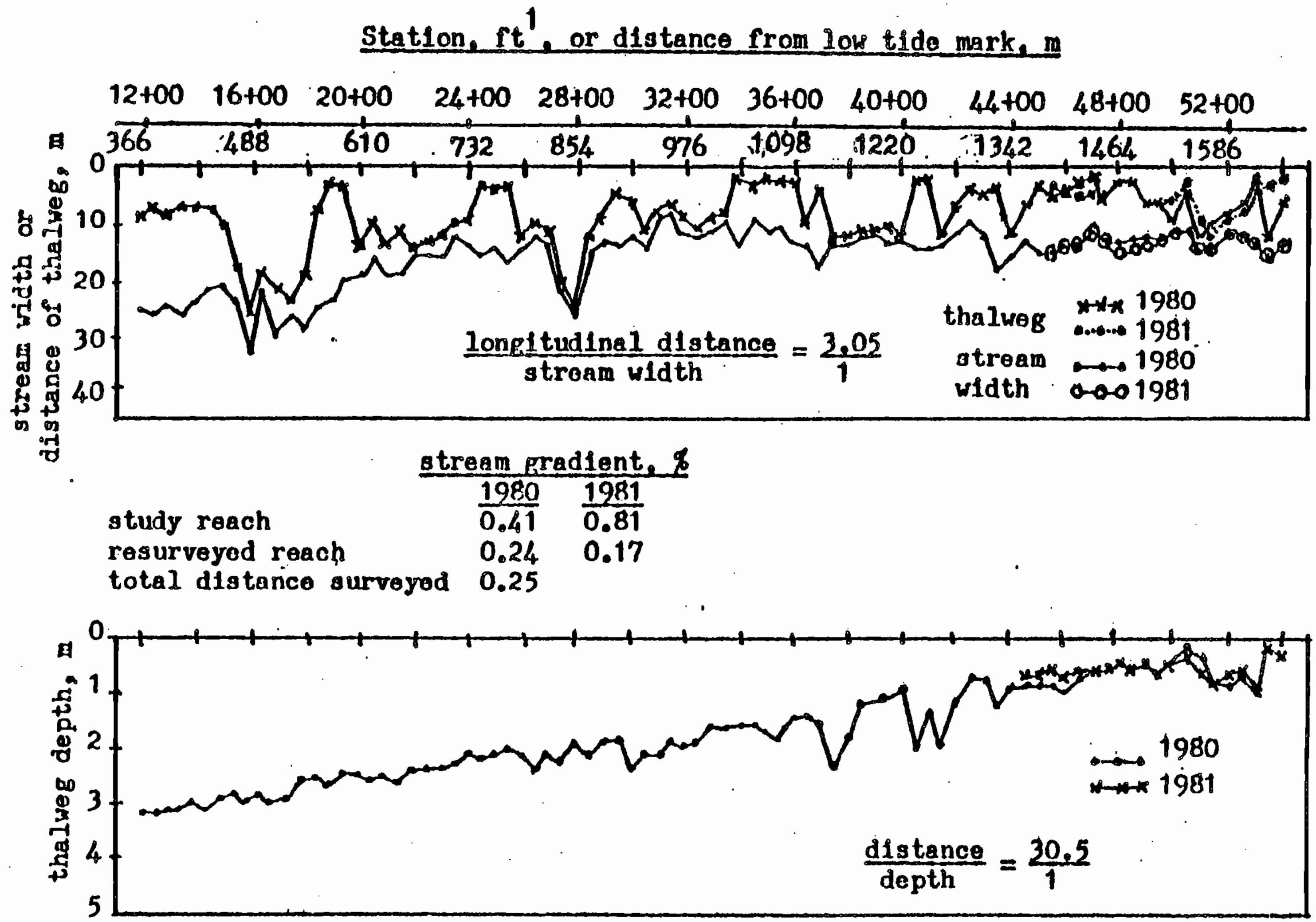


Figure 12. Size distribution curves developed from random samples of surface particles in the study reach, Trap Bay Creek, Chichagof Island, Alaska



	stream gradient, %	
	1980	1981
study reach	0.41	0.81
resurveyed reach	0.24	0.17
total distance surveyed	0.25	

Figure 13. Stream width and distance of thalweg from left bank, (upper graph) and thalweg depth[2] of Trap Bay Creek, Chichagof Island, Alaska

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[1] See text for explanation of station establishment.

[2] Arbitrary zero is based on location of low tide mark, 22 July 1980 (see text).

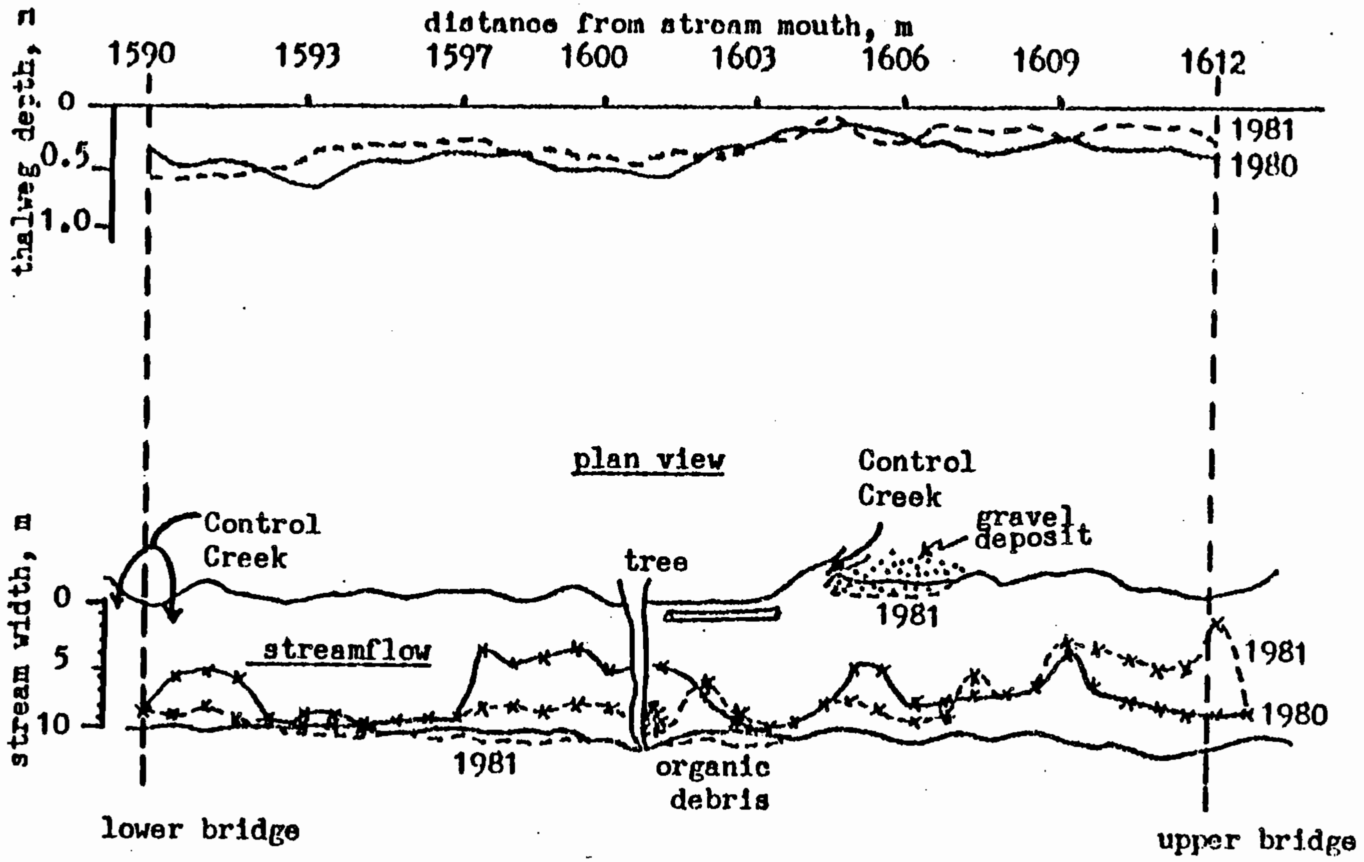


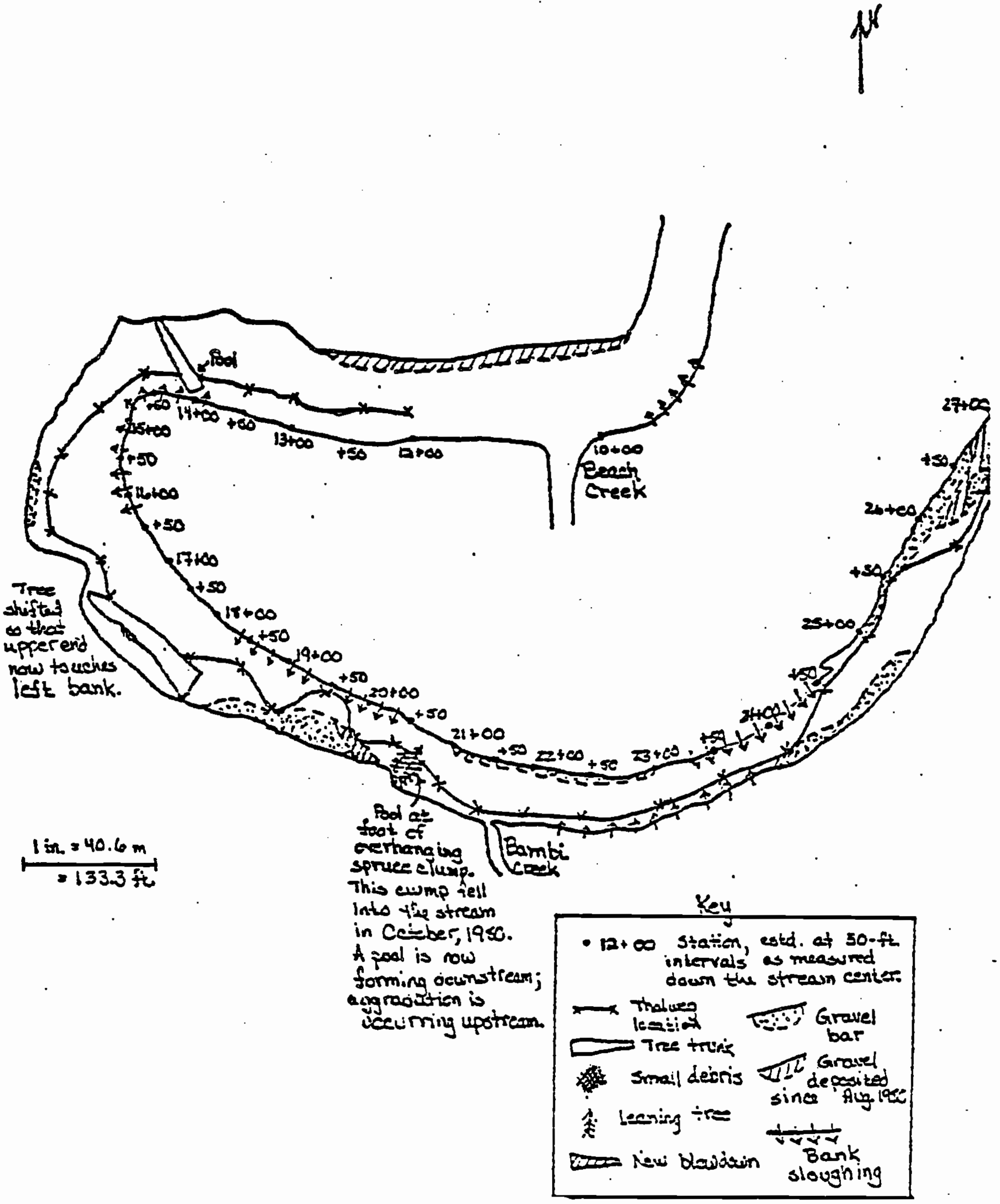
Figure 14. Thalweg profile and planimetric map of the poof-riffle study reach along Trap Bay Creek, Chicagof Island, Alaska (surveyed in September 1980, and August 1981)

stability of the chute.

The map of stream features (Figures 15-18) shows that the chute is less subject to bank sloughing and inputs of large organic debris than are upstream or downstream reaches. This may be both a cause and a result of its relative stability. Cross-sectional profiles taken in this reach (not shown) indicate little net change had taken place from 1980 to 1981. Very few salmon spawn in this reach. This may be because of the difference in streambed material composition, but it may also be due to lack of cover in the form of undercut banks and large organic debris (Hubbardt, Alaska Dept. of Fish and Game, personal communication).

The lower reaches of the channel are subject to a great deal of morphometric change. Bank-sloughing, tree-tipping, and shifting of gravels were widespread within the tidal influence zone (Figures 15-17). The meander just above the mouth of the channel has shifted from west to east several times in the past based on an analysis of aerial photographs, and is actively cutting its banks. This section of channel has also been subjected to much human activity: trampling of the banks, removal of large organic debris, and construction of two fish weirs. The first weir was constructed in 1979 and was destroyed by high flows before it was completed. The second weir was constructed in July of 1980. Some of the changes in this section of the channel are probably due directly to human activity.

The resurvey of the pool-riffle study reach showed that the thalweg elevation has increased and the channel has widened downstream from the upper riffle (Figure 14). Downstream from Station 52 + 62,



Tree shifted so that upper end now touches left bank.

Pool at foot of overhanging spruce clump. This clump fell into the stream in October, 1980. A pool is now forming downstream; aggradation is occurring upstream.

Figure 15. Planimetric map of the lowest 923 m (2700 ft) of Trap Bay Creek showing changes from August 1980 to August 1981

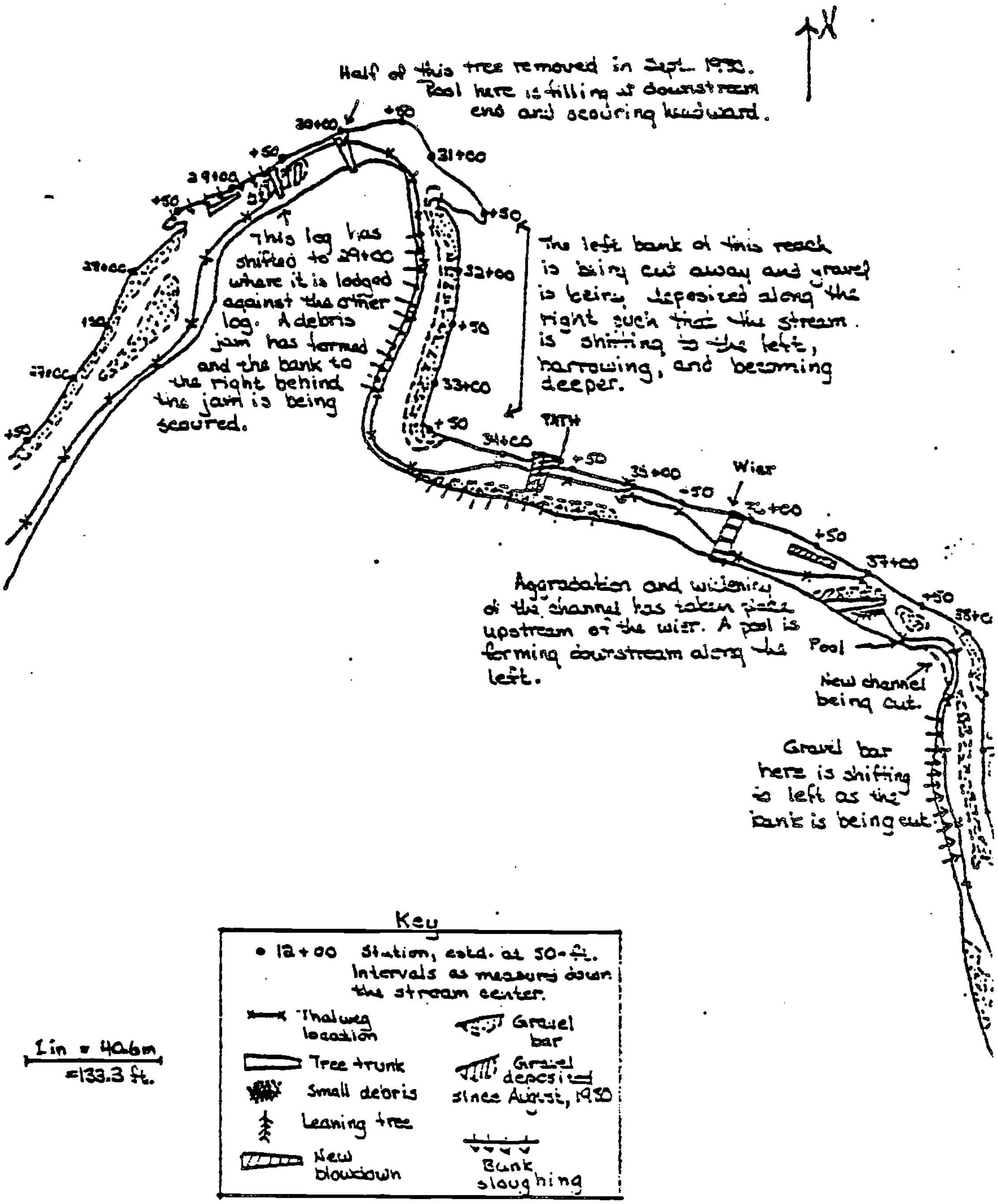


Figure 16. Planimetric map of Trap Bay Creek from 823 m (2700 ft) from stream mouth to 1219 m (4000 ft) from stream mouth showing changes from August 1980 to August 1981

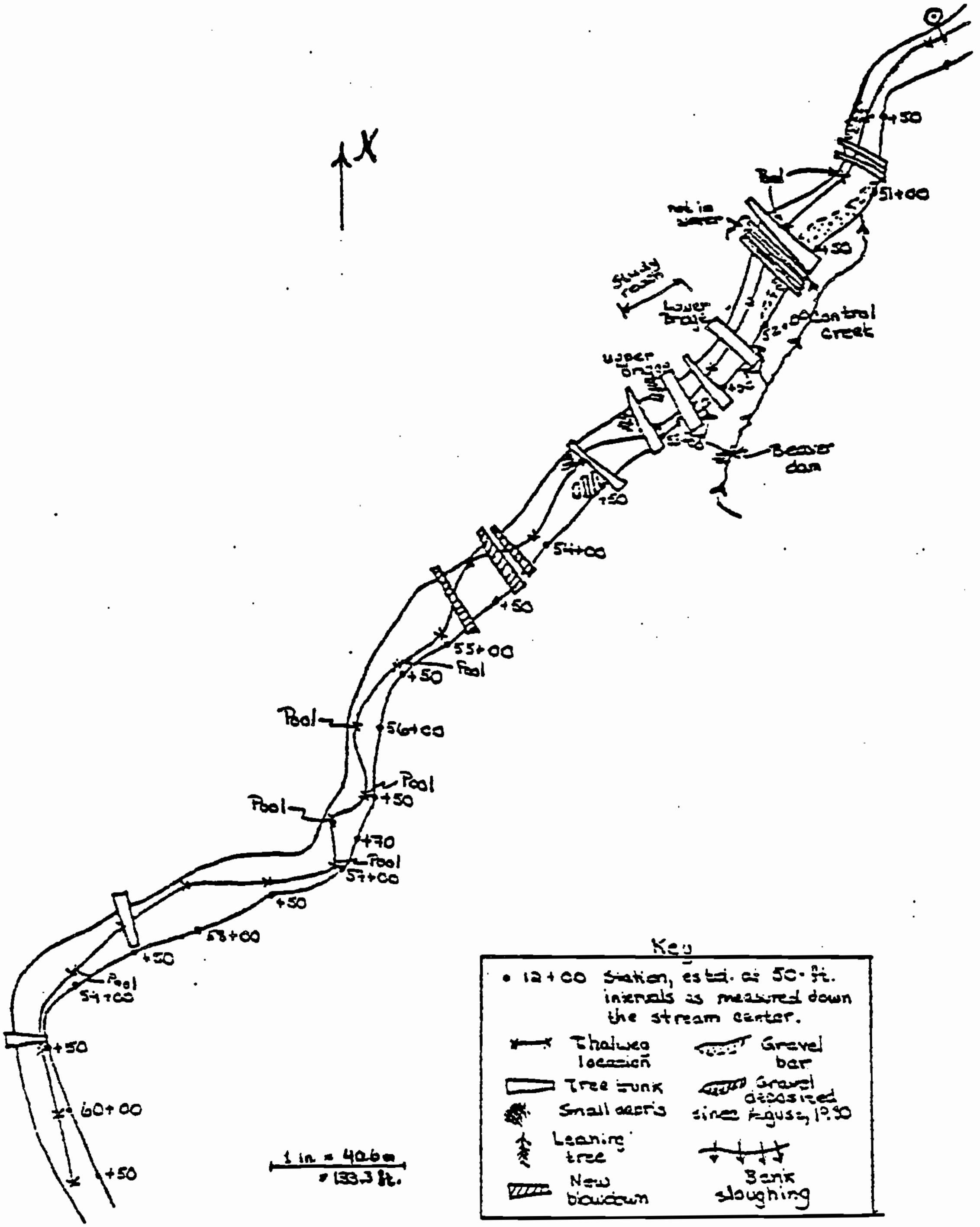


Figure 17. Planimetric map of Trap Bay Creek from 1539 m (5050 ft) from stream mouth to 1844 m (6050 ft) from stream mouth showing changes from August 1980 to August 1981

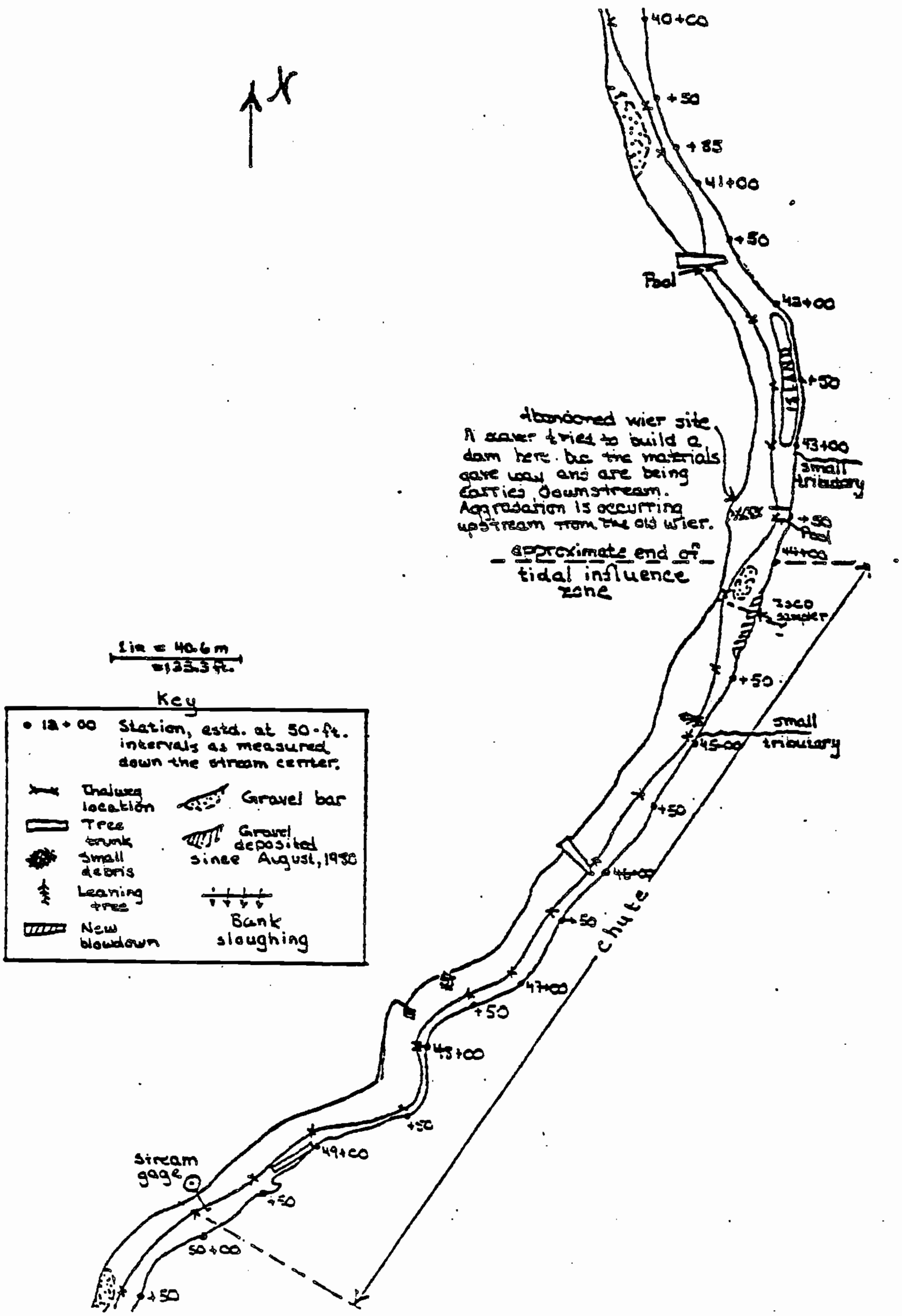


Figure 18. Planimetric map of Trap Bay Creek from 1219 m from stream mouth to 1539 m (5050 ft) from stream mouth showing changes from August 1980 to August 1981

the true left ("true left" is relative to an observer looking downstream) bank is being undercut and the thalweg has shifted towards this bank. Little change in thalweg location occurred in the upper riffle. Deposition has occurred in the lower section of the pool between the riffles. Scouring occurred in another pool located 30.5 m (100 ft) downstream from the pool-riffle study reach and the thalweg elevation decreased by nearly 0.3 m (1 ft).

Upstream from Station 52 + 68 for about 6.1 m (20 ft), the thalweg has tended to shift towards the middle of the stream (Figure 14). Gravels have begun to accumulate at what was the major outlet of Control Creek and debris has accumulated at the true left ends of the two fallen trees near the upper bridge (Figure 18). The debris tends to channel flow into the middle of the stream while the buildup of gravel at the foot of the upper bridge tends to channel it back towards the true left bank.

The cross-sectional profiles taken in the primary study reach (Figure 14) show that, although there has been an increase in the thalweg elevation, there has actually been net scour (see also Table 8). Although more material was transported out of this reach than was transported into it, there was a tendency for the maximum depth of the channel to increase because the channel bottom became more even.

The survey of 1980 included 1951 m (6400 ft) of channel. The gradient of the channel from Station 53 + 00 to Station 64 + 00 was approximately 0.80%. There was much more large organic debris in the upper portions of the channel (Figure 18) and it was difficult to find any pool-riffle sequences which were not a result of the pressure of large organics. Much of the organic material in the stream above the study reach was tree-sized and relatively stable. Smaller debris can be trapped against fallen trees and debris build-ups resulted in localized scouring and deposition in many locations.

Large organics are a dominant influence on channel morphology. Tree-sized material appears to generally remain where it falls for relatively long periods of time, except in the extreme lower reaches of the channel. Localized scour and deposition take place where there are build-ups of debris, disrupting any natural pool-riffle sequences in the upper reaches. Trees in the channel do not appear to block fish passage but, instead, serve as cover for spawning adults. Both large organics and undercut banks are important as cover for juvenile salmon (Swanson, 1980).

Width-depth rations were computed for all of the cross-sections which were resurveyed in 1981 (Table 5). In general, the ratios increased from 1980 to 1981, indicating that the channel is widening and/or becoming more shallow. The average stream width increased from 13.0 to 13.9 m (42.6 to 45.6 ft) and the average depth decreased from 0.91 to 0.82 m (2.99 to 2.69 ft) from 1980 to 1981 over the 914 m (3000 ft) section in which cross-sections were measured. Thus, both widening and aggradation appear to be occurring. The width and depth of cross-sections within the chute remained relatively constant from 1980 to 1981, however, again indicating that it is relatively stable.

The morphological changes that took place in Trap Bay Creek from 1980 to 1981 indicate that it is an active channel undergoing aggradation and widening. Lithology is one factor determining the morphology

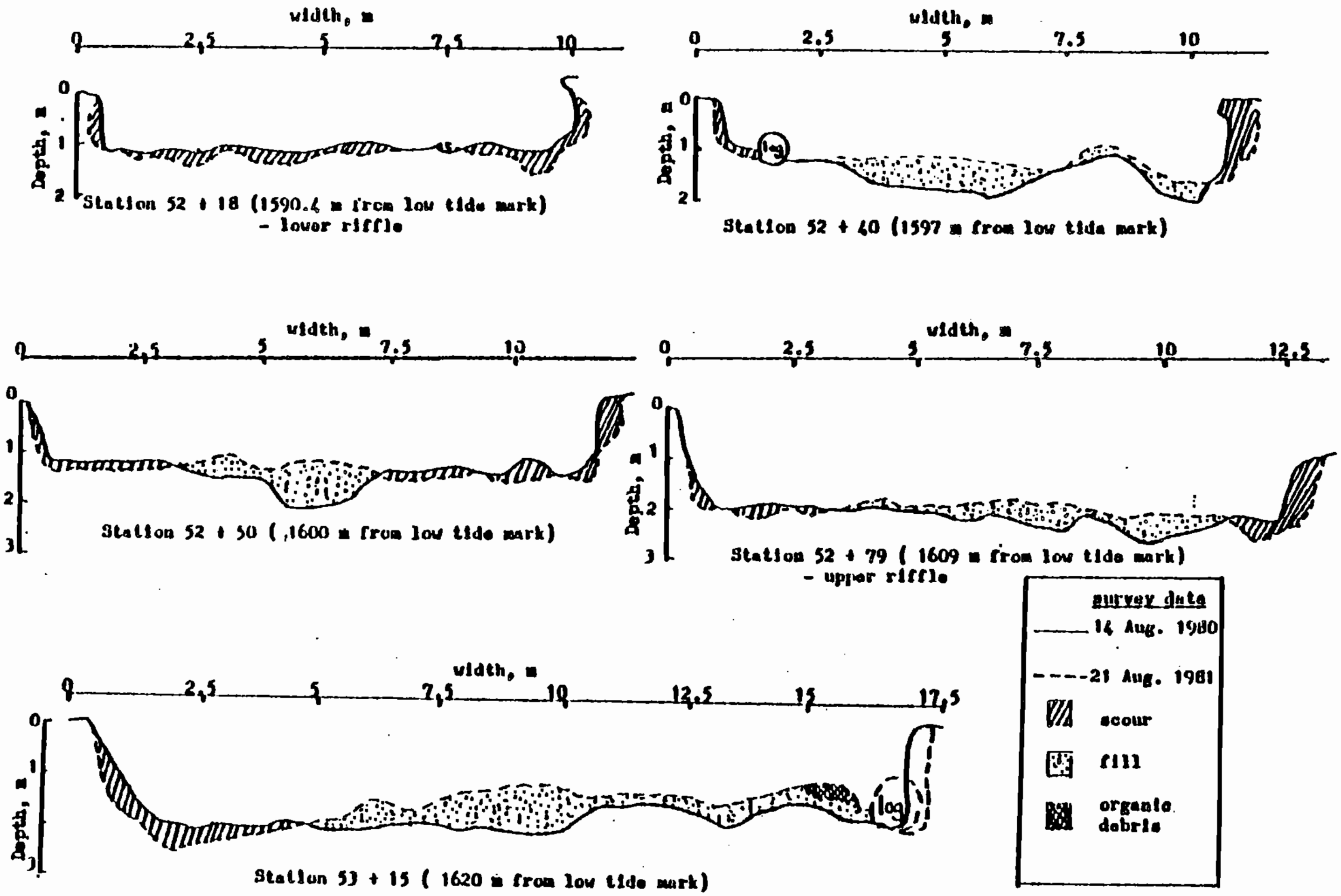


Figure 19. Net channel changes from 14 August 1980 to 21 August 1981 within the pool-riffle study reach of Trap Bay Creek, Chichiagof Island, Alaska

TABLE 5. Width-depth Ratios for Selected Stations[1] in 1980 and 1981, Trap Bay Creek, Chichagof Island, Alaska

Station	1980			1981		
	Width, m	Depth, m	W/D Ratio	Width, m	Depth, m	W/D Ratio
54 + 00 (1645m)	13.5	0.79	17.0	13.6	0.68	19.8
53 + 15	17.2	0.97	17.6	17.7	0.79	22.3
52 + 79	12.8	1.13	11.4	13.4	0.91	14.7
52 + 50	11.1	0.84	13.3	11.7	0.82	14.0
52 + 40	10.2	0.76	13.4	10.9	0.52	21.1
52 + 18	9.9	0.53	18.6	10.7	0.61	17.5
52 + 00	10.4	0.58	18.0	11.8	0.46	25.8
51 + 00	13.7	0.84	16.4	13.7	0.55	25.0
50 + 00	9.8	0.87	11.2	11.3	0.76	14.8
49 + 40	12.5	0.93	13.4	12.5	0.85	14.6
48 + 00	13.7	0.69	20.0	14.0	.049	28.8
46 + 05	14.0	0.84	16.7	13.9	0.84	16.6
44 + 90	14.1	0.76	18.4	14.1	.076	18.4
43 + 50	16.5	0.37	45.0	16.5	0.37	45.0
42 + 00	12.5	0.70	17.9	12.5	0.52	24.2
37 + 50	14.5	0.99	14.6	15.3	1.68	9.1
35 + 00	10.5	0.99	10.6	11.6	0.88	13.1
34 + 00	11.8	0.70	16.8	12.1	0.76	15.9
~~27 + 50~~ (838)	~~18.9~~	~~0.23~~	~~82.7~~	~~24.1~~	~~0.15~~	~~158.0~~
24 + 00 (731m)	13.4	0.41	32.6	15.8	0.38	41.6
average	13.0	0.91		13.9	0.82	
	12.74	0.77	16.5	13.32	0.72	19.5

[1] Stations decrease in value in the downstream direction; see text (pp. 43-44) for explanation of station establishment.

excluded data from 27+50

17.5 [illegible]

[illegible]

T [illegible] = -3.334

t crit = [illegible] 4 df

of Trap Bay Creek as is indicated by the presence of the relatively stable chute. The tides are important in the lower reaches of the channel, especially where there are few trees lining the streambanks. Channel gradient appears to be a function of both lithology and the tidal influence zone.

Large organic material, especially fallen trees, interact with streamflow and sediment transport in determining channel morphology above the tidal influence zone. Smaller organics (branches, twigs, bark, and leaves) are also important in that they can lodge against fallen trees and gravel deposits, causing local deflection of flow. Organic material is also important in providing cover for salmonids.

Total Suspended Solids

Problems involved in processing the total suspended solids (TSS) samples precluded a fully accurate analysis of suspended sediment transport in Trap Bay Creek. Electricity to power the filtering apparatus was not always available, so the entire set of samples usually had to be transported to the FSL in Juneau. Here, additional problems arose because the filter discs being used were not consistent in weight and preweighing in the field was impossible. Trap Bay Creek has a relatively low suspended solids concentration even at peak flows. Filter disc weights varied by as much as a gram, which is three orders of magnitude greater than the total mass of most of the samples. Preweighing of filter discs in the lab before transport to the field gave reasonable accuracy, but was time-consuming and dependant on a lack of mix-ups when the filter discs were used. Data for two sets of samples covering portions of three storm events were considered reliable enough for interpretive use.

The data presented in Table 6 show that TSS concentrations ranged from 0 to 86 $mg \cdot l^{-1}$ during flows ranging from 0.05 to 1.26 cubic meters per second per square kilometer ($m^3 s^{-1} km^{-2}$). The naturally low suspended sediment regime is likely a result of the relatively high erosional resistivity of the rocks in the watershed, low intensity rainfall, rapid soil infiltration rates and subsequent lack of surface runoff. Suspended sediment loads of nonglacial streams in southeast Alaska are generally extremely low (Schmiege _et al._, 1974). The bedload component of many high relief, glacial-form watershed streams is large and this limits the lasting influence of suspended sediment in the streambed. Trap Bay Creek represents a different type of stream than those streams with high suspended to bedload ratios which have been studied in the southern U.S. It appears that most sediment transport occurs as bedload here, and that suspended sediment is relatively unimportant in this undisturbed old growth system.

Sediment rating curves were developed for TSS using the equation (4). r^2 values ranged from 0.18 to 0.999. Prediction of TSS transport at 0.06 $m^3 s^{-1} km^{-2}$, the average annual flow according to the _Water Resources Atlas for Alaska_ (1979), ranged from 2.1 to 26.1 $mg \cdot l^{-1}$ (Table 6). A plot of TSS versus discharge (Figure 20) showed that, although there is a slight hysteresis effect evident for the 24-25 September data, the opposite is true for the 1 October data. A hysteresis effect is commonly seen in TSS data collected from streams in W. Oregon (Milhous and Klingeman, 1973; Beschta, 1981; Edwards, 1979). Data from one event at Trap Bay Creek do not provide a basis

TABLE 6. Summary of Total Suspended Solids (TSS) Data Collected From Trap Bay Creek, Chichagof Island, Alaska, During Two Storms in the Fall of 1980.

24-25 September 1980			30 September - 1 October 1980		
Time, hrs.	Discharge $m^3s^{-1}km^2$	TSS, $mg\ l^{-1}$	Time, hrs.	Discharge $m^3s^{-1}km^2$	TSS, $mg\ l^{-1}$
1800	0.07	10	2300	0.13	48
1900	0.07	0	2400	0.13	42
2000	0.08	5	0100	0.11	44
2100	0.10	28	0200	0.11	33
2200	0.16	32	0300	0.11	25
2300	0.16	27	0400	0.11	28
2400	0.13	0	0500	0.11	21
0100	0.11	26	0600	0.12	34
0200	0.10	1	0700	0.12	40
0300	0.09	1	0800	0.16	18
0400	0.08	32	0900	0.25	51
0500	0.07	2	1000	0.39	49
0600	0.06	0	1200	0.71	61
0700	0.07	0	1300	1.09	63
0800	0.06	3	1400	1.26	86
0900	0.06	0	1500	1.06	72
1000	0.06	0	1600	0.71	52
1100	0.05	2	1700	0.49	38

TSS rating curves[1]

		Predicted TSS transport for the average annual discharge. Q = 0.06[2]
all data	: $TSS = 96.5\ Q^{0.87}\ r^2 = 0.41$	8.25
24-25 September	: $TSS = 2067.2\ Q^{2.36} r^2 = 0.34$	2.76
rising limb	: $TSS = 1412.7\ Q^{2.05} r^2 = 0.67$	4.43
falling limb	: $TSS = 3366.4\ Q^{2.05} r^2 = 0.18$	2.08
30 Sept.-1 Oct.	: $TSS = 65.0\ Q^{0.33}\ r^2 = 0.59$	25.54
rising limb	: $TSS = 64.4\ Q^{0.32}\ r^2 = 0.46$	26.10
falling limb	: $TSS = 68.6\ Q^{0.82}\ r^2 = 1.00$	6.79

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[1] See text for explanation of rating curve development.

[2] Average annual discharge computed using an equation from the *Water Resources Atlas for Alaska* (1979).

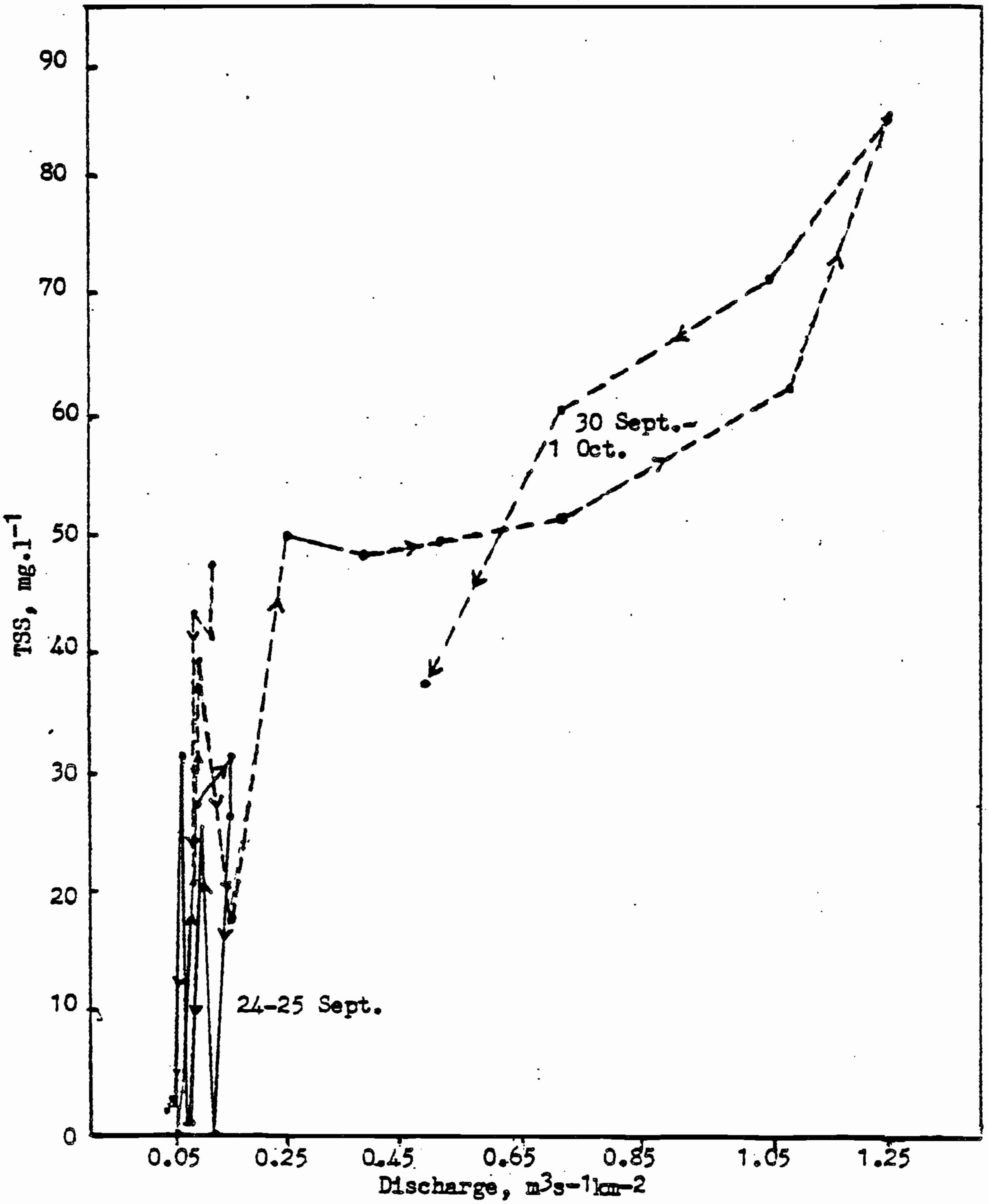

Figure 20. Total suspended solids (TSS) versus stream discharge for two time periods during the Fall of 1980, Trap Bay Creek, Chichagof Island, Alaska

for concluding that TSS hystersis does or does not occur. The 1 October event may have resulted in TSS transport unlike that which occurs during more frequent events.

The fraction of suspended load that is made up of organics is variable and can compose all or none of a given sample (Figures 21 and 22). The proportion of organics does not appear to depend on discharge or on the total amount of TSS in transport. It is interesting that, during the 24-25 September event, organic material makes up a relatively small portion of TSS on the rising limb of the hydrograph, but TSS samples on the falling limb were frequently composed entirely of organic material. In contrast, organics initially comprised 20 to 50 percent of TSS at the beginning of the 1 October event, but are essentially absent from TSS samples collected during the peak and falling limb. This may be another indication that TSS transport during this event was not characteristic of the stream during relatively normal flows.

Bedload Discharge

At the lower riffle of the pool-riffle study reach, bedload discharge, including organic material, ranged from 3.9 to 4200 $kg \cdot hr^{-1}$. At the upper riffle, bedload discharge ranged from 15 to 4400 $kg \cdot hr^{-1}$. The lowest measured transport rate occurred during the first storm of the season, 23 September, at the lower riffle, and during the 7 October storm at the upper riffle. The greatest measured transport rate occurred during the 1 October event at both sites but the time of peak transport differed. Peak bedload transport occurred nearly coincident

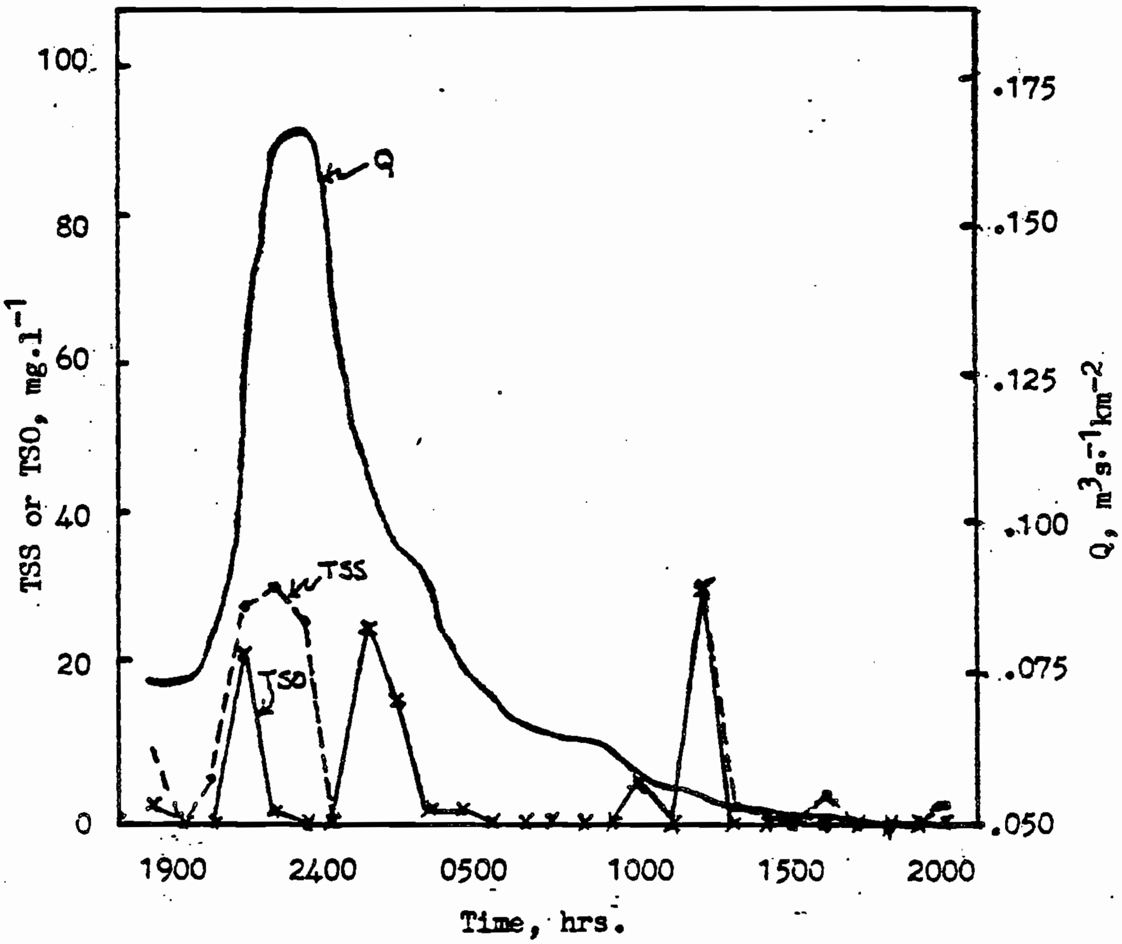

Figure 21. Total suspended soilds (TSS), total suspended organics (TSO), and stream discharge (Q) over time during the storm of 24-25 September 1980, Trap Bay Creek, Chichagof Island, Alaska

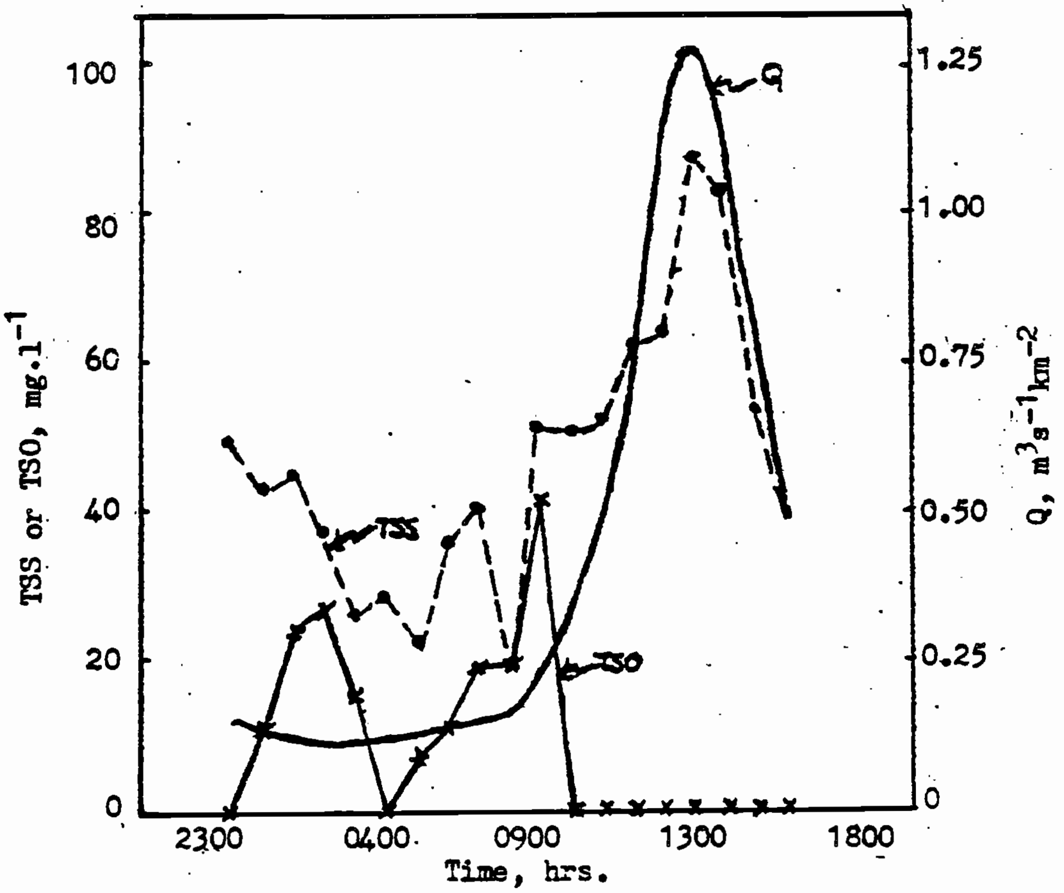

Figure 22. Total suspended (TSS), total suspended organics (TSO), and stream discharge (Q) over time during the storm of 30 Sept.-1 Oct. 1980, Trap Bay Creek, Chichagof Island, Alaska

with the peak of the hydrograph at the lower riffle, but showed wide variability at the upper riffle (Figures 23-33).

Peak transport rates occurred nearly coincident with peak discharge during the 30 Sept. - 1 Oct. and 1 Oct. events. The data are incomplete for the other eight events. Transport rates at the upper riffle exceeded those at the lower riffle during all events except that of 1 Oct., the latter part of the 2 Oct. event, and the 7 Oct. event. Apparently, sediment was transported past the upper riffle and deposited in the pool during lesser, more frequent events. An event of sufficient magnitude was then required to dislodge this material and transport it past the lower riffle. Once this material had been dislodged, transport past the lower riffle was accomplished by lesser magnitude events until all available sediment had been transported and the depositional area became essentially rearmored.

Langbein and Leopold (1960) theorized that a gravel riffle is an expression of a kinematic wave, and that it requires repeated flows of sufficient magnitude to transport material from one zone of concentration to the next. This theory could explain what happened in Trap Bay Creek. Lesser events are capable of transporting material to and past the upper riffle, which represents a "zone of concentration." A series of greater magnitude events was necessary to transport this material past the lower riffle to the next zone of concentration.

The average change in sediment storage in the pool-riffle study reach was computed from estimates of net change in cross-sectional area from 1980 to 1981 in the cross-sectional profiles. Results are shown in Table 7. The average volume of sediment transported during

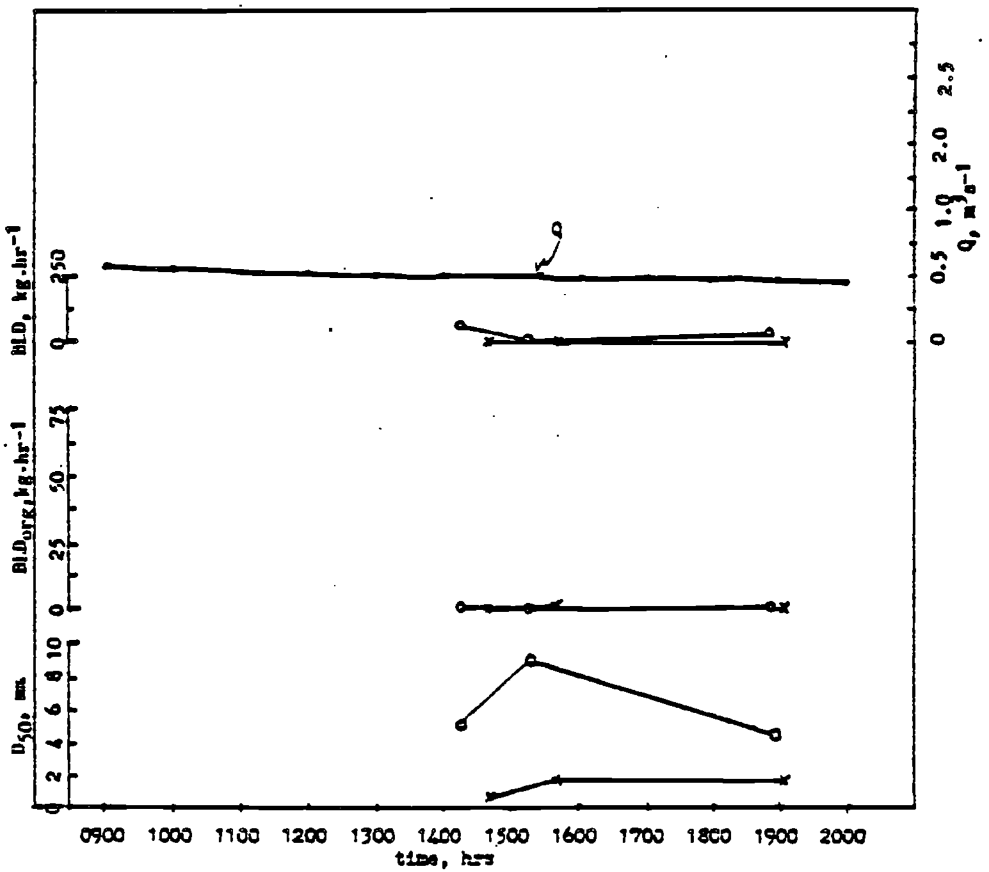

Figure 23. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diamter of bedload sample (D_{50}) over time for the 30 September 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

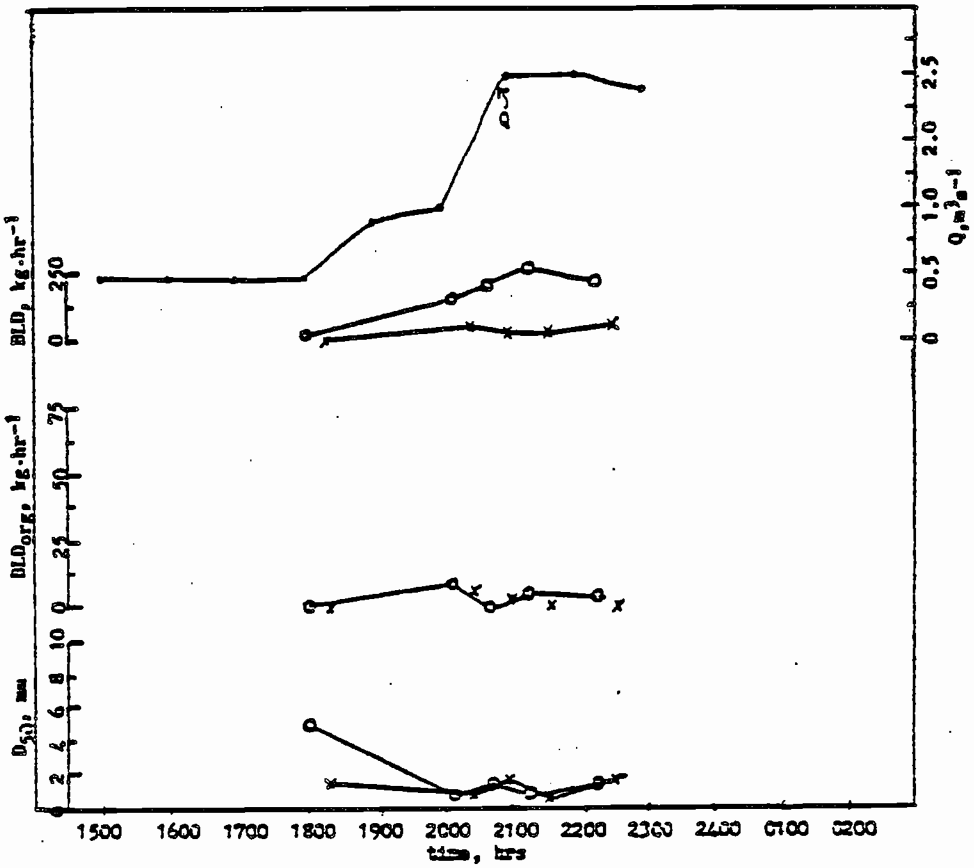

Figure 24. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload samples (D_{50}) over time for the 24 September 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

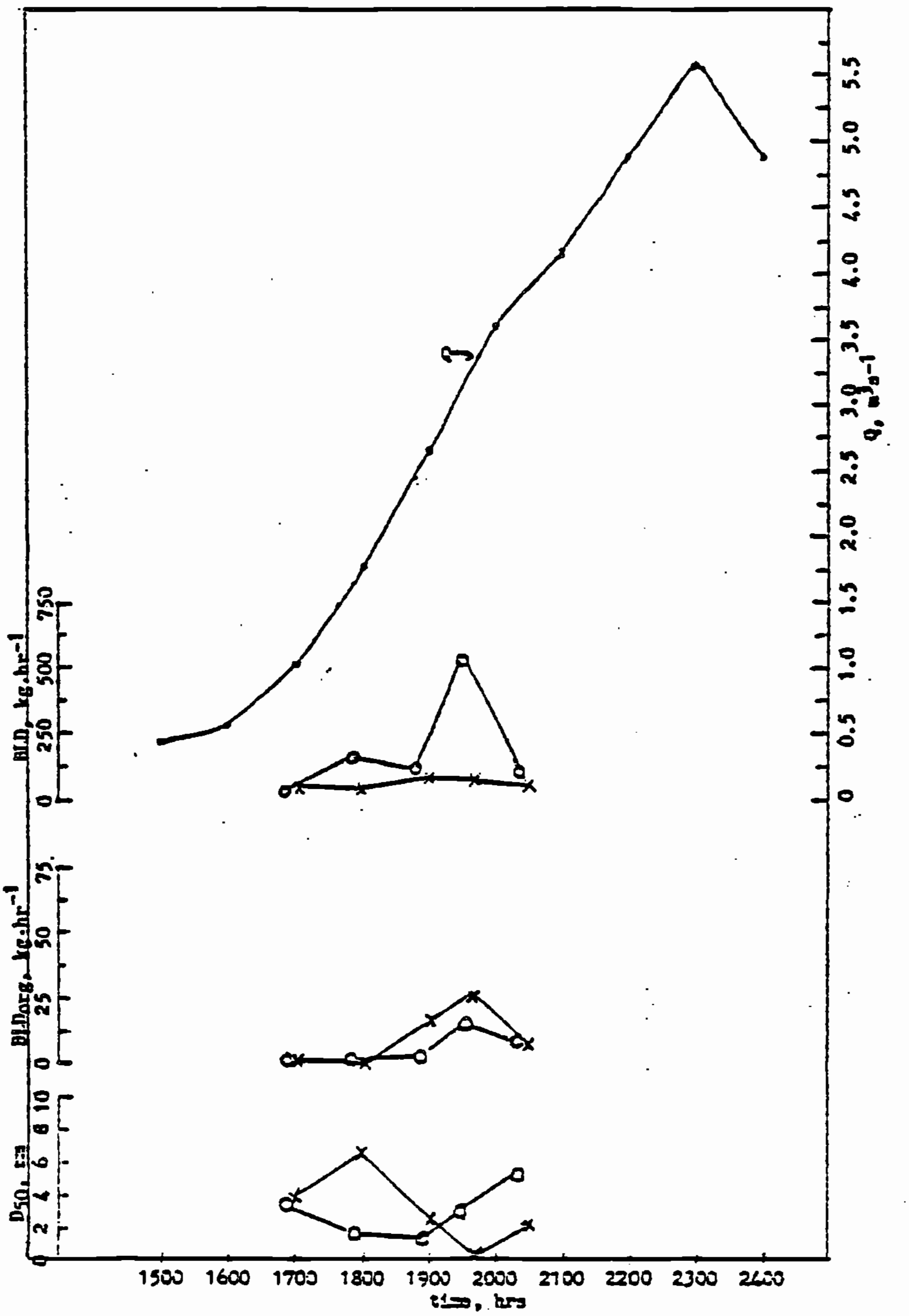

Figure 25. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload sample (D_{50}) over time for the 28 Sept. 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

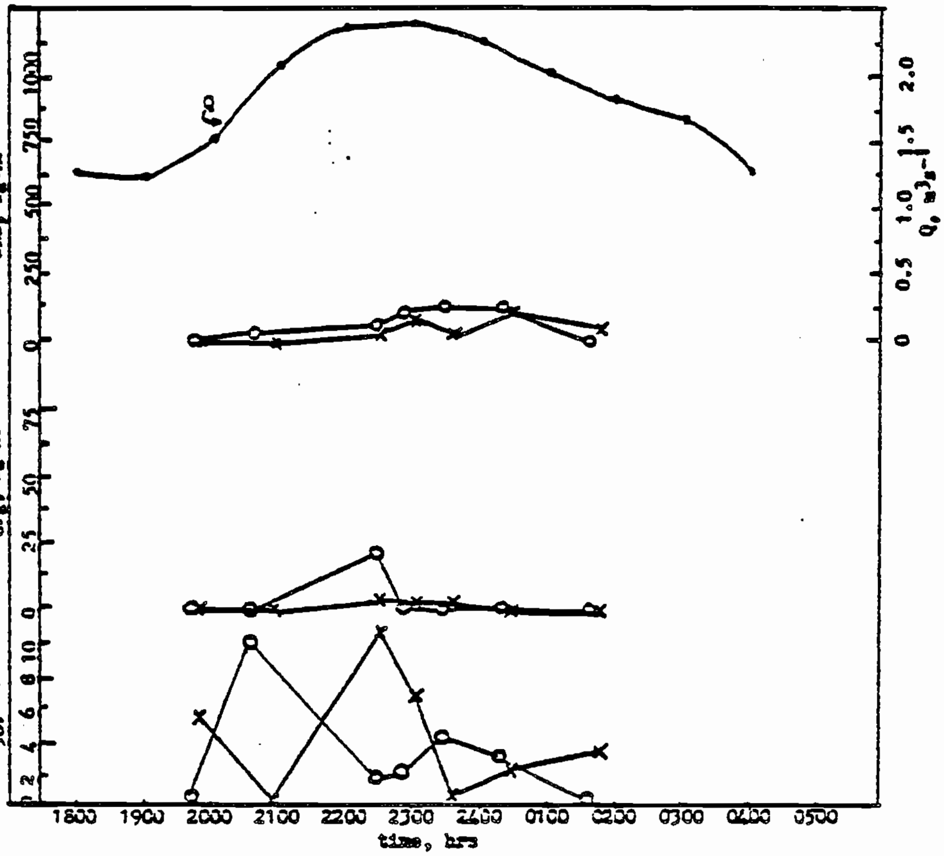

Figure 26. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload sample (D_{50}) over time for the 30 Sept. - 1 Oct. 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

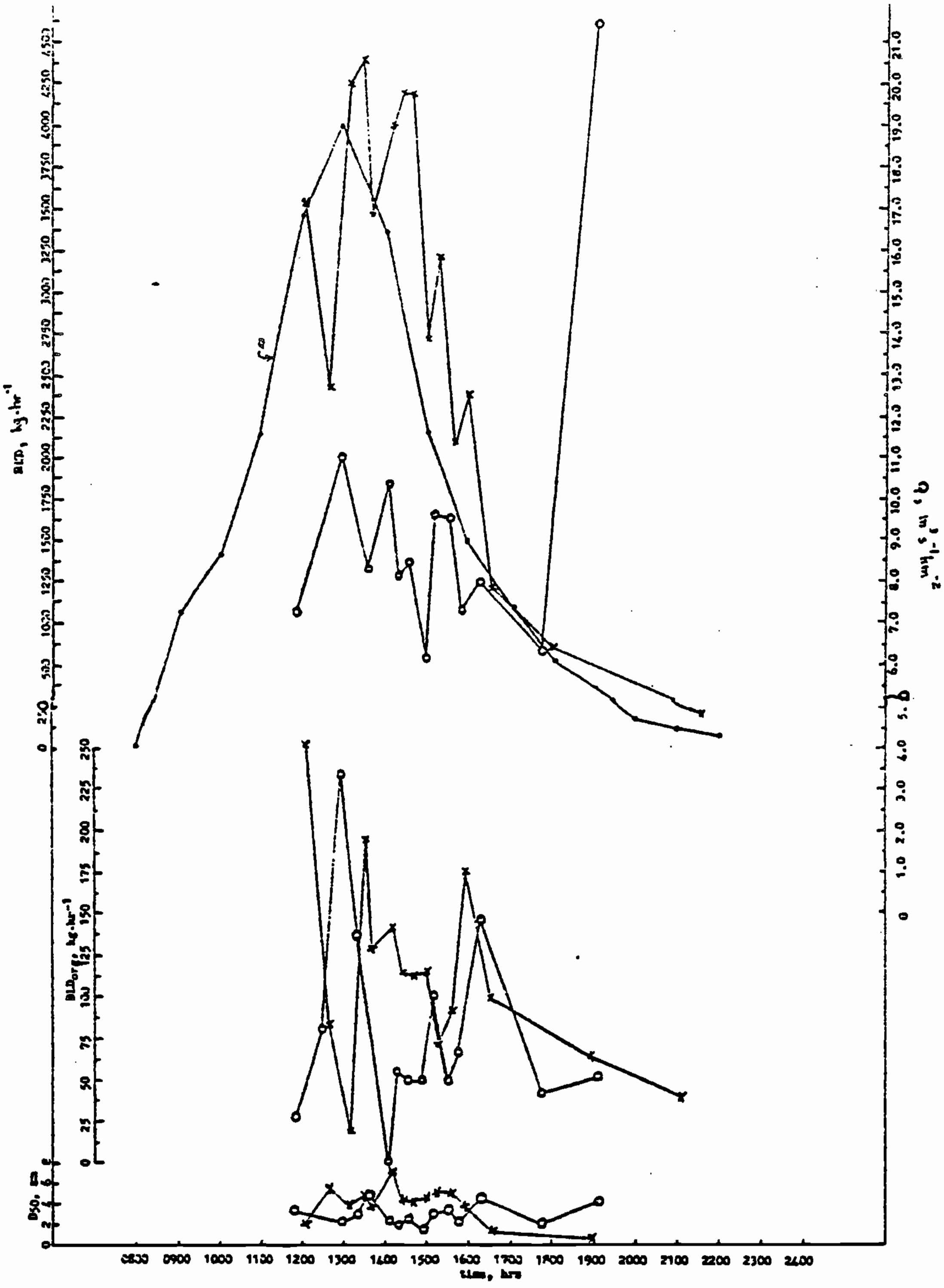

Figure 27. Discharge (Q), bedload (BLD) and inorganic bedload (BLD$_{org}$) in transport, and average particle diameter of bedload sample (D50) over time for the 1 October 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

o indicates samples from the upper riffle
x indicates samples from the lower riffle

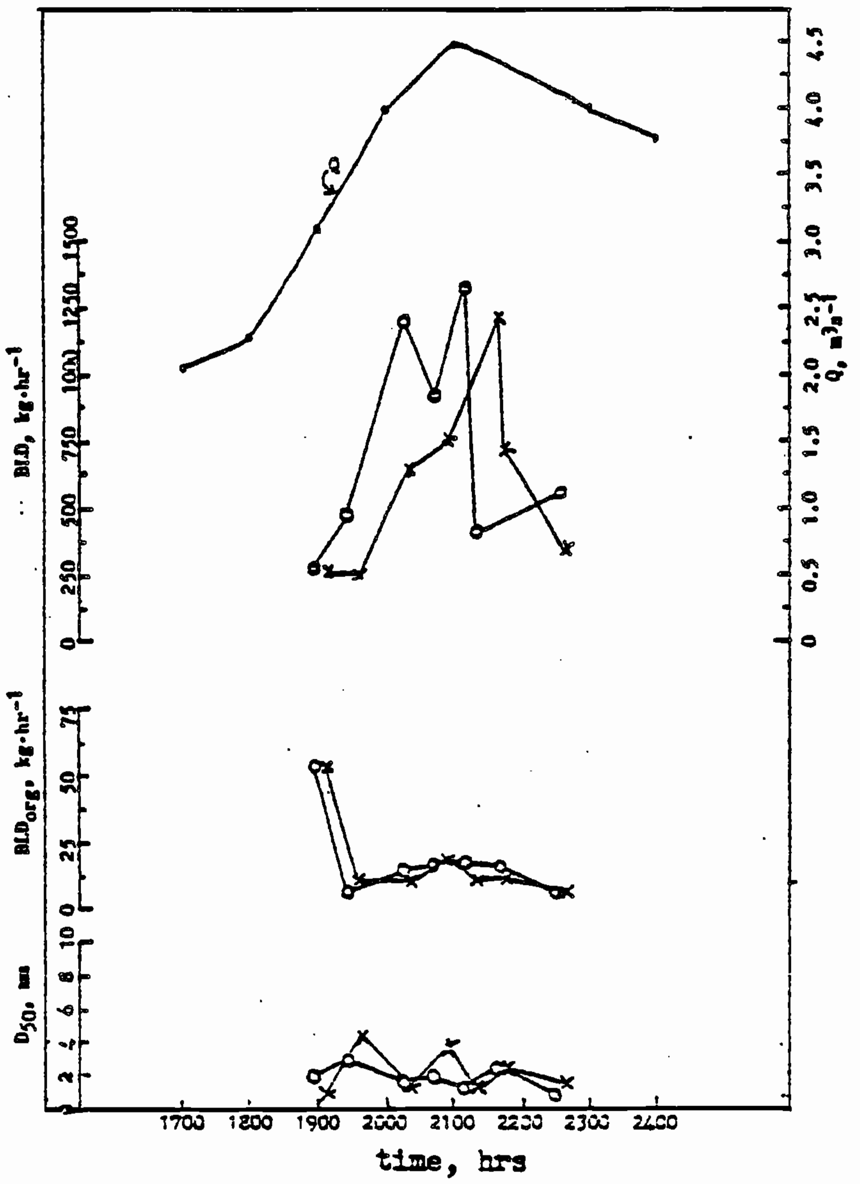

Figure 28. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload sample (D_{50}) over time for the 2 October 1980 storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE:
o indicates samples from the upper riffle
x indicates samples from the lower riffle

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

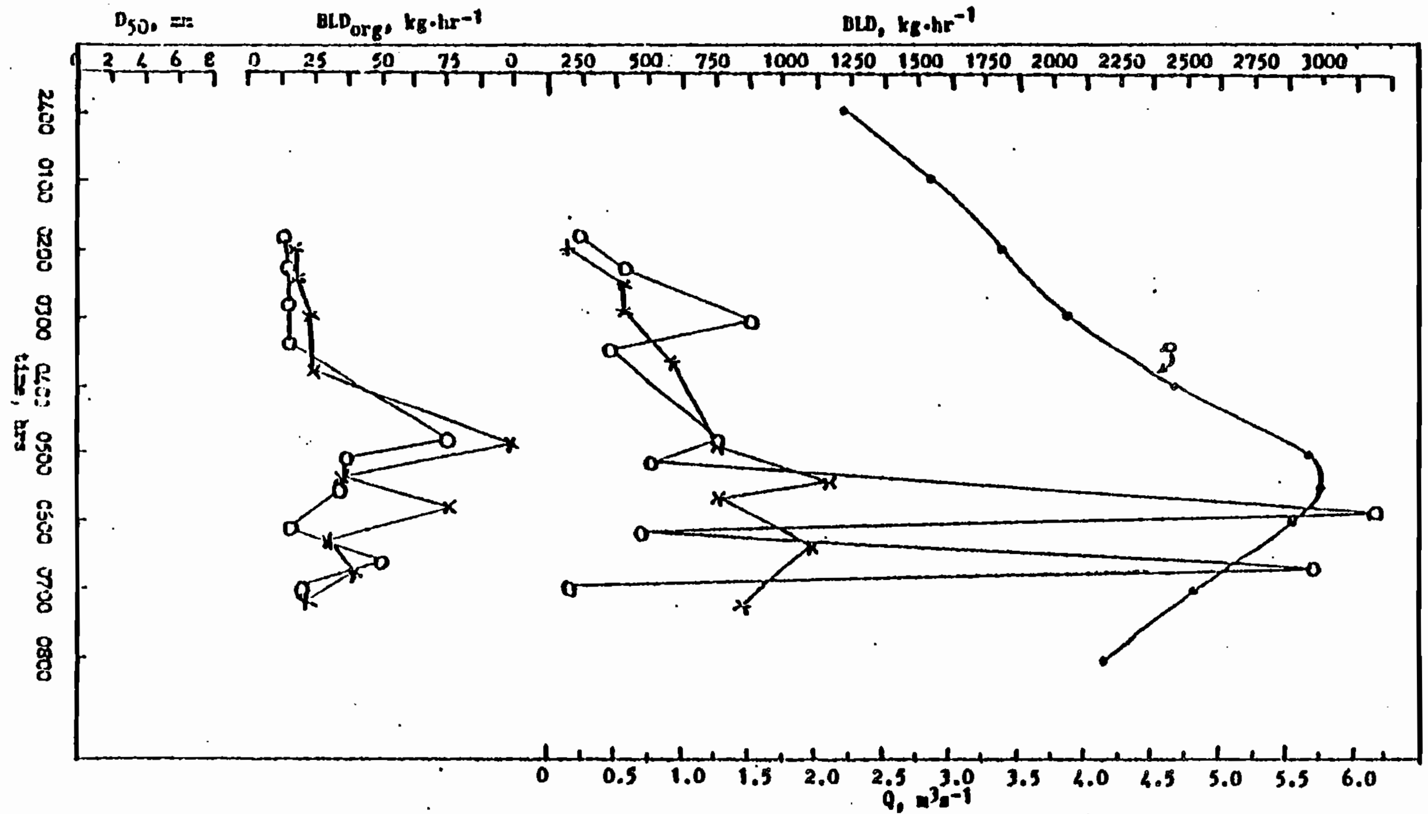

Figure 29. Discharge (Q), bedload (BLD) and organic bedload (BLDorg) in transport, and average particle diameter of bedload sample (D_{50}) over time for 5 October storm at Trap Bay Creek, Chichagof Island, Alaska

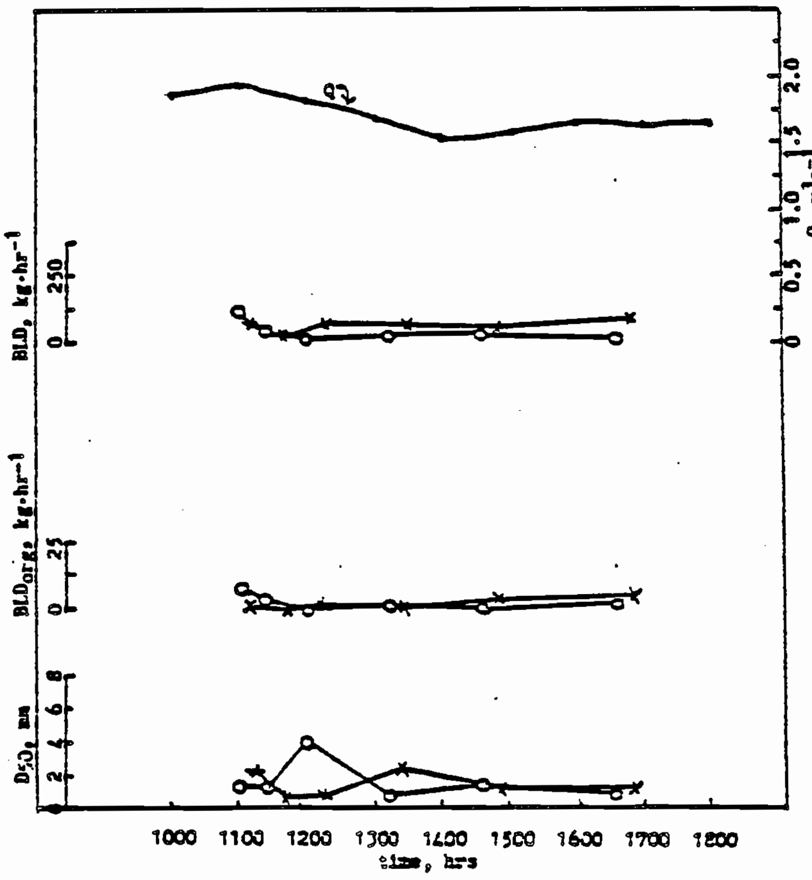

Figure 30. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload sample (D_{50}) over time for the 7 October storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

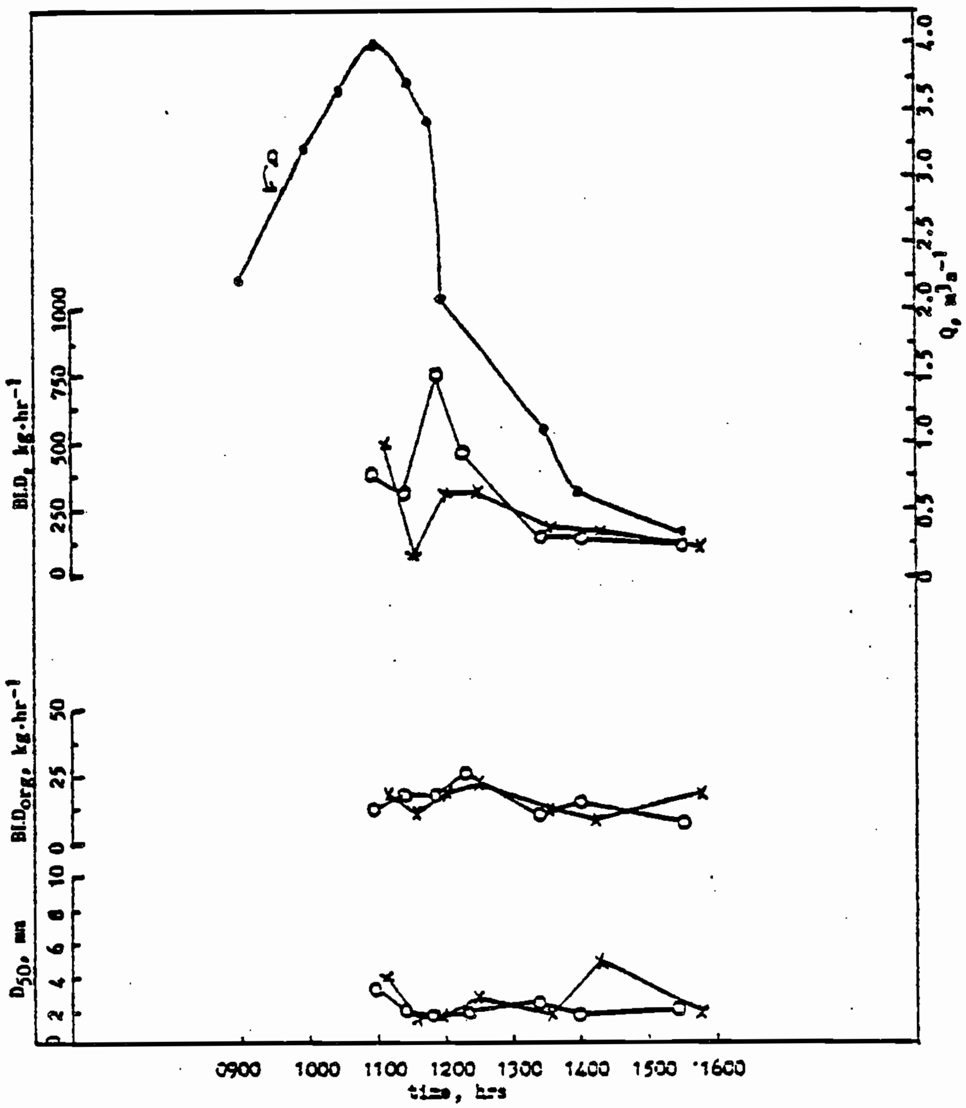

Figure 31. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload sample (D_{50}) over time for the 16 October storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle
x indicates samples from the lower riffle

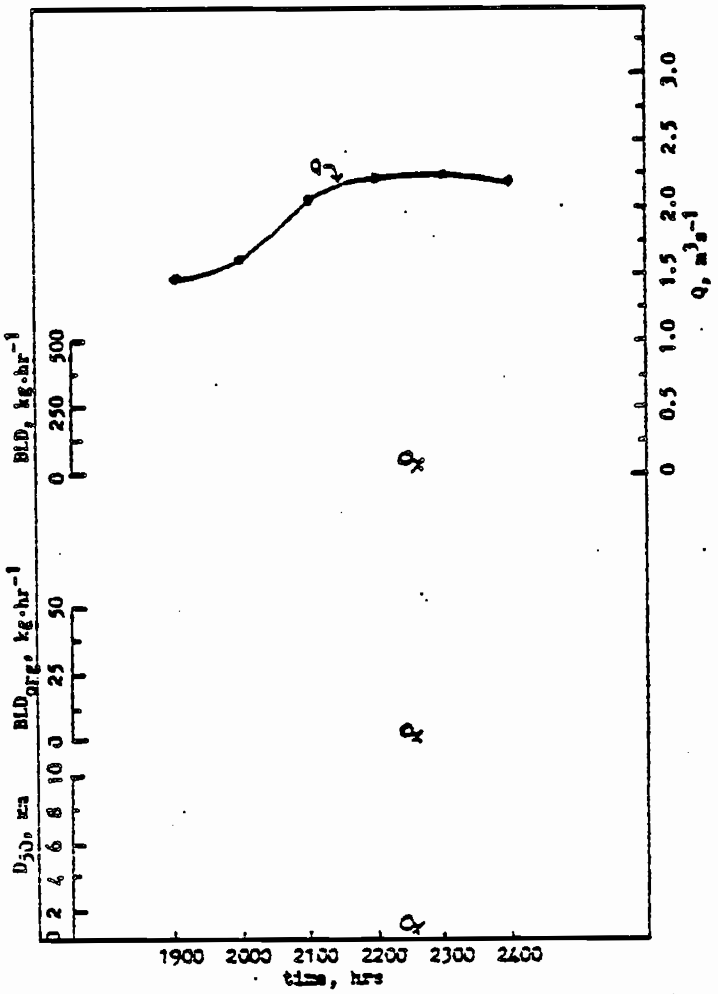

Figure 32. Discharge (Q), bedload (BLD) and organic bedload (BLD_{org}) in transport, and average particle diameter of bedload sample (D_{50}) over time for the 18 October storm at Trap Bay Creek, Chichagof Island, Alaska

NOTE: o indicates samples from the upper riffle

x indicates samples from the lower riffle

each storm was computed at each sampling site by multiplying the average transport rate by the number of hours that significant bedload transport occurred. A summation of these volumes for all storms gave an estimate of the volume of sediment transported past each of the riffles (Table 8). The estimate based on cross-sectional areas was 10.8 tonnes (11.9 tons) of sediment transported out of the study reach from 1980 to 1981. Based on the change in each cross-section, 20.4 tones (22.4 tons) of this material was scoured and 9.6 tonnes (10.6 tones) was deposited. These figures are comparable to the estimates of 11.4 tonnes (12.5 tons) of sediment transport past the upper riffle and 20.7 tonnes (22.8 tons) of sediment transport past the lower riffle. More sediment was transported past the lower riffle, which agrees with the net negative change in cross-sectional area here, and the positive change in area at the upper riffle (Table 7). While these figures are only rough estimates, they indicate that Helley-Smith samples may provide a reasonable estimate of bedload sediment transport if the changes in channel cross-sectional area are considered to represent the change in bedload sediment storage in the study reach.

Plots of bedload discharge > 0.25 mm (not shown) indicated that no hysteresis was obvious. These plots also showed that, at the lower riffle, the bedload transport at a given discharge during the 2 October and 5 October events was greater than it was during any other events. These two moderate events appear to have transported most of the sediment that was made available by the 1 October event past the lower riffle. Bedload discharge during the 16 October event at a given discharge was less than that of the 1 October event even though

TABLE 7. Change in Sediment Storage Computed from Cross-Sectional Area Changes from September, 1980, to August, 1981, for Trap Bay Creek, Chichagof Island, Alaska

	Area, m (ft)	Station[1]	Length, m(ft)	Volume, m^3(ft^3)	Net Change[2], m^3(ft^3)
scour	1.8(19.3)	52 + 00	2.7(9.0)	-4.9(173.3)	-2.36(83.25)
fill	0.9(10.0)			+2.6(90.0)	
scour	1.3(13.5)	52 + 18	6.1(20.0)	-7.6(270.0)	-7.61(269.0)
fill	0.01(0.05)			+0.02(1.0)	
scour	0.7(7.0)	52 + 40	4.9(16.0)	-3.2(112.0)	+3.74(132.0)
fill	1.4(15.3)			+6.9(244.0)	
scour	1.2(13.0)	52 + 50	5.9(19.5)	-7.2(253.5)	-2.76(97.5)
fill	0.7(8.0)			+4.4(156.0)	
scour	0.6(6.75)	52 + 79	9.9(32.5)	-6.2(219.4)	+2.25(79.6)
fill	0.9(9.25)			+8.5(299.0)	
				Total	-6.74(238.2)
					* 1.6 tonnes/m^3[3]
					10.8 tonnes
	Total scour = 20.4 tonnes			Total fill = 9.6 tonnes	

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[1] See text for explanation of station establishment (pp. 43-44)

[2] + indicates net fill; - indicates net scour.

[3] Based on Hillel (1980).

TABLE 8. Approximate Amount of Sediment Transported by Fall, 1980, Storms, Trap Bay Creek, Chichagof Island, Alaska[2]

Storm date	Ave. transport rate, $kg \cdot hr^{-1}$	Time,[1] hrs	Sediment transported tonnes	Sediment transported tons
	upper riffle			
23 Sept.	33.0	4.0	0.13	0.15
24 Sept.	188.8	3.5	0.66	0.73
28 Sept.	198.6	2.5	0.50	0.55
30 Sept.- 1 Oct.	71.1	4.25	0.30	0.33
1 Oct.	962.3	5.75	5.53	6.10
2 Oct.	792.4	2.0	1.59	1.75
5 Oct.	397.4	4.5	1.79	1.97
7 Oct.	35.6	4.0	0.14	0.16
16 Oct.	322.4	2.25	0.73	0.80
		Total	11.37	12.53
	lower riffle			
23 Sept.	5.2	4.0	0.02	0.02
24 Sept.	34.7	3.5	0.12	0.13
28 Sept.	47.3	2.5	0.12	0.13
30 Sept.- 1 Oct.	50.3	4.25	0.22	0.24
1 Oct.	2402.8	5.75	13.82	15.23
2 Oct.	430.8	2.0	0.86	0.95
5 Oct.	839.2	4.5	3.78	4.16
7 Oct.	319.1	4.0	1.28	1.41
16 Oct.	229.1	2.25	0.52	0.57
		Total	20.72	22.84

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[1] Time that significant bedload transport occurred.

[2] As determined by bedload sampling with a Helley-Smith pressure-differential sampler.

the peak flow of the 16 October storm was greater than that of the 2 and 5 October events.

At the upper riffle, transport rates early in the storm season were comparable to transport rates at a given discharge following the 1 October storm. Transport rates increased with storm magnitude. However, the 1 October event did not produce an increase in transport comparable to the increase at the lower riffle except for the slug of material at the end of the storm (Figure 28). Transport rates during the 7 and 16 October storms were comparable to those of the 1 October storm at discharges of one-fourth and one-third, respectively, that of the 1 October event. This could have been a new wave of material moving into the pool to replace the material that was transported out of it by the 1 October storm.

Bedload, CPOM, D_{50}, and D_{90} were regressed against stream discharge using the aforementioned power equation (4). Equations using all data from all storms combined are summarized in Table 9. The data were separated according to the site from which the samples were collected and regressions were developed for each of the riffles (Table 10). In Figure 33, the graphs for all significant relationships are presented; Figure 34 depicts the significant relationships for each riffle. Equations are depicted over the range of discharge observed.

Separation of the data by sampling site indicated that there was a better correlation between discharge and bedload transport at the lower riffle than at the upper riffle. Correlation coefficients for relationships for the two bedload size fractions and CPOM were higher when only data from the lower riffle were used than when equations were

TABLE 9. Relationships Between Bedload (BLD) Transport (BLD > 0.25 mm and BLD 2.0 > mm in $kg \cdot hr^{-1}$), Coarse Particulate Organic Matter (CPOM in $kg \cdot hr^{-1}$), Two Particle Diameters (D_{50} and D_{90} in mm) and Streamflow for the 1980 Fall Storm Season at Trap Bay Creek, Chichagof Island, Alaska

n = 132 (all storms)				
Equation	r^2	F^1	$t^{1,2}$	
			a	b
(BLD > 0.25 mm) = 1534.12 $Q^{1.613}$	0.69	**	**	**
(BLD > 2.0 mm) = 877.47 $Q^{1.719}$	0.66	*	*	*
(CPOM) = 89.15 $Q^{1.857}$	0.71	**	**	**
(D_{50}) = 2.55 $Q^{0.158}$	0.04		*	
(D_{90}) = 13.71 $Q^{0.150}$	0.7		*	

[1] * indicates significance at the 90% level of probability;
** indicates significance at the 95% level of probability.

[2] significance indicates that the regression coefficient differs from zero.

n= ?

TABLE 10. Relationships Between Bedload (BLD) Transport (BLD > 0.25 mm and BLD > 2.0 mm in $\text{kg} \cdot \text{hr}^{-1}$), Coarse Particulate Organic Matter (CPOM in $\text{kg} \cdot \text{hr}^{-1}$), Two Particle Diameters (D_{50} and D_{90} in mm) and Streamflow (Q) for Each Sampling Site on Trap Bay Creek, Chichagof Island, Alaska, for the Fall, 1980, Storm Season

Equation	r^2	F^1	$t^{1,2}$	
			a	b
upper riffle (n = 66)				
$(\text{BLD} > 0.25\ \text{mm}) = 1021\ Q^{1.25}$	0.58		**	*
$(\text{BLD} > 2.0\ \text{mm}) = 555\ Q^{1.30}$	0.56		*	*
$(\text{CPOM}) = 70.3\ Q^{1.77}$	0.66	*	*	*
$(D_{50}) = 2.12\ Q^{-0.5}$	0			
$(D_{90}) = 12.6\ Q^{0.06}$	0.01			
lower riffle (n = 66)				
$(\text{BLD} > 0.25\ \text{mm}) = 2267\ Q^{1.98}$	0.82	**	**	*
$(\text{BLD} > 2.0\ \text{mm}) = 1379\ Q^{1.15}$	0.78	**	*	*
$(\text{CPOM}) = 112\ Q^{1.95}$	0.77	**	*	*
$(D_{50}) = 3.06\ Q^{0.32}$	0.13			
$(D_{90}) = 16.5\ Q^{0.30}$	0.19		*	

[1] * indicates significance at the 90% level of probability;
** indicates significance at the 95% level of probability.

[2] significance indicates that the regression coefficient differs from zero.

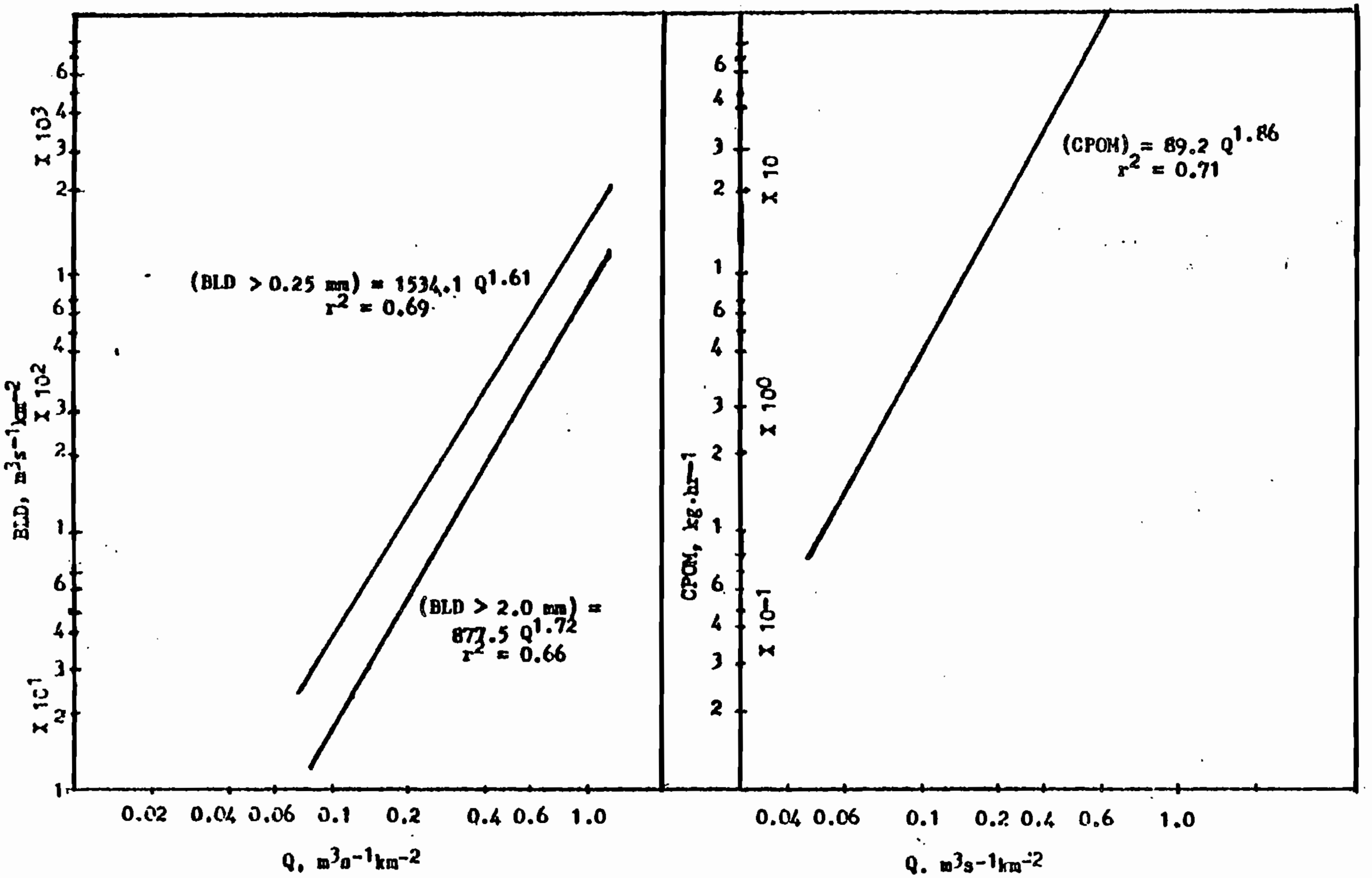

Figure 33. Bedload (BLD), coarse particulate organic matter (CPOM), and particle diameter (D_{50} or D_{90}) vs. streamflow (Q) relationships for all data (n = 132) collected from Trap Bay Creek, Chichagof Island, Alaska, during the Fall, 1980, storm season

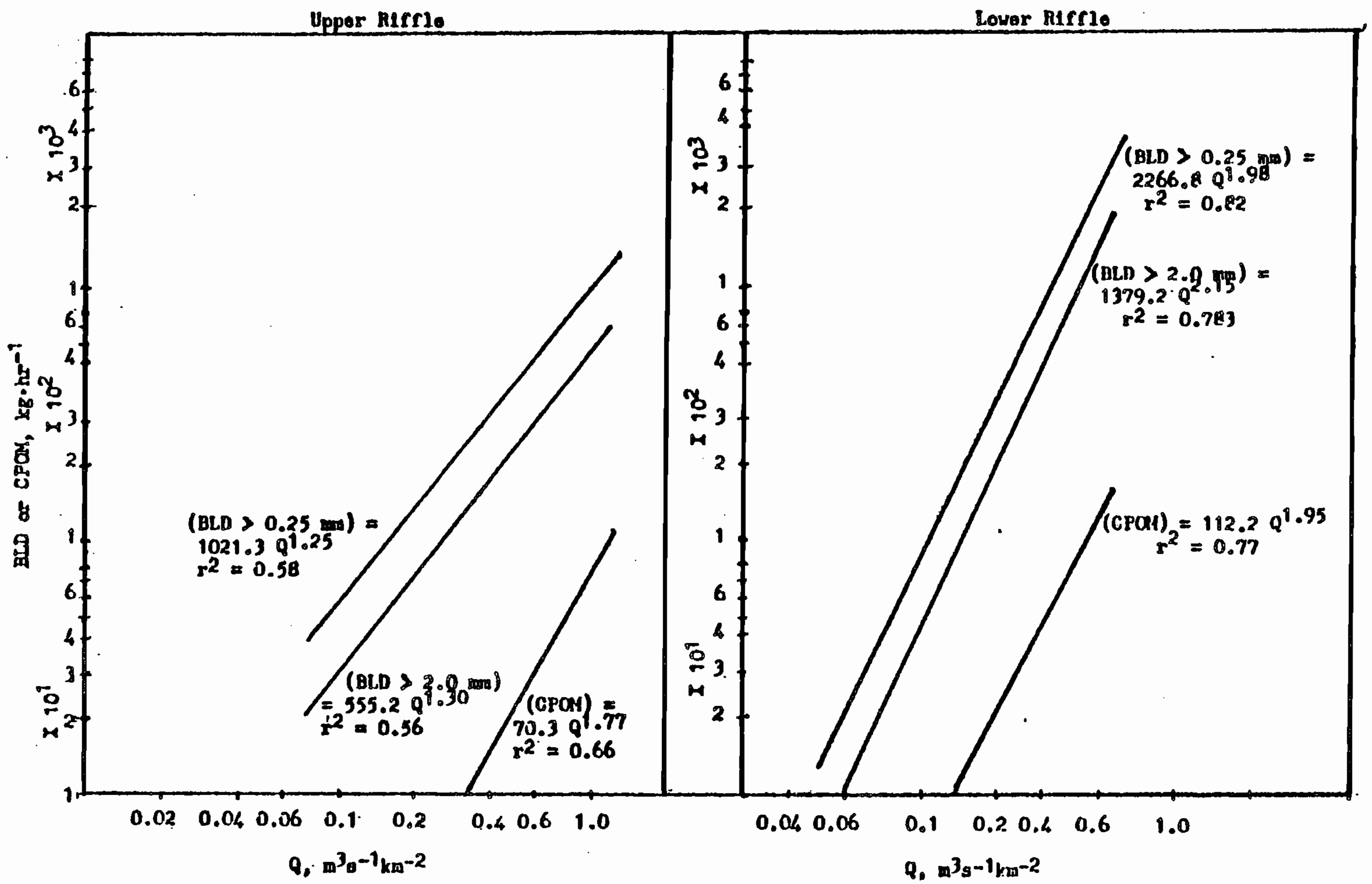

Figure 34. Bedload (BLD), coarse particulate organic matter (CPOM), vs. streamflow (Q) relationships for data collected from each sampling site (n = 66) on Trap Bay Creek, Chichagof, Alaska, during the Fall, 1980, storm season

developed from all data combined.

Data were also separated on the basis of whether samples were collected on the rising (n = 58) or falling (n = 74) limb of the hydrograph (Table 11, Figure 35). Correlation coefficients for bedload and CPOM equations were slightly greater for rising limb data than for falling limb data and the regression coefficients were slightly larger, but the general form of equations for both rising and falling limbs was similar. In contrast, regression coefficients for the lower riffle equations were markedly larger than those for the upper riffle equations.

These findings suggest that bedload transport may be more closely related to stream discharge at the lower riffle, and that slightly greater flows are required to produce the same rate of transport. This would be expected if, as previously stated, the pool tends to undergo aggradation between storm seasons and results in a store of material available for transport during only moderately high streamflow at the upper riffle. Significantly higher streamflow is required to transport this material out of the pool and past the lower riffle. The lack of a difference between the equations developed for the data separated on the basis of the limb of the hydrograph again indicates that little hysteresis occurred during these storms.

Correlation coefficients for D_{50} and D_{90} regression equations were consistently low, so there appears to be a poor relationship between stream discharge and particle size in transport (Tables 9-11). Except for the relationships developed for the upper riffle, D_{50} appears to increase with increasing discharge. D_{90} also shows a slight

TABLE 11. Relationships Between Bedload (BLD) Transport (BLD > 0.25 mm and BLD > 2.0 mm in $\text{kg}\cdot\text{hr}^{-1}$), Coarse Particulate Organic Matter (CPOM in $\text{kg}\cdot\text{hr}^{-1}$), Two Particle Diameters (D_{50} and D_{90} in mm) and Streamflow for the Rising (n = 58) and Falling (n = 74) Limbs of Storm Hydrographs, Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

Equation	r^2	F[1]	t[1,2]	
			a	b
	rising limb			
$(\text{BLD} > 0.25\ \text{mm}) = 1858\ Q^{1.65}$	0.70	**	**	*
$(\text{BLD} > 2.0\ \text{mm}) = 1035\ Q^{1.75}$	0.67	*	**	*
$(\text{CPOM}) = 119\ Q^{1.84}$	0.79	**	**	*
$(D_{50}) = 2.52\ Q^{0.14}$	0.03			
$(D_{90}) = 13.3\ Q^{0.16}$	0.03			
	falling limb			
$(\text{BLD} > 0.25\ \text{mm}) = 1355\ Q^{1.61}$	0.69	**	**	*
$(\text{BLD} > 0.2\ \text{mm}) = 788\ Q^{1.71}$	0.67	*	*	*
$(\text{CPOM}) = 74\ Q^{1.91}$	0.70	*	*	*
$(D_{50}) = 2.56\ Q^{0.17}$	0.06			
$(D_{90}) = 14.1\ Q^{0.19}$	0.10		*	

[1] * indicates significance at the 90% level of probability,
** indicates significance at the 95% level of probability.

[2] significance indicates that the regression coefficient differs from zero.

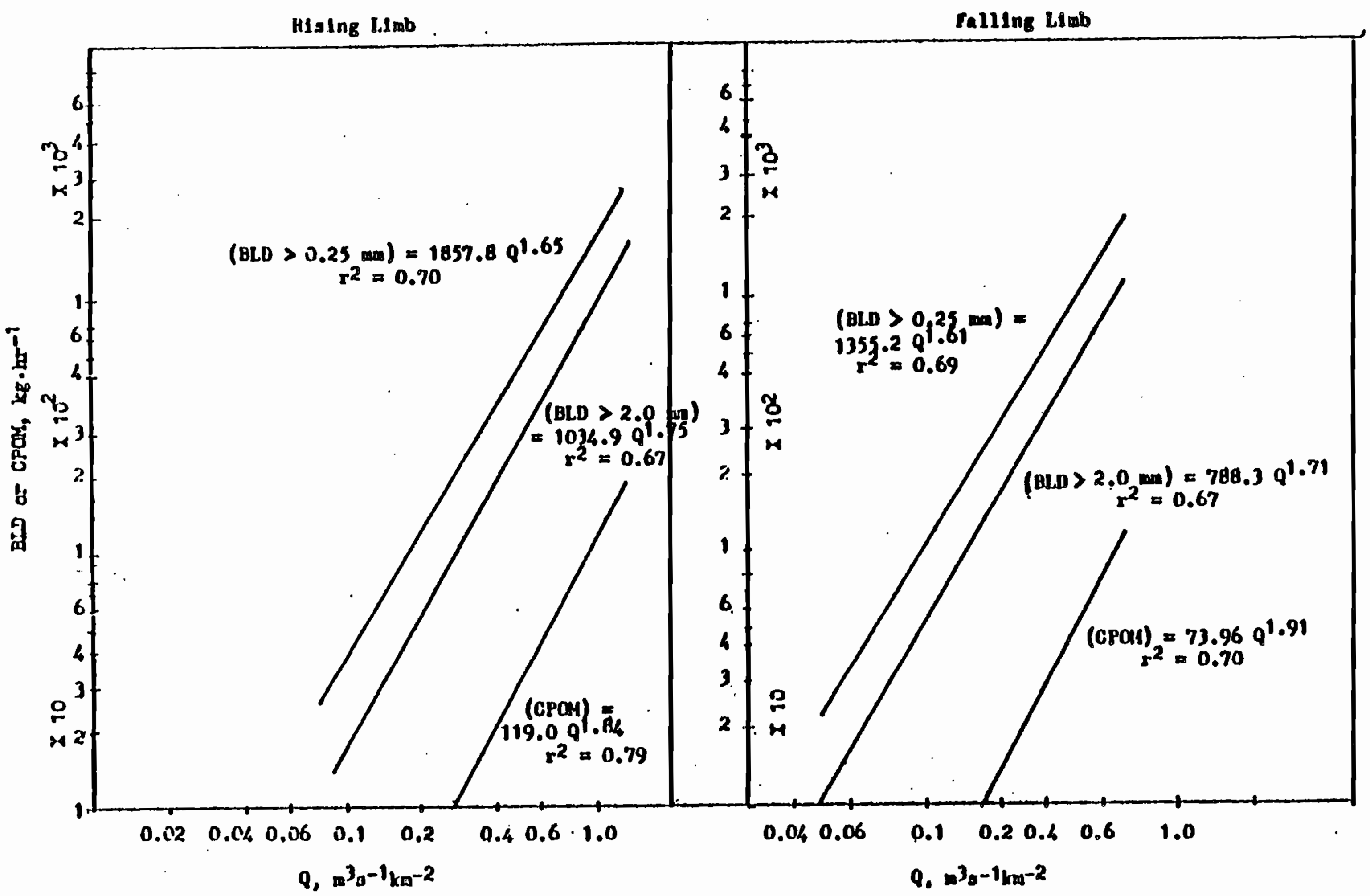

Figure 35. Bedload (BLD) and coarse particulate organic matter (CPOM) vs. streamflow (Q) relationships for rising limb (n = 58) and falling limb (n = 74) data collected from Trap Bay Creek, Chichagof Island, Alaska

increase with increasing discharge, but none of the relationships is very strong.

The data were also separated on the basis of storm event and relationships for individual events were developed (Table 12, Figures 36 and 37). Although there is an overall trend for bedload transport to increase with increasing discharge evident in Figure 38, there is considerable variation between the relationships for different storms. In fact, the relationships developed for the 23 September storm were so far below the scale of those for the other storms, that they could not be included on the graphs. There are no equations for the 18 October event because there were only two data points.

Regression coefficients for the same parameter vary by several orders of magnitude for different storms (Table 12). There is also considerable variation among the test statistics. The r^2 and F-values generally decreased when the data were stratified. Some of this decrease may be attributed to the smaller number of data points used to develop the equations, but it also indicates that bedload transport is a highly unsteady process that is likely to be influenced by a number of factors in a relatively complex manner. No single equation examined here adequately characterizes bedload transport.

The realtionships obtained for D_{50} and D_{90} exhibit no definite trend, either increasing or decreasing. F-values for these equations were very rarely significant, indicating a poor fit of the power equation. "t-values" were occasionally significant for the "a" coefficient (y-intercept). This may mean that there is some "threshold" discharge required to set a given particle size in motion. However, the variability in the "a" coefficients indicates that there is more involved

TABLE 12. Relationships Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm in kg·hr^{-1}), Coarse Particulate Organic Matter (CPOM inkg·hr^{-1}), and Two Particle Diameters (D_{50} and D_{90} in mm) and Streamflow (Q) for Individual Storm Events Which Occurred During the Fall, 1980, Storm Season at Trap Bay Creek, Chichagof Island, Alaska

	r^2	F^1	$t^{1,2}$	
			a	b
23 September (n = 6)				
(BLD > 0.25 mm) = $5.7*10^{17} Q^{11.5}$	0.14			
(BLD > 2.0 mm) = $6.0*10^{16} Q^{11.1}$	0.08			
(CPOM) = $6.6*10^{6} Q^{5.8}$	0.38			
(D_{50}) = $1.3*10^{5} Q^{3.2}$	0.02			
(D_{90}) = $8.5*10^{12} Q^{8.2}$	0.13			
24 September (n = 10)				
(BLD > 0.25 mm) = $5440\ Q^{2.2}$	0.29		**	
(BLD > 2.0 mm) = $491\ Q^{1.46}$	0.16		*	
(CPOM) = $864\ Q^{2.91}$	0.69	**	**	**
(D_{50}) = $0.07\ Q^{-1.5}$	0.55	**	**	**
(D_{90}) = $1.54\ Q^{-0.8}$	0.37	**		**
28 September (n = 10)				
(BLD > 0.25 mm) = $185.1\ Q^{0.48}$	0.07		**	
(BLD > 2.0 mm) = $60.3\ Q^{0.22}$	0.01		**	
(CPOM) = $109.3\ Q^{1.74}$	0.58	**	**	**
(D_{50}) = $0.84\ Q^{-0.6}$	0.12			
(D_{90}) = $3.16\ Q^{-0.7}$	0.18			
30 Sept. - 1 Oct. (n = 14)				
(BLD > 0.25 mm) = $1950\ Q^{2.08}$	0.57	**	**	**
(BLD > 2.0 mm) = $1476\ Q^{2.25}$	0.45	**	**	**
(CPOM) = $67.3\ Q^{1.93}$	0.53	**	**	**
(D_{50}) = $4.47\ Q^{0.48}$	0.02			
(D_{90}) = $9.84\ Q^{-0.9}$	0.06		**	
1 October (n = 32)				
(BLD > 0.25 mm) = $1632\ Q^{1.53}$	0.59	**	**	**
(BLD > 2.0 mm) = $1075\ Q^{1.73}$	0.58	**	**	**
(CPOM) = $101\ Q^{1.54}$	0.60	**	**	**
(D_{50}) = $3.26\ Q^{0.48}$	0.26	*	**	**
(D_{90}) = $15.1\ Q^{0.21}$	0.13		**	*

TABLE 12. - Continued

	r^2	F^1	$t^{1,2}$	
			a	b
2 October (n = 14)				
(BLD > 0.25 mm) = 42254 $Q^{3.37}$	0.61	**	**	**
(BLD > 2.0 mm) = 14368 $Q^{3.37}$	0.50	**	**	**
(CPOM) = 0.74 $Q^{-2.5}$	0.26	*		**
(D_{50}) = 2.09 $Q^{0.12}$	0.01			
(D_{90}) = 64.5 $Q^{1.42}$	0.12		**	
5 October (n = 20)				
(BLD > 0.25 mm) = 10588 $Q^{2.99}$	0.35	**	**	**
(BLD > 2.0 mm) = 13183 $Q^{3.93}$	0.43	**	**	**
(CPOM) = 1230 $Q^{4.21}$	0.58	**	**	**
(D_{50}) = 8.58 $Q^{1.59}$	0.27	**	**	**
(D_{90}) = 31.9 $Q^{0.88}$	0.21	**	**	**
7 October (n = 12)				
(BLD > 0.25 mm) = 966050 $Q^{5.71}$	0.69	**	**	**
(BLD > 2.0 mm) = 163305 $Q^{5.21}$	0.61	**	**	**
(CPOM) = 2285 $Q^{4.43}$	0.16		*	*
(D_{50}) = 7.4 $Q^{0.91}$	0.09			
(D_{90}) = 0.01 $Q^{-6.7}$	0.81	**	**	**
16 October (n = 14)				
(BLD > 0.25 mm) = 717.8 $Q^{1.61}$	0.40	**	**	**
(BLD > 2.0 mm) = 403.5 $Q^{1.65}$	0.41	**	**	**
(CPOM) = 21.0 $Q^{0.40}$	0.06		**	
(D_{50}) = 2.41 $Q^{0.91}$	0			
(D_{90}) = 8.73 $Q^{-0.6}$	0.09		**	

[1] * indicates significance at the 0.90% level of probability; ** indicates significance at the 0.95% level of probability.

[2] significance indicates that the coefficient differs from zero.

NOTE: The 18 October event was not evaluated because there were only two data points.

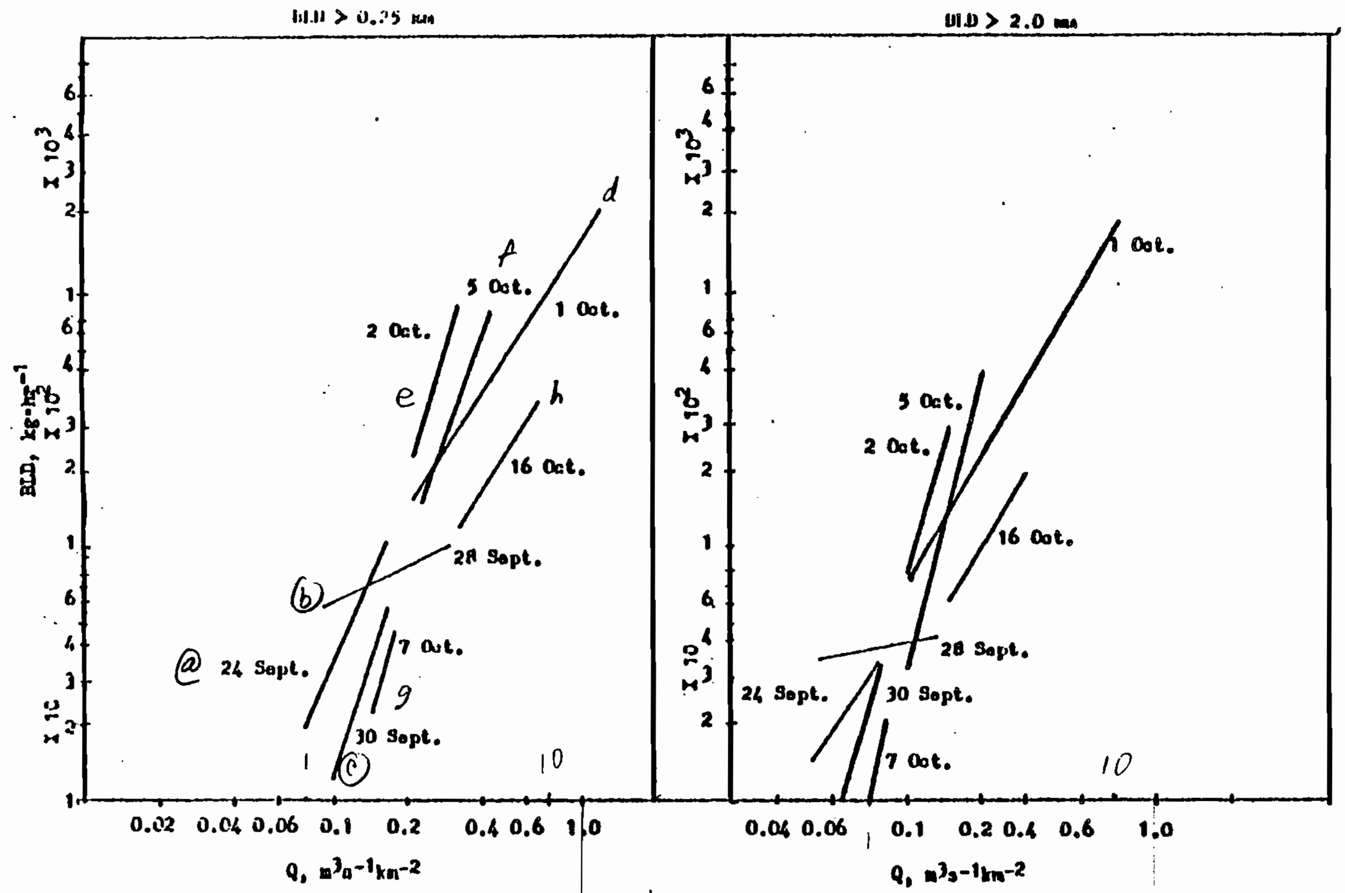

Figure 36. Bedload (BLD) vs. streamflow (Q) relationships for individual storm events for data collected from Trap Bay Creek, Chichagof Island, Alaska, during the Fall, 1980, storm season

NOTE: Relationships are depicted only over the range of streamflow observed. The 23 Sept. and 18 Oct. events are not depicted. (see text). Plots also include some relationships that were not statistically significant (see Table 12).

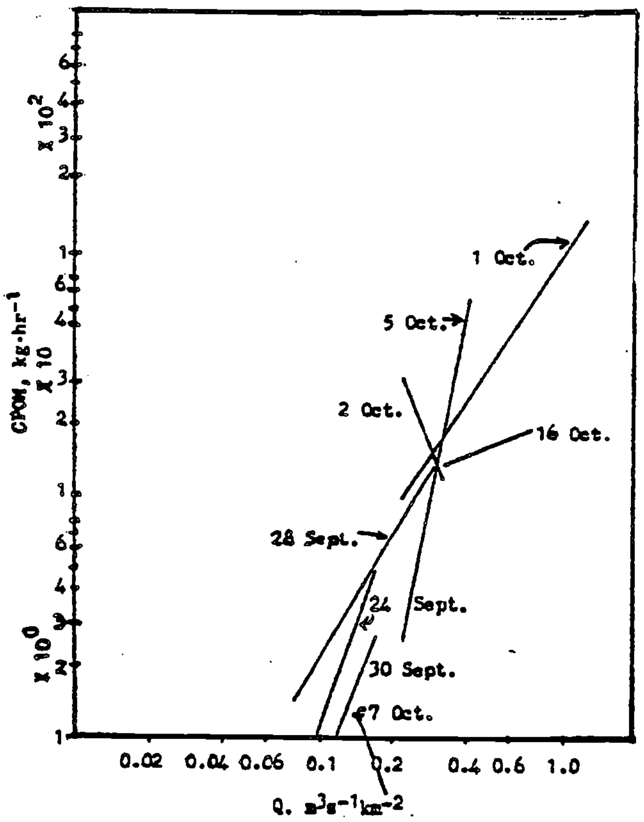

Figure 37. Coarse particulate organic matter (CPOM) vs. streamflow (Q) relationships for individual storm events for data collected from Trap Bay Creek, Chichagof Island, Alaska, during the Fall, 1980, storm season

NOTE: Relationships are depicted only over the range of streamflow observed. The 23 Sept. and 18 Oct. events are not depicted - see text. Plots also include some relationships that were not statistically significant (see Table 12).

in determining what particle size will be set in motion than discharge alone.

The data were also examined to see if stratification by sampling site, hydrograph limb, and site and hydrograph limb combined for each storm to see whether correlations between streamflow and the parameters being examined would improve. These equations are included in Appendix 3. In general, test statistics for relationships for the two size fractions of bedload and CPOM improved when the data were stratified by sampling site for each storm. Total bedload transport (BLD > 0.25 mm) was highly correlated with streamflow during the 1 October event at the lower riffle (r^2 - 0.96), but very poorly correlated with streamflow at the upper riffle during this storm ($r^2 = 0.06$). BLD > 2.0 mm, CPOM, D_{50} and D_{90} were also fairly well correlated with discharge during the 1 October storm at the lower riffle. Bedload transport remained fairly well correlated with streamflow during the two events following the 1 October storm, 2 October and 5 October. The relationships developed for all other events at the lower riffle had relatively low correlation coefficients.

In contrast, correlation coefficients for relationships developed for the upper riffle were highest for the three storms preceding the 1 October event, 24 September, 28 September, and 30 Sept.-1 Oct., and were relatively high for the 7 and 16 October events. Possibly, bedload transport and streamflow are more strongly related during lesser magnitude events at the upper riffle than at the lower riffle because of supply limitations. Material may be available for transport past the upper riffle during low magnitude events, but it is deposited in the pool and is not readily available for transport past the lower riffle. Lower magnitude events may thus result in a build-up of material in the pool but only transport material past the lower riffle sporadically, so there is not a good realtionship between discharge and bedload transport at the lower riffle during these events.

Material transported to depositional areas during lower magnitude events may than become available for transport past the lower riffle only during the following events of sufficient magnitude, such as the 1 October storm at Trap Bay. This storm may have initiated transport of material out of the pool and made the remaining stored material available for transport during the following two events. Discharge could then become the dominant factor in bedload transport because the lower riffle was no longer supply limited.

The poor relationship between discharge and bedload transport at the upper riffle during the 1 October event may indicate that there was little sediment available for transport. The estimated amount of sediment transport past the upper riffle was much less than that for the lower riffle during this storm, and estimated sediment transport at the lower riffle only exceeded that at the upper riffle during the 1 and 7 October events (Table 8). A lack of available sediment for transport past the upper riffle during the 1 October storm could have resulted in both a poor relationship between transport and streamflow, and in a low amount of transport.

CPOM relationships did not show the same trends as did the bedload transport relationships. In general, CPOM was more strongly related to discharge than bedload transport, possibly because CPOM supply is more directly related to streamflow, while bedload supply can be limited by the size and arrangement of particles on the bed.

Relationships developed for the data when they were stratified by rising vs. falling limb on a storm by storm basis are also included in Appendix 3. r^2-values for these relationships were higher for rising-limb relationships for all parameters than they were for falling-limb relationships. That there appears to be a stronger relationship between bedload and CPOM transport and streamflow during rising limbs than during falling limbs was not obvious when all the storms were considered together. This may be a result of the greater number of data points for falling limbs ($n = 74$) than for rising limbs ($n = 58$) or it may be that there is less storm-to-storm variation in the falling limb data.

Finally, data were stratified according to storm, sampling site, and hydrograph limb (Appendix 3). The relationships were generally similar to those developed using various composites of the data. Test statistics were significant for the relationships for bedload and CPOM for the same events that had significant relationships when composites of the data were used (24 September, 1 October, and 5 October). There is considerable variation among regression coefficients for different storms and between rising and falling limbs of the same storm. There is also variation in regression coefficients for relationships developed for the same hydrograph limb between the upper and lower riffles. Variations in relationships tended to be considerably greater for falling limbs than for rising limbs. Obviously, the natural spatial and temporal variation in bedload transport probably precludes the development of a single general equation which will apply during all storms.

Correlation coefficients for equations developed for the larger size fraction of inorganic bedload (BLD > 2.0 mm) tended to be slightly lower than those for relationships of BLD > 0.25 mm and streamflow. Apparently, transport of larger particles (medium to coarse gravel) is not as strongly related to discharge. "a" coefficients for (BLD > 2.0 mm) relationships were generally about half as great as those for (BLD > 0.25 mm) relationships, while "b" coefficients were generally greater. Thus, about half of the material transported at a given discharge was composed of medium to coarse sand and gravel, while the remainder was composed of larger particles. The mass of larger particles in transport tended to increase at a slightly greater rate with increased discharge than did the total mass in transport.

CPOM relationships tended to have significant test statistics for the same events for which bedload relationships were significant. However, different processes appear to control the supply and transport of organic and inorganic particulate matter, even when both are related to streamflow. This is evident if regression coefficients for bedload and CPOM relatioships for the same storm, sampling site, and hydrograph limb are compared.

Organic material enters the system sporadically in the form of coarse particulates (leaves, twigs, needles, and bark). This material is broken down to fine and very fine particulates by aquatic organisms and by mechanical processes, and then becomes available for transport in suspension. CPOM must first be colonized by bacteria and fungi before it becomes a good food source for aquatic organisms (Cummins, 1974). Deciduous plant material is more readily utilized as a food source by these organisms than is evergeen plant material; thus it is reduced to fine particulate form more quickly (Cummins, 1974). Therefore, several factors are important in determining the supply and ultimate partitioning of the organic load of the stream, including the rate and type of material entering the stream, the rate of consumption of organics by aquatic organisms, and the availability of the material for transport (size and location). Even during the fall, when organic inputs are greatest, Trap Bay Creek appears to be supply-limited in organic material available for transport because so little shows up in suspension.

Data collected using the Helley-Smith sampler indicated that during the 1980 Fall storm season at Trap Bay Creek, streamflow was only one of the factors determining bedload transport, that there was a general increase in material transported with increasing discharge, and that transport appeared to occur in pulses or "waves." Particle size diameter did not appear to be related to discharge, nor did there appear to be any relation between particle size diameter and the total mass of material in transport.

Bedload Transport at Flynn Creek, Oregon vs Trap Bay, Alaska

Flynn Creek is a small second order stream in the Alsea River Basin of Western Oregon. Sediment sampling facilities were installed in 1976; several researchers have conducted bedload sediment transport studies there since 1976. Both the Flynn Creek and Trap Bay Creek Watersheds receive most of their precipitation in the form of light to moderate intensity, long duration frontal storms, with 90% or more occurring from November to May. The total precipitation and average temperature of the two areas are very similar.

In contrast to Trap Bay, however, soils at Flynn Creek are relatively deep and are derived from sandstone bedrock. Douglas fir (_Pseudotsuga menziesii_) and red alder (_Alnus rubra_) dominate the overstory. The drainage area of Flynn Creek is 218 ha (O'Leary, 1980) while that of Trap Bay is 1355 ha. The average elevation of Flynn Creek is 320 m and the relief ratio is 0.13, while these parameters for Trap Bay Creek are 590 m and 0.24, respectively. Flynn Creek is about one-third as long, one-tenth as wide, and one-ninth as deep as Trap Bay Creek. Thus, there are several differences between these two streams which must be kept in mind when comparisons of sediment transport are made.

Table 13 lists bedload and CPOM transport relationships developed for Flynn Creek for the 1978 (O'Leary, 1980) and 1979 (Edwards, 1979) water years. These relationships were developed using the same power equation that was used in developing relationships for Trap Bay Creek. The data presented by O'Leary (1980) were collected with a vortex sampler. Data presented by Edwards (1979) were collected with a vortex sampler at the fishtrap and with a Helley-Smith sampler with a large collection bag at the riffle site.

It is at once obvious that the realtionships developed from data collected at the riffle site at Flynn Creek are more similar to those

TABLE 13. Bedload (BLD) and Coarse Particulate Organic Matter (CPOM) Relationships for Flynn Creek, Oregon, and Trap Bay Creek, Chichagof Island, Alaska

Site of collection	Date	Equation[1]	r^2	Source
Flynn Creek, Fish Trap	11/24-25 1978	$\text{BLD} > 0.25\ \text{mm} = 98\ Q^{8.24}$	0.66	O'Leary, 1980
	12/ 2-3 1978	$\text{BLD} > 0.25\ \text{mm} = 110\ Q^{1.41}$	0.32	
	12/13-15 1978	$\text{BLD} > 0.25\ \text{mm} = 694\ Q^{5.43}$	0.55	
Flynn Creek, Riffle Site	2/7 1979	$\text{BLD} > 0.25\ \text{mm} = 1536\ Q^{2.46}$	0.79	Edwards, 1979
		$\text{BLD} > 2.0\ \text{mm} = 770\ Q^{2.64}$	0.71	
	1979 WY	$\text{BLD} > 0.25\ \text{mm} = 137\ Q^{1.98}$	0.90	
	2/ 6-8	$\text{CPOM} = 571\ Q^{2.80}$	0.90	
Flynn Creek, Fish Trap	2/7 1979	$\text{BLD} > 0.25\ \text{mm} = 766\ Q^{4.13}$	0.93	Edwards, 1979
		$\text{BLD} > 2.0\ \text{mm} = 131\ Q^{5.27}$	0.92	
	1979 WY	$\text{CPOM} = 250\ Q^{2.55}$	0.96	
Trap Bay Cr., data from both riffles	10/1 1980	$\text{BLD} > 0.25\ \text{mm} = 1632\ Q^{1.53}$	0.59	
		$\text{BLD} > 2.0\ \text{mm} = 1075\ Q^{1.73}$	0.58	
		$\text{CPOM} = 101\ Q^{1.54}$	0.60	
	1980 storm season	$\text{BLD} > 0.25\ \text{mm} = 1534\ Q^{1.61}$	0.69	
		$\text{BLD} > 2.0\ \text{mm} = 877\ Q^{1.72}$	0.66	
		$\text{CPOM} = 89\ Q^{1.86}$	0.77	

[1] Q represents streamflow in $m^3 s^{-1} km^{-2}$.

developed for Trap Bay Creek than are those developed from data collected at the Fish Trap. There are two reasons why this is to be expected: (1) A vortex sampler was used at the Fish Trap while a Helley-Smith sampler was used at the riffle site, (2) Sand-sized particles are the dominant particles in transport at the Fish Trap while gravels tend to to dominant at the riffle (Edwards, 1980).

In general, "b" coefficients for the equations for Flynn Creek are significantly greater than those for relationships for Trap Bay Creek, indicating that transport tends to increase more rapidly with discharge at Flynn Creek. The "a" coefficients for Flynn Creek relationships tend to be somewhat less than those for Trap Bay Creek. This probably reflects the difference in the average particle sizes of bed material in these two streams, with that of Trap Bay Creek being somewhat larger and more angular (personal observation).

Relationships developed for the peak flow event of 1979 at Flynn Creek, 7 February, and the peak flow event of 1980 at Trap Bay Creek, 1 October, are similar for the riffle site at Flynn Creek. Edwards (1980) reported an estimate of inorganic sediment yield of 2.6 tonnes and an organic sediment yield of 1.5 tonnes at the Fish Trap for the 24-hour period on 7 February 1979, the annual peak flow event. This storm had a peak discharge of 0.75 $m^3s^{-1}km^{-2}$. For the riffle site at Flynn Creek for the same time period, inorganic sediment yield was estimated to be 13.0 tonnes and organic sediment yield was estimated to be 1.7 tonnes. For Trap Bay Creek during the 1 October event which had a peak flow of 2.56 $m^3s^{-1}km^{-2}$, based on the relationships developed for this storm (Table 12) and using data from both riffles, total inorganic sediment yield was 8.0 tonnes and total organic sediment yield was 0.5 tonnes. This is not what the difference in the size and discharge between the two streams would lead one to expect. The low total sediment yield for Trap Bay Creek probably again reflects the difference in the size and shape of bedload particles between the two streams.

The major factor in influencing the size and shape differences in bedload sediment is the geology of the watershed. The sandstone bedrock underlying the Flynn Creek watershed is relatively easily weathered and breaks down to form an abundance of sand-sized particles (O'Leary, 1979). Thus, most of the bedload sediment yield consists of sand-sized particles (Edwards, 1980). Granitic parent material supplies some of the material transported as bedload by Trap Bay Creek. This material is relatively resistant and, when broken down, the particles may compose a large proportion of the armor layer and tend to orient themselves to flow in such a way as to resist transport. Thus, a greater discharge is necessary to initiate bedload transport at Trap Bay Creek than at Flynn Creek because of the larger size and the orientation of the armor layer particles. The low total sediment yield at Trap Bay Creek probably reflects the fact that more energy is required to dislodge and maintain transport of these larger, angular particles.

VII. CONCLUSIONS

1. Based on general observations and a planimetric survey of the lower 1890 m of the stream, the channel morphology of Trap Bay Creek is largely influenced by inputs of large organic debris in conjunction with flows and bedload transport. Tree-sized material serves to trap small debris and sediment, can result in localized deposition and scour, contributes to bank stability, and serves as cover for salmonids.

2. Because of the lithology of the watershed, during average storm events, more sediment is transported out of the system in the form of bedload than is transported as suspended sediment. Both suspended and bedload transport appear to be supply limited, however, so that any increased availability in sediment is likely to result in increased transport rates.

3. Although suspended sediment transport appears to be normally much less than bedload transport, any future research on suspended sediment transport in this stream in Trap Bay Creek, should include modification of analytical procedures and equipment to alleviate problems encountered in this study. These modifications might include the addition of an accurate weighing scale (for filter discs) and a long-running power source (for turbidimeter warm-up) at the field installation.

4. Bedload transport is a dynamic process which is generally related to streamflow. Based on sampling conducted during Fall 1980 at a pool-riffle sequence on Trap Bay Creek, events with a magnitude of less than one year return period appeared mainly to transport material

to the pool where it was temporarily stored. Transport through the pool-riffle sequence occurred when the magnitude of the storm event was great enough to transport material out of the pool and past the riffle. Transport of material dislodged by greater magnitude events may continue during successive low to moderate storms until some form of armoring takes place in the pool or some other form of supply limitation begins to dominate the transport process.

5. Rating curve relationships indicated a general increase in bedload transport with increased discharge, but relationships developed for individual events show considerable variability. Rating curve relationships developed for this study period appear to be site and storm specific for Trap Bay Creek.

6. Over the range of streamflows during which sampling took place, particle size diameter did not appear to be related to discharge, nor did it appear to be related to the total amount of material in transport.

7. Bedload transport during the study period appeared to be more strongly controlled by stream discharge on the rising limb of the hydrograph than on the falling limb. Supply limitations or partial rearmoring of the streambed may have influenced transport on the falling limb. CPOM transport is generally more strongly related to discharge than is bedload transport.

8. The difference in the geology and lithology of Trap Bay and Flynn Creek, as well as watershed and stream size differences, apparently results in some interesting contrasts in sediment transport between these two systems. Suspended sediment is a much larger portion of

total sediment transport in Flynn Creek, and smaller particle sizes characterize the bedload portion relative to bedload in Trap Bay Creek. Extreme spatial and temporal variability in bedload transport is characteristic of both streams. Total sediment yield, however, appears to be greater for Flynn Creek and transport appears to increase more rapidly here with increasing streamflow than in Trap Bay Creek. This may reflect the differences in the size and shape of bedload particles between the two streams, which are ultimately a result of the geologic difference between the two watersheds.

10. The hand-held Helley-Smith sampler provided a means of collecting bedload transport data in a relatively inaccessible area. Samples obtained using the Helley-Smith do not incorporate all of the temporal and spatial variation in bedload transport, but they do appear to provide a useful index to relative transport rates.

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APPENDICES

APPENDIX 1.

List of Common and Scientific Names of Plants and Animals Referred to in This Paper

Plants

Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Western hemlock	Tsuga heterophylla (Raf.) Sarg.
Red alder	*Alnus rubra* Bong.
Lodgepole pine	*Pinus contorta* Dougl.
Western redcedar	*Thuja plicata* Donn.
Blueberry	*Vaccinium alaskaense* Howell.
Huckleberry	*V. parvifolium* Sm.
Salmonberry	*Rubus spectabilis* Pursh.
Devils club	*Oplopanax horridus* (Sm.) Miq.
Skunk cabbage	*Lysichitum americanum* Hult. and St. John
Sedge	*Carex* L.
Nettles	*Urtica Lyallii* S. Wats.

Animals

Beaver	*Castor canadensis* L.
Pink salmon	*Oncorhynchus gorbuscha* Walbaum.
Coho salmon	*O. kisutch* Walbau.
Dolly varden char	*Salvelinus malma* Walbaum.

APPENDIX 2.

Equations For Predicting Mean Annual Flow, Mean Monthly Flows for August Through November, and Peak Flows for Storms of Various Return Periods for Trap Bay Creek, Chichagof Island, Alaska, Taken from the *Water Resources Atlas for Alaska* (1979)

Mean annual flow, $\bar{Q}_{an}$ = $.0312\ P^{1.13}\ A^{1.03}$ = 29.45 cfs $R^{2^{1}}$ = 0.97
90% C.I. = 25-34

Mean August flow, $\bar{Q}_A$ = $.0013\ P_m\ 1.43\ A^{.952}\ T^{.0181} E^{.671} C^{.179}$ = 36.7 cfs
R^2 = 0.96 90% C.I. = 18-42
P_m = mean monthly precip. = 7.6 in.

Mean September flow, $\bar{Q}_S$ = $.0564\ P_m^{1.07}\ A^{.99}\ E^{.34}$ = 44.35 cfs
R^2 = 0.97 90% C.I. = 21-54
P_m = 11.4 in.

Mean October flow, $\bar{Q}_O$ = $1.26\ P_m^{.981}\ A^{1.05}\ C^{-.169}$ - 38.8 cfs
R^2 = 0.97 90% C.I. = 25-57
P_m = 14.25 in.

Mean November flow, $\bar{Q}_N$ = $4.03\ P_m^{.838}\ A^{1.05}\ T^{-.018}\ C^{-.362}$ = 22.0 cfs
R^2 = 0.97 90% C.I. = 14-27
P_m = 10.45 in.

2-year peak flow, Q_2 = $12.4\ P^{1.24}\ A^{.902}\ L^{-.337}\ E^{-.477}$ = 520 cfs
R^2 = 0.94 90% C.I. = 375-910

5-year peak flow, Q_5 = $17.8\ P^{1.20}\ A^{.907}\ L^{-.346}\ E^{0.461}$ = 703 cfs
R^2 = 0.93 90% C.I. = 470-1080

10-year peak flow, Q_{10} = $19.8\ P^{1.15}\ A^{.898}\ L^{-.352}\ E^{-.417}$ = 840 cfs
R^2 = 0.93 90% C.I. = 535-1145

25-year peak flow, Q_{25} = $23.7\ P^{1.2}\ A^{.905}\ L^{-.355}\ E^{-.408}$ == 946 cfs
R^2 = 0.93 90% C.I. = 595-1490

50-year peak flow, Q_{50} = $26.2\ P^{1.09}\ A^{.903}\ L^{-.356}\ E^{-.371}$ = 1079 cfs
R^2 = 0.92 90% C.I. = 640-1650

100-year peak flow, Q_{100} = $30.3\ P^{1.06}\ A^{.904}\ .^{-.359}\ E^{-.371}$ = 1196 cfs
R^2 = 0.91 90% C.I. = 710-1890

P = mean annual precipitation from map = 95 in.
A = basin area = 5.23 sq.mi.
L = proportion of basin in main channel lakes - used 1% to avoid negative logarithm.
E = mean basin elevation:

$$E_{ave} = E_{min} + .324(E_{max} + E_{min}) = 1254 \text{ ft.}$$

T = % of basin above treeline = 3.7%
C = south distance to Gulf of Alaska = 277.5 mi.

APPENDIX 3.

Relationships Between Bedload Transport, Coarse Particulate Organic Matter Transport, Two Particle Diameters, and Streamflow Which Were Not Included in the Text

TABLE 16. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for Individual Storm Events at the Upper Riffle, Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

Storm	n	equation	r^2	F^3	t^3	
					a	b
		BLD > 0.25 mm, $kg\cdot hr^{-1}$				
23 Sept.	3	$884505\ Q^{3.10}$	0.03			
24 Sept.	5	$23742\ Q^{2.52}$	0.82	**	**	**
28 Sept.	5	$1316\ Q^{1.27}$	0.44		**	
30 Sept.- 1 Oct.	6	$1846\ Q^{1.93}$	0.76	**	**	**
1 Oct.	16	$966\ A^{-0.3}$	0.06		**	
2 Oct.	7	$119058\ Q^{4.26}$	0.84	**	**	**
5 Oct.	10	$2812\ Q^{2.04}$	0.20		**	*
7 Oct.	6	$2.5*10^{8}Q^{8.0}$	0.51		**	*
16 Oct.	7	$927\ Q^{1.83}$	0.48	*	**	**
		BLD > 2.0 mm, $kg.hr^{-1}$				
23 Sept.	3	$7*10^{6}\ Q^{4.54}$	0.06			
24 Sept.	5	$1302\ Q^{1.56}$	0.70	*	**	**
28 Sept.	5	$1142\ Q^{1.49}$	0.54		**	*
30 Sept.- 1 Oct.	6	$1464\ Q^{2.12}$	0.64	**	**	**
1 Oct.	16	$567\ Q^{-0.4}$	0.07		**	
2 Oct.	7	$12015\ Q^{3.05}$	0.48		**	*
5 Oct.	10	$4843\ Q^{3.27}$	0.36	*	**	*
7 Oct.	6	$2.7*10^{9}Q^{10.8}$	0.70	**	**	**
16 Oct.	7	$516\ Q^{1.90}$	0.59	**	**	**
		CPOM, $kg.hr^{-1}$				
23 Sept.	3	$5*10^{14}\ Q^{10.6}$	0.07			
24 Sept.	5	$835\ Q^{2.77}$	0.81	**	**	**
28 Sept.	5	$59\ Q^{1.47}$	0.60		**	*
30 Setp.- 1 Oct.	6	$71\ Q^{0.61}$	0.61	**	**	**
1 Oct.	16	$80\ Q^{0.32}$	0.08		**	
2 Oct.	7	$1.6\ Q^{-0.8}$	0.14			
5 Oct.	10	$2399\ Q^{.57}$	0.61	**	**	**
7 Oct.	6	$0.1\ Q^{-0.9}$	0.00			
16 Oct.	7	$25\ Q^{0.82}$	0.28		**	

TABLE 16. - continued

Storm	n	equation	r^2	F^3	t^3 a	t^3 b
		D_{50}, mm				
23 Sept.	3	$2.7*10^{12}\ Q^{8.12}$	0.45			
24 Sept.	5	$0.02\ Q^{-2.1}$	0.83	**	**	**
28 Sept.	5	$3.94\ Q^{0.20}$	0.04			
30 Sept.- 1 Oct.	6	$4.81\ Q^{0.39}$	0.06		*	
1 Oct.	16	$2.50\ Q^{-0.2}$	0.07		**	
2 Oct.	7	$0.36\ Q^{-1.3}$	0.17			
5 Oct.	10	$16.93\ Q^{2.16}$	0.52	**	**	**
7 Oct.	6	$2272.20\ Q^{4.10}$	0.21			
16 Oct.	7	$2.43\ Q^{0.22}$	0.06		**	
		D_{90}, mm				
23 Sept.	3	$2.9*10^{12}\ Q^{7.77}$	0.50			
24 Sept.	5	$1.00\ Q^{-1.0}$	0.81	**		**
28 Sept.	5	$9.27\ Q^{-0.2}$	0.05		**	
30 Sept.- 1 Oct.	6	$8.60\ Q^{-0.1}$	0.02		**	
1 Oct.	16	$3.21\ Q^{-0.2}$	0.06		**	
2 Oct.	7	$14.41\ Q^{0.43}$	0.01			
5 Oct.	10	$17.18\ Q^{0.19}$	0.03		**	
7 Oct.	6	$17093.10\ Q^{4.25}$	0.21			
16 Oct.	7	$7.77\ Q^{-0.4}$	-.09		**	

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[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3 s^{-1} km^{-2}$.

[3] * indicates significance at the 90% level of probability; ** indicates significance at the 95% level of probability.

TABLE 17. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for Individual Storm Events at the Lower Riffle, Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980 Storm Season

Storm	n	equation	r^2	F^3	t^3 a	t^3 b
		BLD > 0.25 mm, $kg.hr^{-1}$				
23 Sept.	3	$2.5*10^6\ Q^{3.95}$	0.14			
24 Sept.	5	$1288\ Q^{1.89}$	0.52		**	*
28 Sept.	5	$35\ Q^{-0.2}$	0.13		**	
30 Setp.- 1 Oct.	6	$3715\ Q^{2.57}$	0.21		*	
1 Oct.	16	$2583\ Q^{1.90}$	0.96	**	**	**
2 Oct.	7	$26384\ Q^{3.49}$	0.74	**	**	**
5 Oct.	10	$42970\ Q^{4.03}$	0.61	**	**	**
7 Oct.	6	$0.09\ Q^{-3.5}$	0.23			
16 Oct.	7	$504\ Q^{1.26}$	0.32		**	*
		BLD > 2.0 mm, $kg.hr^{-1}$				
23 Sept.	3	$0.03\ Q^{-1.3}$	0.10			
24 Sept.	5	$214\ Q^{1.31}$	0.30	**	*	
28 Sept.	5	$4\ Q^{-0.8}$	0.14			
30 Sept.- 1 Oct.	6	$1503\ Q^{2.41}$	0.11			
1 Oct.	16	$1720\ Q^{2.12}$	0.95	**	**	**
2 Oct.	7	$27326\ Q^{4.06}$	0.70	**	**	**
5 Oct.	10	$37775\ Q^{4.68}$	0.54	**	**	**
7 Oct.	6	$0.01\ Q^{4.19}$	0.12			
16 Oct.	7	$290\ Q^{1.31}$	0.25		**	
		CPOM, $kg.hr^{-1}$				
23 Sept.	3	$13408\ Q^{3.20}$	0.47			
24 Sept.	5	$1025\ Q^{3.14}$	0.71	**	**	**
28 Sept.	5	$189\ Q^{1.97}$	0.59	**	**	*
30 Sept.- 1 Oct.	6	$35\ Q^{1.59}$	0.14			
1 Oct.	16	$127\ Q^{1.62}$	0.65	**	**	**
2 Oct.	7	$0.3\ Q^{-3.2}$	0.43	*		*
5 Oct.	10	$1057\ Q^{3.75}$	0.72	**	**	**
7 Oct.	6	$0.0002\ Q^{-4.8}$	0.03			
16 Oct.	7	$18\ Q^{0.04}$	0			

TABLE 17. - continued

Storm	n	equation	r^2	F^3	t^3	
					a	b
		D_{50}, mm				
23 Sept.	3	$5.6*10^{15}\ Q^{-9.9}$	0.58			
24 Sept.	5	$0.31\ Q^{-0.7}$	0.23			
28 Sept.	5	$0.19\ Q^{-1.4}$	0.37			
30 Sept.- 1 Oct.	6	$1.77\ Q^{-0.2}$	0			
1 Oct.	16	$3.90\ Q^{0.59}$	0.36	**	**	**
2 Oct.	7	$12.02\ Q^{1.52}$	0.12		*	
5 Oct.	10	$4.09\ Q^{0.97}$	0.10			
7 Oct.	6	$0.64\ Q^{-0.4}$	0.01			
16 Oct.	7	$2.49\ Q^{0.03}$	0			
		D_{90}, mm				
23 Sept.	3	$200.90\ Q^{1.05}$	0			
24 Sept.	5	$2.72\ Q^{-0.7}$	0.11			
28 Sept.	5	$1.17\ Q^{-1.2}$	0.31			
30 Sept.- 1 Oct.	6	$57.27\ Q^{0.80}$	0.06		*	
1 Oct.	16	$16.29\ Q^{0.32}$	0.27	**	**	**
2 Oct.	7	$179.34\ Q^{2.07}$	0.40	**	**	*
5 Oct.	10	$0.03\ Q^{-0.03}$	0.13		**	
7 Oct.	6	$164.06\ Q^{1.81}$	0.06			
16 Oct.	7	$11.05\ Q^{-0.5}$	0.08		**	

[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3s^{-1}km^{-2}$.

[3] * indicates significance at the 90% level of probability;
** indicates significance at the 95% level of probability.

TABLE 18. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] For the Rising Limbs of Storm Hydrographs For Individual Storm Events at Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

Storm	n	equation	r^2	F^3	t^3	
					a	b
		BLD > 0.25 mm, $kg.hr^{-1}$				
24 Sept.	5	$8345\ Q^{2.51}$	0.58		**	*
28 Sept.	10	$185\ Q^{0.48}$	0.07		**	
30 Sept.- 1 Oct.	6	$187\ Q^{1.14}$	0.15		*	
1 Oct.	14	$1689\ Q^{1.60}$	0.74	**	**	**
2 Oct.	9	$128345\ Q^{4.44}$	0.81	**	**	**
5 Oct.	12	$4677\ Q^{2.38}$	0.45	**	**	**
		BLD > 2.0 mm, $kg.hr^{-1}$				
24 Sept.	5	$760\ Q^{1.71}$	0.36		**	
28 Sept.	10	$60\ Q^{0.23}$	0.01			
30 Sept.- 1 Oct.	6	$102\ Q^{1.16}$	0.06			
1 Oct.	14	$1095\ Q^{1.63}$	0.72	**	**	**
2 Oct.	9	$52119\ Q^{4.25}$	0.78	**	**	**
5 Oct.	12	$4764\ Q^{3.10}$	0.52	**	**	**
		CPOM, $kg.hr^{-1}$				
24 Sept.	5	$2728\ Q^{3.41}$	0.85	**	**	**
28 Sept.	10	$109\ Q^{1.74}$	0.58	**	**	**
30 Sept.- 1 Oct.	6	$13772\ Q^{4.38}$	0.70	**	**	**
1 Oct.	14	$107\ Q^{2.20}$	0.82	**	**	**
2 Oct.	9	$1.4\ Q^{-2.1}$	0.20			
5 Oct.	12	$2463\ Q^{4.70}$	0.75	**	**	**
		D_{50}, mm				
24 Sept.	5	$0.06\ Q^{-1.6}$	0.68	*	*	**
28 Sept.	10	$0.17\ Q^{-0.7}$	0.12			
30 Sept.- 1 Oct.	6	$10.69\ Q^{0.68}$	0.02			
1 Oct.	14	$3.54\ Q^{0.07}$	0.01			
2 Oct.	9	$3.99\ Q^{0.55}$	0.03			
5 Oct.	12	$3.68\ Q^{1.19}$	0.20		**	*

TABLE 18. - continued

Storm	n	equation	r^2	F^3	t^3	
					a	b
		D_{90}, mm				
24 Sept.	5	$1.13\ Q^{-0.9}$	0.76	*		**
28 Sept.	10	$3.16\ Q^{-0.7}$	0.18			
30 Sept.- 1 Oct.	6	$48.14\ Q^{0.72}$	0.17			
1 Oct.	14	$16.58\ Q^{0.23}$	0.25		**	*
2 Oct.	9	$81.66\ Q^{1.54}$	0.21		**	*
5 Oct.	12	$24.60\ Q^{0.69}$	0.16		**	*

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[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3s^{-1}km^{-2}$.

[3] * indicates significance at the 90% level of probability; ** indicates significance at the 95% level of probability.

TABLE 19. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for the Falling Limbs of Storm Hydrographs For Individual Storm Events at Trap Bay Creek, Chichagof Island, Alaska During the Fall, 1980, Storm Season

Storm	n	equation	r^2	F^3	t^3	
					a	b
		BLD > 0.25 mm, $kg.hr^{-1}$				
23 Sept.	4	$3948117\ Q^{3.91}$	0.03			
24 Sept.	5	$15\ Q^{-0.9}$	0.01			
30 Sept.- 1 Oct.	6	$1424\ Q^{1.66}$	0.60	**	**	**
1 Oct.	18	$1451\ Q^{0.86}$	0.27	**	**	**
2 Oct.	5	$3337\ Q^{1.75}$	0.05			
5 Oct.	8	$222844\ Q^{6.02}$	0.15			
7 Oct.	12	$11337\ Q^{3.22}$	0.07			
16 Oct.	14	$718\ Q^{1.61}$	0.40	*	**	**
		BLD > 2.0 mm, $kg.hr^{-1}$				
23 Sept.	4	$992\ Q^{1.62}$	0			
24 Sept.	5	$3\ Q^{-1.2}$	0.03			
30 Sept.- 1 Oct.	6	$1075\ Q^{1.82}$	0.47	*	**	**
1 Oct.	18	$893\ Q^{1.05}$	0.24	**	**	**
2 Oct.	5	$75617\ Q^{5.18}$	0.23	*		
5 Oct.	8	$166805\ Q^{6.33}$	0.14			
7 Oct.	12	$15066\ Q^{3.88}$	0.08			
16 Oct.	14	$404\ Q^{1.65}$	0.41	*	**	**
		CPOM, $kg.hr^{-1}$				
23 Sept.	4	$19896\ Q^{3.36}$	0.27			
24 Sept.	5	$3\ Q^{0.13}$	0			
30 Sept.- 1 Oct.	6	$61\ Q^{2.09}$	0.77	**	**	**
1 Oct.	18	$78\ Q^{0.35}$	0.14		**	**
2 Oct.	5	$254\ Q^{2.83}$	0.96	**	**	**
5 Oct.	8	$1216\ Q^{4.39}$	0.13			
7 Oct.	12	$0.0006\ Q^{-2.7}$	0.01			
16 Oct.	14	$21\ Q^{0.40}$	0.06			
		D_{50}, mm				
23 Sept.	4	$4.27\ Q^{0.16}$	0			
24 Sept.	5	$0.22\ Q^{-0.9}$	0.09			
30 Sept.- 1 Oct.	6	$4.74\ Q^{0.06}$	0.07			
1 Oct.	18	$3.13\ Q^{0.51}$	0.20	*	**	**
2 Oct.	5	$45.29\ Q^{2.99}$	0.10			
5 Oct.	8	$4.89\ Q^{0.83}$	0.02			
7 Oct.	12	$51.59\ Q^{1.99}$	0.05			
16 Oct.	14	$2.41\ Q^{0.09}$	0			

TABLE 19. - continued

Storm	n	equation	r^2	F^3	t^3	
					a	b
		D_{50}, mm				
23 Sept.	4	$7*10^{10}\ Q^{6.80}$	0.08			
24 Sept.	5	$21.36\ Q^{0.59}$	0.06			
30 Sept.- 1 Oct.	6	$7.70\ Q^{-0.3}$	0.07			
1 Oct.	18	$14.26\ Q^{0.10}$	0.02			
2 Oct.	5	$2*10^{6}\ Q^{11}$	0.40			
5 Oct.	8	$31.26\ Q^{0.78}$	0.03			
7 Oct.	12	$1949.2\ Q^{3.11}$	0.12		*	
16 Oct.	14	$8.73\ Q^{-0.6}$	0.09			

[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3 s^{-1} km^{-2}$.

[3] * indicates significance at the 90% level of probability; ** indicates significance at the 95% level of probability.

TABLE 20. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for the Rising Limbs of Individual Storm Events at the Upper Riffle of Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

Storm	n	equation	r^2	F^3	t^3	
					a	b
		BLD > 0.25 mm, $kg.hr^{-1}$				
24 Sept.	3	$11220\ Q^{2.23}$	0.99		**	**
28 Sept.	5	$1316\ Q^{1.28}$	0.44		**	**
30 Sept.- 1 Oct.	3	$1288\ Q^{1.91}$	0.99	**	**	**
1 Oct.	7	$1175\ Q^{-0.1}$	0			
2 Oct.	5	$174582\ Q^{4.50}$	0.92	**	**	**
5 Oct.	6	$1641\ Q^{0.54}$	0.54	*	**	**
		BLD > 2.0 mm, $kg.hr^{-1}$				
24 Sept.	3	$708\ Q^{1.36}$	0.90		**	**
28 Sept.	5	$1142\ Q^{1.49}$	0.54		**	*
30 Sept.- 1 Oct.	3	$2570\ Q^{2.56}$	0.81		*	
1 Oct.	7	$687\ Q^{0.14}$	0.03			
2 Oct.	5	$27290\ Q^{3.57}$	0.86	**	**	**
5 Oct.	6	$3175\ Q^{2.88}$	0.89	**	**	**
		CPOM, $kg.hr^{-1}$				
24 Sept.	3	$1039\ Q^{0.82}$	0.82			
28 Sept.	5	$59\ Q^{1.47}$	0.60		**	*
30 Sept.- 1 Oct.	3	$1303166\ Q^{6.55}$	0.90		*	
1 Oct.	7	$116\ Q^{-0.3}$	0.01			
2 Oct.	5	$3\ Q^{-1.5}$	0.11			
5 Oct.	6	$4227\ Q^{5.45}$	0.86	**	**	**
		D_{50}, mm				
24 Sept.	3	$0.03\ Q^{-2.0}$	0.86			
28 Sept.	5	$3.94\ Q^{0.20}$	0.04			
30 Sept.- 1 Oct.	3	$46.24\ Q^{1.42}$	0.11			
1 Oct.	7	$2.62\ Q^{0.72}$	0.09			
2 Oct.	5	$0.62\ Q^{-0.9}$	0.23			
5 Oct.	6	$37.06\ Q^{2.70}$	0.87	**	**	**

TABLE 20. - continued

Storm	n	equation	r^2	F^3	t^3	
					a	b
		D_{90}, mm				
24 Sept.	3	$0.46\ Q^{-1.1}$	0.86			
28 Sept.	5	$9.27\ Q^{-0.3}$	0.05			
30 Sept.- 1 Oct.	3	$66.07\ Q^{0.86}$	0.54			
1 Oct.	7	$15.24\ Q^{0.46}$	0.05			
2 Oct.	5	$31.41\ Q^{0.92}$	0.12			
5 Oct.	6	$15.45\ Q^{0.07}$	0.02		**	

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[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3 s^{-1} km^{-2}$.

[3] * indicates significance at the 90% level of probability; ** indicates significance at the 95% level of probability.

TABLE 21. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for the Rising Limbs of Individual Storm Events at the Lower Riffle of Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

					t^3	
Storm	n	equation	r^2	F^3	a	b
		BLD > 0.25 mm, $kg.hr^{-1}$				
28 Sept.	5	$35\ Q^{-0.2}$	0.13		**	
30 Sept.- 1 Oct.	3	$53\ Q^{0.68}$	0.05			
1 Oct.	7	$2646\ Q^{1.87}$	0.95	**	**	**
2 Oct.	4	$66221\ Q^{4.14}$	0.96		**	**
5 Oct.	6	$12647\ Q^{0.50}$	0.50		**	*
		BLD > 2.0 mm, $kg.hr^{-1}$				
28 Sept.	5	$5\ Q^{-0.8}$	0.14			
30 Sept.- 1 Oct.	3	$8\ Q^{0.05}$	0			
1 Oct.	7	$1829\ Q^{1.93}$	0.97	**	**	**
2 Oct.	4	$112460\ Q^{5.06}$	0.99	*	**	**
5 Oct.	6	$5834\ Q^{3.32}$	0.39		**	*
		CPOM, $kg.hr^{-1}$				
28 Sept.	5	$189\ Q^{1.97}$	0.59		**	*
30 Sept.- 1 Oct.	3	$152\ Q^{2.18}$	0.93		*	*
1 Oct.	7	$126\ Q^{2.33}$	0.88	**	**	**
2 Oct.	4	$0.5\ Q^{-2.8}$	0.35			
5 Oct.	6	$1178\ Q^{3.68}$	0.77	**	**	**
		D_{50}, mm				
28 Sept.	5	$0.19\ Q^{-1.4}$	0.37			
30 Sept.- 1 Oct.	3	$2.10\ Q^{-0.2}$	0			
1 Oct.	7	$4.27\ Q^{0.16}$	0.10		**	
2 Oct.	4	$64.57\ Q^{2.71}$	0.29			
5 Oct.	6	$0.71\ Q^{-0.3}$	0.03			

TABLE 21. - continued

Storm	n	equation	r^2	F^3	t^3 a	t^3 b
		D_{90}, mm				
28 Sept.	5	$1.15\ Q^{-1.2}$	0.31			
30 Sept.- 1 Oct.	3	$36.78\ Q^{0.60}$	0.03			
1 Oct.	7	$17.38\ Q^{0.25}$	0.41		**	*
2 Oct.	4	$392.64\ Q^{2.61}$	0.55		*	
5 Oct.	6	$45.71\ Q^{1.46}$	0.70	**	**	**

[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3 s^{-1} km^{-2}$.

[3] * indicates significance at the 90% level of probability;
** indicates significance at the 95% level of probability.

TABLE 22. Relationships[1] between bedload transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for the Falling Limbs of Individual Storm Events at the Upper Riffle of Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

Storm	n	equation	r^2	F^3	t^3 a	t^3 b
		BLD > 0.25 mm, $kg.hr^{-1}$				
30. Sept.- 1 Oct.	3	$1479\ Q^{1.65}$	0.68		**	
1 Oct.	9	$824\ Q^{-0.5}$	0.15		**	
5 Oct.	4	$527229\ Q^{7.51}$	0.15			
7 Oct.	6	$2.5*10^{8}\ Q^{9.00}$	0.51		**	*
16 Oct.	7	$926\ Q^{1.83}$	0.48	*	**	**
		BLD > 2.0 mm, $kg.hr^{-1}$				
30 Sept.- 1 Oct.	3	$1115\ Q^{1.82}$	0.53		*	
1 Oct.	9	$460\ Q^{-0.7}$	0.17			
5 Oct.	4	$1116863\ Q^{9.00}$	0.17			
7 Oct.	6	$2.7*10^{9}\ Q^{11}$	0.70	**	**	**
16 Oct.	7	$516\ Q^{1.90}$	0.59	**	**	**
		CPOM, $kg.hr^{-1}$				
30. Sept.- 1 Oct.	3	$56\ Q^{2.03}$	0.98	*	**	**
1 Oct.	9	$63\ Q^{0.47}$	0.20			
5 Oct.	4	$96\ Q^{2.09}$	0.26			
7 Oct.	6	$0.1\ Q^{-.09}$	0.21			
16 Oct.	7	$25\ Q^{0.82}$	0.06		**	
		D_{50}, mm				
30 Sept.- 1 Oct.	3	$4.73\ Q^{0.45}$	0.13			
1 Oct.	9	$2.36\ Q^{-0.4}$	0.20		**	
5 Oct.	4	$119.90\ Q^{4.45}$	0.26			
7 Oct.	6	$2269.90\ Q^{4.10}$	0.21			
16 Oct.	7	$2.43\ Q^{0.22}$	0.06			

TABLE 22. - continued

Storm	n	equation	r^2	F^3	t^3	
					a	b
		D_{90}, mm				
30 Sept.- 1 Oct.	3	$7.77\ Q^{-0.2}$	0.03			
1 Oct.	9	$13.40\ Q^{-0.3}$	0.23		**	*
5 Oct.	4	$1202.28\ Q^{4.72}$	0.88	**	**	**
7 Oct.	6	$17100.15\ Q^{4.25}$	0.21			
16 Oct.	7	$7.76\ Q^{-0.5}$	0.09			

[1] No equations were developed for events represented by less than three data points.

[2] Streamflow, Q, is in $m^3s^{-1}km^{-2}$.

[3] * indicates significance at the 90% level of probability;
** indicates significance at the 95% level of probability.

TABLE 23. Relationships[1] Between Bedload Transport (BLD > 0.25 mm and BLD > 2.0 mm), Coarse Particulate Organic Matter Transport (CPOM), Two Particle Diameters (D_{50} and D_{90}), and Streamflow[2] for the Falling Limbs of Individual Storm Events at the Lower Riffle of Trap Bay Creek, Chichagof Island, Alaska, During the Fall, 1980, Storm Season

Storm	n	equation	r^2	F^3	t^3	
					a	b
		BLD > 0.26 mm, $kg.hr^{-1}$				
30 Sept.- 1 Oct.	3	$4.7*10^6\ Q^{-9.4}$	0.36			
1 Oct.	9	$2553\ Q^{1.94}$	0.97	**	**	**
5 Oct.	4	$783610\ Q^{6.57}$	0.92	*	**	*
7 Oct.	6	$0.09\ Q^{-3.5}$	0.23			
16 Oct.	7	$504\ Q^{1.26}$	0.32		**	*
		BLD > 0.2 mm, $kg.hr^{-1}$				
30 Sept.- 1 Oct.	3	$3.7*10^5\ Q^{-7.9}$	0.17			
1 Oct.	9	$1729\ Q^{0.95}$	0.95	**	**	**
5 Oct.	4	$301995\ Q^{6.32}$	0.83	*	**	**
7 Oct.	6	$0.01\ Q^{-4.2}$	0.12			
16 Oct.	7	$290\ Q^{1.31}$	0.25		**	
		CPOM, $kg.hr^{-1}$				
30 Sept.- 1 Oct.	3	$2.7*10^{18}\ Q^{24}$	0.95	**	*	*
1 Oct.	9	$103\ Q^{0.61}$	0.47	**	**	**
5 Oct.	4	$31332\ Q^{7.38}$	0.72		**	*
7 Oct.	6	$1.9*10^4\ Q^{-4.8}$	0.03			
16 Oct.	7	$18\ Q^{0.04}$	0			
		D_{50}, mm				
30 Sept.- 1 Oct.	3	$9.12\ Q^{2.02}$	0.01	**	**	**
1 Oct.	9	$4.11\ Q^{1.17}$	0.76			
5 Oct.	4	$0.92\ Q^{-1.1}$	0.25			
7 Oct.	6	$0.64\ Q^{-0.4}$	0			
16 Oct.	7	$2.49\ Q^{0.03}$	0			

TABLE 23. - continued

Storm	n	equation	r^2	F^3	t^3	
					a	b
		D_{90}, mm				
30 Sept.- 1 Oct.	3	$6.58\ Q^{-0.5}$	0.64		*	
1 Oct.	9	$59.29\ Q^{0.38}$	0.23		**	
5 Oct.	4	$2.40\ Q^{-2.0}$	0.31			
7 Oct.	6	$164.06\ Q^{1.81}$	0.06			
16 Oct.	7	$11.05\ Q^{-0.5}$	0.08			

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[1] No equations were develped for events represented by less than three data points.

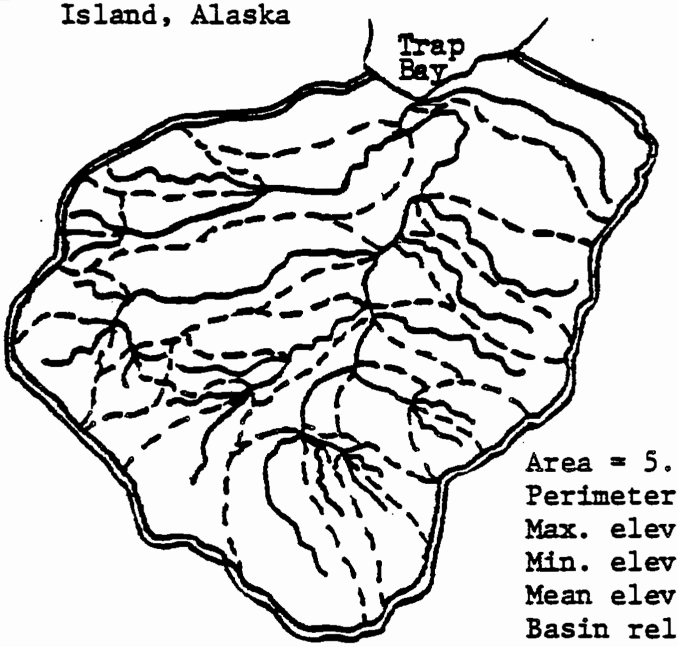
[2] Streamflow, Q, $m^3 s^{-1} km^{-2}$.

[3] * indicates significance at the 90% level of probability; ** indicates significance at the 95% levl of probability.

APPENDIX 4.

Morphometric Characteristics of Trap Bay Creek, Chichagof Island, Alaska

TABLE 14. Morphometric Characteristics of Trap Bay Creek, Chichagof Island, Alaska



Area = 5.23 mi^2 = 13.55 km^2
Perimeter = 9 mi = 14.5 km
Max. elev. = 3780 ft
Min. elev. = 0 ft
Mean elev. = 1935 ft
Basin relief = 3400 ft
Relief ratio = 0.24

Total no. streams = 26
1 3rd-order, 5 2nd-order, 20 1st-order

	1st-order	2nd-order	3rd-order
area of basins	3.0 mi^2	3.4 mi^2	5.23 mi^2
mean	0.15	0.68	5.23
length	7.2 mi	4.8 mi	2.1 mi
mean	0.36	0.96	2.1
relief	20650 ft	5000 ft	2510 ft
mean	1033	1000	2510

total stream length = 14.1 mi = 22.7 km

Drain density = 2.7 mi/mi^2
Constant of channel maintenance = 1/DD = 0.37 mi^2/mi
Stream frequency = 4.97/mi^2
Relative density = SF/DD^2 = 0.68

Mainstream slope = relief/length - 0.17 ft/ft
Mean slope 1st-order = 0.54 ft/ft
Mean slope 2nd-order = 0.20 ft/ft

Length to basin center = 1.63 mi
Basin length = 2.69 mi
Basin width = 2.75 mi

Bifurcation ratio = 4.47 (B)
Basin area ratio = 0.17 (BAR)
Stream length ratio = 0.41 (SLR)
Stream relief ratio = 0.64 (SRR)
Stream slope ratio = 1.78 (SRR)
SLR/B = 10.78

Length of flow (5280/2*DD)= 978 ft
Lemniscate (BL^2/4-A) = 0.35
Basin elongation ((A/3.14)$^{1/2}$ - 2/BL) = 0.96
Compactness coefficient = 1.11
Circularity = 0.81

Form Factor 1 (A/BL^2) = 0.72
Form Factor 2 (BL/BW) = 0.98
Texture-Slope Product (DD*RR) = 0.65
Watershed Topography Factor (B*SSR/SLR) = 6.92