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Transport of Bedload Sediment and Channel Morphology of a Southeast Alaska Stream

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Abstract

During 1980-81, transport of bedload sediment and channel morphology were determined at Trap Bay Creek, a third-order stream that drains a 13.5-square kilometer watershed on Chichagof Island in southeast Alaska. Bedload sediment was sampled for 10 storms: peak flows ranged from 0.6 to 19.0 cubic meters per second, and transport rates ranged from 4 to 4400 kilograms per hour. Peak transport rates typically occurred during peak streamflow. Transport of bedload sediment at a riffle over 1600 meters upstream from the mouth of the watershed was greater for most storm events than that measured at another riffle 22 meters downstream. Transport was greatest at the downstream riffle, however, during the most severe storm of the season and during another storm 1 week later. Both magnitude of storm and availability of sediment appeared to determine the transport of bedload sediment in Trap Bay Creek. Regression relationships were developed between streamflow (independent variable), several transport variables, and particle sizes in two diameter classes (D_{50} and D_{90}). Analysis revealed that total bedload discharge was positively correlated with streamflow; transport of either diameter class, however, had no consistent relationship with streamflow from one storm to the next. Relationships between particulate organic matter and streamflow were also highly variable from storm to storm. Observations indicated that large organic debris, especially fallen trees, played a major role in determining channel morphology; tidal action was an important factor affecting channel characteristics in the lower 1300 meters of the channel.

Keywords: Bedload, sediment transport, channels (stream), stormflow, southeast Alaska.

Introduction

The distribution of sediment by particle size and total sediment load of mountain streams is influenced by numerous factors, including geology, geomorphology, and climate. Additional changes in the sediment load can result from land use activities which often affect the spatial and temporal availability of sediment. Such changes can alter the dynamic equilibrium between sediment transport and water discharge, thus initiating changes in channel form and altering the physical and biological characteristics of the system (Hall and Krygier 1967, Heede 1975, Park 1977).

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In steep mountainous topography of the Pacific Northwest, accelerated sedimentation from mass soil movements often follows road building and timber harvesting (Beschta 1978, Lyons and Beschta 1983, Swanson and Fredriksen 1982, Swanston and Swanson 1976). The steep slopes and erodable soils characteristic of watersheds in southeast Alaska are similarly subject to mass movement following timber harvest (Swanston 1974). Because fisheries resources are often adversely affected by increased sedimentation (Chapman 1961, Hall and Krygier 1967, Phillips 1971), these nonpoint sources of sediment represent a concern in southeast Alaska, where timber and fisheries provide substantial economic benefits to the State.

Suspended sediment consists of the relatively small particles in transport by a stream; these particles are usually dispersed throughout the water column by stream turbulence. The biological effects of increased suspended sediment in small streams has been documented (Brusven 1980, Hynes 1970, Nuttal 1972). Bedload sediment consists of relatively coarse particles transported near or on the bottom of the stream; average velocities of these particles are much less than that of the stream. These larger sediment sizes can have an important effect on the quality of spawning gravel and the morphology of mountain streams, but little is known about the relationships between bedload sediment transport, flow conditions, and characteristics of the stream system. To identify these interactions we began a study in an undisturbed watershed in southeast Alaska. Results are presented and compared with those for another mountain stream, Flynn Creek, in western Oregon.

Study Site
Description

The study stream, Trap Bay Creek, is located in the northeast corner of Chichagof Island in the Tongass National Forest and drains a watershed about 13.5 km^2 in area (fig. 1). Elevation of the watershed ranges from sea level to 1320 m.

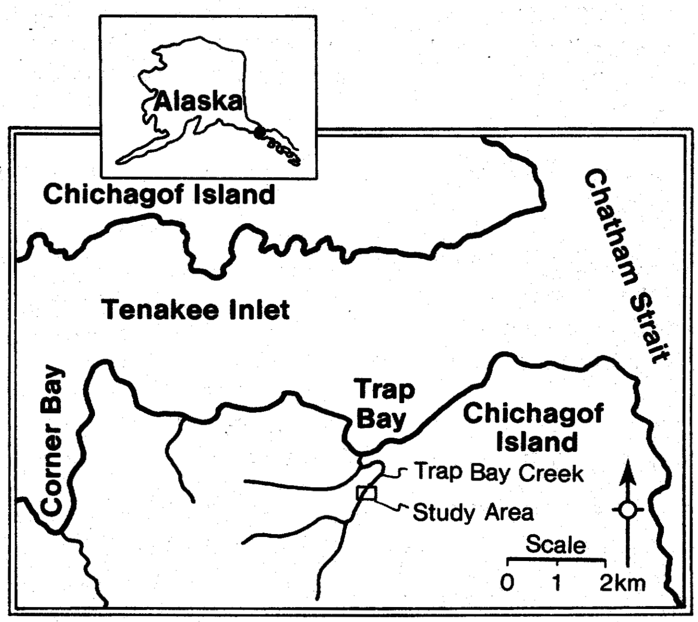

Figure 1.—Location of Trap Bay Creek.

The watershed is a glacial cirque valley bounded by serrate ridges with a horn peak at the southern end. Slope gradient ranges from nearly level adjacent to the valley floor to greater than 100 percent along the sides of the ridges. Vegetation is characteristic of the temperate rain forests of southeast Alaska. Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) dominate the old-growth forest, with scattered western redcedar (*Thuja plicata* Donn.) and red alder (*Alnus rubra* Bong.). The understory consists of blueberry (*Vaccinium alaskaense* Howell), huckleberry (*Vaccinium parvifolium* Sm.), ferns, mosses, and numerous vascular plants. Dense thickets of salmonberry (*Rubus spectabilis* Pursh.), ferns, skunk cabbage (*Lysichitum americanum* Hult. and St. John), and nettles (*Urtica lyallii* S. Wats.) alternate with alder clones and an occasional hemlock in riparian zones. Devils club (*Oplopanax horridus* (Sm.) Miq.) can also be found along streams and in the forest, especially in clearings and on steep slopes with shallow soils.

Climate

The climate is cool, moist, maritime, and typical of the southeast Alaska panhandle. There is little variation in daily temperature, primarily because of the moderating influence of the sea; air temperatures rarely exceed 18 °C in summer or drop much below freezing in winter. Low pressure frontal systems release large amounts of rainfall in southeast Alaska when they are lifted orographically by coastal mountains as they move inland from the Gulf of Alaska. The watershed receives about 1700 mm of annual precipitation, mostly as light to moderate rainfall. October is typically the wettest month, whereas April, May, and June are often relatively dry (Harris and others 1974). Upper elevations of the watershed may receive appreciable snowfall during the fall and winter.

Geology and Soil

Detailed geologic maps are not available for most of southeast Alaska. Sidle and Swanston (1982) found soils of a northwest facing slope on the east side of the watershed to be underlain by graywacke, a poory sorted sandstone composed of quartz and feldspar surrounded by a clay matrix. Mid- to upper-slope soils were 15 to 50 cm thick and well-drained.

Soils at elevation less than 1500 m have developed primarily from compacted ablation till, which typically overlies the bedrock in southeast Alaska's glacial cirque valleys (Harris and others 1974). Soils that have developed under forests are generally Spodosols and are typically covered by a thick organic layer 15 to 25 cm thick. Organic soils (muskegs) cover much of the lowland area of the watershed and may help regulate streamflow (Harris and others 1974).

Stream System

The streambed of Trap Bay Creek is composed of small to medium cobbles, gravel, and coarse sand, with increased abundance of silt and fine sands in areas of deposition. Gravel bars are numerous and obvious during low flows. Cobbles several centimeters in diameter and larger armor most stream riffles; sand and gravel particles are common between and underneath the armor particles.

The study reach for sampling bedload is located between 1590 and 1612 m from the mouth of the stream and has an average channel gradient of approximately 0.5 percent. It consists of two riffles separated by an 18-m long channel depression or pool. Bankfall widths were 13.7 m and 12.6 m at the upper and lower riffles, respectively. Between these two riffles bankfull width averages 10.7 m. Stream banks average approximately 0.8 m high at bankfull. Bed materials in this reach are similar to those found throughout the stream, with cobbles paving the riffles and finer particles more abundant in the pool.

Channel characteristics of Trap Bay Creek are strongly influenced by the stabilizing roots of streamside vegetation and by large organic debris (trees and root wads). Many pool-riffle sequences have formed where smaller pieces of organic debris (small logs and tree branches) have accumulated against fallen trees. Large organic debris is somewhat less important morphologically in the lower reaches where tides greater than 6 m can cause flotation of otherwise stable debris. Tides influence the lowest 1300 m of the channel where streambanks are subject to frequent sloughing because the protection by tree roots is no longer available.

Methods

Bedload transport was sampled in the study reach of Trap Bay Creek during 10 storms occurring in September and October 1980. Data from a water-level recorder located 1520 m from the mouth of the stream was used with periodic flow measurements to develop storm hydrographs.

Temporary bridges were constructed over the channel at each end of the study reach (1590 m and 1612 m from the mouth) to facilitate collecting samples from each riffle and to prevent disturbing the streambed during sampling. Bedload samples were taken with a handheld Helley-Smith[1/] pressure-differential sampler equipped with a square 7.6-cm aperture (Emmett 1981). A 6000-cm^2 collection bag (0.2-mm mesh) reduced the possibility of clogging (Beschta 1981, Johnson and others 1977).

Subsamples were taken at equally spaced positions across the stream; the 8-10 subsamples were combined to form a single bedload sample for each bridge location. The relative proportion of organic and inorganic sediment was determined by burning the samples at 320 °C for 24 hours. Inorganic residues were then sieved to obtain distribution by particle size.

Sediment rating curves were developed using a power equation:

$$BLD = aQ^b;$$

where:

BLD = bedload discharge, in kg hr^{-1};
Q = streamflow, in $m^3 s^{-1}$; and
a and b = regression coefficients.

This equation form was selected because it generally provided the best "straight-line" relationship between variables. Power equations were also used to correlate streamflow to transport of particulate organic matter (POM), the median diameter of particles in a bedload sample (D_{90}), and to analyze data on bedload transport from Flynn Creek, Oregon (Edwards 1980, O'Leary and Beschta 1981).

Only transport of POM was studied; no analysis was made of particle size. The Helley-Smith sampler is effective at trapping particles 0.2 mm in diameter and larger traveling within 7.6 cm of the bed; thus the data represent a conservative estimate of total POM transport.

[1/] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Measurements of channel morphology were taken within the lowest 1650 m of the channel in summer 1980. Thalweg elevations, bankfull width, and the distance of the thalweg from the east bank were measured at 15-m intervals. The locations of large organic debris, gravel bars, and pools were determined and referenced to stakes marking the 15-m intervals. Cross section profiles were measured approximately every 50 m of stream length. More frequent measurements (every 0.6 m) were made within the study reach where bedload was sampled. In August 1981, a 260-m section of the lower channel (between 1390 and 1650 m) was surveyed again, taking detailed thalweg elevations and cross section profiles between 1590 and 1610 m.

Results and Discussion

Streamflow

Return periods of the storms occurring during the sampling period cannot be definitively rated because historical records on precipitation and streamflow are not available for the Trap Bay Creek area. Estimates of the recurrence intervals, however, were obtained by comparing peakflows with regionally developed equations (USDA Forest Service 1979). All storms during which sampling was conducted were estimated to have recurrence intervals of less than 2 years, except for the more severe storm of October 1, which probably had a recurrence interval from 2 to 5 years.

The lag time between the onset of precipitation and hydrograph peak varied from less than 1 to more than 5 hours, depending on the intensity of rainfall and antecedent precipitation. Stormflows generally lasted over 6 hours. The relatively large storm of October 1 released nearly 70 mm of precipitation over a 10-hour period, with a peak intensity of 13 mm hr^{-1}; 33 mm of precipitation had also fallen the previous day.

Bedload Transport

Bedload discharge ranged from 4 to 4200 kg hr^{-1} and from 15 to 4400 kg hr^{-1} at the downstream and upstream riffles, respectively. The greatest transport rates at both sites occurred during the October 1 storm event, with relatively high bedload transport occurring nearly coincident with the hydrograph peak. At the upstream riffle, however, the maximum rate sampled occurred well into the recession limb of the storm hydrograph (fig. 2).

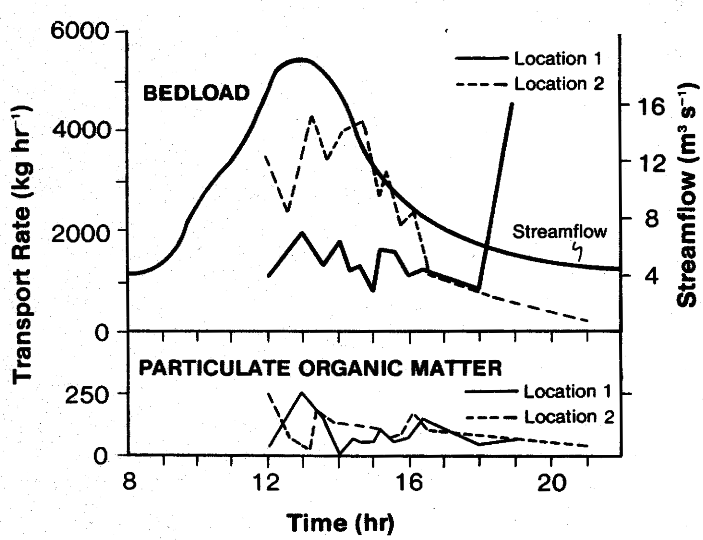

Figure 2.—Storm hydrograph for October 1, 1980, with transport rate of bedload and particulate organic matter at two sampling stations in Trap Bay Creek. Location 1 is 22 m upstream of location 2.

Transport rates at the upstream riffle exceeded those at the downstream riffle during nearly all storms. Apparently sediment was transported past the upstream riffle and deposited in the pool during the relatively small and more frequent hydrologic events. During the large storm of October 1, however, this situation was reversed (fig. 2), with more material being exported past the downstream riffle than was coming in from above. Langbein and Leopold (1968) 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 the apparent discrepancies in transport rates sampled in Trap Bay Creek at two locations only 22 m, or approximately two channel widths, apart. Lesser flow events were capable of transporting material to and past the sampling location at the upstream riffle, which represents one zone on concentration. An event of greater magnitude was required to initiate transport of this material past the downstream riffle to the next zone of concentration.

An estimated 10.8 t of material was removed from storage in the study reach from 1980 to 1981, based on changes in cross section of the channel (fig. 3). Estimates of sediment transport for the 10 storms during the fall 1980, based on the Helley-Smith bedload samples, are 11.4 t of material transported past the upstream riffle and 20.7 t of material transported past the downstream riffle. The difference of 9.3 t, most of which can be attributed to effects of the October 1 storm, agrees closely with the estimate based on cross section changes. Much of the sediment exported from this reach appears to have come from near the sides of the channel (both banks and bed) (fig. 3).

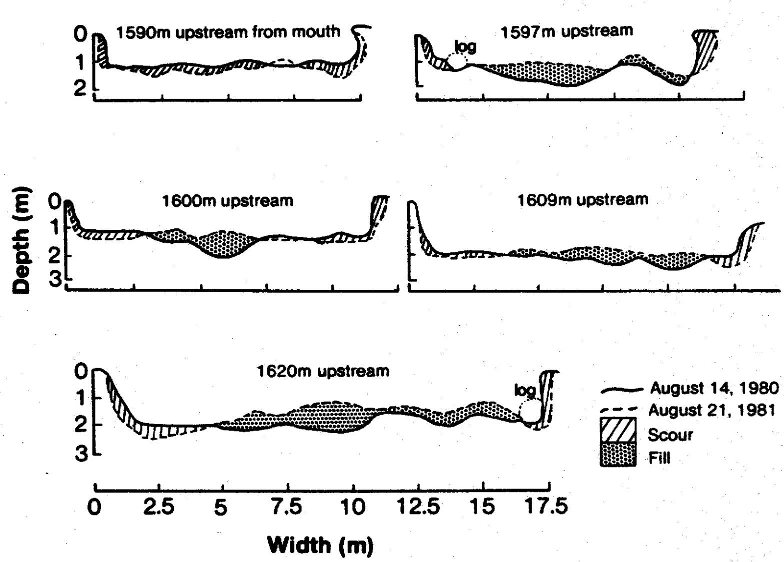

Figure 3.—Net changes in channel cross sections for selected locations upstream from the watershed mouth.

Rating curves between bedload transport and streamflow were developed for individual storms by using data from both upstream and downstream sampling locations (fig. 4). Separate sets of equations developed for bedload transport at each sampling location or for rising and falling hydrograph conditions did not greatly increase the coefficients of determination (r^2). Equations developed from all sample data from Trap Bay Creek, and also from Flynn Creek in Oregon, are shown in table 1.

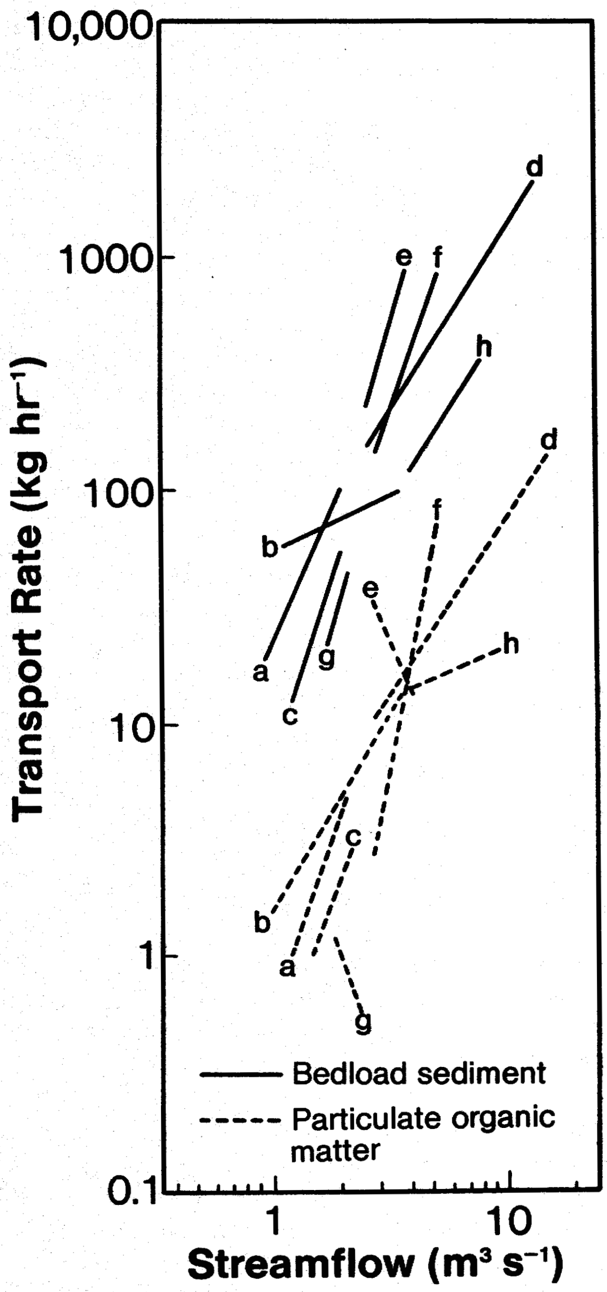

Figure 4.—Transport of bedload sediment and particulate organic matter for individual storm events: a = September 24, b = September 28, c = September 30, d = October 1, e = October 2, f = October 5, g = October 7, and h = October 17.

In general, bedload transport at Trap Bay Creek was positively correlated with streamflow, although considerable variation is evident between the rating curves for individual storms (fig. 4). These results suggest that extrapolation of rating curves to estimate bedload transport during other storms or flow levels will result in large errors and that data on bedload transport need to be collected over a wide range of flow conditions before a representative relationship can emerge from the large amount of background variability. Peak flows greater than 2.0 $m^3 s^{-1}$ were required to produce appreciable movement of bedload sediment.

Coefficients of determination for equations developed from larger bedload particle sizes (> 2.0 mm) during individual storms averaged approximately 0.50 and were essentially the same as those for rating curves developed from particles > 0.25 mm. Supply limitations could influence the relationships between bedload transport and stream discharge. Streamflow was a dominant factor influencing bedload transport during moderate events at the upper riffle because material was readily available for transport. Transport past the lower riffle was limited, however, except during and following the storm October 1, an event of relatively large magnitude. The energy available during small storms was apparently insufficient to transport material through the study reach. Hence, the dynamics of sediment supply (Δ storage) and availability of energy interact in such a manner that sediment transport rates at two locations in a channel may appear to behave independently. Although there appeared to have been a general increase in material transport with increasing discharge at Trap Bay Creek, streamflow was only one factor influencing bedload transport. Furthermore, transport appeared to occur in pulses or "waves," probably because of differences in hydraulic conditions and characteristics of the armor layer of the two riffles.

No significant relationships ($\alpha = 0.10$) were found between streamflow and particle sizes D_{50} and D_{90}. Average diameters of D_{50} and D_{90} were approximately 2 and 11 mm, respectively. Again, the apparent lack of a strong correlation between rates of bedload transport and streamflow during individual storms or between particle size and streamflow should perhaps be expected if sediment is being routed downstream as a wave or series of waves. With transport occurring in such a manner, rates of bedload transport could vary widely at a given flow; such variability is reflected in the data collected at Trap Bay Creek. Furthermore, there was no obvious relationship between particle size and rate of bedload transport.

Considerable variability is apparent in transport of POM (fig. 4). Different factors (density, size, and shape) and processes may control the supply and transport of organic and inorganic material, even though both types are partially correlated with streamflow. A seasonal trend towards reduced POM at a given discharge is suggested by data from latter fall storms, a pattern typically found with suspended sediment loads (Beschta 1978, Beschta 1980, Paustian and Beschta 1979).

Channel Morphology

The resurvey of the study reach in August 1981 indicated fill at the upstream end and scour at the downstream end of the reach (fig. 5). Furthermore, the channel widened downstream from the upper riffle. Downstream from the 1504 m location, the left bank was being undercut and the thalweg elevation shifted towards this bank. A substantial shift in thalweg occurred at the upstream riffle but little change was apparent at the downstream riffle. Fill had occurred in the downstream portion (from 1592 to 1602 m) of the reach, a section of stream that could be characterized as a shallow pool. In contrast, scouring had occurred in another pool 30.5 m downstream from the study reach and the thalweg elevation there decreased by nearly 0.3 m. Cross section profiles within the study reach (fig. 3) tend to confirm indications of scour and fill from the thalweg surveys: where thalweg depths decreased, channel cross sections show net fill; and where depths increased, net scour prevailed.

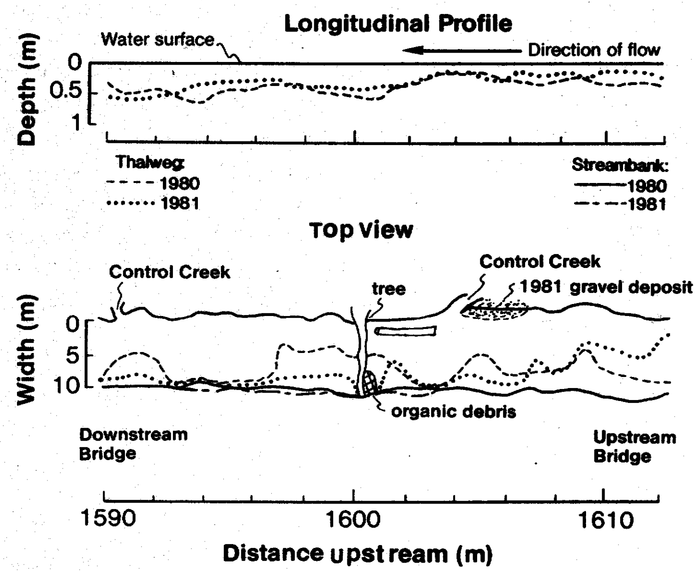

Figure 5.—Thalweg depth, thalweg position, and channel characteristics of Trap Bay Creek between bridges used for sampling bedload sediment.

Large organic debris appeared to have an important influence on channel morphology, especially upstream from the study reach. Here, much of the debris was tree-sized and had remained in place for relatively long periods of time. Smaller debris tended to become trapped and concentrated against fallen trees, resulting in localized channel scouring and thus obscuring the occurrence of pool-riffle sequences formed solely by fluvial processes. Trees in the channel, however, did not appear to block fish passage but, instead, provided cover for spawning adults.

Results of the 1980 survey measurements (fig. 6) indicate a general increase downstream in thalweg depth with respect to the water surface. The 1981 resurvey, from 1350 to 1500 m along the channel, indicated that sediment has been routed out of the upper portions of the channel with depositions immediately downstream. No significant changes in stream width occurred between 1980 and 1981.

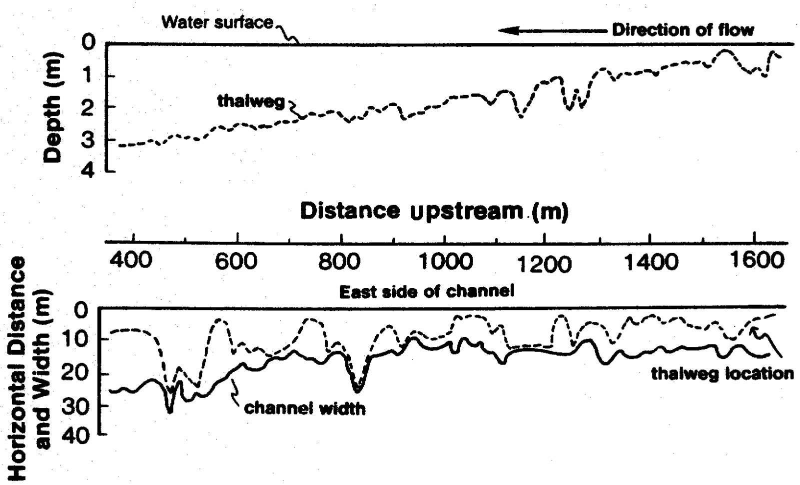

Figure 6.—Thalweg depth, thalweg location (distance from east side of channel), and channel width of a 1200-m section of Trap Bay Creek, 1980.

Morphometric change was observed in the channel, mostly downstream from 1300 m, where the stream was subject to tidal influence and human activity associated with several ongoing research projects. These changes included widespread bank-cutting, tree-tipping, and shifting of gravels within the tidal influence zone. Trampling along the banks, removal of large organic debris, and the construction of two fish weirs undoubtedly contributed to some of the changes that took place. Width-depth ratios were determined for 20 cross sections between the 730- and 1645-m channel locations in 1980 and remeasured in 1981. Data for the cross section at 838 m were excluded because the width-depth ratio was nearly an order of magnitude greater than at other cross sections. A highly significant ($\alpha = 0.01$) increase in the width-depth ratio occurred: from 16.5 in 1980 to 18.5 in 1981.

Trap Bay Creek appears to be a morphologically active stream. Tidal action, high flows, and instream research activities are effecting morphology changes in the lower portions of Trap Bay Creek, whereas stormflows and large organic debris are important factors above the tidal influence zone.

Comparison of Trap Bay Creek and Flynn Creek

Flynn Creek is a third-order stream that drains a 2.2-km^2 watershed in the Alsea River basin of western Oregon; its sediment transport has been studied extensively (Edwards 1980, Jackson and Beschta 1982, O'Leary and Beschta 1981, VanSickle and Beschta 1983). Both Flynn Creek and Trap Bay Creek watersheds receive most of their precipitation in the form of light to moderate rainfall from frontal storms of long duration; total precipitation and average temperatures are similar for the two areas. In contrast to the Trap Bay watershed, soils at Flynn Creek are deeper (most about 1 m) and are derived from sandstone bedrock. Forest vegetation consists predominantly of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and red alder (*Alnus rubra* Bong.). Average elevation of Flynn Creek watershed is 320 m with a relief ratio of 0.13; for the Trap Bay Creek watershed they are 590 m and 0.24. The Flynn Creek watershed is about one-third as long and one-tenth as wide as the Trap Bay watershed.

Power equations of relationships between bedload transport and streamflow have also been developed for Flynn Creek (table 1). In general, "b" coefficients for the Flynn Creek equations were greater than those for Trap Bay Creek, indicating that transport tended to increase more rapidly with increasing discharge at Flynn Creek. The "a" coefficients tended to be somewhat less for Flynn Creek equations, which probably reflects the difference in drainage area and, hence, the size of flow events.

Table 1—Equations for transport of bedload sediment and particulate organic matter for Trap Bay Creek, southeast Alaska, and Flynn Creek, western Oregon

Particle size stream, and location	Drainage area	Water year	Equation[1/]	r^2	n	Source of information[2/]
	km					
For particles ≥ 0.25 mm:						
Trap Bay Creek, AK—						
Riffle study reach	13.50	1981	BLD = $23.0\,Q^{1.61}$	0.69	132	1
Flynn Creek, OR—						
Fishtrap site	2.18	1978	BLD = $12.6\,Q^{4.51}$	0.58	187	2
Fishtrap site	2.18	1979	BLD = $30.6\,Q^{4.13}$	0.93	59	3
Fishtrap site	2.18	1980	BLD = $2.9\,Q^{-1.22}$	0.62	114	4
Riffle site	2.05	1979	BLD = $262.7\,Q^{2.46}$	0.79	26	3
Bedrock chute	1.51	1979	BLD = $60.6\,Q^{1.98}$	0.90	6	3
For particles ≥ 2 mm:						
Trap Bay Creek, AK—						
Riffle study reach	13.50	1981	BLD = $10.0\,Q^{1.72}$	0.66	132	1
Flynn Creek, OR—						
Fishtrap site	2.18	1979	BLD = $2.2\,Q^{5.27}$	0.92	59	3
Riffle site	2.05	1979	BLD = $115.7\,Q^{2.64}$	0.77	26	3
For particles ≥ 0.2 mm:						
Trap Bay Creek, AK—						
Riffle study reach	13.50	1981	POM = $0.7\,Q^{1.86}$	0.71	132	1
Flynn Creek, OR—						
Fishtrap site	2.18	1979	POM = $35.5.\,Q^{2.55}$	0.96	59	3
Riffle site	2.05	1979	POM = $41.5\,Q^{2.70}$	0.81	26	3

1/ BLD = bedload sediment transport, in kg hr^{-1}; Q = streamflow, in $m^3\,s^{-1}$; and POM = particulate organic matter, in kg hr^{-1}

2/ 1 = Estep (1983), 2 = O'Leary and Beschta (1981), 3 = Edwards (1980), 4 = Beschta and others (1981).

A difference in the size and shape of bedload particles between the two streams may be reflected in the data collected from sampling bedload sediment during the largest storm at Flynn Creek (February 7, 1979) (Edwards 1980, Jackson and Beschta 1982) and the largest storm at Trap Bay Creek (October 1, 1980) (Estep 1983). The February 7 storm at Flynn Creek had a recurrence interval of approximately 1.8 years and for the 24-hour period produced a measured bedload yield of 13 t at a riffle. Riffles in Flynn Creek are typically characterized by a loosely formed armor layer comprised of 1- to 5-cm gravels overlaying a sand-gravel mixture (Jackson and Beschta 1982). The October 1 storm at Trap Bay Creek had a much longer recurrence interval (2-5 years) and for a 24-hour period produced a measured bedload yield of approximately 8 t. Particles comprising the armor layer at Trap Bay Creek are generally five times larger in diameter than those at Flynn Creek. Hence, greater relative discharge would be necessary to initiate and maintain transport of the larger and more angular particles in Trap Bay Creek than would be required to disrupt the armor and transport particles characterizing the bed of Flynn Creek. Interestingly, the D_{50} class of sediment in transport generally remained below 5 mm during both storms. These results would indicate, based on the work of Parker and Klingeman (1982) that the composition of the underlying bed material is quite similar for both streams.

Summary and Conclusions

The hand-held Helley-Smith sampler (modified with a larger bag) and temporary bridges over the stream provided a means of obtaining bedload sediment transport data in a relatively inaccessible area. Samples obtained enabled determination of bedload and POM transport in mountain streams.

Transport of bedload sediment was highly variable, both in time and space, but, in general, was positively correlated with streamflow. The rating curve relationships developed during this study period appeared to be site and storm specific. Diameter of particle size was not significantly related to discharge or to the total amount of material in transport. Transport of POM was positively correlated with streamflow even though the mechanisms controlling the availability and mobility of organic matter are obviously different than for sediment transport.

Storm events with a recurrence interval less than 1 year appeared to transport sediment past the upstream riffle of the study reach and into a pool where it was temporarily stored. Transport past the lower riffle required an event of greater magnitude. Once the streambed had been disturbed, transport past the lower riffle was accomplished by lesser magnitude events until an armor layer had reformed or the amount of sediment became limited. Unlike transport during storms of lesser magnitude, sediment transport during the storm of greatest magnitude did not increase proportionally at the riffle. Therefore, sediment availability appears to be limited at both upper and lower riffles. Any activity resulting in increased availability of sediment (increased input of sediment from upstream and/or alterations of the hydraulic characteristics of the stream) are likely to increase overall transport rates.

Extreme spatial and temporal variation in bedload transport was characteristic of both Flynn Creek and Trap Bay Creek. Although Trap Bay Creek is larger and steeper than Flynn Creek, total sediment yield appeared to be less and transport appeared to increase less rapidly with increasing streamflow. This may reflect the difference in the size and shape of particles comprising the bed: particles along the surface of the bed are typically larger and more angular at Trap Bay than those at Flynn Creek. An armor layer that resists transport is more likely to form in Trap Bay Creek.

Trap Bay Creek is a morphologically active stream that widened and filled in throughout its lower 1700 m between 1980 and 1981. Changes in channel morphology appear to be influenced by large organic debris in conjunction with streamflow and transport of bedload sediment. In addition, tidal action and research activities may have affected changes in the lower 1300 m of the channel.

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Metric Equivalents

1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 meter (m) = 3.28 feet
1 kilometer (km) = 0.62 mile
1 tonne (t) = 2,205 pounds
°C = 5/9 (°F-32)

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